PROGRAMA DE DOCTORADO EN INGENIERÍA DE LA CONSTRUCCIÓN

TESIS DOCTORAL

EVALUACION MULTICRITERIO DE LA SOSTENIBILIDAD SOCIAL PARA EL DESARROLLO DE PROYECTOS DE INFRAESTRUCTURAS

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La verdadera dirección del desarrollo del pensamiento no es de lo individual a lo social, sino de lo social a lo individual.

L.S. Vygotsky

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RESUMEN

Hoy en día existe un consenso por el cual las consideraciones económicas, ambientales y sociales en el desarrollo de los países constituyen dimensiones necesarias para alcanzar la sostenibilidad. En el ámbito de la construcción se han impulsado agendas que promueven el desarrollo sostenible considerando el ciclo de vida de los proyectos. Sin embargo, se reconoce que la limitación fundamental de la sostenibilidad, es que tiende a centrarse en las consideraciones biofísicas y económicas del entorno construido; sin prestar la suficiente atención a los aspectos sociales. La no consideración temprana de los aspectos sociales afecta al desarrollo de la infraestructura en la sociedad a corto y largo plazo. Dado que los impactos sobre la sociedad son multidimensionales, una representación que evalúe los aspectos sociales también debe serlo. La valoración de los aspectos sociales y la calidad de vida superan los aspectos cuantitativos. En efecto, los resultados de una evaluación son igual de trascedentes que la legitimidad participativa de su proceso. En este sentido los métodos de toma de decisiones multicriterio constituyen una alternativa que representa de un modo óptimo la evaluación multidimensional y participativa de los aspectos sociales. Con todo, la sostenibilidad social en la evaluación de infraestructuras no ha sido adecuadamente tratada hasta este momento.

A la vista de estos antecedentes, la dimensión social en la evaluación de las infraestructuras requiere una revisión y nuevos enfoques en la toma de decisión en las fases tempranas del desarrollo del proyecto. Todo ello conduce a plantear el objetivo general de la investigación de la siguiente forma: *Evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones*. Este objetivo general se desglosa en diferentes objetivos específicos que buscan explorar las áreas de mejora en el tratamiento de la sostenibilidad social. A partir de este punto, se proponen metodologías para estimar la contribución a la sostenibilidad social a través de la evaluación multicriterio de infraestructuras.

El alcance de la investigación se concentra en la evaluación de infraestructuras de ingeniería civil en las etapas de formulación, factibilidad y planificación; y la consideración de múltiples aspectos sociales. El documento presentado se compone por seis artículos complementarios (tres de ellos ya publicados y otros tres en proceso de revisión en revistas científicas). En general para el desarrollo de los objetivos de la investigación los estudios utilizan diferentes técnicas: panel de expertos Delphi, el Proceso Analítico Jerárquico (AHP), la teoría de la utilidad, sistemas estocásticos, métodos multiobjetivo y las técnicas de razonamiento Bayesiano.

La investigación se ha aplicado a distintos contextos internacionales. La contextualización de los criterios sociales en el ciclo de vida se implementó en infraestructuras chilenas. Se aplicó un método de aprendizaje activo de la sostenibilidad en un curso de posgrado en España con estudiantes internacionales. Por su parte, dos métodos de estimación de la contribución social, a corto y largo plazo, en infraestructuras viarias se implementaron en El Salvador.

A partir de los resultados de la investigación se han propuesto métodos para tratar la dimensión social en la evaluación multicriterio de infraestructuras civiles e integrarla en el proceso de toma de decisión. Las propuestas han surgido a partir de una exploración de las necesidades de mejora de los métodos multicriterio para evaluar la sostenibilidad social. De esta forma se proponen tratamientos integrados para fortalecer la dimensión social en el proceso de evaluación de la sostenibilidad. Específicamente se proponen sistemas de participación multidisciplinar y multisectorial integrados; se considera la contribución no compensatoria de las infraestructuras a la mejora social a corto y largo plazo; se promueve la equidad intergeneracional de las oportunidades de mejora social; se trata la incertidumbre interna de los métodos propuestos; y, finalmente, se mejora la interacción con el contexto y la promoción del aprendizaje social en los procesos de evaluación. Esta investigación aporta las herramientas que respaldan a los organismos públicos encargados de la planificación territorial y de la priorización de infraestructuras para apoyar los procesos de toma de decisión.

Los resultados de los métodos propuestos presentan las siguientes limitaciones: el desempeño se ajusta al conjunto de alternativas de infraestructuras evaluadas; considera el impacto de primer orden de la infraestructura sobre los criterios sociales; y la independencia de los indicadores que interactúan sobre un mismo criterio. Las futuras investigaciones podrían simplificar los tratamientos propuestos a través de la adaptación a contextos y tipos específicos de infraestructuras, integrados con la evaluación de las dimensiones económicas y ambientales de la sostenibilidad.

ABSTRACT

There is a consensus nowadays that the economic, environmental and social considerations in a country's development are needed to achieve sustainability. In the area of construction, agendas have been advanced to promote sustainable development that takes the life cycle of a project into consideration. Nevertheless, it is clear that the fundamental limitation of sustainability is that it tends to concentrate on the biophysical and economic considerations of the built environment without paying sufficient attention to the social aspects. Not including the social aspects early on affects a society's short and long-term infrastructure development. Since the impacts on society are multidimensional, a representation that evaluates the social aspects must be also. The assessment of the social aspects and quality of life go beyond the quantitative aspects. Indeed, the results of an evaluation are just as significant as the participatory legitimacy of its process. In this sense, multicriteria decision-making methods are an alternative that optimally represent the multidimensional and participatory assessment of the social aspects. However, social sustainability in the evaluation of infrastructures has not been adequately addressed to date.

In this light, the social dimension in the assessment of infrastructures requires a review and new approaches in the decision-making in the early phases of a project's development. All this leads to the proposal of the general aim of the study as follows: To assess the social sustainability of infrastructures by integrating it into the decision-making. This general aim is split into different specific objectives that seek to explore the areas for improvement in the treatment of social sustainability. From this point, methodologies are proposed to estimate the contribution to social sustainability through multicriteria infrastructure assessment.

The scope of this investigation focuses on the assessment of civil engineering infrastructures in the formulation, feasibility and planning stages as well as consideration of multiple social aspects. The document presented is composed of six complementary articles (three already published and three others in the review process in scientific journals). In general, for the development of the research goals the studies use different techniques: a Delphi panel of experts, an analytic hierarchy process (AHP), utility theory, stochastic systems, multi-objective methods and Bayesian reasoning techniques.

The research has been applied to different international contexts. The social criteria were contextualized in the life cycle of Chilean infrastructures. An active learning method about sustainability was applied in a graduate course in Spain with international students. Additionally, two methods to estimate short and long-term social contribution were implemented on road infrastructures in El Salvador.

From the results of the investigation, methods have been proposed to address the social dimension in the multicriteria assessment of civil infrastructures and integrate it into the decision-making process. The proposals arose from an exploration of the needs to improve the multicriteria methods to assess social sustainability. Thus, integrated

treatments are put forward to strengthen the social dimension in the sustainability assessment process. Specifically, integrated systems of multidisciplinary and multi-sector participation are proposed; the non-compensatory contribution of infrastructures to social improvement is considered in the short and long terms; the intergenerational equity of social improvement opportunities is promoted; the internal uncertainty of the proposed methods is addressed; and, finally, interaction with the context and the promotion of social learning in the assessment processes is improved. This study contributes the tools that support public entities responsible for land-use planning and the prioritization of infrastructures to strengthen the decision-making processes.

The results of the proposed methods present the following limitations: the performance is adjusted to the set of evaluated infrastructure alternatives, considers the first-order impact of the infrastructure on social criteria and the independence of the indicators that interact on the same criterion. Future studies could simplify the proposed treatments by adapting to contexts and specific types of infrastructures, integrated with the assessment of the economic and environmental dimensions of sustainability.

RESUM

Hui en dia hi ha un consens pel qual les consideracions econòmiques, ambientals i socials en el desenrrollament dels països constitueixen dimensions necessàries per a aconseguir la sostenibilitat. En l'àmbit de la construcció s'han impulsat agendes que promouen el desenvolupament sostenible considerant el seu cicle de vida. No obstant això, es reconeix que la limitació fonamental de la sostenibilitat, és que tendix a centrar-se en les consideracions biofísiques i econòmiques de l'entorn construït; sense prestar la suficient atenció als aspectes socials. La no consideració primerenca dels aspectes socials afecta el desenrrollament de l'infraestructura a la societat a curt i llarg termini. Atès que els impactes sobre la societat són multidimensionals, una representació que evalue els aspectes socials també ha de ser-ho. La valoració dels aspectes socials i la qualitat de vida superen els aspectes quantitatius. En efecte, els resultats d'una evaluació són igual de transcendents que la legitimitat participativa del seu procés. En este sentit els mètodes de presa de decisions multicriteri constituïxen una alternativa que representa d'una manera òptima l'evaluació multidimensional i participativa dels aspectes socials. Amb tot, la sostenibilitat social en l'evaluació d'infraestructures no ha segut adequadament tractada fins ara.

A la vista d'estos antecedents, la dimensió social en l'evaluació de les infraestructures requerix una revisió i plantejar nous enfocaments en la presa de decisió en les fases primerenques del desenrrollament del projecte. Tot això conduïx a plantejar l'objectiu general de la investigació de la següent manera: Evaluar la sostenibilitat social de les infraestructures integrant-la en la presa de decisions. Est objectiu general es desglossa en diferents objectius específics que busquen explorar les àrees de millora en el tractament de la sostenibilitat social. A partir d'est punt, es proposen metodologies per estimar la contribució a la sostenibilitat social a través de l'evaluació multicriteri d'infraestructures.

L'abast de la investigació es concentra en l'evaluació d'infraestructures d'enginyeria civil en les etapes de formulació, factibilitat i planificació; i la consideració de múltiples aspectes socials. El document presentat es compon de sis articles complementaris (tres d'ells ja publicats i tres més en procés de revisió en revistes científiques). En general per al desenrrollament dels objectius de la investigació els estudis utilitzen diferents tècniques: panell d'experts Delphi, el Procés Analític Jeràrquic (AHP), la teoria de la utilitat, sistemes estocàstics, mètodes multiobjectiu i les tècniques de raonament Bayesià.

L'investigació s'ha aplicat a diferents contextos internacionals. La contextualització dels criteris socials en el cicle de vida es va implementar en infraestructures xilenes. Es va aplicar un mètode d'aprenentatge actiu de la sostenibilitat en un curs de postgrau a Espanya amb estudiants internacionals. Per altra banda, es van implementar dos mètodes d'estimació de la contribució social, a curt i llarg terme, en infraestructures viàries a El Salvador.

A partir dels resultats de la investigació s'han proposat mètodes per tractar la dimensió social en l'avaluació multicriteri d'infraestructures civils i integrar-la en el procés de presa de decisió. Les propostes han sorgit a partir d'una exploració de les necessitats de millora

dels mètodes multicriteri per a evaluar la sostenibilitat social. D'esta manera es proposen tractaments integrats per a enfortir la dimensió social en el procés d'evaluació de la sostenibilitat. Específicament es proposen sistemes de participació multidisciplinar i multisectorial integrats; es considera la contribució no compensatòria de les infraestructures a la millora social a curt i llarg terme; es promou l'equitat intergeneracional de les oportunitats de millora social; es tracta la incertesa interna dels mètodes proposats; i, finalment, es millora la interacció amb el context i la promoció de l'aprenentatge social en els processos d'evaluació. Esta investigació aporta les ferramentes que donen suport als organismes públics encarregats de la planificació territorial i de la priorització d'infraestructures per recolzar els processos de presa de decisió.

Els resultats dels mètodes proposats presenten les següents limitacions: el rendiment d'un conjunt d'alternatives d'infraestructures evaluades; l'impacte de primer ordre de la infraestructura sobre els criteris socials; i els indicadors independents que interactuen sobre un mateix criteri. Les futures investigacions podrien simplificar els tractaments proposats a través de l'adaptació a contextos i tipos específics d'infraestructures, integrats amb l'evaluació les dimensions econòmiques i ambientals de la sostenibilitat.

CAPÍTULO 1

INTRODUCCIÓN

1.1 Antecedentes

A inicio de los setenta se estableció el concepto de desarrollo sostenible como base del progreso económico que puede beneficiar a las generaciones actuales y futuras sin dañar a los recursos o los organismos biológicos en el planeta (NEPA 1969). Años más tarde, el Informe Brundtland fortaleció esta definición, donde el concepto de desarrollo se transforma en un concepto más cualitativo, complejo, multidimensional e intangible. Este enfoque compatibilizó lo económico, lo social y lo ambiental, sin comprometer las posibilidades del desarrollo de las nuevas generaciones (WCED 1987). De esta forma durante la evolución de los últimos treinta años del siglo XX, la discusión enfatizó en las necesidad de mejorar las condiciones medio ambientales para las generaciones futuras; a finales de siglo, la comunidad internacional comienza a comprender que el objetivo debe pasar por aumentar las capacidades humanas (Anand and Sen 2000). En la actualidad la sostenibilidad constituye una ciencia multidisciplinar con un enfoque holístico que integra la totalidad de los problemas interconectados a escala local, nacional y mundial, lo cual implica un replanteamiento de las relaciones de los grupos humanos entre sí y con el medio ambiente (Vilchés et al. 2014). En este sentido, solo las acciones locales y de corto plazo son insuficientes para alcanzar un estado sostenible (Vilchés et al. 2014).

A partir de 1992 la industria de la construcción inició planes de acción propuestos por las Naciones Unidas, a través de la Agenda 21 para la Construcción Sostenible en el Desarrollo de los Países. Este plan se suscribió por más de 178 países (UNCED 1992). Desde entonces, se ha propuesto el seguimiento de una agenda orientada a la sostenibilidad que incluye las consideraciones sociales a lo largo del ciclo de vida del proyecto: diseño y planificación, construcción, uso-mantenimiento y fin de vida (Boyle et al. 2010). Sin embargo, no ha sido suficiente y se reconoce que la limitación fundamental de la sostenibilidad hoy en día, es que tiende a centrarse en las consideraciones biofísicas y económicas del entorno construido; sin tener la suficiente atención de los aspectos sociales (CIB 2002, Diaz-Sarachaga et al. 2016).

Polese y Stren (2000) definen la sostenibilidad social como el estado logrado a partir del desarrollo compatible con la evolución armónica de la sociedad civil, fomentando un entorno propicio para la convivencia de diversos grupos culturales y sociales, al mismo tiempo que motiva a la integración social mejorando la calidad de vida para todos los segmentos de la población. Por su parte McKenzie (2004) sostiene que la sostenibilidad social se produce cuando los procesos, sistemas, estructuras y relaciones formales e informales apoyan activamente la capacidad de las generaciones actuales y futuras de crear comunidades saludables y habitables. Las comunidades socialmente sostenibles son equitativas, diversas, conectadas y democráticas. Sin embargo, falta definir una estructura empírica y profunda de los procesos de sostenibilidad social en los proyectos de construcción de las infraestructuras. Los aspectos constituyentes de la sostenibilidad social se definen de diversos modos dependiendo de la perspectiva de los participantes en el proyecto y las fases del ciclo de vida. (Valdés-Vásquez y Klotz, 2013).

Desde la década de los noventa se han formulado los principios sociales que debería abordar la construcción sostenible. En este sentido, se mencionan los siguientes: el aseguramiento de las necesidades básicas (Hill y Bowen 1997); los diseños que recogen la identidad y diversidad cultural de las ciudades (Gardner 1989); la equidad inter e intra-generacional (Goodland 1995; Hill y Bowen 1997); y la seguridad laboral, la salud humana y la adecuada capacitación laboral (Hill y Bowen 1997). Además, la participación aporta la democracia y la equidad en la toma de decisiones sostenibles (Munda 2004). Sin embargo la implementación de estos aspectos no se acaba de entender claramente. En particular, la valoración temprana de los aspectos sociales en la toma de decisión de infraestructuras requiere una revisión metodológica. En la práctica profesional el análisis coste-beneficio (ACB) constituye uno de los método tradicionales más empleados para evaluar y priorizar las infraestructuras. Sin embargo, el ACB presenta algunos inconvenientes al considerar las externalidades sociales no monetarias. Bueno et al. (2015) y Mostafa y El-Gohary (2014) plantean que el problema del ACB radica en que se centra en la rentabilidad de los beneficios de corto plazo. Además agregan que el método no considera la distribución de los aportes de una alternativa. El ACB se limita a medir los impactos cuantitativos de la sostenibilidad, reduciendo los criterios que influyen en la toma de decisión (Tudela et al. 2006). Además, en el ACB la participación no se considera en el proceso de evaluación (Tudela et al 2006). En este sentido los métodos de toma de decisiones multicriterio son una alternativa que representa de mejor forma la evaluación multidimensional y participativa de los aspectos sociales (Munda 2004). Además, permiten una mayor flexibilidad para tratar aspectos interconectados y complementan otras técnicas que representan mejor la evaluación de cada aspecto social (García-Segura et al. 2015, Mkrtchyan et al 2016). Sin embargo, existen limitaciones como la falta de un sustento objetivo o la heterogeneidad asociada al contexto que obligan a un tratamiento específico aún no completamente comprendido (Labuschagne et al. 2005). En consecuencia, la dimensión social de la sostenibilidad en la evaluación de las infraestructuras requiere una revisión y tratamientos adecuado para la toma de decisión en las fases tempranas del desarrollo del proyecto.

1.2 Contexto de la investigación

Este epígrafe establece los fundamentos que conforman la investigación. Inicialmente, se presenta el contexto general de la investigación, centrado en los aspectos sociales de las infraestructuras y el enfoque de evaluación. A continuación, se introduce el contexto específico con una visión más refinada, proporcionando una sinopsis concisa de los propósitos principales de la investigación; en esta sección se identifican las lagunas del conocimiento y las preguntas de la investigación. Finalmente, se establecen los objetivos de investigación.

1.2.1 Contexto general

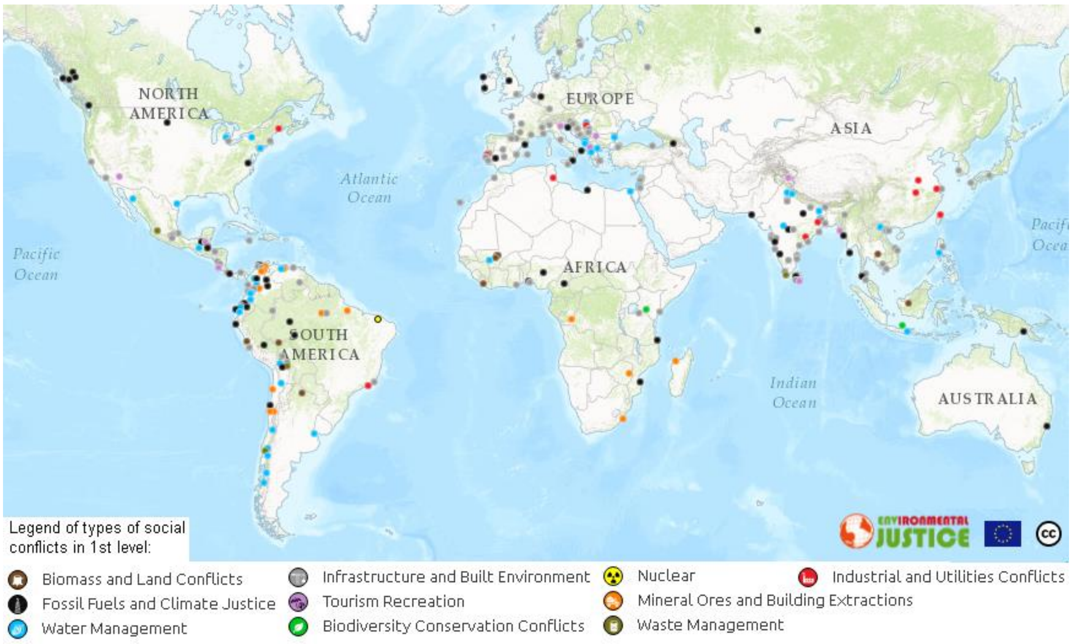
El alcance de la investigación se limita al estudio de la dimensión social en el desarrollo de proyectos[1] de infraestructuras civiles. En esta subsección se exponen los problemas producidos por la desatención de los aspectos sociales en el desarrollo de las infraestructuras y la necesidad de una consideración adecuada. En este sentido, se expone la aptitud de los métodos multi-criterio para evaluar el aporte de las infraestructuras a la sostenibilidad social.

El crecimiento de las economías industriales intensifican las actividades extractivas y de producción. De este modo, el dinamismo económico no planificado influye en el desarrollo de las infraestructuras para acelerar el crecimiento nacional. Esto genera impactos sobre la sociedad y el medio ambiente que producen conflictos y resistencia en todo el mundo. De acuerdo con el Atlas de la Justicia Social (Temper et al. 2015), en un 14% (293) de los casos registrados las infraestructuras presentan conflictos sociales con algún grado de importancia. Estos casos no son un total absoluto (293) dado que las bases de datos de aspectos sociales no son frecuentes y las que existen presentan información incipiente (Temper et al. 2015).

La Figura 1.1 resalta 293 proyectos de infraestructuras (transporte, tratamientos de agua-alcantarillado, puertos y aeropuertos) involucrados en los conflictos sociales. Los conflictos sociales derivados del desarrollo de infraestructuras han afectado principalmente a las comunidades locales. Específicamente en el 67% de los conflictos las áreas afectadas fueron las rurales y semi-urbanas. En efecto, en la mayor cantidad de los casos la población vulnerable se concentra en las áreas rurales o suburbios. Además, la población vulnerable tiene una menor capacidad para soportar los cambios generados por las intervenciones de las infraestructuras (van de Walle 2002). Por su parte, el

[1] En el contexto de esta investigación, "proyecto" debe entenderse en su sentido más general que abarca el ciclo de vida de la infraestructura.

momento de conflicto es principalmente derivado de una resistencia preventiva de los afectados, seguido del momento de implementación (construcción o explotación) (Temper et al. 2015).

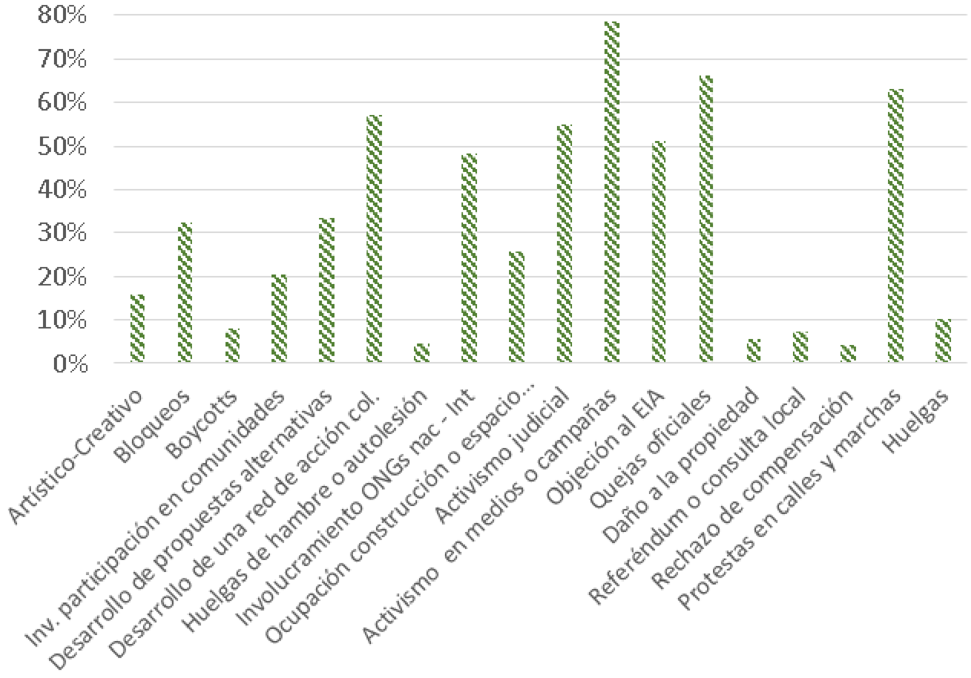


Fuente: Base de datos de Temper et al. (2015)

Figura 1.1: Localización de infraestructuras con registro de conflictos sociales en 1º y 2º nivel de importancia

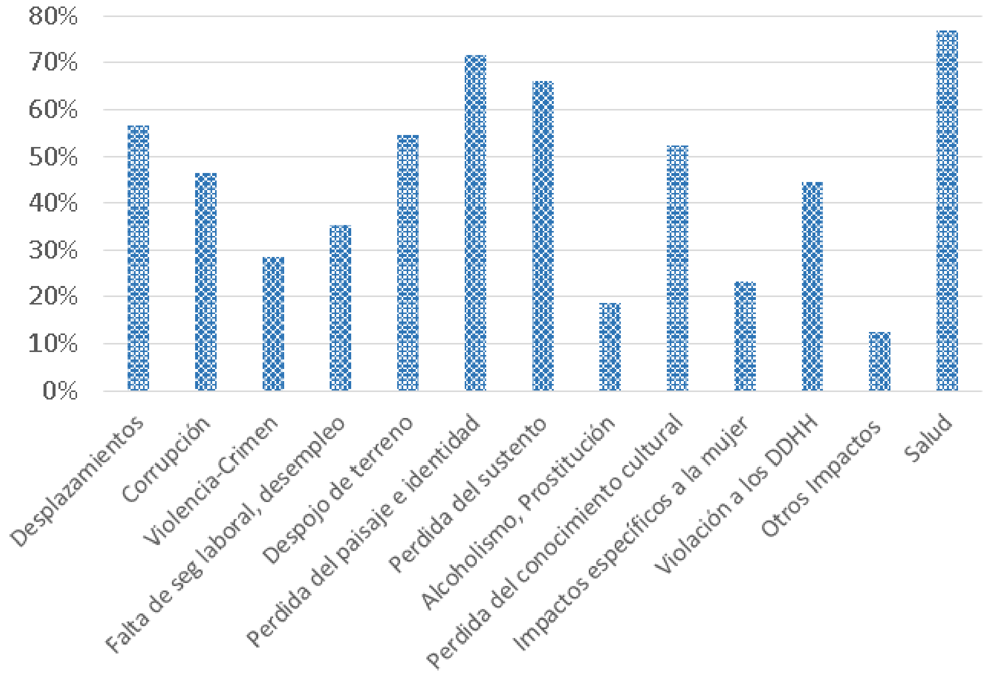
El inadecuado tratamiento de los conflictos sociales afecta el resultado de los proyectos, superando a los problemas técnicos (Naderpajouh et al. 2014). De hecho, los conflictos sociales se manifiestan a través de movimientos activistas de los grupos de interés que hacen sentir su punto de vista hacia la sociedad. La Figura 1.2 representa las formas de movilización empleadas por los grupos afectados, respecto de los 293 casos detectados. Entre ellas, el uso de medios de comunicación y campañas publicitarias son el sistema más usado. Además, las quejas oficiales, manifestaciones en la vía pública y la conformación de redes de acciones colectivas dificultan el normal desarrollo de un proyecto. Por lo general, los conflictos sociales apuntan a dinámicas de creciente participación e interacción de los actores de interés para buscar solución a sus demandas en el corto plazo (Naderpajouh et al. 2014).

El desarrollo de las infraestructuras impacta múltiples aspectos sociales no siempre considerados en las etapas iniciales de desarrollo de los proyectos (Valdés-Vásquez y Klotz 2013). La Figura 1.3 muestra los impactos sociales registrados en los casos de infraestructuras. Entre ellos los impactos sobre la salud de la población y de los trabajadores, la pérdida de identidad local y la alteración del sustento familiar son los más frecuentes, superando el 60% de los casos. Los impactos sociales abarcan aspectos no necesariamente cuantificables. Aspectos como la identidad local, pérdida de la cultura tradicional o la corrupción son difíciles de tratar a priori.



Fuente: Elaboración propia basada en la base de datos de Temper et al. (2015)

Figura 1.2: Formas de movilización de los grupos afectados



Fuente: Elaboración propia basada en la base de datos de Temper et al. (2015)

Figura 1.3: Impactos sociales de los proyectos de infraestructuras

Por otro lado, bajo una mirada de desarrollo, la eficiencia operativa de las infraestructuras permite una reducción de los costes y mejora la aptitud del uso para la sociedad. En este sentido, las infraestructuras constituyen un nexo intermediario que abre oportunidades para el desarrollo social. Sin embargo, como se mostró previamente, hoy en día los procesos de desarrollo resultan espacialmente desnivelados y desiguales. Por ejemplo, en Iberoamérica la reasignación generalizada de los recursos se enfoca hacia las áreas de mayor concentración de la actividad económica y productiva (Lupano 2013). Esto empuja a una jerarquización de localizaciones de infraestructuras dependiendo de la evolución del mercado. Ciertamente, esta jerarquización contribuye a una segmentación territorial con brechas de desarrollo (Lupano 2013). En consecuencia, la ausencia de infraestructura adecuada y productividad conduce a un fenómeno circular de pobreza y de desigualdad entre regiones.

Las infraestructuras no solo son relevantes por su naturaleza socio-económica y productiva sino especialmente por su impacto social (Lupano 2013). Por ejemplo, las infraestructuras de transporte permiten el acceso a las viviendas, oportunidades de trabajo y a los bienes culturales. En este sentido, Munda (2004) expone que el desarrollo para alcanzar la sostenibilidad debe considerar dos aspectos. Primero, el sentido ético de la equidad en la distribución de los beneficios y costos actuales e intergeneracionales. Segundo, considerar un modelo de desarrollo no basado exclusivamente en el crecimiento económico industrializado. En la evolución social existe una interacción constante y activa de los organismos con su entorno explicado a través del Paradigma de la Co-evolución (Maturana y Varela 1997). En esta línea, en un contexto geográfico las personas tienden a agruparse y el éxito del grupo depende de auto regulación en base a la cultura, sistemas de valores, creencias y formas del arte que sustentan la organización social y racionalizan el comportamiento. De esta forma, el contexto es clave en el logro de la sostenibilidad.

El conocimiento acumulado y las experiencias locales son resultado de un largo proceso co-evolutivo imprescindible en una evaluación social. En este sentido, la participación es esencial en el desarrollo sostenible (Munda 2004, Tudela et al. 2006). Además, los aspectos sociales no tienen una medida estándar. Es decir, existe una multiplicidad de observadores con valores legítimos; además, en un sistema democrático, la participación es indispensable. Los métodos de evaluación de impacto social convencionales consideran estos elementos a través de técnicas cualitativas para un periodo limitado. Sin embargo, no son adecuados a efectos de comparación de infraestructuras, predicción del impacto e implementación (Delgado y Romero 2016, Karami et al. 2017). En efecto, las agencias públicas encargadas de la priorización de infraestructuras requieren de estructuras metodológicas que apoyen su proceso de toma de decisión (Resendez et al. 2014, Delgado y Romero 2016).

Considerando lo anterior, existe una dificultad técnica de cómo representar las múltiples identidades en un modelo de toma de decisión. Si es aceptado que el mundo real es multidimensional, entonces la evaluación de proyectos públicos requiere integrar distintos puntos de vista. Los métodos multicriterios satisfacen esta condición, sin embargo aún los aspectos sociales presentan una menor consideración en las evaluaciones (Labuschagne et al. 2005, Diaz-Sarachaga et al. 2016). Además, el tratamiento integrado en los métodos de evaluación que consideren la equidad (Thomopoulos et al. 2013), las necesidades del contexto y la participación (Valdés-Vásquez y Klotz 2013), la incertidumbre (Delgado y Romero 2016), o el aprendizaje social (Griffths et al. 2012, Valdés-Vásquez y Klotz 2013), no son abordados completamente. En efecto, estas condiciones fundamentales para alcanzar un estado de sostenibilidad social no están íntegradas en los procesos de toma de decisión. De acuerdo a lo anterior, la implementación de los métodos multicriterios que abordan aspectos sociales ha sido variable y no complemente adecuada en todos los ámbitos del desarrollo de una infraestructura. Esto puede deberse a la escasez de estudios de implementación de la sostenibilidad social en infraestructuras (Labuschagne et al. 2005). Además existe una falta de datos longitudinales que den cuenta de las condiciones que determinan el desarrollo social (Chow et al. 2014, Labuschagne y Brent 2006). A lo anterior se agrega la necesidad de entrenamiento para tratar los aspectos sociales por parte de ingenieros o tomadores de decisión (Valdés-Vásquez y Klotz 2013, Griffths et al. 2012). De esta forma, el marco social requiere un estudio dentro del análisis global de la evaluación multicriterio.

La evaluación multicriterio es, en principio, una estructura adecuada para dar operatividad a la evaluación social de infraestructuras (Munda 2004, Thomopoulos et al. 2013). Algunos estudios multicriterio han representado criterios cuantitativos y cualitativos simultáneamente (Tudela et al. 2006, Resendez et al. 2014, Díaz-Sarachaga et al. 2016). Además, permiten una mayor flexibilidad para tratar aspectos interconectados (Mkrtchyan et al 2016) y complementar con otras técnicas que permitan una mejor representación, incluso en contextos con información limitada (Delgado y Romero 2016). Estas cualidades no son propias de otras técnicas de evaluación.

1.2.2 Contexto específico

La subsección anterior introdujo el contexto general del enfoque social en la evaluación de las infraestructuras y la consideración de los métodos multicriterio para su representación. En esta subsección se provee una sinopsis de las principales líneas de investigación en que se ha enfocado esta tesis. Dado lo anterior, la pregunta general de investigación es la siguiente: *¿Es posible evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones?* Esta pregunta busca indagar en la implementación de tratamientos adecuados para evaluar la sostenibilidad social e integrarla en la toma de decisión de la mejor infraestructura, en consideración a un contexto determinado. Derivado de esta pregunta de investigación surge el siguiente objetivo general de la tesis: *Evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones*.

A partir de la pregunta general de la investigación, se plantean las preguntas secundarias para abordar las brechas específicas de la investigación. Los subsiguientes seis capítulos de esta tesis abordan las preguntas secundarias de la investigación. En la Figura 1.4 se ilustra la relación constituyente de los capítulos de esta tesis. En primer lugar el capítulo 2 identifica el estado del arte de los métodos multicriterios para la evaluación social de infraestructuras; a partir de este punto se proponen estudios para abordar las mejoras detectadas en el análisis de la laguna del conocimiento. El capítulo 3 contextualiza criterios sociales trascedentes en el ciclo de vida de las infraestructuras. El capítulo 4 propone un método para el aprendizaje de la sostenibilidad de infraestructuras con énfasis en la dimensión social. El capítulo 5 presenta un método multicriterio que evalúa la sostenibilidad social al corto y largo plazo y prioriza alternativas de infraestructuras que ya han sido predefinidas. El capítulo 6 expone un tratamiento de la incertidumbre de los datos de entrada del método propuesto en el capítulo 5. Finalmente, el capítulo 7 presenta una generalización del método anterior en que las alternativas aún no han sido definidas; este método determina las características de infraestructuras y sus contextos con mejor contribución social para establecer alternativas.

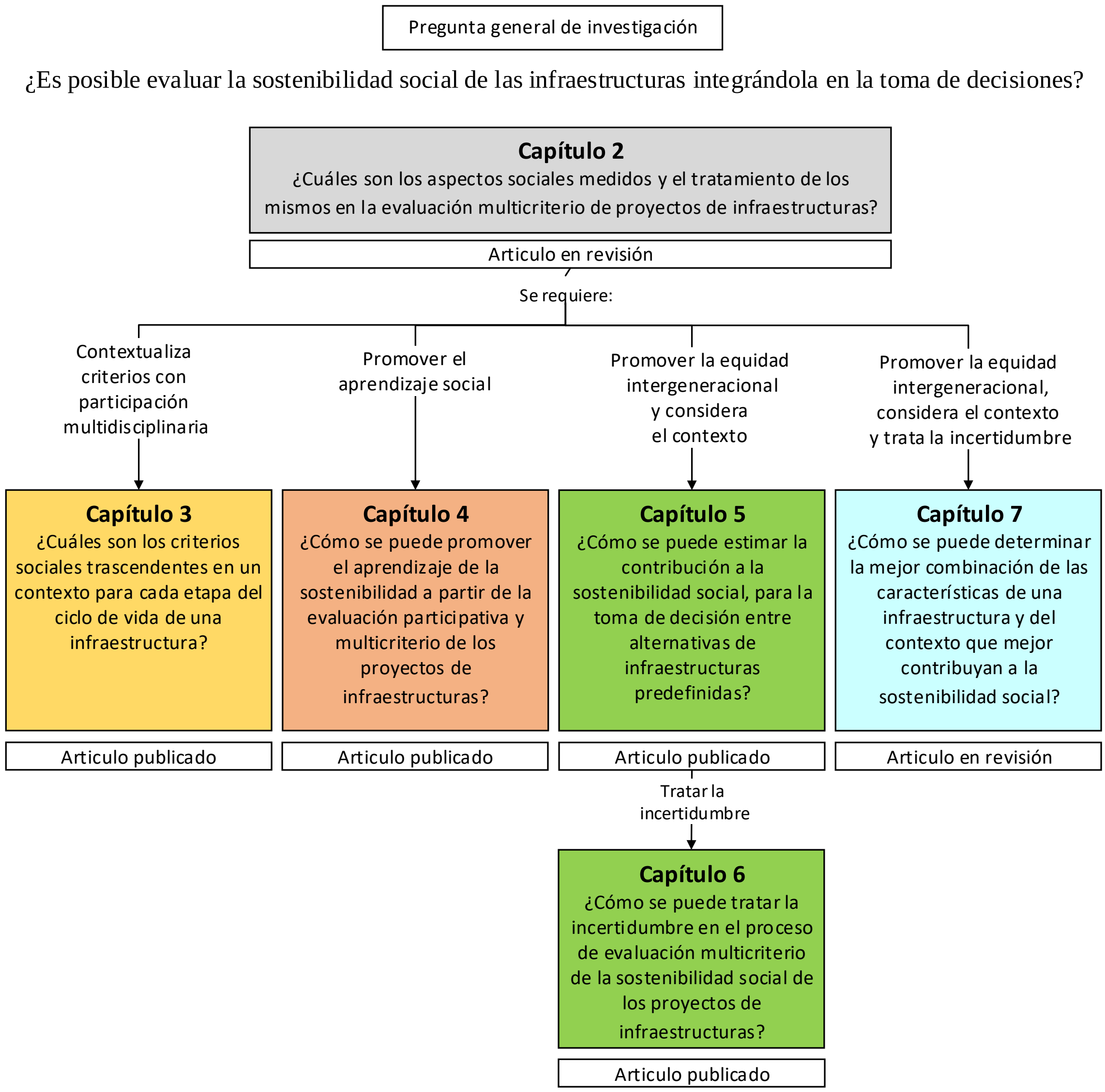


Figura 1.4: Relación de los capítulos constituyentes de la tesis

Capítulo 2: Trends in the multi-criteria assessment of the social sustainability of infrastructures - Tendencias en la evaluación multi-criterio de la sostenibilidad social de infraestructuras.

El enfoque general de esta tesis está centrado en la evaluación multicriterio de la sostenibilidad social de proyectos de infraestructuras. En este contexto el capítulo 2 aporta el estado del conocimiento de los aspectos sociales en los métodos multicriterio.

Los métodos tradicionales presentan debilidades al momento de evaluar aspectos sociales de la sostenibilidad. Aspectos como la equidad, variables cualitativas y consideraciones democráticas no están representadas (Mostafa y El-Gohary 2014). Los métodos multicriterios son una alternativa de evaluación que puede considerar los aspectos sociales (Thomopoulos et al. 2013). Sin embargo, los aspectos sociales aún presentan una menor consideración en la evaluación de la sostenibilidad (Diaz-Sarachaga et al. 2016). Algunos estudios consideran la evaluación social multicriterio: representando criterios cuantitativos y cualitativos (Tudela et al. 2006); considerando la equidad social en la distribución de los efectos de la infraestructura (Thomopoulos et al. 2013); contextualizando la evaluación y a los participantes de acuerdo al momento y lugar de implementación (Valdés-Vásquez y Klotz 2013); tratando la incertidumbre de los datos (Delgado y Romero 2016); o promoviendo un aprendizaje (ISI 2015). La implementación de estos tratamientos ha sido variable y no complemente entendida en todos los ámbitos del desarrollo de una infraestructura (Griffths et al. 2012, Valdés-Vásquez y Klotz 2013). De esta forma, los métodos multicriterios empleados para tratar la dimensión social de las infraestructuras requieren una revisión. Estos argumentos constituyen el punto de partida de esta sección de la investigación.

Dado este contexto, la brecha y la pregunta de investigación del capítulo 2 son:

- *Brecha de investigación del capítulo 2*: Existe una necesidad de explorar los aspectos sociales y su tratamiento en la evaluación multicriterio de proyectos de infraestructuras.
- *Pregunta de investigación del capítulo 2*: ¿Cuáles son los aspectos sociales medidos y el tratamiento de los mismos en la evaluación multicriterio de proyectos de infraestructuras?

Capítulo 3: Social sustainability in the life cycle of chilean public infrastructure - Sostenibilidad social en el ciclo de vida de las infraestructuras públicas chilenas.

Dentro del ámbito general de esta tesis, el capítulo 3 contextualiza los criterios sociales trascedentes en ciclo de vida de infraestructuras, a través de un procedimiento de evaluación que tenga en cuenta la sostenibilidad social.

Los aspectos sociales se abordan en la literatura a partir de 1970 (NEPA 1969) y con mayor énfasis a partir del informe Brundtland (WCED 1987). Entre los estudios identificados, Labuschagne et al. (2005) propone una estructura conceptual de la sostenibilidad social que presenta una completitud de aspectos e integración de enfoques. Sin embargo los aspectos sociales considerados en una toma de decisión dependen del punto de vista de los actores involucrados del contexto (Valdés-Vásquez y Klotz 2013), y las etapas del ciclo de vida de la infraestructura (Boyle et al. 2010). Una opción metodológica expuesta en la literatura es el método Delphi. El método Delphi ha sido aplicado para lograr el consenso a través del juicio de especialistas (Hallowell y Gambatese 2010). De esta forma, es necesario identificar los criterios sociales influenciados en el ciclo de vida de las infraestructuras de acuerdo con el contexto. Estos argumentos constituyen el punto de partida en esta sección de la investigación.

La brecha y la pregunta de investigación del capítulo 3 son:

- *Brecha de investigación del capítulo 3*: Existe una necesidad de contextualizar los criterios sociales impactados en el ciclo de vida de una infraestructura.
- *Pregunta de investigación del capítulo 3*: ¿Cuáles son los criterios sociales trascendentes en un contexto para cada etapa del ciclo de vida de una infraestructura?

Capítulo 4: Appraisal of infrastructure sustainability by graduate students using an active-learning method - Evaluación de la sostenibilidad de infraestructuras por estudiantes de posgrado usando un método de aprendizaje activo.

Una de las necesidades de mejora dentro del ámbito general de esta tesis es fortalecer el aprendizaje social dentro del proceso de evaluación. En este sentido, el capítulo 4 propone un método de aprendizaje activo a través de una evaluación multicriterio de la sostenibilidad de infraestructuras.

Byrne et al. (2013) exponen la necesidad de un análisis reflexivo que mejore la forma de pensar respecto de la sostenibilidad para causar un impacto sobre las toma de decisión de los profesionales. Un método de aprendizaje activo promueve los juicios de valor sobre la sostenibilidad, está centrado en el estudiante, motiva, promueve la participación y actúa desde la experiencia práctica (Whitmer et al. 2010). En un proyecto de infraestructura las opiniones respecto de la sostenibilidad dependen de la perspectiva de cada actor. La conciencia, experiencia y el conocimiento influyen en la toma de decisión sostenible (Byrne et al. 2013). Las decisiones sostenibles requieren de métodos que integren diversas opiniones, en un proceso estructurado y representativo de los participantes (Munda 2004). Además, existen experiencias exitosas en la ingeniería que promueven la sostenibilidad a través de técnicas de aprendizaje activo (Du et al. 2013, El-Adaway 2015); sin embargo, las estrategias focalizadas en la sostenibilidad de infraestructuras en un contexto estructurado y participativo son escasas.

De esta forma la brecha y la pregunta de investigación del capítulo 4 son:

- *Brecha de investigación del capítulo 4*: Se necesitan métodos que promuevan el aprendizaje social de la sostenibilidad con un enfoque en la evaluación participativa y multicriterio de los proyectos de infraestructuras.
- *Pregunta de investigación del capítulo 4*: ¿Cómo se puede promover el aprendizaje de la sostenibilidad a partir de la evaluación participativa y multi-criterio de los proyectos de infraestructuras?

Capítulo 5: Method for estimating the social sustainability of infrastructure projects – Método para estimar la sostenibilidad social de proyectos de infraestructuras.

Dentro del enfoque general de esta tesis se requiere mejorar la contextualización y el alcance intergeneracional en los métodos de evaluación. Esto se ha logrado a través de la evaluación de la sostenibilidad social a corto y largo plazo para establecer la viabilidad de los proyectos de infraestructuras. Bajo estos enfoques se consideran dos líneas de estudio. La primera incluida en el capítulo 5 propone un método para comparar la contribución a la sostenibilidad social de proyectos de infraestructuras predefinidos. Por su parte en el capítulo 7 se propone un método generalizado, en que las alternativas de proyectos no están definidas, para determinar las características de infraestructuras y contextos con mayor contribución social. Específicamente, el capítulo 5 propone un método determinista que emplea funciones de transferencia y el método Delphi para valorar la relación de cada alternativa en su contexto. Luego, los valores de contribución social a corto y largo plazo de cada alternativa se comparan mediante la distancia al ideal, maximizando su aportación social.

Los organismos públicos encargados de la toma de decisiones requieren de métodos para comparar socialmente alternativas de proyectos de infraestructura (Resendez et al. 2014, Delgado y Romero et al. 2016). Estas alternativas corresponden a proyectos predefinidos en la etapa viabilidad. Otras evaluaciones económicas o ambientales se han desarrollado en esta instancia para predecir el impacto de los proyectos y corregir falencias oportunamente (Gervasio y Da Silva 2012, Penadés-Pla et al. 2016). Sin embargo, normalmente la evaluación de la sostenibilidad social se ha tratado de igual forma que las evaluaciones ambientales y económicas (Domínguez-Gómez 2016). En otros casos evaluaciones cualitativas del impacto social dificultan la comparación para la toma de decisiones (Delgado y Romero 2016, Karami et al. 2017). Los métodos multicriterios son adecuados para representar la realidad multidimensional de los aspectos sociales (Munda 2004). Además, una estructura jerárquica facilita la representación de la influencia de criterios para medir el aporte de cada alternativa (Saaty 2004). En efecto, algunos estudios proponen estructuras jerárquicas para medir la sostenibilidad (Tudela et al. 2006, de la Cruz et al. 2015). Sin embargo la contribución social requiere considerar la interacción con el contexto y el alcance intergeneracional; que no han sido incluidos en los procesos de evaluación. Específicamente, la contribución social de una infraestructura depende de su interacción con el contexto de ubicación (Valdés-Vásquez y Klotz 2013). En un contexto, el nivel de desarrollo y los intereses de la comunidad pueden afectar la percepción de una infraestructura (Max-Neef 1995). Además, la distribución de los beneficios de una infraestructura tiene un efecto al corto y largo plazo, no necesariamente simultáneos (Gannon y Liu 2001, Foth et al. 2013, Mostafa y El-Gohary 2014). De este modo, ambos horizontes de evaluación deben complementarse para el aprovechamiento intergeneracional de los recursos públicos. Estos argumentos constituyen el punto de partida de esta sección de la investigación.

La brecha del conocimiento y la pregunta de investigación explorada del capítulo 5 son:

- *Brecha de investigación del capítulo 5:* En las fases de viabilidad se requieren estudios que evalúen la sostenibilidad social de proyectos de infraestructuras e influyan en la toma de decisión entre alternativas predefinidas.
- *Pregunta de investigación del capítulo 5:* ¿Cómo se puede estimar la contribución a la sostenibilidad social, para la toma de decisión entre alternativas de infraestructuras predefinidas?

Capítulo 6: Assessing the social sustainability contribution of an infrastructure project under conditions of uncertainty - Evaluación de la contribución a la sostenibilidad social de una infraestructura bajo condiciones de incertidumbre.

Dentro del enfoque general de esta tesis, el capítulo 6 propone un tratamiento para la incertidumbre complementario al método propuesto en el capítulo 5.

Los aspectos sociales requieren un tratamiento adecuado en la evaluación de la sostenibilidad. En esta línea el capítulo 5 propone un método determinístico para la evaluación multicriterio de la sostenibilidad social de infraestructuras (Sierra et al. 2017). Sin embargo en un proyecto de infraestructura, la evaluación de los aspectos sociales no está libre de incertidumbre, en especial cuando la valoración depende del ser humano (Delgado y Romero 2016). Además, la estimación temprana de los efectos de una infraestructura no es necesariamente confiable (Gervásio y Da Silva 2012). En algunos casos las fuentes de información local permiten preestablecer la variabilidad de ciertos aspectos sociales. Sin embargo, las bases de datos relacionadas con infraestructuras y aspectos sociales cualitativos aún son escazas (Diaz-Sarachaga et al. 2016). Por lo tanto la experiencia de expertos locales pueden ser una fuente de información que puede ser modelada para tratar con la incertidumbre (de la Cruz et al. 2015, Jato-Espino et al. 2014). De esta forma, estos enfoques constituyen el punto de partida en esta sección de la investigación

La brecha del conocimiento y la pregunta de investigación explorada en el capítulo 6 son:

- *Brecha de investigación del capítulo 6:* Es necesario incorporar tratamientos de la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de los proyectos de infraestructuras.
- *Pregunta de investigación del capítulo 6*: ¿Cómo se puede tratar la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de los proyectos de infraestructuras?

Capítulo 7: Bayesian network method for making decision about social sustainability of infrastructure projects – Método de redes Bayesianas para la toma de decisiones respecto de la sostenibilidad social de proyectos de infraestructuras.

Dentro del enfoque general de esta tesis se requiere mejorar la contextualización y el alcance intergeneracional en los métodos de evaluación. Estas condiciones se incluyen en los métodos propuestos en los capítulos 5 y 7 para evaluar la sostenibilidad social a corto y largo plazo. El capítulo 7 propone una generalización del método del capítulo 5, en que las alternativas aún no han sido definidas (no se conocen sus características ni el contexto de ubicación). Por lo tanto, se busca identificar las características de infraestructuras y de contextos que mejor contribuyan a la sostenibilidad social. Las alternativas que se empleen deben cumplir con las características que defina la solución óptima. De este modo la implementación del método se realiza previamente a la aplicación del método del capítulo 5. El método propuesto en este capítulo 7 es, por lo tanto, más general que el del capítulo 5. Específicamente, la contribución de cada combinación de características a la sostenibilidad social se obtiene mediante redes bayesianas; a continuación, se lleva a cabo una optimización multiobjetivo que maximiza la contribución social de una combinación de características.

La planificación de infraestructuras orientada hacia la sostenibilidad debe compatibilizar las características de los proyectos y sus contextos de ubicación (Malekpour et al. 2015). Sin embargo una toma de decisión entre características de una infraestructura tipo y los contextos, debe considerar cada variable de decisión y sus combinaciones de respuesta. Esto implica una evaluación sobre una muestra poblacional difícil de tratar bajo las técnicas multicriterio convencionales (Diez y Druzdel 2007). Además, análogamente a las propuestas de los capítulos 5 y 6 la evaluación de la sostenibilidad social de un proyecto debe considerar: un alto grado de incerteza (Gervásio y Da Silva 2012, Delgado y Romero 2016); la interacción con el contexto (Mostafa y El-Gohary 2014); y el alcance intergeneracional a través de la consideración simultanea de corto y largo plazo (Munda 2004, Gannon y Liu 2001). En este caso, una estructura de toma de decisión causa-efecto puede representar las relaciones entre variables de decisión de infraestructuras y contextos con los criterios de evaluación, y la contribución social a corto y largo plazo (Gannon y Liu 2001, Labuschagne et al. 2005, Foth et al. 2013). De esta forma, las técnicas de razonamiento Bayesiano pueden dar una mejor operatividad al modelo. Esta técnica da un tratamiento probabilístico de los aspectos dependientes e independientes de la estructura (Mkrtchyan et al. 2016). Los organismos públicos pueden emplear este método para orientar la planificación de alternativas de infraestructuras hacia la sostenibilidad social. Estas consideraciones constituyen el punto de partida en este capítulo.

La brecha del conocimiento y la pregunta de investigación explorada en el capítulo 7 son:

- *Brecha de investigación del capítulo 7:* Faltan herramientas para determinar las características de una infraestructura y del contexto que mejor contribuyan a la sostenibilidad social cuando las alternativas no están aún definidas.
- *Pregunta de investigación del capítulo 7*: ¿Cómo se puede determinar la mejor combinación de las características de una infraestructura y del contexto que mejor contribuyan a la sostenibilidad social?

1.2.3 Objetivos de la investigación

Para abordar las preguntas de investigación se precisa el cumplimiento de un objetivo principal compuesto de seis objetivos secundarios de investigación alineados con cada capítulo intermedio:

Objetivo principal:

El objetivo principal de la tesis es: *Evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones*.

Objetivos secundarios:

- Explorar los aspectos sociales y su tratamiento en la evaluación multicriterio de proyectos de infraestructuras (Capítulo 2).
- Contextualizar los criterios sociales trascendentes en el ciclo de vida de una infraestructura (Capítulo 3).
- Plantear un método de aprendizaje social de la sostenibilidad a través de la evaluación participativa y multicriterio de proyectos de infraestructuras (Capítulo 4).
- Proponer un método para evaluar la contribución de proyectos de infraestructuras a la sostenibilidad social, que permita la toma de decisión entre alternativas predefinidas (Capítulo 5).
- Formular un tratamiento de la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de proyectos de infraestructuras (Capítulo 6).
- Plantear un método multicriterio que determine las características generales de una infraestructura y del contexto (sin que existan alternativas predefinidas) que mejor contribuyan a la sostenibilidad social (Capítulo 7).

1.3 Métodos de investigación

La presente tesis emplea diferentes enfoques para dar respuesta a los objetivos de investigación. Un enfoque deductivo permite recoger desde la teoría los razonamientos lógicos y suposiciones teóricas para ser adaptados a contextos específicos. De esta forma, los estudios exploratorios de la literatura han permitido establecer el estado de conocimiento de esta investigación (Capítulo 2). Además, el enfoque deductivo permitió dar funcionalidad a las variables definidas desde la teoría, a través de una propuesta de diferentes métodos (Capítulos 4 al 7). Por otro lado un enfoque inductivo se construye a partir casos específicos para conformar teorías más generalizadas; en esta línea, a partir de un estudio de caso se determinaron los criterios sociales trascendentes en el desarrollo de proyectos de infraestructuras chilenos (Capítulo 3).

El alcance general de la investigación recurre a los métodos multi-criterio para abordar la evaluación de los aspectos sociales. Este conjunto de métodos permite evaluar aspectos sociales multidimensionales que requieren tratamientos diferenciados, procesos participativos y complementarse con otras técnicas; todo en forma simultanea (Munda 2004, Tudela et al. 2006, Delgado y Romero 2016). Estas condiciones son limitadas en la implementación de otros métodos.

De acuerdo a lo anterior, en cada capítulo, se emplean diversos métodos multi-criterios y herramientas de investigación que se exponen a continuación:

- En el capítulo 2 se emprende una revisión del estado del arte a través de dos fases. En la fase uno son seleccionados un conjunto de estudios aptos a través de una estrategia de búsqueda en la base de datos *Web of Science*. En la segunda fase se lleva a cabo un seguimiento de las referencias y citaciones de los estudios seleccionados. Los estudios se seleccionan de acuerdo al tipo de documento y pertinencia con la línea de investigación. Una revisión en profundidad sobre una muestra final de 94 estudios permite extraer los datos de análisis, establecer afinidades y contrastes.

- En el capítulo 3 se emplea un estudio de caso que aplica el método Delphi a 24 expertos multidisciplinarios relacionados con el desarrollo social y de infraestructuras. El método Delphi es una técnica de comunicación estructurada y sistemática para predecir conceptualizaciones complejas a través del libre juicio de especialistas (Hallowell y Gambatese 2010). En complemento una estadística no paramétricas de tipo binomial y coeficiente de Kendall establece la convergencia de opiniones. Estos métodos permiten capturar la información del contexto en un tiempo razonable y una representación teórica. Además permiten que los propios especialistas se retroalimenten, siendo apropiado para reducir la incertidumbre y promover el aprendizaje del contexto.

- En el capítulo 4 se aplica un enfoque de aprendizaje activo a través de la propuesta de un método multi-criterio de evaluación de la sostenibilidad de infraestructuras. El aprendizaje activo de la sostenibilidad aporta una implementación práctica en escenarios de la vida real, promueve el pensamiento crítico y la investigación acción participativa (Du et al. 2013). Complementariamente, se aplican el Proceso Analítico Jerárquico (AHP en inglés), un análisis de conglomerados y un caso de estudio. El AHP permite promueve un análisis crítico a través de la comparación del nivel de importancia de los múltiples criterios tomados en cuenta. Una escala de importancia, la determinación de valores propios e índices de consistencia son parte del método (Saaty 2004). El análisis de conglomerados permite agrupar los juicios de los múltiples evaluadores (estudiantes) y establecer perfiles de preferencia. Finalmente, a través de un caso de estudio se aplica la evaluación del método en desarrollo de un proyecto de infraestructura.

- El capítulo 5 propone un método multi-criterio de evaluación de la sostenibilidad social de infraestructuras. Específicamente, se emplea el método AHP-Delphi, el método integrado de valor de estructuras sostenibles (MIVES) y un sistema de programación por compromiso. La combinación de los métodos AHP y Delphi permite consensuar los pesos de los criterios usados en la estructura de evaluación. Además a la vista de los participantes su aplicación y procesamiento de la información es más intuitiva y rigurosa que otros métodos, lo que aporta legitimidad. La función de valor del método MIVES normaliza los criterios de la sostenibilidad social de acuerdo al nivel de desarrollo del contexto (de la Cruz et al. 2015). Esta función permite establecer diferentes curvas de valor con contornos suaves al adecuar sus parámetros. Otras funciones alteran significativamente la satisfacción de los atributos de una infraestructura. El sistema de programación por compromiso optimiza las alternativas de infraestructuras de acuerdo a la relación de distancia de un punto ideal y anti-ideal (Sierra et al. 2017). Esta técnica multiobjetivo permite identificar soluciones equilibradas e intuitivas a vista de los participantes en una gráfica de Pareto.

- El capítulo 6 complementa el método propuesto del capítulo 5 a través de la inclusión del tratamiento de la incertidumbre. Se emplea el enfoque probabilístico y el método de Montecarlo para tratar los criterios inciertos (de la Cruz et al. 2015). Este enfoque permite distribuir la incertidumbre hasta el final de proceso y trata indicadores definidos de acuerdo al contexto de evaluación. Además, el uso de herramientas de investigación social (entrevistas, estudios de campo y revisión documental) permite estimar los parámetros locales no documentados en cada distribución (Munda 2004, Delgado y Romero 2016).

- Finalmente el capítulo 7 emplea un modelo de toma de decisión multi-criterio basado en la teoría de razonamiento Bayesiano. Se utiliza un grafo acíclico que representa las dependencias probabilísticas e independencias entre un conjunto de nodos constituidos por variables de decisión y contribuciones a la sostenibilidad (Mkrtchyan et al. 2016). Este enfoque permite integrar la experiencia de los tomadores de decisión, representar la incertidumbre y la interrelación de variables que influyen sobre la sostenibilidad en un solo método. Complementariamente, un algoritmo de búsqueda armónica (García-Segura et al. 2015) optimiza un conjunto de características de diseño de un proyecto de infraestructuras socialmente sostenible. Este último requiere de pocos parámetros de ajuste y trabaja en contextos poblacionales con amplia diversificación, lo cual le hacen suficientemente robusto.

1.4 Estructura general de la investigación

La estructura general de esta investigación sigue el formato de 6 artículos, donde los capitulo intermedios son manuscritos autónomos publicados (capítulos 3, 4, y 5) o en proceso de publicación (capítulos 2, 6 y 7) en revistas científicas indexadas. En consistencia con lo anterior, cada capítulo incorpora sus propias referencias, y el conjunto de todas ellas se incluye al final de la tesis. El capítulo 1 entrega una visión general de la tesis destacando la necesidad principal y desglosando el objetivo de investigación en 6 documentos. Específicamente este capítulo contextualiza el ámbito de la investigación, precisa la laguna del conocimiento y los objetivos de investigación. Además, proporciona una visión general de los métodos y enfoques de investigación empleados. La Figura 1.5 ilustra la actuación en cada uno de los capítulos intermedios. Dado el formato independiente de cada capítulo existe un cierto grado de superposición de la revisión de la literatura y métodos empleados. Es por ello que el capítulo 8 presenta una discusión integrada que da respuesta a los objetivos de investigación. Finalmente, el capítulo 9 expone las contribuciones, recomendaciones, limitaciones y proporciona sugerencias de trabajos futuros.

	Laguna del conocimiento	Objetivo de investigación	Método de investigación
Capítulo 2	Existe una necesidad de explorar los aspectos sociales y su tratamiento en la evaluación multicriterio de proyectos de infraestructuras	Explorar los aspectos sociales y su tratamiento en la evaluación multicriterio de proyectos de infraestructuras	**Revisión de la literatura** 1995 – 2017. Indaga en base de datos WOS y seguimiento de referencias y citaciones.
Capítulo 3	Existe una necesidad de contextualizar los criterios sociales impactados en el ciclo de vida de una infraestructura	Contextualizar los criterios sociales trascendentes en el ciclo de vida de una infraestructura	**Estudio de caso** que emplea el método Delphi en 24 expertos; una prueba binomial y el coeficiente de Kendall.
Capítulo 4	Se necesitan métodos que promuevan el aprendizaje social de la sostenibilidad con un enfoque en la evaluación participativa y multicriterio de los proyectos de infraestructuras.	Plantear un método de aprendizaje social de la sostenibilidad a través de la evaluación participativa y multicriterio de proyectos de infraestructuras	**Diseña un método de aprendizaje-activo** a través de análisis multicriterio AHP, análisis de clúster y un caso de estudio.
Capítulo 5	En las fases de viabilidad se requieren estudios que evalúen la sostenibilidad social de proyectos de infraestructuras e influyan en la toma de decisión entre alternativas predefinidas	Proponer un método para evaluar la contribución de proyectos de infraestructuras a la sostenibilidad social, que permita la toma de decisión entre alternativas predefinidas	**Diseña un método evaluación multi-criterio** a través de Delphi, AHP, MIVES y una programación por compromiso
Capítulo 6	Es necesario incorporar tratamientos de la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de los proyectos de infraestructuras	Formular un tratamiento de la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de proyectos de infraestructuras	**Emplea un tratamiento probabilístico y método de Montecarlo** para tratar la incertidumbre en la evaluación multi-criterios
Capítulo 7	Faltan herramientas para determinar las características de infraestructuras y de contextos que mejor contribuyan a la sostenibilidad social cuando las alternativas no están aún definidos	Plantear un método multicriterio que determine las características generales de una infraestructura y del contexto (sin que existan alternativas predefinidas) que mejor contribuyan a la sostenibilidad social	**Emplea la teoría de redes bayesianas y un algoritmo de búsqueda armónica** para diseñar un método de apoyo a la toma de decisión.

Figura 1.5: Estructura general de la investigación

1.5 Referencias

Anand S. y Sen A. (2000). Human development and economic sustainability. World Development, 28(12): 2029-2049.

Boyle C., Mudd G., Mihelcic J.R., Anastas P., Collins T., Cilligan P., Edwards M., Gabe J., Gallagher P., Handy S., Krumdieck S., Kao J.J., Lyles L.D., Mason I., Mcdowall R., Pearce A., Riedy C., Russell J., Schnoor J., Trotz M., Venables R., Zimmerman J.B., Fuchs V., Miller S., Page S. and Reeder-Emery K. (2010). Delivering sustainable infrastructure that supports the urban built environment. Environmental Science and Technology, 44(1): 4836–4840.

Byrne, E.P., Desha C.J., Fitzpatrick, J.J., Hargroves, K., (2013). Exploring sustainability themes in engineering accreditation and curricula. Int. J. of Sustain. in High. Educ. 14(4), 384–403, doi: 10.1108/IJSHE-01-2012-0003.

Bueno, P.C., Vassallo, J.M., Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods. Transp. Rev. 35(5): 622–649, doi:10.1080/01441647.2015.1041435

Chow, J.Y.J., Hernandez, S. V., Bhagat, A., McNally, M.G. (2014). Multi-Criteria Sustainability Assessment in Transport Planning for Recreational Travel. Int. J. Sustain. Transp. 8(2): 151–175. doi:10.1080/15568318.2011.654177

CIB (Internacional Council for Research and Innovation in Building and Construction) (2002). Agenda 21 for Sustainable Construction in Developing Countries. Report Publication No. E0204, Pretoria, South Africa.

De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J., (2015). Chapter 4 Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1 : The MIVES - Monte Carlo Method, in: Corona, C., Arredondo, A., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 69–106. doi:10.4018/978-1-4666-6631-3.ch004

Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. Environ. Model. Softw. 77(1): 108-121, doi: 10.1016 / j.envsoft.2015.12.011.

Diaz-Sarachaga, J.M., Jato-Espino, D., Alsulami, B., Castro-Fresno, D. (2016). Evaluation of existing sustainable infrastructure rating systems for their application in developing countries. Ecol. Indic. 71(1): 491–502, doi:10.1016/j.ecolind.2016.07.033

Diez, F. J., Druzdrel, M. J. (2007). "Canonical probabilistic models for knowledge engineering" Technical Rep. CISIAD-06-01, Universidad Nacional de Educacion a Distancia, Madrid, Spain, ⟨http://www.ia.uned.es/~fjdiez/papers/canonical.pdf⟩ (Feb. 01, 2016).

Domínguez-Gómez, J. A. (2016). Four conceptual issues to consider in integrating social and environmental factors in risk and impact assessments. Environmental Impact Assessment Review, 56(1): 113–119, doi: 10.1016/j.eiar.2015.09.009

Du, X., Su, L., Liu, J., (2013). Developing sustainability curricula using the PBL method in a Chinese context. J. of Clean. Prod. 61(1): 80–88, doi: 10.1016/j.jclepro.2013.01.012.

El-Adaway, I., Pierrakos, O., Truax D., 2015. Sustainable construction education using problem-based learning and service learning pedagogies. J. Prof. Iss. Eng. Ed. Pr. 141(1), doi: 10.1061/(ASCE)EI.1943-5541.0000208.

Foth, N., Manaugh, K., El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006, J. Transp. Geogr., 29(1): 1-10, doi: 10.1016/j.jtrangeo.2012.12.008

Gannon, C. A., Liu, Z. (2001). Transporte: Infraestructura y servicios, Banco Mundial, Washington, D.C. http:// www.worldbank.org

García-Segura, T., Yepes, V., Alcala, J., Pérez-López, E. (2015). Hybrid harmony search for sustainable design of post-tensioned concrete box-girder pedestrian bridges. Eng. Struct. 92(1): 112-122, doi:10.1016/j.engstruct.2015.03.015.

Gardner, J.E., (1989). Decision making for sustainable development: selected approaches to environmental assessment and management. Environmental Impact Assessment Review, 9(1): 337-366, doi: 10.1016/0195-9255(89)90028-0

Gervásio, H., Da Silva. L. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Syst. Appl. 39(8): 7121–7131, doi: 10.1016/j.eswa.2012.01.032.

Griffiths, K., Browne, V., Williams, V., Elliott, P. (2012). The changing face of engineering down under. Eng. Sustain. 165 (ES3): 223–232. doi:10.1680/ensu.10.00037

Goodland, R., (1995). The concept of environmental sustain ability. Annual Review of Ecological System, 26(1): 1- 24.

Hallowell M., Gambatese, J. (2010). Application of the Delphi method to CEM research. J. Constr. Eng. Manage. 136(1): 99-107. doi:10.1061/(ASCE)CO.1943-7862.0000137.

Hill R. and Bowen P. (1997). Sustainable construction: principles and a framework for attainment. Construction Management and Economics, 15(1): 223–239, doi: 10.1080/014461997372971

ISI - Institute for Sustainable Infrastructure (2015). ENVISION Rating System For Sustainable Infrastructure. Washington, DC 20005

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V.C., Ballester-Muñoz, F. (2014). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. Expert Syst. Appl. 41(15): 6807–6817, doi:10.1016/j.eswa.2014.05.008

Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). System dynamic simulation: A new method in social impact assessment (SIA). Environmental Impact Assessment Review, 62(1): 25–34, doi:10.1016/j.eiar.2016.07.009

Labuschagne, C., Brent, A.C. (2006). Social Sustainability Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry. Int. J. Life Cycle Assess. 11(1): 3–15, doi: 10.1065/lca2006.01.233

Labuschagne C., Brent A.C. and Van Erck R.P.G. (2005). Assessing the sustainability performance of industries. J. Clean. Prod., 13(4): 373–385, doi: 10.1016/j.jclepro.2003.10.007

Lupano, J.A., 2013. La infraestructura de transporte sostenible y su contribución a la igualdad en Ámerica Latina y el Caribe. Com. Económica para América Lat. y el Caribe 38.

Malekpour, S., Brown, R.R., de Haan, F.J., (2015). Strategic planning of urban infrastructure for environmental sustainability: Understanding the past to intervene for the future. Cities , 46(1): 67–75. doi:10.1016/j.cities.2015.05.003

Maturana, H., y Varela, F., (1997). De máquinas e seres vivos. Autopoiese, a Organização do Vivo. Porto Alegre: Artes Médicas.

Max-Neef, M. (1995). Economic growth and quality of life: A threshold hypothesis. Ecol. Econ. 15(1): 115–118, doi:10.1016/0921-8009(95)00064-X

Mckenzie, S., (2004). Social sustainability: Toward some definitions, Working Paper Series No. 27. Hawke Research Institute, Magill.

Mkrtchyan, L., Podofillini, L., Dang, V.N. (2016). Methods for building conditional probability tables of Bayesian belief networks from limited judgment: An evaluation for human reliability application. Reliab. Eng. Syst. Saf. 151(1): 93-112, doi: 10.1016/j.ress.2016.01.004.

Mostafa, M., El-Gohary, N. (2014). Stakeholder-sensitive social welfare–oriented benefit analysis for sustainable infrastructure project development, J. Constr. Eng. Manage. 140(9), doi: 10.1061/(ASCE)CO.1943-7862.0000788.

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. Eur. J. Oper. Res. 158(3): 662–677, doi:10.1016/S0377-2217(03)00369-2

Naderpajouh, N., Mahdavi A., Hastak M and Aldrich D.P (2014). Modeling Social Opposition to Infrastructure Development. J. Constr. Eng. Manage., 140(8), doi: 10.1061/(ASCE)CO.1943-7862.0000876

National Environmental Policy Act - (NEPA) (1969). (Pub. L. 91-190, 42 U.S.C. 4321-4347) Washington, USA, January 1, 1970

Penadés-Plà, V., García-Segura, T., Martí, J., Yepes, V. (2016). A Review of Multi-Criteria Decision Making Methods Applied to the Sustainable Bridge Design. Sustainability, 8(12): 1295, doi: 10.3390/su8121295

Polese, M., Stren, R. (2000). The Social Sustainability of Cities: Diversity and the Management of Change, 15-16 pp, University of Toronto Press, Toronto.

Resendez, L; Dueñas-Osorio, L. P., Padgett, J.E. (2014). Social Sustainability in Economic, Social, and Cultural Context. The international journal of social sustainability in Economic, social and cultural context. 11(1): 25-38.

Saaty, T. L. (2004). Decision-making the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng, 13(1): 1-35, doi: 10.1007/s11518-006-0151-5

Sierra, L.A., Pellicer, E., Yepes, V., (2017). Method for estimating the social sustainability of infrastructure projects. Environ. Impact Assess. Rev. 65(1): 41–53, doi:10.1016/j.eiar.2017.02.004

Thomopoulos, N., Grant-Muller, S. (2013). Incorporating equity as part of the wider impacts in transport infrastructure assessment: An application of the SUMINI approach. Transportation. 40(2): 315–345, doi:10.1007/s11116-012-9418-5

Temper, L., Bene, D., Martinez-Alier, J., (2015). Mapping the frontiers and frontlines of global environmental justice: the EJAtlas. J. Polit. Ecol. 22(1): 255–278.

Tudela, A., Akiki, N., Cisternas, R., (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investment. Transp. Res. Part A Policy Pract. 40(5): 414–423, doi:10.1016/j.tra.2005.08.002

UNCED (1992). Agenda 21: Action Plan for the Next Century. United Nations Conference on Environment and Development, Rio de Janerio: United Nations.

van de Walle, D. (2002). Choosing Rural Road Investments to Help Reduce Poverty. World Dev. 30(1): 575–589, doi:10.1016/S0305-750X(01)00127-9

Valdés-Vásquez R. y Klotz L.E. (2013). Social sustainability considerations during planning and design: framework of processes for construction projects. J. Constr. Eng. Manage., 139(1), doi: 10.1061/(ASCE)CO.1943-7862.0000566

Vilchés, A., Gil Pérez, D., Toscano, J.C., Macías, O. (2014). Ciencia de la Sostenibilidad. Organización de Estados Iberoamericanos. Artículo en línea obtenido de http://www.oei.es/decada/accion.php?accion=24 [Fecha de consulta: 15/05/2017].

WCED (World Commission on Environment and Development) (1987). Our Common Future. Oxford University Press, Oxford (United Kingdom).

Whitmer, A., Ogden, L., Lawton, J., Sturner, P., Groffman, P.M., Schneider, L., Hart, D., Halpern, B., Schlesinger, W., Raciti, S., Bettez, N., Ortega, S., Rustad, L., Pickett, S.T.A., Killilea, M., (2010). The engaged university: providing a platform for research that transforms society. Front. in Ecol. and the Environ. 8(6): 314–321, doi: 10.1890/090241.

CAPÍTULO 2

TRENDS IN THE MULTI-CRITERIA ASSESSMENT OF THE SOCIAL SUSTAINABILITY OF INFRASTRUCTURES

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Nowadays multi-criteria methods enable nonmonetary aspects to be incorporated into the assessment of infrastructure sustainability. Yet evaluation of the social aspects is still neglected and the multi-criteria assessment of these social aspects is still an emerging topic. Therefore, the aim of this article is to review the current state of multi-criteria infrastructure assessment studies that include social aspects. The review includes an analysis of the social criteria, participation and assessment methods. The results identify mobility and access, safety and local development among the most frequent criteria. The Analytic Hierarchy Process and Simple Additive Weighting methods are the most frequently used. Treatments of equity, uncertainty, learning, participation and context, however, require greater consideration. In this sense, current practices must be improved in order to incorporate a more appropriate treatment of social assessment.

KEYWORDS: infrastructure; multi-criteria; social sustainability; equity; stakeholders; uncertainty.

2.1 Social sustainability in infraestructures

The social dimension is one of the pillars of sustainability. However, evaluation of the social aspects is taken less into consideration than the economic and environmental dimensions (Missimer et al. 2017). Indeed, some public projects have not yet integrated the social aspects sufficiently and instead focus their attention on socioeconomic performance (Valdés-Vázquez and Klotz 2013, Torres-Machi et al. 2017). Polese and Stren (2000) define social sustainability as "development that is compatible with harmonious evolution of civil society, fostering an environment conducive to the compatible cohabitation of culturally and socially diverse groups while at the same time encouraging social integration, with improvements in the quality of life for all segments of the population." Infrastructures represent an intermediary link that opens opportunities for sustainable social development. By contrast, not including the social dimension in an infrastructure's development may have detrimental effects on the project and society. In the short term, the dynamics of increasing participation by stakeholders and their interactions imply risks that challenge the fulfillment of the project when its suitable social treatment is not preconceived (Munda 2004, Sierra et al. 2016, 2017). In addition, the non-reversal of effects that may put the quality of intra-generational life at risk has long-term repercussions on the state of development of future generations (Axelsson et al. 2013, Sierra et al 2017).

In professional practice, the cost-benefit analysis (CBA) is one of the most frequently used traditional methods to prioritize infrastructures. However, the CBA has disadvantages when nonmonetary social externalities are included. Mostafa and El-Gohary (2014) raise the issue that the CBA presumes that a decision is inadequate if the benefits do not at least exceed the costs. They add that the method is limited when it comes to measuring the qualitative impact of sustainability and the aspects of social equity. In addition, public opinion is not part of the evaluation process in the CBA (Tudela et al. 2006). Other studies raise the absent democratic and ethical nature of the CBA

(Hyard 2012, Mostafa and El-Gohary 2014), i.e., the decision of an alternative is centered on the generation of benefits for a majority. In this light, the CBA is justified given the possibility that the winners of the public project will compensate the losers, even if that compensation does not really occur (Hyard 2012).

In this situation, multi-criteria methods are one way to integrate all the aspects of sustainability (Tudela et al. 2006, Munda 2006, Penadés-Pla et al. 2016). These methods are suitable for dealing with uncertain aspects, objectives in conflict, different ways of presenting the information and various perspectives. Social sustainability is difficult to quantify, however, and continues to be the most neglected element of sustainability (Valdés-Vásquez and Klotz 2013, Diaz-Sarachaga et al. 2016). This may be due to the shortage of social sustainability implementation studies (Labuschagne and Brent 2008, Colantonio 2011). There is also a lack of longitudinal data that can give account of the conditions that determine social development (Labuschagne and Brent 2006, Colantonio 2011, Chow et al. 2014). Added to this is the need for training for engineers or decision-makers in dealing with the social aspects (Valdés-Vásquez and Klotz 2013, Griffths et al. 2012, Pellicer et al. 2016). Thus, the social framework requires a suitable treatment as part of the analysis of multi-criteria decisions.

In terms of the approach of this study, Figure 2.1 illustrates the elements that a multi-criteria social sustainability assessment must consider. Initially, the definition of the criteria that comprise social sustainability in construction projects are not clearly delineated. According to the application contexts, the participants' perspective and the stages during the life cycle, social criteria have more or less prominence (Labuschagne and Brent 2006; Valdés-Vásquez and Klotz 2013; Sierra et al. 2016). In this sense, the universal social indicators are too general to be useful. The social criteria must be adapted for decision-making at all levels of society: at the human-family, community-local, regional-country levels (Di Cesare et al. 2016). In an implementation, not only the measurable but also the intangible criteria that can be simulated technically must be considered. Additionally, the evaluation method must safeguard the effect of each criterion, avoiding full compensations (Munda et al. 2004; Gervásio and Da Silva et al. 2012).

An assessment method must give account of equity in the distribution of the benefits of an infrastructure. In fact, the concept of sustainability implies the safeguarding of the present and the intergenerational conditions (Bueno et al. 2015). Multi-criteria studies dealing with social equity are limited. Among them, the SUMINI method has implemented a specific indicator to measure sustainable mobility inequality in cities (Thomopoulos et al. 2009, 2013). From another approach, a participatory and transparent process promotes the use of criteria and weights according to fair standards of social equity (Hyard 2012). In this sense, a method must consider the criteria that represent all the sectors of society including minorities and the most vulnerable (van de Walle 2002, Munda 2006, Soltani et al. 2015).

Valdés-Vásquez and Klotz (2013) emphasize consideration of location within the processes of sustainable development of the infrastructure. The level of development of a place affects the degree of satisfaction and the needs required there (Missimer et al. 2017, Sierra et al. 2017). In addition, the moment of impact in the life cycle of the infrastructure also affects the significance of a social criterion (Labuschagne and Brent 2006, Sierra et al. 2016). Respect for cultural diversity and local experience are at times more useful than expert opinions (Munda 2004). In these cases the use of social tools, such as interviews or field studies, can capture the contextual information (van de Walle 2002, Karami et al. 2017). One of the main ways to consider the context is through stakeholder participation (Soltaní et al. 2015). Identification of the social impact must be associated with the interested parties on whom it falls (Di Cesare et al. 2016). In this case, the decision-makers and the rest of society must establish a mutual interaction to support a sound decision. Thus, a technocratic approach in which decisions are based solely on the contributions of experts is not recommended. Munda (2004, 2006) holds that from this participation the scientific team can improve their knowledge of the issue and the context to draw reasoned conclusions.

In the viability stage, project features have a high degree of uncertainty (Pan 2009, Zavadskas et al. 2015). If it is possible to anticipate the future state of the system, there is a stochastic uncertainty (Gervásio and Da Silva 2012). Another formulation, called fuzzy uncertainty, concentrates on the ambiguity of the information of an event. This situation is very common in human systems with a clear intention but a less clear extension (Umer et al. 2016). Similarly, grey systems theory is characterized as having poor information and small samples. In this case, the definition thresholds of an event are clear but the intention is not (Delgado and Romero 2016). In the short term of a social assessment process, increasing the participants from society diversifies the response and increases the uncertainty of the system (Pellicer et al. 2016); nevertheless, after a systematic evaluation of the parts it is possible to arrive at a better adjustment in the assessment of the aspects (Hallowell and Gambatese 2010, Sierra et al. 2016). In this vein, it should be pointed out that social assessment is not a single-cycle activity. On the contrary, the judgments and agreements on the social impacts promote a dynamic learning process (Munda 2004, Pellicer et al. 2016, Missimer et al. 2017). A method that promotes a process of long-term learning must be adaptive, flexible and with a high institutional commitment. In addition, the feedback and consultations among the participants are fundamental (Muench et al 2011, ISCA 2012, ISI 2015). In a method with these characteristics, the participants focus their learning on the needs of the context. Thus, the understanding of the context and the adjustment of the participants' interest improve the precision in future assessments.

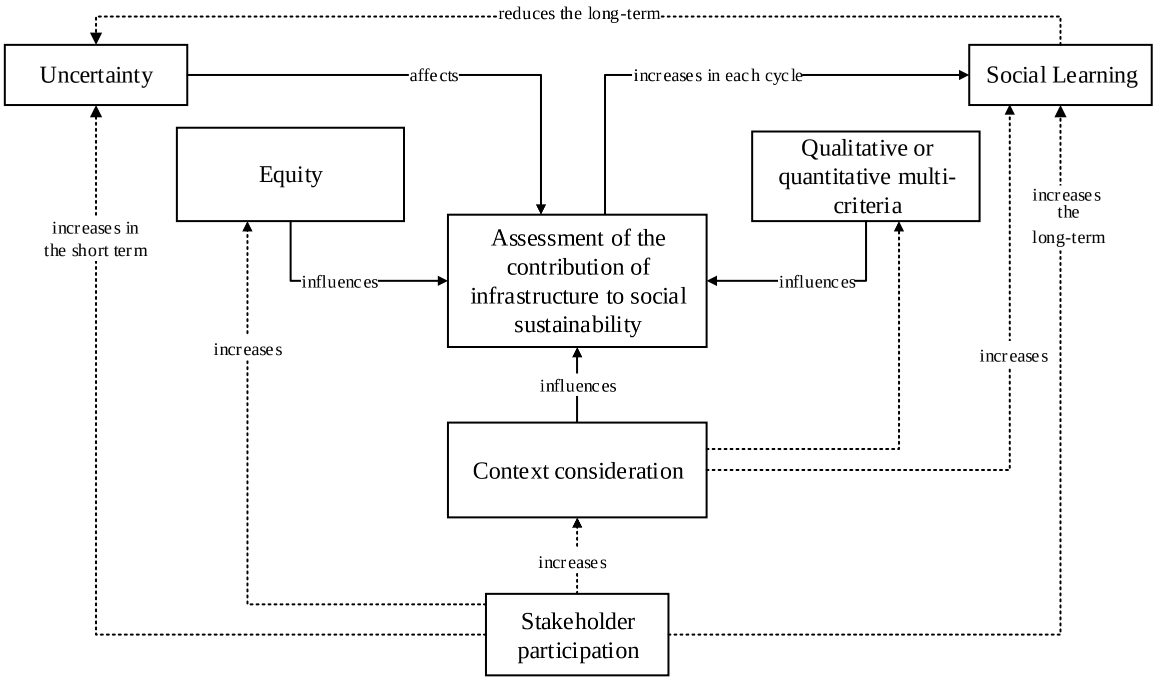

Figure 2.1: Relationship of the elements considered in the social sustainability assessment process for this study

2.2 Muti-criteria assessment methods

In the last decade, research into multi-criteria decision-making (MCDM) methods has expanded widely into different disciplines. Jato-Espino et al. (2014a), Penadés-Pla et al. (2016) and Zamarrón et al. (2017) have identified different multi-criteria methods applied to infrastructure projects. MCDM are comprised of multi-attribute (MADM), multi-objective (MODM), and complementary techniques (Zamarrón et al 2017). Multi-attribute techniques are able to decide on the best options from among previously selected infrastructures; in these techniques, the weights of the criteria influence the decision-making (Jato-Espino et al. 2014a). Conversely, multi-objective techniques identify optimal solutions that satisfy different general objectives in conflict (Yepes et al. 2015). The complementary techniques facilitate the most representative processing of the data. Thus, the multi-criteria methods are usually hybrid methods to address different realities in the infrastructure assessment.

Some studies, however, focus their evaluation on the social impact of a single infrastructure. In this regard, the life cycle analysis (LCA) is implemented through information inventories (Sahely et al. 2005, Labuschagne and Brent 2006, Gervásio and Da Silva 2013), whereas system dynamics determine the long-term effect from assessment scenarios (Shen et al. 2005, Hong et al. 2011, Zhang et al. 2014). Generally a multi-criteria evaluation process is comprised of four stages. First, the problem and the assessment structure are defined. Then the weights of the criteria that integrate the assessment structure are determined. After this, the different alternatives are evaluated with respect to each criterion. Finally, the evaluation of the alternatives is weighted against the weight of each criterion (Bueno et al. 2015, Soltani et al. 2015). Table 2.1 shows a summary of the infrastructure assessment methods included in this review.

Table 2.1: Summary of the main multi-criteria assessment methods

Type	Method	Description
MADM	Analytic Hierarchy Process (AHP)	Structured technique for the analysis of multi-criteria decision-making issues according to a pairwise comparison scale. It considers the decision-maker's consistency and weights obtained through the eigenvalues (Saaty 2004).
MADM	Analytic Network Process (ANP)	Generalization of the AHP, it allows interdependence between criteria without a hierarchical pattern (Saaty 2004).
MADM	Integrated Value Model for Sustainability Assessment (MIVES)	Unified methodology that combines the concepts of multi-criteria decision analysis and value engineering to synthesize the types of criteria on a value index. It uses a generic value function that standardizes each indicator. The AHP is used to determine the weights of the hierarchical decision-making structure (de la Cruz et al. 2015a).
MADM	Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Belonging to the methods of the outranking family and based on the selection of a preference function for each criterion that is part of the multi-criteria decision-making issue. This method is based on the pairwise comparison between alternatives to establish a relationship of outranking of one over another. The method applies a positive and negative assessment for each alternative and creates a ranking in relation to the decision weights (Gervásio and Da Silva et al 2012).
MADM	Simple Additive Weighting (SAW)	Technique that determines an average weighting for each alternative through the addition of the contribution of each attribute multiplied by its weights (Jato-Espino et al. 2014a).
MADM	Grey Relational Analysis (GRA)	Method based on Grey systems theory applicable with vague and incomplete information. The GRA determines a correlation index of alternatives through which it is possible to obtain a prioritization (Chen et al. 2014).
MADM	Mutli-Attribute/Value Utility Theory (MAUT/MAVT)	The MAUT is a methodology used to make decisions by comparing the utility values of a series of attributes with uncertainty. The MAVT is a technique that converts the attributes that comprise a MCDM problem into a single value through the value functions (Jato-Espino et al. 2014a, Soltani et al. 2015)
MADM	Emergy	This analyzes the contributions to nature and the human economy by means of a conversion factor that reflects the solar energy needed to make a unit of a product or service (Li et al 2012, Reza et al. 2014).
MADM	Life Cycle Assessment (LCA)	Method that evaluates the impact on the environment and society with respect to the infrastructure and its processes of design, construction, use and maintenance and final disposition. This tool needs data and the assessment of the social aspects of infrastructures is still emerging (Di Cesare et al. 2016, Zastrow et al. 2017).
MODM	Complex Proportional Assessment(COPRAS)	Step-by-step method that seeks to prioritize a set of alternatives according to their significance and degree of utility (Aghdaie et al. 2012).
MODM	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Technique based on the concept that the best alternative for a multi-criteria decision-making problem is the one closest to a positive ideal solution and farthest from a negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives through the weights of their criteria and standardized scores (Kucukvar et al. 2014).
MODM	Vlse Kriterijuska Optimizacija Komoromisno Resenje (VIKOR)	Method to determine a list of ranking by compromise between a set of alternatives according to the measurement closest to an ideal solution. The method formulates conditions to guarantee acceptable advantages of one alternative over another (Curiel-Esparza et al. 2016).
MODM	Goal Programming (GP)	Extension of linear programming methods that seeks optimized variables that satisfy multiple goals in the best way according to certain values to be reached. The goals are formulated as restrictions and the objective functions seek to minimize the sum of the absolute deviations of each objective (Wey and Wu 2007, 2008).
Comple mentary	Grey Systems Theory	Philosophy of data manipulation according to the information they contain, usable with vague and incomplete information. This block groups the methods listed such as Grey *Numbers* that can handle the uncertainty; *Grey Clustering* is to classify objects of observation in defined classes (Delgado and Romero 2016).
Comple mentary	Fuzzy sets	A fuzzy number is an extension of a regular number in the sense that it does not refer to a unique value but to a set of possible values that vary with a weight between 0 and 1, called membership function (Pan 2008, 2009)
Comple mentary	Monte Carlo Simulation	Non-deterministic methods used to find approximate solutions to complex problems experimenting with random numbers (Gervásio and Da Silva 2012, del Cruz et al. 2015a).
Comple mentary	System Dynamics (SD)	Complementary technique serves to analyze complex, dynamic and nonlinear interactions between variables and generally used to simulate an evaluation process. The SD is a tool that has been used to model sustainable development scenarios (Zhang et al. 2014, Karami et al. 2017).
Comple mentary	Delphi Method	Iterative and systematic method designed to obtain a consensus from a group of experts who respond to a questionnaire reiteratively (Hallowell and Gambatese 2010)
Comple mentary	Entropy	Method that measures the weights of the criteria with the purpose of representing the intrinsic information transmitted for the decision-making. For each criterion an entropy function is applied and a determined degree of divergence with respect to the set of evaluated alternatives (Delgado and Romero 2016)

2.3 Point of departure

Traditional methods present weaknesses when social aspects of sustainability are assessed. The treatment of elements like equity, qualitative variables and democratic considerations are some of the difficulties (Hyard 2012, Mostafa and El-Gohary 2014). The multi-criteria methods are an assessment alternative that can take the social aspects into account (Munda 2004, Thomopoulos et al. 2013). However, the social aspects still get less attention in the sustainability assessment (Labuschagne and Brent 2006, Diaz-Sarachaga et al. 2016). Some studies have taken the multi-criteria social assessment into account, representing quantitative and qualitative criteria (Gervásio and Da Silva et al. 2012, Di Cesare et al. 2016), considering social equity in the distribution of the effects of the infrastructure (Thomopoulos et al. 2009, 2013), contextualizing the assessment structure and the participants according to the time and place of implementation (Valdés-Vásquez and Klotz 2013, Karami et al. 2017), providing participation mechanisms (Munda 2006, Soltaní et al. 2015, Di Cesare et al. 2016), dealing with the uncertainty of the data (Delgado and Romero 2016, Zavadskas et al. 2015), or promoting a social learning process (ISCA 2012, ISI 2015). The implementation of these treatments has been variable and not completely understood in all the development areas of an infrastructure (Griffths et al. 2012, Valdés-Vásquez and Klotz 2013, Pellicer et al. 2016). Thus, the multi-criteria methods used to deal with the social dimension of infrastructures require a review. These arguments are the starting point of this study.

Accordingly, this study presents a review of the multi-criteria assessment methods of infrastructure social sustainability. In particular, this work endeavors to identify the approaches and trends of (1) the social criteria taken into account; (2) the participation of the stakeholders; (3) the multi-criteria methods used; and (4) the consideration of equity, context and social learning in the assessment of infrastructures. This article is structured into the following sections: First, the authors set out the research method used. Then, the results of the data analysis are presented. At this point the social aspects involved, the participants of the process and the methods of multi-criteria social assessment for infrastructures are analyzed. In addition, the treatment of equity, social learning and consideration of the context are examined. Finally, the results and conclusions of the article are discussed.

2.4 Research method

The research process was comprised of two stages. In the first stage, an exploratory search established the initial studies. The second stage was a follow-up of the references and citations of the studies selected in the first stage. Figure 2.2 represents the scopes, keywords and Boolean operators of the search strategy in the initial stage. The search was carried out through the scientific database *Web of Science*. The search period concentrated on 1995 to 2017 (January) since the multi-criteria methods in construction only acquired relevance from the 1990s (Jato-Espino et al. 2014a). From the search strategy, the studies were selected according to the type of document and relevance. Ultimately, 48 studies were subjected to an in-depth review.

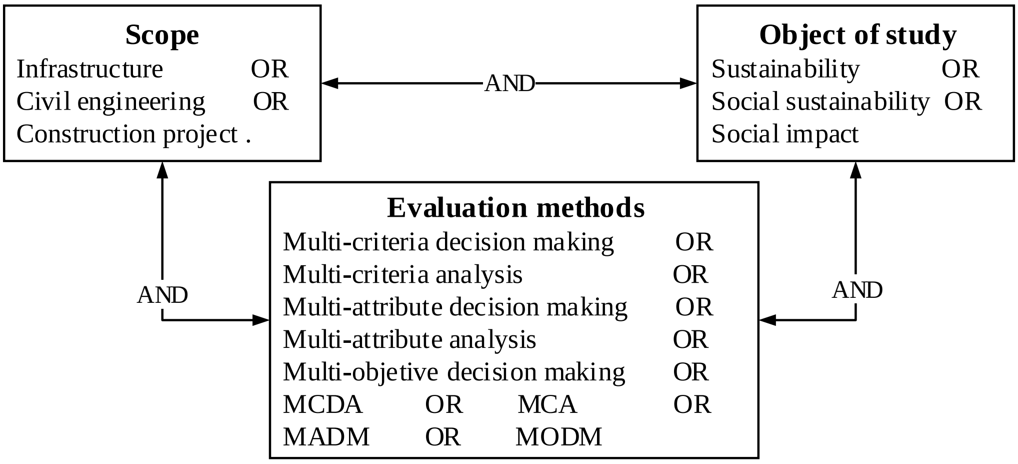

Figure 2.2: Initial search strategy

Similarly, in the second stage a review was carried out by type of document, relevance as well as an in-depth review to identify the suitable works. The newly selected studies underwent the same treatment. Figure 2.3 illustrates the methodological cycle used to identify the 94 studies finally selected.

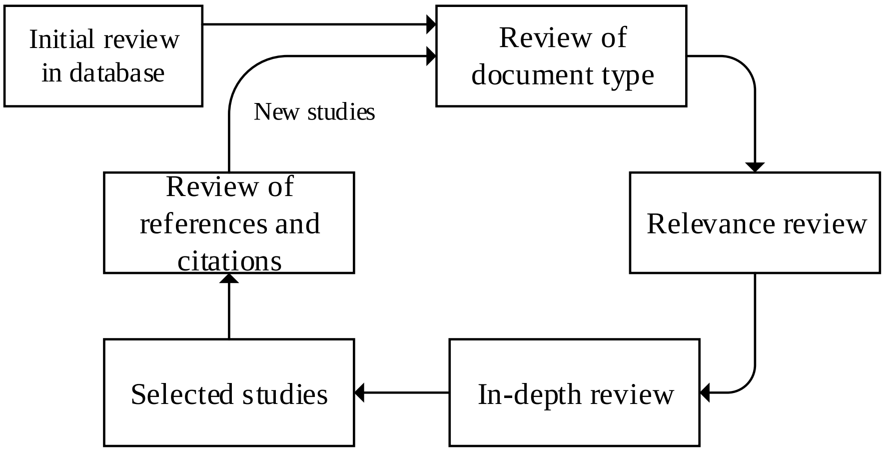

Figure 2.3: Methodological cycle of the review

From the review method, three study categories were determined. In the first 60 articles evaluate infrastructure sustainability and include the social dimension in the analysis. In the second, seven studies are based on *Rating Systems* for the assessment of infrastructure sustainability and they include social aspects. Finally, 27 articles set out multi-purpose infrastructure assessment methods and include social aspects.

2.5 Results

According to the objectives of the article, 94 studies were analyzed with respect to the following fields: (1) the relevant social criteria and the life cycle stages applied for each infrastructure; (2) the participants in the evaluation process; (3) the assessment techniques used and their approaches; and (4) the consideration of equity, context and learning in the assessment process. The results of the analysis of each information field are presented in the following sub-sections.

2.5.1 Relevant social aspects in the infrastructure assessment

On this point, the research team grouped by affinity the social aspects mentioned in each study under 23 criteria. Table 2.2 explains the social criteria demonstrated in the review process and classifies them in seven approaches.

Table 2.2: Social criteria

#	Criterion and Description
Human capital approach:	
1	**Basic needs** that include the conditions of food, housing and shelter necessary to satisfy the human being's living conditions (Karami et al. 2017).
2	**Education** takes into account the aspects of formal education (Gilmour et al. 2011, Axelsson et al. 2013), training (Fernández-Sánchez and Rodríguez-López, 2010) and civic education, and raising awareness of the local population (Ugwu et al. 2006a, Shaiu et al. 2015)
3	**Health** involves the effects on the human being's physical and mental state due to accidental causes (Li et al 2012, Resendez et al. 2014), long-term diseases (Ugwu and Haupt 2007, Chow et al. 2014) or exposure to sources of pollution (Jeon 2010, Yadollahi et al. 2015).
Community capital approach :	
4	**Public opinion** includes the perception of the community with respect to the general acceptance of the project, unease or satisfaction with the construction or the operation of the infrastructure (Dasgupta and Edwin 2005, Gilmour et al. 2011, Zavadskas et al. 2015).
5	**Esthetics and degradation** is the extent to which the infrastructure design fits with the harmony of the surroundings and public sensitivity (Pan 2008, Hong et al. 2011, Balali et al. 2014)
6	**Safety of the environmental** corresponds to all those physical risks and implications of criminality for the local population (Bonsall and Kelly 2005, Shen et al. 2011).
7	**Identity and cohesion** consider the displacement or resettlement of families (Koo et al. 2009), the strengthening of the local characteristics (Bueno and Vassallo 2015), integration of physically challenged people (Gilmour et al. 2011) and/or the inclusion or discrimination of social groups (Diaz-Sarachaga et al. 2017, Resendez et al. 2014).
Cultural capital approach,:	
8	**The cultural criterion** combines aspects related to the protection of a community's intangible cultural values (Ugwu et al. 2006b, Axelsson et al. 2013) and/or the tangible cultural values or property (Shen et al. 2011, Jeong et al. 2014).
Productive capital approach:	
9	**Private property** combines aspects related to the protection of the condition of the house (Labuschagne and Brent 2006), acquisitions of rights of way (Koo et al 2009) or changes in the assessment of a community's assets (Boz and El-Adaway 2015).
10	**Mobility and accessibility** integrate suitable coverage of transportation services (Shang et al. 2004, Umer et al. 2016), modes of non-motorized mobility (Shaiu et al. 2015) or access to public services (Gilchrist and Allouche 2005).
11	**Urbanization services** include integration with the existing infrastructure, the type of sanitary, electrical and communication networks (Gilmour et al. 2011, Delgado and Romero 2016), as well as sports infrastructure and public spaces (Labuschagne and Brent 2006, Gilchrist and Allouche 2005).
12	**Research, development and innovation (R+D+i)** promotes technological development in the infrastructure project to generate social contributions (Labuschagne and Brent 2006, ISI 2015).
13	**Land use** makes reference to the efficiency and effects of the changes of ground use in the community for the development of the infrastructure (Wey and Wu 2007, Thomopoulos et al. 2013).
14	**Distribution of production benefits** refers to equity in the distribution of the contributions and costs of the infrastructure among the local and regional population (Van de Walle 2002, Muench et al. 2011).
Social and institutional capital approach :	
15	**Stakeholders participation** groups the aspects related to the contribution of information to the community and involvement of their participation in the decision-making about the project (Labuschagne and Brent. 2006, Gilmour et al. 2011)
16	**Public management skills** take into account the aspects related to the skills of the administration (Labuschagne and Brent 2008) and the transparency and integrity (Karami et al. 2017) of the public agencies involved in the development of the infrastructure.
Socioeconomic system approach :	
17	**Economy and regional development** includes the aspects that enhance the development of the main economic activity or its diversification in the region (Caliskan 2006, Labuschagne and Brent 2008). In addition, effects on the collection of taxes that alter the funds for public expenditure (Gilchrist and Allouche 2005). The maintenance costs assumed by the regional administration are another aspect included in this criterion (Gervásio and Da Silva 2012, Li et al. 2012)
18	**Economy and local development** include the improvement or harm to local business (Kucukvar et al. 2014, Resendez et al. 2014), and the alteration of the operational costs of the users of the infrastructure (Koo et al. 2009, Reza et al. 2014).

#	Criterion and Description
19	**Employment** takes into account the aspects related to the number of work opportunities associated directly and indirectly to the development of an infrastructure (Labuschagne and Brent 2008, Hong et al. 2011, Delgado and Romero 2016)
Business-community relations approach :	
20	**User-oriented design** refers to the design of infrastructures being compatible with the needs of a context (Pan 2008, Valdés-Vásquez and Klotz 2013). In addition, the construction and maintenance processes must be compatible with the safety of those performing these functions (Fernández-Sánchez and Rodriguez - Lopez 2010).
21	**Working training** involves all those aspects in which a company promotes the professional development of its employees. Training in matters of safety, health and safety protective equipment, and health and safety plans are some of the aspects included (Labuschagne and Brent 2008, Fernández-Sánchez and Rodriguez-Lopez 2010).
22	**Work health and safety** involves the practices of a company that protect workers' lives. Training in matters of safety, health and safety equipment, and health and safety plans are some of the aspects considered (Shen et al. 2005, Yadollahi et al. 2015)
23	**Ethical labor practices** combines the aspects related to dignity and ethics in the employer-employee contractual relation. Aspects such as a suitable work load, child labor and gender equality are included (Labuschagne and Brent 2006, MacAskill and Guthrie 2013, Axelsson et al. 2013)

In particular, Table 2.3 shows the number of times that a social criterion is considered in the multi-criteria assessment studies. As of 2006, the diversification of the social criteria used in the infrastructure assessment was remarkable. The criteria of economy and local development, mobility and accessibility, environmental health and safety are the most frequent. This article identifies the life cycle of the infrastructure (planning-design, construction, use-maintenance, end of life) where the impact on each social criterion occurs.

Figure 2.4(upper) represents the percentage of times each social criterion has been considered at each stage of the life cycle. Generally, the use-maintenance stage is impacted in more than 50% of the criteria, followed by the construction stage. The end of life stage is less considered because in most cases it is not clearly defined.

Figure 2.4(lower) illustrates the proportion of the type of infrastructures linked with each social criterion. Infrastructure types include transportation (road, railway, subway, ports, cycle paths and pedestrian infrastructure), bridges, tunnels, sewage, water and energy networks (water, sanitation, gas networks, or electrical energy distribution system), hygiene treatment plants (managed landfills and waste treatment plants), mining and civil infrastructure in general (studies that do not specify a type of infrastructure). Thus, the transport infrastructure has the greatest representation in the studies and includes the greatest diversity of social criteria.

Table 2.3: Evolution of social criteria by year

Social criteria	**Year of publication**																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	**Total**
1. Basic human needs																	1	**1**
2. Education		1				3		1		1	1		1	1	1	2	1	**13**
3. Health		2	1		3	4	4	5	2	3	5	5	5	5	6	5	1	**56**
4. Public opinion			1		3	3	2	2	1	1	3		1	3	3	1	1	**25**
5. Aesthetics			1			4	1	2		2	3	2	2	5	1	2		**25**
6. Security of the environment	1			1	5	5	4	4	2	4	5	4	4	5	3	4		**51**
7. Identity and social cohesion				1	1	3	1	2	2	4	3	1	4	5	4	2	3	**36**
8. Culture and inheritance			1		1	5	4	3	1	2	4	2	3	4	1	2	3	**36**

Social criteria	**Year of publication**																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	**Total**
9. Private property					3	2		2	1		1			3	2	1	3	**18**
10. Mobility and access	1	2	2	1	3	5	6	2	2	4	7	5	6	6	3	3		**58**
11. State of urbanization services					1	1	1	1		1	2	1		1		2		**11**
12.Research & innovation						3	1			2	2	2		1	2	1		**14**
13.Land use		1	2		2	3	5	1	2		3		1	1	3			**24**
14. Distribution of the productive benefit		1					1		1	3	1		3	1	1		2	**14**
15. Stakeholder participation		1	1		2	3	2	3	2	2	2	2	2	1		1	3	**27**
16. Public management capability						1		1			1			1		2	1	**7**
17. Economy and regional development				1	2	2	4	2		3	2	3	3	3	5	3		**33**
18. Economy and local development	1	1		1	2	6	5	3	1	3	4	4	3	7	8	3	3	**54**
19. Employment		1	1	1	1	3	4	2		2	3		2	4	4	3	3	**34**
20. User-oriented design					1		1	1	1	1	1	1		2				**9**
21. Staff training						1	1	1		1					1	2		**7**
22. Occupational health and safety	1				2	3	2	3	2	1	1		1	4	4	2		**26**
23. Ethical Labor Practices						1		1					2			2		**6**
Total of studies	**1**	**2**	**2**	**1**	**5**	**6**	**8**	**6**	**4**	**6**	**7**	**6**	**8**	**14**	**9**	**6**	**3**	**94**

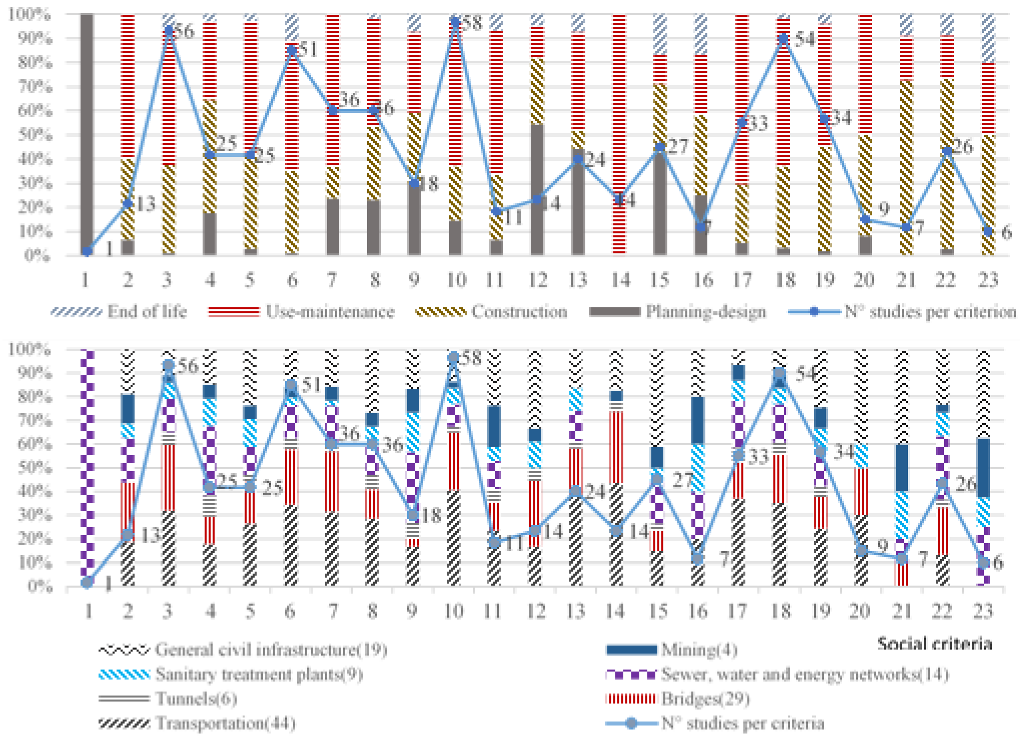

Figure 2.4: Social criteria impacted by each stage of the life cycle (upper) and infrastructure type (lower).

Specifically, the distribution criteria for the production benefits (14) and the economy and regional development (17) are more strongly linked to the use-maintenance stage. Aspects such as ground assessment, technological processes and citizen participation (12, 13, 15 respectively) have a greater presence in planning and design. Aspects like the local inconveniences (4) and labor related criteria (21, 22, and 23) are more represented in the construction stage. Other cases are environmental safety (6) and user-oriented design (20), the impacts of which have been shown in the use-maintenance and construction stages. For their part, transportation infrastructures, bridges and tunnels are strongly related to the criteria of health, environmental safety, identity and cohesion, mobility and access, ground use, distribution of the production benefits and regional and local development (3, 6, 7, 10, 13, 14, 17, and18). Public participation (15) is applied to civil engineering infrastructures in general.

2.5.2 Participants in the process of social assessment of infrastructures

Sixty seven percent (64 studies) of the reviewed methods include multiple evaluators at some stage of the process. Figure 2.5 represents the number of times each group of actors participates in infrastructure assessment processes. The experts, consultants and contractors, government, academia and nongovernmental organizations (NGOs) have greater participation than the local context. The "experts" are categorized as professionals with experience in engineering with no specification as to their origin. In addition, Fig. 5 represents the work of each participant in the assessment process. In absolute terms, the determination of the weights and the decision-making structure (i.e., the criteria and relations) are the most frequent tasks. According to the number of cases, there is a connection between the determination of the weights and the work done by the experts, consultants-contractors and academia-NGOs. However, the decision-making structure is linked to the functions of the government.

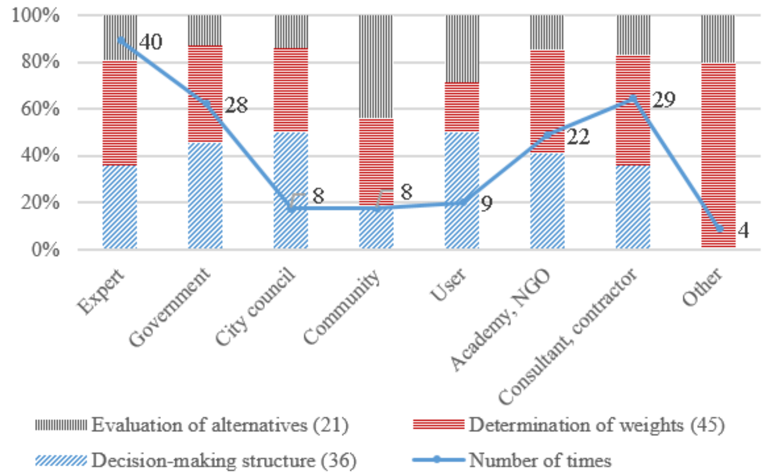

Figure 2.5: Participation in the multi-criteria social assessment of infrastructures

In this review, weight determination was the specified process with the highest participation (45 studies). Thus, the methods to determine weights and group the participants' opinions were identified. Methods like the AHP (23), ANP (3) and Entropy (4) comprise the methods for determining weights. Other weight determination methods include direct allocation (8) and order relation (7). In the direct allocation methods, the evaluator identifies a direct score that represents the importance of each criterion (Shen et al. 2011, Koo et al. 2009, Balali et al. 2014). In the order relation methods, the evaluator organizes the criteria by order of importance, through which weights are obtained (Jeon 2010, 2013, Ramani et al. 2011, Chen et al. 2014). Some studies consider more than one method for weight determination. Bueno and Vasallo (2015) take into account the opinion of evaluators through the AHP and the contextual conditions through a direct score. Chen et al. (2014) combine objective weights through entropy and subjective weights through the AHP. On the other hand, 23 studies do not report the method used to group the participants' opinions. The remaining studies (11) mostly use the Delphi method. Other methods of opinion aggregation include SAW (2) (Thomopoulos et al. 2009, 2013), the geometric mean (3) (Shang et al. 2004, Jato-Espino et al. 2014b, Curiel-Esparza et al. 2016), probability distributions (1) (Su et al. 2016), and fuzzy operators (5) like the determination of the center of gravity (Pan 2008, 2009, Wey and Wu 2007).

2.5.3 Multi-criteria methods for social assessment of infrastructure

The methods for determining criteria weights and assessing alternatives were recorded, as well as the treatment of uncertainty that each method uses. Figure 2.6 shows the number of methods that determine the weight of the criteria. In addition to the weight determination methods in Section 2.5.2, the score by credits is included. This is the case of the Rating Systems that deal with the importance of each criterion through pre-established credits (CEEQUAL 2010, Muench et al. 2011, ISCA 2012, ISI 2015). The most commonly used method to determine the weights with multiple evaluators is the AHP. On the other hand, among the single-evaluator methods, direct allocation and the use of credits are more frequent. Figure 2.7 represents the frequency of use of 14 assessment methods of the infrastructure alternatives, called "A". The A methods are AHP, ANP, MIVES, TOPSIS, LCA, COPRAS-G, GRA, VIKOR, PROMETHEE, SAW, GP, SD and Emergy. In addition, in three studies the arithmetic mean was also used to group the value of the criteria (Dasgupta and Edwin 2005, Boz and El-Adaway 2015). These 14 methods act independently or complement others. For example the CBA complements the evaluation of SAW and the AHP through a cost-benefit structure (van de Walle 2002, Chang et al. 2009). The Emergy method was used together with the LCA to combine the assessment of the criteria into one unit (Li et al. 2012, Reza et al. 2014). In addition, in 58 studies six treatments of the indicators of each criterion made possible the implementation of the A methods. These treatments improve the representation of the value of a criterion with respect to the context or the remaining indicators.

In Figure 2.7, the treatments of the performance indicators are represented in the B group, which include the use of techniques of social cost, artificial scales, value or utility functions (MAUT), scoring systems, linguistic variables and grey clustering. The social cost quantifies the data of a context through monetary functions for each criterion that represent the cost for the user or society (Gilchrist and Allouche 2005, Koo et al. 2009, Gervásio and Da Silva 2012). The artificial scales standardize different units according to interpolation functions (Dasgupta and Edwin 2005, Ramani et al 2011, Thomopoulos et al. 2013). The utility or value functions (MAUT) identify the degree of satisfaction in the condition of certainty (value function) or uncertainty (utility function) (De la Cruz et al. 2015a,b, Diaz-Sarachaga et al. 2017). The qualitative criteria have been processed through a scoring system or by linguistic variables. The first corresponds to a scoring system that depends on the degree of compliance of the infrastructure attributes (Boz and El-adaway 2015, Muench et al. 2011, ISI 2015). The linguistic variables link a nondeterministic verbal concept to the performance of an indicator in each alternative (Abu-Dabous and Alkass 2008, Kucukvar et al. 2014, Delgado and Romero 2016). Grey clustering classifies limited and uncertain information from each alternative in defined classes to enable their assessment (Delgado and Romero 2016).

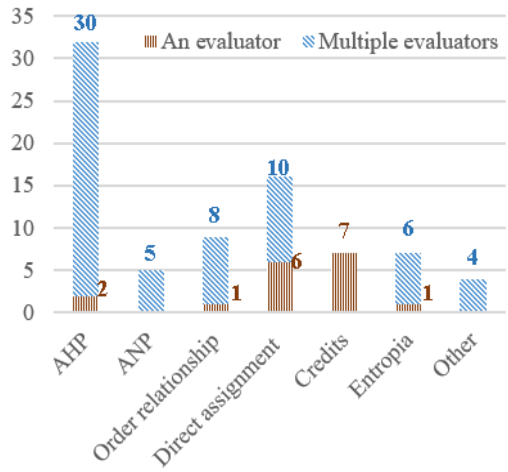

Figure 2.6: Methods for determining the weights of social criteria

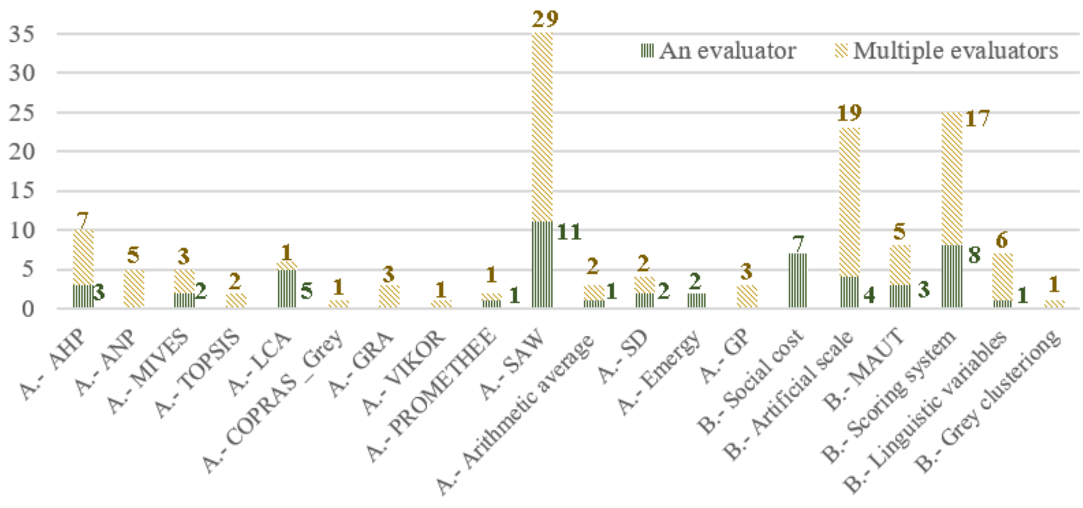

Figure 2.7: Methods for the social assessment of infrastructure alternatives

In particular, the social cost has been used in the LCA and in some cases with PROMETHEE and Emergy. Social cost has been used to assess such aspects as rights of way, loss of productivity and cost of delays or operations. The linguistic variables have dealt with the uncertainty regarding the input variables in the TOPSIS, COPRAS-G and AHP (Abu-Dabous and Alkass 2008, Aghdaie et al. 2012, Umer et al. 2016). On the other hand, the artificial scales and scoring systems treat the quantitative and qualitative variables in SAW, ANP, SD, GP and arithmetic means. The value functions (MAUT) have been used mainly through the MIVES.

Of all the selected studies, 22% (21 studies) treat the uncertainty of the data input into the model. The three identified methods to deal with uncertainty are the fuzzy sets, Grey System theory and probability distributions. The fuzzy sets complement the weight assessment through the AHP and Entropy (De la Cruz et al.2015b, Kucukvar et al. 2014, Jato-Espino et al. 2014a), and in eight studies alternatives were assessed through MIVES, AHP, SAW and TOPSIS (Pan 2009, De la Cruz et al. 2015b, Kucukvar et al. 2014). Grey Systems theory deals with uncertainty in two studies through grey clustering and COPRAS-G when assessing infrastructures (Aghdaie et al. 2012, Delgado and Romero 2016). Finally, in 11 studies probability distributions were constructed for each uncertain criterion. LCA, MIVES and PROMETHEE have used probabilistic systems to deal with uncertainty. Some studies have required contextual information to establish the probability distributions (Bonsall and Kelly 2005, Gervásio and Da Silva 2012, 2013); in others consensus of the parameters facilitates their implementation (Abu-Dabous and Alkass 2008, De la Cruz et al. 2015a).

2.5.4 Equity, learning and context in the social assessment of infrastructures

The characteristics of equity, orientation to social learning and consideration of the context were observed in the sample of 94 studies. These are important as they underscore the social approach of sustainability assessment methods. Of all the studies reviewed, 16% (15 studies) considered equity in the assessment process. The evaluations of transport infrastructures (11) and bridges (7) were those of greatest integration in this approach. Figure 2.8 represents the distribution of the equity treatments in the assessment methods. In the methods, equity was considered cross-sectionally to the measurement system or through specific indicators. In the first case, equity is considered a cross-sectional mechanism to the measurement system and intervenes in each indicator and result (Bonsall and Kelly 2005, Thomopoulos et al. 2009). In the second case, equity is a part of the assessment system through specific indicators compensated by others without guaranteeing the equity of the system (Jeon 2010, Shaiu et al. 2015). In both cases, quantitative information from contextual censuses or databases was needed. On this point the most frequent information treatments were through (a) the use of econometric models, (b) functions of difference between groups or (c) the measurement of vulnerability. In the first place, the econometric models focused on the costs and regional economic benefits of large projects and their distribution in the population in the long term. The application of this treatment has been limited to theoretical examples (Brocker et al. 2010, Mostafa y El-Gohary 2014). On the other hand, the difference functions measure the inequality of the costs or benefits of an infrastructure among the affected groups of an area of influence. The criteria dealt with using this technique include impacts on health, mobility and safety, which have implications for all the population groups (Jeon et al. 2010, 2013, Thomopoulos et al. 2009). Third, the measurement of vulnerability estimates the impact on specific groups or areas with less resilience to the variation in certain social criteria. It is assumed that the contributions generated for more vulnerable zones contribute to equity. The most frequently named vulnerable groups are the population with low income, seniors, indigenous population, families without a car, women and the disabled (Resendez et al 2014, Bonsall and Kelly 2005). Likewise, spatial vulnerability is identified through census data on education, health or poverty (van de Walle 2002, Axelsson et al. 2013). Most of the works point to intragenerational equity. The inclusion of intergenerational equity was dealt with only through two econometric approaches and with theoretical applications (Nishijima et al. 2007, Mostafa and El-Gohary 2014).

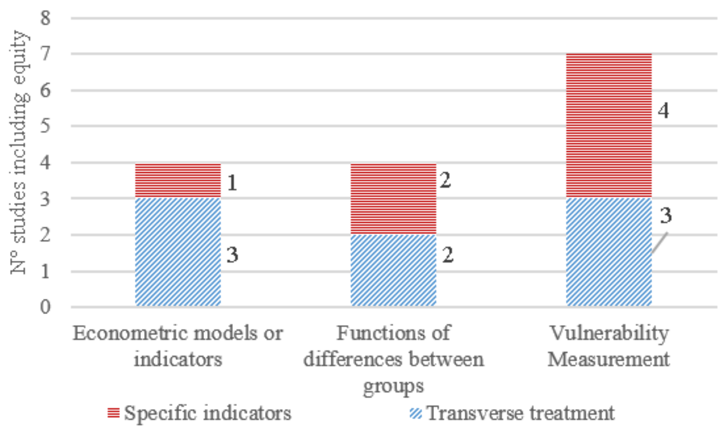

Figure 2.8: Distribution of the treatment of equity in multi-critera social assessment methods

The measurement of sustainability does not necessarily seek a result but rather a process that must promote the social learning of those involved (Munda 2006). Cyclical assessment processes are advisable so that the proposed mechanisms orient society towards better decisions. This approach is relevant in decision-making processes regarding public resources that impact on society. Only 17% (15 studies) include some system of social learning. Figure 2.9 represents the proportion of the studies that deal with social learning in their assessment methods. Learning in the assessment processes has been considered through progressive evaluations or through cognitive instruments. The former promotes an assessment of the impact of an infrastructure progressively on its development. In this process, feedback and incentives of certification by third parties are contributed to the project team, including promoters, planners and contractors. This approach is applied in the Rating Systems ENVISION (ISI 2015), CEEQUAL (2010), IS (ISCA 2012), SIRSDEC (Diaz-Sarachaga et al. 2017) and Greenroads (Muench et al. 2011). The cognitive instruments, on the other hand, help the evaluators understand the factors that affect sustainability. Specifically, cognitive maps helped define the evaluation structures (criteria, indicators and their relationship) (Ugwu et al. 2006a, Caliskan 2006, Gilmour et al 2011). In other cases geographic information systems make it possible to visualize different alternative scenarios to subject them to evaluation (Jeon et al. 2010, 2013). In this light, social learning is more relevant if the evaluators represent society. However, in some cases participation in the assessment process is limited only to experts or a decision-maker.

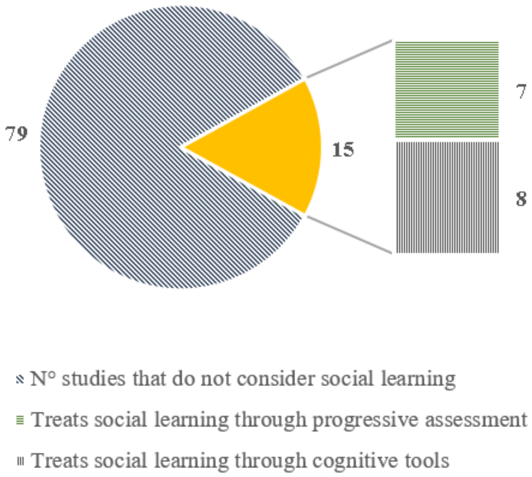

Figure 2.9: Distribution of the studies that deal with social learning

However, a selection of criteria and their relationships are not applicable to every context; different levels of development affect the degree of satisfaction, and local needs are not always associated with those of the country (Valdés-Vásquez and Klotz 2013, Munda 2006). 86% (81 studies) considered the context in some way. The context is represented through: (T1) stakeholders who define the assessment structure; (T2) the personal opinion of the stakeholders who evaluate criteria or alternatives; (T3) a synthesis of the contextual information so that the actor evaluates and makes the decision; (T4) the contextual information processing through an assessment mechanism; or (T5) a mixed system in which part of the process corresponds to the stakeholders' opinions and another to quantitative information processing. Thus, Figure 2.10 represents the distribution of the treatments that involve the context in the assessment process. First, in this review 36 studies were detected in which the stakeholders define the assessment structure. Of these, in only 23 (25%) is there participation by representatives of government, municipality, community, users, academia or NGOs (Axelsson et. al 2013, Shang et al. 2004, Shaiu et al. 2015). In the remaining cases, the stakeholders are limited to experts, consultants or contractors. This situation is present in all the treatments (Balali et al. 2014, Boz and El-Adaway 2015, Umer et al. 2016). In other cases there is only one evaluator (Resendez et al. 2014, MacAskill and Guthrie 2013, Karami et al. 2017).

Second (T2), the comparison methods (AHP, ANP), the scoring systems and linguistic variables are frequent for processing the stakeholders' personal opinions (Balali et al. 2014, Boz and El-Adaway 2015, Pan 2008). In the third treatment (T3), participants receive feedback with contextual information (Karami et al. 2017, Resendez et al. 2014, Wey and Wu 2007). The contextual information is compiled from regional databases, territorial development plans or censuses. For the local cases the information was assimilated from approximate secondary sources (Resendez et al. 2014) or specific field studies (Karami et al 2017). In any case, the way in which the data are presented influences the stakeholder's assessment. In the fourth treatment (T4), the quantitative social information of the context is processed and stakeholders are not required. The social criteria dealt with under this modality were health and safety, regional economic development, the impact on the user (operational costs, travel times, accidents) and employment. The use of artificial scales and the social cost have been common in this treatment (Gilchrist and Allouche 2005, Koo et al. 2009, Shaiu et al. 2015). Nevertheless, some studies presented limitations in the availability of data on the social state (Sahely et al 2005, Labuschagne and Brent 2006, Chow et al. 2014). In others, the criteria used correspond to those with availability of information (Gervásio and Da Silva 2012, 2013). Finally, some methods collect the stakeholders' opinions and also process the quantitative information of the context (T5). The artificial scales frequently involve the scope of a project with respect to the capability of a context. Similarly to the previous treatments, the exclusive participation of experts and the limitation of the use of criteria with available information were demonstrated (Ugwu and Haupt 2007, Ugwu et al 2006b, Jeon et al. 2013).

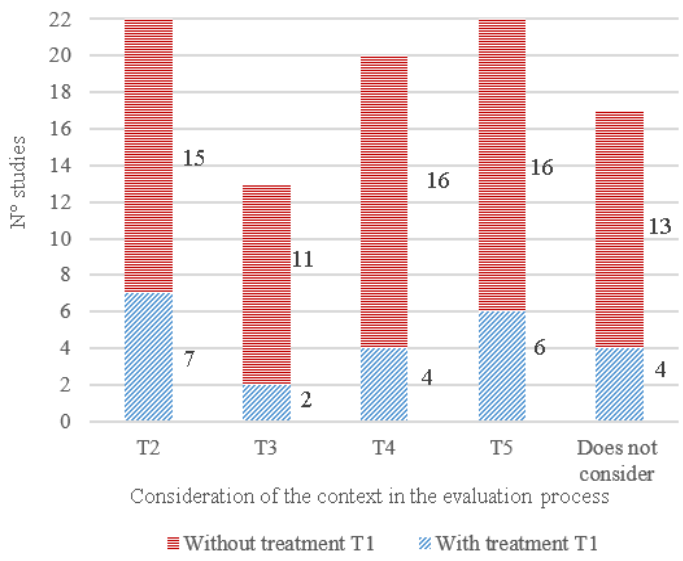

Figure 2.10: Distribution of the treatments for consideration of the context

2.6 Discussion

Last years have seen an increase in studies that consider the social aspects in multi-criteria assessments of infrastructures. Aspects such as esthetics, cohesion and culture or research and innovation were unusual at the beginning of this century (Table 2.3). The impacts on use-maintenance stage and the transport infrastructure assessment were those of greatest frequency in 13 of the 23 social criteria (Figure 2.4). In general, 56% of the studies focused on the assessment of five social criteria. These are environmental health and safety (accident rate), identity and cohesion (inclusion or discrimination), mobility and access (travel times or delays or distances), economy and regional development (maintenance costs), and economy and local development (user operational costs).

On the other hand, in 67% of the studies there is some degree of participation in the assessment process. However, in only 17% of the opportunities is the local context involved. Munda (2004) suggests that local participation helps understand the assessment problem beyond a technical approach. In addition, academia is meant to integrate the participation team to interpret suitable conclusions. Mainly, the participatory processes are centered on determining the weights of the social criteria. The AHP is used to determine weights in a participatory way (Caliskan 2006, Curiel-Esparza et al. 2016). Some authors, however, question the application of subjective weights (Munda 2004, 2006). Others prefer a direct allocation of weights based on predefined principles (Chow et al. 2014, Bueno and Vassallo 2015). The Delphi method is used to add participants' opinions (Ramani et al. 2011, Bueno and Vassallo 2015). In this vein, Karami et al. (2017) and Aghdaie et al. (2012) promote the use of the Delphi and other qualitative techniques in social assessment processes.

The most frequently used method for evaluating infrastructure alternatives was SAW. Normally SAW groups the assessment of an alternative in an indicator that compensates for the criteria considered. Yet some authors suggest that a full compensation of a sustainable assessment process is inadequate (Munda 2006, Gervacio and Da Silva 2012). The scoring systems and artificial scales are the most frequently used treatments for the qualitative and quantitative variables, respectively (Dasgupta and Edwin 2005, Ugwu and Haupt 2007, Zhang et al. 2014). On the other hand, the transportation infrastructures are those that have the highest number of studies. In this vein, Bueno et al. (2015) set out the evolution of the sustainability assessment for transportation infrastructures.

Treatment of the uncertainty of the input data was demonstrated in only 22% of the studies. The main treatments of uncertainty are the probabilistic methods and fuzzy logic. Indeed, the early assessment of the infrastructure projects requires a treatment of the uncertainty (Gervásio and Da Silva 2012, 2013). In addition, the criteria with high variability and influential in decision-making take priority in the treatment of their uncertainty (de la Cruz et al. 2015a, b).

For its part, the equity approach was considered in only 16% of the studies, either through a cross-sectional mechanism (van de Walle 2002, Thomopoulos et al. 2013) or by specific criteria (Resendez et al. 2014, Bueno and Vassallo 2015). Equity is determined either quantitatively through econometric models, from functions of differences between social groups or the vulnerability of specific groups (Table 4). The application of econometric models was based on theoretical examples. In all the applied cases geolocation databases and population distributions were used. In fact, some studies report that the lack of local data limits the implementation (Sahely et al. 2005, Labuschagne and Brent 2006, Chow et al. 2014). This situation is common in developing countries, where the parameters used are adapted from other contexts (Diaz-Sarachaga et al. 2017b). On the other hand, some methods of social research can fill the data gap (Munda 2004, Karami et al. 2017). Intergenerational equity was recognized in only two studies with theoretical examples (Nishijima et al. 2007, Mostafa and El-Gohary 2014).

The learning approach was included in 17% of the studies. Some cases apply a progressive assessment of the impact of the project with feedback and incentives (CEEQUAL 2010, ISI 2015, Muench et al. 2011, ISCA 2012). Other studies apply conceptual maps or geographic information systems (Ugwu et al. 2006a, b, Gilmour et al. 2011, Jeong et al. 2014). In these cases greater analysis time and participant commitment are required (Ugwu et al. 2006a, Valdés-Vásquez and Klots 2011). Finally, the studies consider context through stakeholder participation or the use of local databases. Most of the stakeholder groups, however, are comprised of experts (Ugwu and Haupt 2007, Ugwu et al 2006a, b, Jeon et al. 2013). By contrast, Solatani et al. (2015) point out that consideration of the social context from participation requires societal representation. In addition, in some cases the local data regarding social aspects are not available. Therefore, some proposals adapt the information from the macrocontext increasing the uncertainty (Resendez et al. 2014, Diaz-Sarachaga et al. 2017). Thus, consideration of the social criteria has been limited to the information available (Gervásio and Da Silva 2013). Some cases complement the contextual information with social studies (Chow et al. 2014, Delgado and Romero 2016).

2.7 Conclusions

Multi-criteria assessment methods have integrated social aspects in the evaluation of infrastructure sustainability. Assessment of the social dimension, however, requires certain treatments not always covered in the assessment systems. This article examines the treatment of the social aspects in multi-criteria assessment methods.

A review is performed focusing on multi-criteria infrastructure assessment methods that consider social aspects. From the results, 23 social criteria used in the assessment methods are grouped. The most common social criteria are health and safety, identity and cohesion, mobility and access, and regional and local development. The evaluation at the stage of use-maintenance and transport infrastructures is the most frequent. Although there are participatory processes, most are based on experts and governmental institutions, that structure the assessment system and weight the criteria.

The compensatory methods, AHP and SAW, are the most used to assess the weights and alternatives, respectively. As a complement, the Delphi method centers on the participants' opinions; scoring systems treat the qualitative variables, whereas the artificial scales treat the quantitative variables. Treatment of uncertainty is rare. Equity and social learning are not considered in more than 20% of the studies. On the other hand, the context is taken into account mainly through participation; however, the local community is less involved. Therefore, although the multi-criteria methods provide a platform to assess the social dimension, its treatment requires an improvement. There is a need for studies of methods that integrate improvements in the multi-criteria assessment of the social infrastructure aspects.

These results are limited to a set of studies of multi-criteria methods published between 1995 and January 2017, which include social aspects in the infrastructure assessment. This paper contributes to improve the development of methods that include the evaluation of the social aspects. In particular, the public agencies charged with infrastructure assessment can benefit, promoting improvements in the consideration of the social aspects within the decision-making processes.

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2.8 References

Abu Dabous, S., Alkass, S. (2008). Decision support method for multi-criteria selection of bridge rehabilitation strategy. Constr. Manag. Econ. 26(8): 883–894, doi:10.1080/01446190802071190

Aghdaie, M.H., Zolfani, S.H., Zavadskas, E.K. (2012). Prioritizing constructing projects of municipalities based on AHP and COPRAS-G: A case study about footbridges in Iran. Balt. J. Road Bridg. Eng. 7(2):145–153, doi:10.3846/bjrbe.2012.20

Axelsson, R., Angelstam P., Degerman E., Teitelbaum S., Andersson K., Elbakidze M., Drotz M.K. (2013). Social and Cultural Sustainability: Criteria, Indicators, Verifier variables for measurement and maps for visualization to support planning, AMBIO. A Journal of the Human Environmental, 42(2): 215–228, doi: 10.1007/s13280-012-0376-0

Balali, V., Mottaghi, A., Shoghli, O., Golabchi, M. (2014). Selection of Appropriate Material, Construction Technique, and Structural System of Bridges by Use of Multicriteria Decision-Making Method. Transp. Res. Rec. J. Transp. Res. Board 2431(1): 79–87, doi:10.3141/2431-11

Bonsall, P., Kelly, C. (2005). Road user charging and social exclusion: The impact of congestion charges on at-risk groups. Transp. Policy 12(5): 406–418, doi:10.1016/j.tranpol.2005.06.007

Boz, M.A., El-adaway, I.H. (2015). Creating a Holistic Systems Framework for Sustainability Assessment of Civil Infrastructure Projects. J. Constr. Eng. Manag. 141(2): 4014067–1, doi:10.1061/(ASCE)CO .1943-7862.0000911

Bröcker, J., Korzhenevych, A., Schürmann, C. (2010). Assessing spatial equity and efficiency impacts of transport infrastructure projects. Transp. Res. Part B Method. 44(7): 795–811, doi:10.1016/j.trb.2009.12.008

Bueno, P.C., Vassallo, J.M. (2015). Setting the weights of sustainability criteria for the appraisal of transport projects. Transport 30(3): 298–306, doi:10.3846/16484142.2015.1086890

Bueno, P.C., Vassallo, J.M., Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods. Transp. Rev. 35(5): 622–649, doi:10.1080/01441647.2015.1041435

Caliskan, N. (2006). A decision support approach for the evaluation of transport investment alternatives. Eur. J. Oper. Res. 175(3): 1696–1704, doi:10.1016/j.ejor.2005.02.035

CEEQUAL ltd (2010). The Assessment and Awards Scheme for improving sustainability in civil engineering and the public realm. Assessment Manual for Projects in the UK and Ireland (No. ver. 4.1). United Kingdom.

Chen, S., Leng, Y., Mao, B., Liu, S. (2014). Integrated weight-based multi-criteria evaluation on transfer in large transport terminals: A case study of the Beijing South Railway Station. Transp. Res. Part A Policy Pract. 66(1): 13–26. doi:10.1016/j.tra.2014.04.015

Chow, J.Y.J., Hernandez, S. V., Bhagat, A., McNally, M.G. (2014). Multi-Criteria Sustainability Assessment in Transport Planning for Recreational Travel. Int. J. Sustain. Transp. 8(2): 151–175, doi:10.1080/15568318.2011.654177

Colantonio, A. (2011). Social Sustainability: Exploring the Linkages Between Research, Policy and Practice, in: Jaeger, C., Tábara, D., Jaeger, J. (Eds.), European Research on Sustainable Development. Springer, Berlin, pp. 35–57, doi:10.1007/978-3-642-19202-9_5.

Curiel-Esparza, J., Mazario-Diez, J.L., Canto-Perello, J., Martin-Utrillas, M. (2016). Prioritization by consensus of enhancements for sustainable mobility in urban areas. Environ. Sci. Policy 55(1): 248–257, doi:10.1016/j.envsci.2015.10.015

Dasgupta, S., Tam, E.K. (2005). Indicators and framework for assessing sustainable infrastructure. Can. J. Civ. Eng. 32(1): 30–44, doi:10.1139/l04-101

De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J. (2015a). Chapter 4 Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1 : The MIVES - Monte Carlo Method, in: Corona, C., Arredondo, A., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 69–106, doi:10.4018/978-1-4666-6631-3.ch004

De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J. (2015b). Chapter 5: Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 2: The Fuzzy-MIVES Method, in: Corona, C., Lozano, J., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 107–140, doi:10.1017/CBO9781107415324.004

Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. Environ. Model. Softw. 77(1): 108-121, doi: 10.1016 / j.envsoft.2015.12.011.

Diaz-Sarachaga, J.M., Jato-Espino, D., Alsulami, B., Castro-Fresno, D. (2016). Evaluation of existing sustainable infrastructure rating systems for their application in developing countries. Ecol. Indic. 71(1): 491–502, doi:10.1016/j.ecolind.2016.07.033

Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D. (2017). Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC). Environ. Sci. Policy. 69(1): 65–72, doi: 10.1016/j.envsci.2016.12.010

Di Cesare, S., Silveri, F., Sala, S., Petti, L. (2016). Positive impacts in social life cycle assessment: state of the art and the way forward. Int. J. Life Cycle Assess. In Press, doi:10.1007/s11367-016-1169-7

Fernández-Sánchez, G., Rodríguez-López, F. (2010). A methodology to identify sustainability indicators in construction project management - Application to infrastructure projects in Spain. Ecol. Indic. 10(6): 1194–1201, doi:10.1016/j.ecolind.2010.04.009

Gervásio, H., Da Silva. L.S. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Syst. Appl. 39(8): 7121–7131, doi: 10.1016/j.eswa.2012.01.032.

Gervásio, H., Da Silva, L.S. (2013). Life-cycle social analysis of motorway bridges. Struct. Infrastruct. Eng. 9(10): 1019–1039, doi:10.1080/15732479.2011.654124

Gilchrist, A., Allouche, E.N. (2005). Quantification of social costs associated with construction projects: State-of-the-art review. Tunn. Undergr. Sp. Technol. 20(1): 89–104, doi:10.1016/j.tust.2004.04.003

Gilmour, D., Blackwood, D., Banks, L., Wilson, F. (2011). Sustainable development indicators for major infrastructure projects. Proc. Inst. Civ. Eng. Eng. 164(1): 15–24, doi:10.1680/muen.800020

Hallowell M., Gambatese, J. (2010). Application of the Delphi method to CEM research. J. Constr. Eng. Manage. 136(1): 99-107, doi:10.1061/(ASCE)CO.1943-7862.0000137.

Hong, Y., Liyin, S., Tan, Y., Jianli, H. (2011). Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. Autom. Constr. J. 20(8): 1060–1069, doi:10.1016/j.autcon.2011.04.007

Hyard, A. (2012). Cost-benefit analysis according to Sen: An application in the evaluation of transport infrastructures in France. Transp. Res. Part A Policy Pract. 46(4): 707–719, doi:10.1016/j.tra.2012.01.002

ISCA Infrastructure Sustainable Council of Australia (2012). Infrastructure Sustainable (IS) Overview [WWW Document]. http://isca.org.au/is-rating-scheme/about-is (accessed 4.8.17).

ISI - Institute for Sustainable Infrastructure (2015). ENVISION Rating System For Sustainable Infrastructure. Washington, DC 20005

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., Canteras-Jordana, J.C. (2014a). A review of application of multi-criteria decision-making methods in construction. Autom. Constr. 45(1): 151–162, doi:10.1016/j.autcon.2014.05.013

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V.C., Ballester-Muñoz, F. (2014b). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. Expert Syst. Appl. 41(15):6807–6817, doi:10.1016/j.eswa.2014.05.008

Jeon, C.M., Amekudzi, A. a., Guensler, R.L. (2010). Evaluating Plan Alternatives for Transportation System Sustainability: Atlanta Metropolitan Region. Int. J. Sustain. Transp. 4(4): 227–247. doi:10.1080/15568310902940209

Jeon, C.M., Amekudzi, A.A., Guensler, R.L. (2013). Sustainability assessment at the transportation planning level: Performance measures and indexes. Transp. Policy 25(1): 10–2, doi:10.1016/j.tranpol.2012.10.004

Jeong, J.S., García-Moruno, L., Hernández-Blanco, J. (2014). Un modelo web para la asistencia en la toma de decisiones en la integración de las construcciones rurales mediante planificación espacial multi-criterio. Inf. la Construcción 66(533): 1–10, doi:dx.doi.org/10.3989/ic.13.001

Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). System dynamic simulation: A new method in social impact assessment (SIA). Environ. Impact Assess. Rev. 62(1): 25–34, doi:10.1016/j.eiar.2016.07.009

Koo, D.-H., Ariaratnam, S.T., Kavazanjian, E. (2009). Development of a sustainability assessment model for underground infrastructure projects. Can. J. Civ. Eng. 36: 765–776, doi:10.1139/L09-024

Kucukvar, M., Gumus, S., Egilmez, G., Tatari, O. (2014). Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision making method. Autom. Constr. 40(1):33-43, doi:10.1016/j.autcon.2013.12.009

Labuschagne, C., Brent, A.C. (2006). Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry. Int. J. Life Cycle Assess. 11(1): 3–15, doi: 10.1065/lca2006.01.233

Labuschagne, C., Brent, A.C. (2008). An industry perspective of the completeness and relevance of a social assessment framework for project and technology management in the manufacturing sector. J. Clean. Prod. 16(3):253–262, doi:10.1016/j.jclepro.2006.07.028

Li, D., Hui, E.C.M., Xu, X., Li, Q. (2012). Methodology for assessing the sustainability of metro systems based on emergy analysis. J. Manag. Eng. 28(1): 59–69, doi:10.1061/(ASCE)ME.1943-5479.0000092.

MacAskill, K., Guthrie, P. (2013). Risk-based approaches to sustainability in civil engineering. Eng. Sustain. 166(ES4): 181–190, doi:10.1680/ensu.12.00001

Missimer, M., Robert, K.H., Broman, G. (2017). A strategic approach to social sustainability - Part 1: exploring social system. J. Clean. Prod. 140(1): 32–41, doi:10.1016/j.jclepro.2016.03.170

Mostafa, M., El-Gohary, N. (2014). Stakeholder-sensitive social welfare–oriented benefit analysis for sustainable infrastructure project development, J. Constr. Eng. Manage. 140(9): 04014038, doi: 10.1061/(ASCE)CO.1943-7862.0000788.

Muench, S., Anderson, J., Hatfield, J., Koester, J.R., Soderlund, M. (2011). Greenroads Manual v1. 5. Seattle, WA: University of Washington.

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. Eur. J. Oper. Res. 158(3): 662–677, doi:10.1016/S0377-2217(03)00369-2

Munda, G. (2006). Social multi-criteria evaluation for urban sustainability policies. Land use policy. 23(1): 86–94, doi:10.1016/j.landusepol.2004.08.012

Nishijima, K., Straub, D., Havbro Faber, M. (2007). Inter-generational distribution of the life-cycle cost of an engineering facility. J. Reliab. Struct. Mater. 1(3): 33–46.

Pan, N.F. (2009). Selecting an appropriate excavation construction method based on qualitative assessments. Expert Syst. Appl. 36(3): 5481–5490, doi:10.1016/j.eswa.2008.06.097

Pan, N.F. (2008). Fuzzy AHP approach for selecting the suitable bridge construction method. Autom. Constr. 17(8): 958–965, doi:10.1016/j.autcon.2008.03.005

Pellicer, E., Sierra, L., Yepes, V. (2016). Appraisal of infrastructure sustainability by graduate students using an active-learning method, J. Clean. Prod. 113(1): 884-896, doi:10.1016/j.jclepro.2015.11.010.

Penadés-Plà, V., García-Segura, T., Martí, J., Yepes, V. (2016). A Review of Multi-Criteria Decision-Making Methods Applied to the Sustainable Bridge Design. Sustainability 8(12): 1295, doi:10.3390/su8121295

Polese, M., Stren, R. (2000). The Social Sustainability of Cities: Diversity and the Management of Change, 15-16 pp, University of Toronto Press, Toronto.

Ramani, T.L., Zietsman, J., Knowles, W.E., Quadrifoglio, L. (2011). Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement. J. Transp. Eng. 137(6): 404–415, doi:10.1061/(ASCE)TE.1943-5436.0000255.

Resendez, L., Dueñas-Osorio, L., Padgett, J.E.(2014). Social Sustainability in Economic, Social and Cultural Context. The international journal of social sustainability in Economic, social and cultural context. 11(1): 25–38.

Reza, B., Sadiq, R., Hewage, K. (2014). Emergy-based life cycle assessment (Em-LCA) for sustainability appraisal of infrastructure systems: A case study on paved roads. Clean Technol. Environ. Policy. 16(2): 251–266, doi:10.1007/s10098-013-0615-5

Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng, 13(1): 1-35, doi: 10.1007/s11518-006-0151-5

Sahely, H.R., Kennedy, C. a, Adams, B.J. (2005). Developing sustainability criteria for urban infrastructure systems. Can. J. Civ. Eng. 32(1): 72–85, doi:10.1139/l04-072

Shang, J.S., Tjader, Y., Ding, Y. (2004). A unified framework for multicriteria evaluation of transportation projects. IEEE Trans. Eng. Manag. 51(3): 300–313, doi:10.1109/TEM.2004.830848

Shen, L.Y., Wu, Y.Z., Chan, E.H.W., Hao, J.L. (2005). Application of system dynamics for assessment of sustainable performance of construction projects. J. Zhejiang Univ. Sci. 6 A(4): 339–349, doi:10.1631/jzus.2005.A0339

Shen, L.Y., Wu, Y., Zhang, X. (2011). Key Assessment Indicators for the Sustainability of Infrastructure Projects. J. Constr. Eng. Manag. 137(6): 441–541, doi:10.1061/(ASCE)CO.1943-7862 .0000315

Sierra, L., Pellicer, E., Yepes, V. (2016). Social sustainability in the life cycle of Chilean public infrastructure. J. Constr. Eng. Manage. 142(5), doi: 10.1061/(ASCE)CO.1943-7862.0001099.

Sierra, L., Pellicer, E., Yepes, V. (2017). Method for estimating the social sustainability of infrastructure projects. Environ. Impact Assess. Rev. 65(1): 41-53, doi: 10.1016/j.eiar.2017.02.004.

Soltani, A., Hewage, K., Reza, B., Sadiq, R. (2015). Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Manag. 35(1): 318–328. doi:10.1016/j.wasman.2014.09.010

Su, C.W., Cheng, M.Y., Lin, F.B. (2006). Simulation-enhanced approach for ranking major transport projects. J. Civ. Eng. Manag. 12(4): 285–291, doi:10.1080/13923730.2006.9636405

Thomopoulos, N., Grant-Muller, S., Tight, M.R. (2009). Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology. Eval. Program Plann. 32(1): 351–359, doi:10.1016/j.evalprogplan.2009.06.013

Thomopoulos, N., Grant-Muller, S. (2013). Incorporating equity as part of the wider impacts in transport infrastructure assessment: An application of the SUMINI approach. Transportation. 40(2): 315–345, doi:10.1007/s11116-012-9418-5

Torres-Machi, C., Pellicer, E., Yepes, V., Chamorro, A. (2017). Towards a sustainable optimization of pavement maintenance programs under budgetary restrictions. J. Clean. Prod. 148(1):90-102, doi: 10.1016/j.jclepro.2017.01.100

Tudela, A., Akiki, N., Cisternas, R. (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investment. Transp. Res. Part A Policy Pract. 40(5): 414–423, doi:10.1016/j.tra.2005.08.002

Ugwu, O.O., Kumaraswamy, M.M., Wong, A., Ng, S.T. (2006a). Sustainability appraisal in infrastructure projects (SUSAIP): Part 1. Development of indicators and computational methods. Autom. Constr. 15(2): 239–25, doi:10.1016/j.autcon.2005.05.006

Ugwu, O.O., Kumaraswamy, M.M., Wong, a., Ng, S.T. (2006b). Sustainability appraisal in infrastructure projects (SUSAIP): Part 2. A case study in bridge design. Autom. Constr. 15(2):229-238, doi:10.1016/j.autcon.2005.05.005

Ugwu, O., Haupt, T. (2007). Key performance indicators and assessment methods for infrastructure sustainability: south-african construction industry perspective. Build. Environ. 42(2): 665–680, doi:10.1016/j.buildenv.2005.10.018

Umer, A., Hewage, K., Haider, H., Sadiq, R. (2016). Sustainability assessment of roadway projects under uncertainty using Green Proforma: An index-based approach. Int. J. Sustain. Built Environ. In Press, doi:10.1016/j.ijsbe.2016.06.002

Valdés-Vásquez, R., Klotz L.E. (2013). Social sustainability considerations during planning and design: framework of processes for construction projects, J. Constr. Eng. Manage. 139(1): 80-89, doi: 10.1061/(ASCE)CO.1943-7862.0000566.

van de Walle, D. (2002). Choosing Rural Road Investments to Help Reduce Poverty. World Dev. 30, 575–589, doi:10.1016/S0305-750X(01)00127-9

Wey, W.M., Wu, K.Y. (2007). Using ANP priorities with goal programming in resource allocation in transportation. Math. Comput. Model. 46 (7-8): 985–1000, doi:10.1016/j.mcm.2007.03.017

Wey, W.M., Wu, K.Y. (2008). Interdependent urban renewal project selection under the consideration of resource constraints. Environ. Plan. B Plan. Des. 35(1): 122–147, doi:10.1068/b33045

Yadollahi, M., Ansari, R., Majid, M. Z. A., Yin C.H. (2015). A multi-criteria analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia. Struct. Infrastruct. Eng. 11(5): 638-654, doi:10.1080/15732479.2014.894002.

Yepes, V., García-Segura, T., Moreno-Jiménez, J.M. (2015). A cognitive approach for the multi-objective optimization of RC structural problems. ACME, 15(4):1024-1036, doi:10.1016/j.acme.2015.05.001

Zamarrón-Mieza, I., Yepes, V., Moreno-Jiménez, J.M. (2017). A systematic review of applocation of multi-criteria decision analysis for aging-dam management. J. Clean. Prod. 147(1): 217–230, doi:10.1016/j.jclepro.2017.01.092

Zastrow, P., Molina-Moreno, F., García-Segura, T., Martí, J.V., Yepes, V. (2017). Life cycle assessment of cost-optimized buttress earth-retaining walls: a parametric study. J. Clean. Prod. 140:1037-1048, doi: 10.1016/j.jclepro.2016.10.085

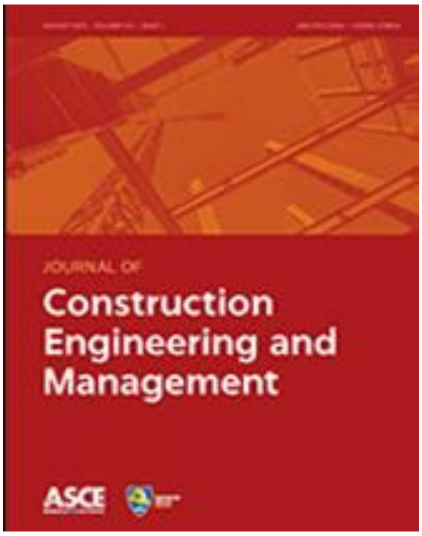
Zavadskas, E.K., Baušys, R., Lazauskas, M. (2015). Sustainable Assessment of Alternative Sites for the Construction of a Waste Incineration Plant by Applying WASPAS Method with Single-Valued Neutrosophic Set. Sustainability. 7(12): 15923–15946, doi:10.3390/su71215792

Zhang, X., Wu, Y., Shen, L., Skitmore, M. (2014). A prototype system dynamic model for assessing the sustainability of construction projects. Int. J. Proj. Manag. 32(1): 66–76, doi:10.1016/j.ijproman.2013.01.009

CAPÍTULO 3

SOCIAL SUSTAINABILITY IN THE LIFE CYCLE OF CHILEAN PUBLIC INFRASTRUCTURE

Publicación



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To enhance concern for the social aspects of sustainability and to delineate the criteria to be considered at each stage of the lifecycle of an infrastructure, this paper aims to determine the relevance of a set of criteria that evaluate social sustainability throughout the lifecycle of a public civil infrastructure. This research presents the results of a case study applying the Delphi method to 24 Chilean experts consulted in a series of three rounds. In addition, binomial statistical tests and Kendall's coefficient were used to show the convergence of the experts. Thus, it was identified that of 36 initial criteria assessed at each stage of the lifecycle, the consideration of 20 is required at the design stage, 29 at the construction stage, 33 during operation, and 27 at demolition. The most relevant criteria, per lifecycle stage, were Stakeholder Participation (design and demolition stages), External Local Population (design stage), Internal Human Resources (construction and demolition stages), Macro-Social Action of Socioenvironmental Activities (construction stage), and Macro-Social Action of Socioeconomic Activities (operation stage).

KEYWORDS: Case Study; Chile; Delphi; Infrastructure; Life Cycle; Social Sustainability.

3.1 Introduction

At the beginning of the 1970s, the concept of sustainable development had already been established as "economic development that can be of benefit to current and future generations without damaging the planet's resources or biological organisms" (NEPA 1969). Years later, the Brundtland Report (WCED 1987) broadened this definition, and the development concept was transformed into a more qualitative, complex, multidimensional and intangible concept. This focus made economic, social and environmental concerns compatible, without jeopardizing the development opportunities of new generations or the future life of the planet (WCED 1987; UNCED 1992). In the last 30 years of the 20th century, the discussion on sustainable development emphasized the need to bequeath a better natural world for future generations, whereas only at the end of the century did the international community begin to understand that the goal must be to increase human abilities (Anand and Sen 2000).

In 1992 the construction industry initiated action plans proposed by the United Nations and its organizations through the "Agenda 21 for Sustainable Construction in Developing Countries". This plan was signed at its inception by more than 178 countries in the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil (UNCED 1992). Since then, awareness of pursuing an agenda oriented toward sustainability has been heightened, and this includes the social considerations throughout the life cycle of the project: design, construction, operation, and demolition (Boyle et al. 2010; Pellicer et al. 2014; Venegas 2003). However, this has not been enough, and the fundamental limitation of sustainability nowadays is clear: it tends to concentrate on the biophysical and economic considerations of the constructed environment, without adequate consideration of the social aspects involved (CIB 2002; Torres-Machí et al. 2014 and

2015). Indeed, some public sector projects have not sufficiently considered certain elements of social performance, which should be their main objective (Shen et al. 2010).

Not including the social dimension in an infrastructure's development will have detrimental effects in the short and long term that determine the results of the project. In the mid-short term, the dynamics of infrastructure development with the growing participation of various actors (Bakht and El-Diraby 2015) and their interactions involves emerging risks that challenge the achievement of the project results (Yepes et al. 2015), when prompt social treatment is not preconceived (Naderpajouh et al. 2014). These dynamics generally dominate other potential risks, such as the technical and economic complexities of the project (Alarcón et al. 2011). On the other hand, in the long term, not adequately considering the social aspects may have detrimental effects that can jeopardize the quality of intra-generational life (Lehmann et al. 2013; Axelsson et al. 2013).

Today the definition of the criteria that comprise social sustainability in construction projects has yet to be clearly delineated, depending on the application contexts, the participants' perspectives and the life cycle stages (Bakht and El-Diraby 2015; Labuschagne and Brent 2006; Pellicer et al. 2014; Valdés-Vásquez and Klotz 2013). In Chile in particular, despite recent initiatives adding concern for the social aspects (Government of Chile 2013), the focus remains on conceptual guidelines with a tangential orientation toward sustainability through social responsibility and not the social impact of the infrastructure.

A literature review was conducted to examine the social impacts addressed by various authors since 1970. Among the studies, a structure of social sustainability was identified; it focuses on the social impact that business initiatives exert on society (Labuschagne et al. 2005). It broadly covers the impacts surveyed and it has also been used in construction studies (Flores et al. 2013; Huang et al. 2012; Lang et al. 2007). However, making decisions that include social aspects depends on the points of view of the actors involved as well as on the contexts of application (Bakht and El-Diraby 2015; Vanclay 2002; Valdés and Klotz 2013). Therefore, any structure of social sustainability must be clarified and defined (Labuschagne and Brent 2006; Slootweg et al. 2001; Valdés and Klotz 2013) during the life cycle stages (Boyle et al. 2010) and the incidence that the construction projects have in this life cycle must be explained from the social viewpoint (Valdés and Klotz 2013).

Thus, this article aims to: (1) identify the criteria of the social sustainability structure best suited to the nature of each stage of a public infrastructure's life cycle; and (2) determine the degree of relevance of each criterion in the development of this infrastructure. These goals are limited to public infrastructure and a number of experts consulted regarding the Chilean context. This paper includes the background (next section) to define the social sustainability criteria used as well as subsequent sections describing the method, results, discussion and conclusions of the research.

3.2 Social sustainability factors and criteria

In the process of identifying social sustainability guidelines, this study included a review of previous contributions to establish the social impacts or factors, as well as the criteria that address these social impacts on a public civil infrastructure project during its life cycle. To achieve this goal, previously, two basic concepts have to be defined: social impacts (or factors) and criteria. Social impacts are "all social and cultural consequences to human populations of any public or private actions that alter the ways in which people live, work, play relate to one another, organize to meet their needs, and generally cope as members of society" (ICPGSIA 1994, page 107); these impacts are dealt with in the next paragraph. On the other hand, the rest of the section handles some approaches to criteria found in the literature review, considering the simple definition of a criterion as the cause for making a decision from a social viewpoint.

First, the literature review identified the main articles and international norms focused on social aspects or factors, and 110 contributions were obtained, beginning in 1970. These documents were organized to fulfill three objectives: conceptualization of the aspects (Hill and Bowen 1997; Vanclay 2002; Valdés and Klotz 2013), methodological applications and indicators (Azapagic 2004; Labuschagne et al. 2005; Fernández-Sánchez and Rodríguez-López 2010), and policy recommendations for evaluation (ICPGSIA 1994; ISO 2010; GRI 2013). With all the impacts compiled from the literature review, the research team assembled nine categories of social impacts or factors, subdivided in 20 groups, according to their conceptual affinity; the columns in

Table 3.1: Evolutionary sample of studies that integrate at least 40% coverage of social impacts displays these categories and groups. The research team made use of a focus group to validate them; this focus group was formed by the research team, as well as three additional members, all of them professors with more than 20 years of academic and professional experience. Later on, the contributions were classified according to these 20 groups.

Table 3.1 shows (in rows) the most relevant contributions: those that deal with 40% of the social impacts, at least; this percentage of coverage is calculated dividing the number of factors in the article by the total identified, in percentages.

Table 3.1: Evolutionary sample of studies that integrate at least 40% coverage of social impacts

		Human Capital			Community					Productive Capital			Social Capital	Institutional Capital		Socioeconomic System		Company Product	Company - Labor Practices			
Literature		Basic needs	Education	Health care systems	Perceptions of the community	Esthetics and degradation	Security in the surroundings	Identity and social cohesion	Cultural capital	Private property	Impact on mobility	Infr. services, sports and recreation	Stakeholders' participation	Capability of public administration work	Transparency and Integrity	General economic systems (Region / Country)	Job opportunities and / or stability	Product development and performance, compatible with human activity	Training of Human Resources	Occupational health and safety	Labor Practices	% Coverage of the
Conceptualizing the social aspect	Armour (1990)				x	x	x	x	x		x	x				x						**40**
	Hill and Bowen (1997)	X	x					x	x							x		x	x	x		**40**
	Vanclay (1999)			x	x	x	x	x	x	x	x	x	x		x	x				x		**65**
	Vanclay (2002)			x	x	x	x	x	x	x	x	x		x	x	x	x			x	x	**75**
	Labuschagne (2005)		x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	x	**80**
	Wang (2004)	X	x	x				x	x									x	x	x		**40**
	Griffiths et al. (2012)			x	x	x	x	x	x	x	x	x	x			x		x		x		**65**
	Vallance (2011)	X						x	x			x	x	x	x		x					**40**
	Valdes and Klotz (2013)		x	x	x	x		x	x		x	x	x				x	x	x	x		**65**
References and methodological applications	Spangenberg (2002)	X	x	x							x	x	x		x	x	x			x	x	**55**
	Egre and Seneca (2003)			x				x	x	x	x				x	x	x				x	**45**
	Azapagic (2004)	x	x	x				x	x				x		x		x	x	x	x	x	**60**
	Burdge (2004)			x			x	x	x			x	x			x	x				x	**45**
	Gilchrist and Allouche (2005)			x	x	x				x	x	x				x				x		**40**
	Ugwu (2006 a and b)			x	x	x	x	x	x		x	x	x				x			x		**55**
	Labuschagne (2006)		x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	x	**80**
	Ugwu and Haupt (2007)			x	x	x		x	x		x							x		x		**40**
	Lockie (2009)						x	x	x	x	x	x	x	x		x	x					**50**
	Koo et al. (2008)			x	x	x	x		x		x	x								x		**40**
	Koo et al. (2009)			x	x	x	x		x		x	x								x		**40**
	Fernandez-Sanchez and Rodriguez-Lopez (2010)			x		x	x	x	x		x		x		x			x		x		**50**
Policy recommendations for evaluation	ICPGSIA (1994)		x	x	x		x		x			x	x		x	x	x			x	x	**60**
	DGMA (2000a,b)		x	x		x			x		x	x				x	x			x		**45**
	ICPGSIA (2003)		x	x	x		x	x	x			x	x		x	x	x			x	x	**65**
	Indicators of sustainable development (2007)	x	x	x			x				x	x			x		x					**40**
	ISO 26000 (2010)			x				x	x	x	x	x	x		x		x	x	x	x	x	**70**
	GRI (2013)	x	x	x				x	x				x		x		x	x	x	x	x	**60**

Regarding the criteria, during the 1980s authors like Finterbuch (1985) established the first methodologies and aspects to consider when assessing the social impacts of construction projects. Nevertheless, since the 1990s social criteria have been further defined and specified (ICPGSIA 1994; Burdge 1995). From the outset, the criteria sought to overcome the conditions of poverty associated with shortages of resources (Hill and Bowen 1997); this has evolved in our era into social vulnerability, which encompass better the aspects to be considered (Vanclay 2003).

In the last decade, Vanclay (2002) has delved more deeply into the effect of the social aspects, and differentiated between those which involve a direct impact for society and those that are agents of change which, under certain circumstances, may involve some social risk. This differentiation complements the studies by Slootweg et al. (2001), who established an iterative integration model of the social and environmental impacts; human interventions imply change processes that subsequently become impacts.

By the beginning of the 2000s, these criteria were already being adapted to the review of particular cases and integrated into methodological proposals that aimed to involve social aspects in sustainability assessment (Azapagic 2004; Shen et al. 2010; Ugwu and Haupt 2007; Fernández-Sánchez and Rodríguez-López 2010). Thus, a large number of the aspects formulated in the 1990s were included in more comprehensive studies developed by Labuschagne et al. (2005), Labuschagne and Brent (2006) and Labuschagne and Brent (2008). These studies proposed a conceptual structure of the social dimension that deals with the impacts of the company on the social systems in which it operates. The structure of social sustainability integrates the Global Reporting Initiative, the United Nations Sustainability Indicators, the Wuppertal Sustainability Indicators, and was contrasted against more than 31 international regulations and scientific studies (Labuschagne and Brent 2008).

In this study, the criteria established by Labuschange et al. (2005) were used as a foundation, insofar as these were adequate for public infrastructure initiatives. There are three main reasons to use these criteria as the point of departure: (1) they present the highest level of social impact coverage (80%) among the literature reviewed (

Table 3.1); (2) they have been used in methodological applications (Flores et al. 2013; Huang et al. 2012; Lang et al. 2007); and (3) they were drafted on the basis of an exhaustive review and contrast with regulations and studies by authors who have addressed this topic in the last 20 years. Thirty-one criteria integrate social sustainability, classified into four macro-groups: internal human resources (10 criteria), external local population (12 criteria), social participation of stakeholders (four criteria), and social activities at a regional or national level (five criteria).

3.3 Research method

As indicated in the Introduction, this research intends to identify and prioritize the criteria of the social sustainability structure for each stage of the life cycle of a public infrastructure. In order to do so, the research process follows the steps summarized in Figure 3.1. First, the impacts or factors were obtained from the literature review explained in the previous section, by means of grouping them in 20 groups; this process was validated by a focus group. After analyzing previous contributions, the work of Labuschange et al. (2005) was taken as the point of departure of the social sustainability criteria. The next step is to enhance prioritize and justify the social sustainability criteria suitable for each stage of the life cycle of a public infrastructure implementing the Delphi technique (explained in the following section). Finally, using semistructured interviews with the same members of the panel, the previous results are confirmed and justified.

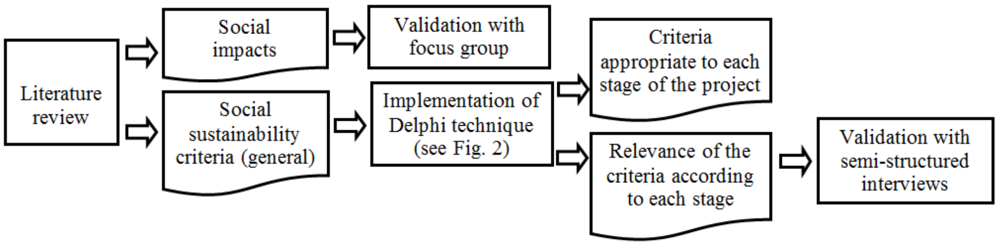

Figure 3.1: Research process

3.3.1 The Delphi method

The Delphi method is a technique of structured and systematic communication useful to achieve these objectives, because it is a tool that can address complex conceptualizations involving reflective and critical analysis (Cortes et al. 2012; Sourani and Sohail 2014; Alshubbak et al. 2015), while maintaining the freedom of judgment of specialists who do not interact (Hallowell and Gambatese 2010). Delphi is based on the principle that decisions from a structured group of individuals are more accurate than those from unstructured groups (Rowe and Wright 1999). The Delphi technique has recently come to be applied in many complex situations where a consensus is required (Hallowell and Gambatese 2010; Cortes et al. 2012; Alshubbak et al. 2015). Application of the Delphi technique involves specific steps (Figure 3.2). For a rigorous implementation, this article followed the guidelines proposed by Hallowell and Gambatese (2010) and Cortes et al. (2012), including the expertise and number of experts on the panel, feedback process and number of rounds.

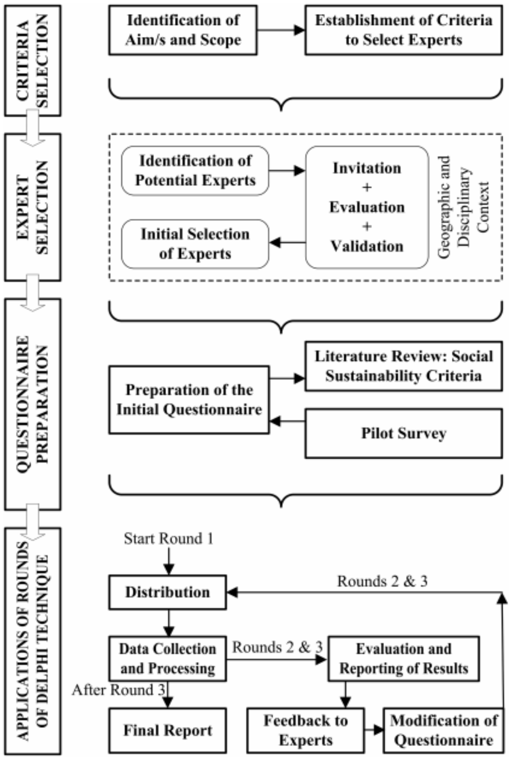

Figure 3.2: Steps in the Delphi method

3.3.2 Selection of the expert panel

The success of the Delphi method depends first on all on the selection of the participants (Hallowell and Gambatese 2010). Accordingly, 33 potential experts were preselected, residents in the geographical study area (Chile) and with experience and training in the area of "Public Civil Infrastructure Development" (Profile 1) and "Socio-Environmental Development" (Profile 2). The expert selection process was conducted on the basis of two criteria:

- According to Hallowell and Gambatese (2010), each panelist had to fulfill at least four of the following requirements: (1) primary or secondary author of at least three peer-reviewed journal articles; (2) invited to speak at a conference; (3) member or chair of a nationally recognized committee; (4) at least 5 years of professional experience in the construction industry; (5) faculty member at an accredited institution of higher learning; (6) advanced degree in the field of civil engineering, construction management, or other related fields (minimum BS); or (7) professional registration.
- Additionally, the expert selection was validated from a self-evaluation of the level of competence in the research topic, through the technique proposed by the Russian State Committee for Science and Technology (Oñate et al. 1998); with this technique, each expert as scored according to two parameters: knowledge and argument. The average of these two parameters gives the level of competence of the expert. Table 3.2 explains the computation.

Table 3.2: Formulation of coefficients for panel self-evaluation

COEFFICIENT	**FORMULA**	**EXPLANATION**
Knowledge (K_c)	$V \times 0.1 = K_c$	V is the self-assessment of the potential expert on a scale of 1-10 (0 means no specific knowledge of the subject, whereas 1 displays specific knowledge of the subject)
Argument (K_a)	$0{,}2 + \sum_{i=1}^{2} A_i = K_a$	SOURCE OF ARGUMENT / HIGH / MEDIUM / LOW A_1.- Theoretical analysis / 0.3 / 0.2 / 0.1 A_2.- Experience in the field / 0.5 / 0.4 / 0.2
Competence (K)	$\frac{(K_c + K_a)}{2} = K$	• If $0.8 < K \leq 1.0$, then K is high. • If $0.5 < K \leq 0.8$, then K is medium • If $K \leq 0.5$, then K is low

The definitive expert panel had 24 members. The expert panel is characterized in Table 3 according to its profile. Considering the criteria provided in Table 3.2, the individualized validation of the expert panel's competence is checked; all the experts can be considered as highly competent, as shown in Table 3.4.

Table 3.3: Characterization of the expert panel

Requirements	**Full expert panel (%)**	**Profile 1** (62.5%)	**Profile 2** (37.5%)
A	45.8	20.8%	25.0%
B	66.7	29.2%	37.5%
C	33.3	12.5%	16.7%
D	[5-8] = 16.7	12.5%	4.2%
	[9-12] = 37.5	16.7%	20.8%
	[13-16] = 16.7	8.3%	8.3%
	[>17] = 29.2	25.0%	4.2%
E	70.8	45.8%	25.0%
F	BS = 33.3	25.0%	8.3%
	MSc = 41.7	25.0%	16.7%
	PhD = 25.0	12.5%	12.5%
G	62.5	50.0%	12.5%

Notes:

A: Primary or secondary author of at least 3 peer-reviewed journal articles.

B: Invited to speak at a conference

C: Member or chair of a nationally recognized committee (Chilean Network Executive Committee LCA; Foundation of Overcoming Poverty; Executive Committee of the Network for Research in Psychology, Economics and Consumer –Chile; Climate Knowledge and Innovation Community Association; Regional Roads Department - Ministry of Public Works – Chile)

D: At least 5 years of professional expertise

E: Faculty member at an accredited institution of higher learning

F: Advanced degree in the field of civil engineering or other related fields (minimum BS)

G: Professional registration (Association of Civil Constructors; Association of Civil Engineering; Association of Architects)

Profile 1: Experience and training in the area of public civil infrastructure

Profile 2: Experience and training in the area of social-environmental issues

Table 3.4: Competence coefficients of the expert panel

Number	**Coefficient of knowledge (K_b)**	**Coefficient of argument (K_a)**	**Coefficient competence (K)**
1	0.7	0.9	0.80
2	0.8	0.9	0.85
3	0.8	0.8	0.80
4	0.9	1	0.95
5	0.8	1	0.90
6	0.7	1	0.85
7	0.9	1	0.95
8	0.8	1	0.90
9	0.8	1	0.90
10	0.8	0.8	0.80
11	0.7	0.9	0.80
12	0.7	1	0.85
13	0.8	1	0.90
14	0.8	0.9	0.85
15	0.7	1	0.85
16	0.7	1	0.85
17	0.7	0.9	0.80
18	0.8	0.9	0.85
19	0.8	0.9	0.85
20	0.7	1	0.85
21	0.9	1	0.95
22	0.9	1	0.95
23	0.9	0.9	0.90
24	0.7	0.9	0.80

3.3.3 Questionnaire and measurement instrument

An initial questionnaire was designed on the basis of the literature review, the criteria of the social sustainability structure proposed by Labuschagne et al. (2005), and prior consultation with three experts in the subject area using the same focus group. The questionnaire requires information that addresses two main questions:

- Which social sustainability criteria affect the life cycle stages of a public civil infrastructure (design, construction, operation, and demolition)?
- What is the level of significance that each social sustainability criterion has with respect to the life cycle stages of a public civil infrastructure?

The responses were quantified using two measurement instruments:

- The answers associated with question 1 were valued on a dichotomizing scale (Agree-1 or Disagree-0) with respect to the experts' consideration of each social sustainability criterion at each stage. The responses were processed through a binomial nonparametric test that guarantees the reliability and convergence of the opinions according to the statistical significance of the probability that agreement is reached (Siegel 1983).
- The answers associated with question 2 were valued on a 5-point Likert scale that measured the degree of relevance (High-5, Remarkable-5, Moderate-3, Low-2 or Insignificant-1) that each criterion confers on social sustainability among the life cycle stages. To measure the consistency of the experts on the order of significance, Kendall's coefficient of concordance (or Kendall's W) was determined. This

nonparametric statistic was used to evaluate the statistical significance of the order granted by the experts (Singh et al. 2009).

3.3.4 Survey process

A description of the study method and objectives was presented to the potential experts through an invitation via e-mail. Once they had agreed to participate, the facilitator arranged an individual meeting by video conference. During this meeting questions were answered, and further details of the study were provided regarding the conceptualization of the aspects involved and the dynamics of work. The questionnaire was sent and the experts' opinions were processed, analyzed and taken into account in the following round.

Three rounds were needed to reach a consensus with respect to the desired objectives and to ensure accuracy and rigor in the study; the process was stopped when more than 50% of the experts agreed, obtaining statistical significance in the binomial test, as explained in the "Results" section. Feedback to the experts entailed informing the group's points of view with a report of the results via e-mail before proceeding to the following round. The experts then received a new questionnaire; they were asked to reconsider their responses, particularly in those cases where information provided in the previous round had not significantly demonstrated a consensus on the variable under discussion.

When consensus was achieved in the third round, the facilitator arranged a semi-structured individual interview with each expert via video conference, during which he/she was asked to confirm, first, and justify, later, the level of significance of each criterion for the infrastructure's life cycle. This can be considered as a fourth round of validation of the Delphi method.

3.4 Results

The results of the Delphi method are presented in Table 3.5, which identifies an infrastructure's life cycle stages with the criteria affecting social sustainability. The table not only shows the order of general importance of the social sustainability criteria for each stage (scale from 1st to 4th place), but also the mean degree of relevance (Likert scale from 1 to 5) of each profile defined in Table 3.5. The order of importance assigned by the experts reached statistical validity for all the criteria evaluated. Once the first round of the questionnaire was agreed upon by the panel, five criteria were incorporated in the second round at the panel's suggestion and reviewed by the research team (Criteria 1.11 to 1.15).

Table 3.5: Agreement and importance of the social sustainability criteria at the lifecycle stages

Criteria contributing to social sustainability				Agreement reached at ROUND 3		General order of relevance (1st to 4th)				Average degree of relevance profile 1 (Likert 1 – 5)				Average degree of relevance profile 2 (Likert 1 – 5)			
				Kendall's W	Asymptotic Significance	Design	Construction	Operation	Demolition	Design	Construction	Operation	Demolition	Design	Construction	Operation	Demolition
INTERNAL HUMAN RESOURCES	Job stability	1.1	Job opportunities	0.927	0.000		1.5	1.7	3.0		4.80	4.51	2.87		4.44	3.92	2.78
		1.2	Job benefits (e.g. remunerations, salary stability, social security, bonuses)	0.928	0.000		2.8	2.6	2.0		3.07	3.18	3.73		2.89	2.91	3.44
	Work Health and Safety	1.3	Health and safety practices to protect workers	0.560	0.000	3.5	1.8	2.4	1.9	2.91	4.93	4.20	5.00	2.85	5.00	4.11	4.78
		1.4	Occurrence of accidents and incidents	0.969	0.000		1.5	3.0	1.6		4.93	3.53	4.93		5.00	3.56	4.89
	Training and self-development	1.5	Training, further education of personnel and career development	0.914	0.000		1.5	1.6	2.9		4.60	4.67	3.47		5.00	4.56	3.00
		1.6	Innovation and research	0.266	0.000	1.7	2.7	2.6	3.0	4.33	3.87	3.60	3.73	4.44	3.56	3.89	3.44
	Employability practices	1.7	Disciplinary practices of contracting party	0.927	0.000		1.3	2.9	1.8		4.80	3.20	4.40		4,56	3.11	4.22
		1.8	Conditions of labor contract	0.922	0.000		1.7	2.8	1.5		4.73	3.40	4.73		4,44	3.56	4.67
		1.9	Equity (e.g. gender, social condition, race)	0.307	0.000			1.6	2.8			2.60	1.00			2.67	1.44
		1.10	Work-related sources (Child labor and others)	--	--												
	Work climate or proposed by experts	1.11	Personal satisfaction	0.869	0.000		2.5	1.3	2.3		3.13	4.20	3.40		3.11	4.33	3.11
		1.12	Workers' self-care and socialization conditions	0.854	0.000		2.1	1.6	2.3		4.00	4.47	3.87		3.89	4.22	3.67
		1.13	Workforce's awareness of sustainability	0.846	0.000	1.3	3.3	1.9	3.5	4.47	2.80	3.87	2.60	4.44	2.44	3.78	2.33
		1.14	Consideration of employees' sociocultural-religious aspects	--	--			1.0				3.47				3.56	
		1.15	Leadership conditions	0.227	0.001	3.0	2.3	2.1	2.6	3.27	3.73	3.80	3.60	3.22	3.44	3.78	3.33
EXTERNAL LOCAL POPULATION	Human cap.	2.1	People's health	0.826	0.000	1.8		1.9	2.3	4.73		4.73	4.40	4.89		4.78	4.56
		2.2	People's education	0.934	0.000	1.5		2.5		3.20		2.57		3.33		2.22	
	Productive capital	2.3	Private property - dwellings	0.922	0.000	1.4	1.6	3.5	1.9	4.53	3.91	2.41	3.87	4.33	4.56	2.33	4.01
		2.4	Sanitary, electrical. telecommunications and other services	0.789	0.000	1.9	3.9	1.6	2.6	4.27	2.60	4.60	3.80	4.56	2.67	4.67	4.00
		2.5	Mobility infrastructure (Roads and transportation)	0.399	0.000	1.9	3.5	2.6	2.1	4.53	3.40	3.87	4.49	4.44	3.33	4.11	4.22
		2.6	Operability and development of public institutions.	0.785	0.000	2.0	1.4	2.9	1.7	3.70	4.55	2.45	3.89	3.44	4.23	2.75	4.40
	Community Capital	2.7	Stimuli for the senses (scents. noises. visual. vibrations)	0.889	0.000	1.4	3.3	1.8	3.6	5.00	3.60	4.80	3.33	4.89	3.56	4.44	3.22
		2.8	Safety	0.760	0.000	3.9	1.8	2.5	1.8	2.73	4.67	4.00	4.67	2.67	4.67	4.22	4.67
		2.9	Local economic benefits	0.921	0.000		1.9	1.2	2.9		3.87	4.53	2.60		3.89	4.44	2.78
		2.10	Material cultural property (e.g. heritage)	0.811	0.000	1.2	2.0	3.7	3.1	4.60	3.80	2.47	2.93	4.78	4.00	2.11	3.11
		2.11	Influence or generation in the development of social pathologies	--	--	1.0				4.33				4.67			
		2.12	Communal cohesion and identity	0.906	0.000	1.4		1.6		4.73		4.27		4.44		4.56	
MACRO-SOCIAL ACTIVITIES	Socioecon. activities	3.1	Socioeconomic benefits at Regional – National leve	0.976	0.000		2.0	1.0			3.27	4.73			3.78	5.00	
		3.2	Social marketing opportunities at Regional – National level	0.974	0.000		2.0	1.0			3.53	4.73			3.67	4.78	
	Socioenviron. activities	3.3	Socioenvironmental auditing and monitoring of projects	0.498	0.000	2.3	1.6	3.6	2.5	4.13	4.60	3.13	3.93	4.11	4.56	3.22	4.11
		3.4	Compliance with execution of environmental commitments	0.875	0.000		1.3	2.8	2.0		4.60	3.33	4.07		4.56	3.44	4.11
		3.5	Influence on legislation	0.626	0.000		1.9	1.5			2.07	2.33			2.00	2.33	
PARTICIPATION OF STAKEHOLDERS	Provision of information	5.1	Provision of information through collective audiences	0.933	0.000	1.2	2.9		2.0	5.00	3.33		4.27	4.89	3.44		4.44
		5.2	Provision of information through selective audiences	0.640	0.000	1.9	2.2	3.9	2.1	4.80	4.40	3.27	4.65	4.44	4.67	3.22	4.35
	Inf. of participants	5.3	Consideration of actors' opinions regarding project development	0.888	0.000	1.2	3.2	3.7	1.9	4.93	3.13	2.60	4.33	5.00	3.44	2.89	4.22
		5.4	Empowerment (Involvement) of the actors	0.407	0.000	1.5	2.6	3.1	2.8	4.87	4.27	3.40	4.13	5.00	4.11	3.33	4.00

Note: [shaded cell] Criteria rejected by the experts in the indicated life cycle stage

In light of the responses and considering the criteria at each stage of a public civil infrastructure's life cycle, the statistical validation of the binomial test with 5% bilateral error identified the criteria which, according to the experts, had to be taken into account. Two sets of results were obtained from this analysis: (1) approved criteria, i.e., evaluations with statistical significance and agreement percentages over 50%; and (2) rejected criteria, i.e., evaluations with statistical significance and agreement percentages under 50%. Table 3.5 shows the results of the criteria included by the experts according to the applicable stage. Of the 36 criteria evaluated at each of the four stages (144 evaluations), 75.7% (109) were approved and 24.3% (35) were rejected. The aspects not included in some of the stages are consistent with the group decision of the 24 experts, as well as the selection of the profiles separately. The criteria that were not rejected and their order of importance were obtained according to the experts' experience, assuming a normal infrastructure development dynamic, and it may be that with certain project characteristics some criteria might not be pertinent. In addition, the general order of importance in the life cycle is statistically consistent for all the criteria evaluated with Kendall's W about the 24 experts' opinion (Table 3.5).

The order of importance of each stage is consistent in almost every case with the degree of relevance of each profile that the expert panel recommended (Table 3.2). However, the profiles disagreed in the assessment of four criteria:

- "Health and Safety" was considered more important in the construction stage, instead of the demolition stage, for social-oriented experts (profile 2).
- "Training, Further Education and Career Development" was scored higher by construction-oriented experts (profile 1) in the operation stage.
- "Innovation and Research" was rated first in the design stage for both profiles, but operation was rated second by social-oriented experts (profile 2) instead of construction (profile 1).
- "Provision of Information" in the construction stage was more important for social-oriented experts (profile 2), ahead of design (the most important for profile 1).

3.5 Discussion

According to the experts surveyed and interviewed in this study, not all the stages of an infrastructure's life cycle contribute equally to the categories of social sustainability (internal human resources, external local population, activities at regional or national level and stakeholder participation). In fact, it was found that activities during the design stage significantly affect most of the criteria of the Stakeholder Participation, which is consistent with Valdés and Klotz (2013); in this stage, decisions influence highly the permanent conditions of use of the infrastructure. The remaining categories, although subject to impact, have fewer criteria affected. Similarly, the activities in the construction stage have a greater influence on the categories of Internal Human Resource" and Macro Socio-Environmental Activities due to the higher impact on the built environment; this agrees with the results in Naderpajouh et al. (2014). The operation stage influences the Macro Socio-Economic Activities and External Local Population, which is associated with the functioning of the human dynamic systems presented by Boyle et al. (2010); as these authors infer, facets such as commercial profit, tax collection, capital improvement, and benefits for the local economy, are aligned with this proposal. The demolition stage impacts the Stakeholder Participation, especially with regard to the demolition planning phase but also the Internal Human Resources after the process of construction.

Based on the results in Table 3.5 and the experts' justification in their decision-making, certain logics of transcendence were postulated. In this regard, experts stressed the direct impact of construction and demolition processes on the Job Opportunities and Job Benefits, as well as the relevance in certain works of conservation infrastructure (e.g. road works); in this sense, ILO (2015) points out construction stage as the fourth economic activity worldwide contributing to employment (8.4%.), whereas Menéndez (2003) shows the importance of regular maintenance during the operation stage for local employment generation. On the other hand, workers' Health and Safety conditions are highly valued at every stage, with construction and demolition being the most relevant, which is consistent with the findings of Ugwu and Haupt (2007). In addition, the employee's development capacities (Training, Further Education and Career Development) present transverse trends to the development of the infrastructure (Labuschangne et al. 2005). However, the experts considered that the processes of the design stage provide better conditions for promoting Innovation and Research; these estimations are in line with the conclusions drawn by Valdés and Klotz (2013).

The experts were of the opinion that some Employability Practices (Disciplinary Practices or Conditions of Labor Contract) are consistent with ISO 26000 (2010), but they specified that their importance becomes more significant when the stages are shorter. During the stages of longer duration or stages with fewer participants, the relationships of trust and responsibility become more important to the functioning of the infrastructure than organizational or contractual norms. This notion is in line with Alarcón et al. (2005), whose findings show the relation between motivation, trust relationships and the conditions enable the growth of the individual in a working environment in Chilean construction companies. In particular, the experts suggested that in hiring and promotion at the design, construction and demolition stages, they prioritize ability, experience and team work, which was also recognized by Alarcón et al. (2005). The experts added that the requirement of the project in a limited time reduces possible discriminatory actions (Inequality) on human resource management. Additionally, in the Chilean construction sector, the experts referred to the unlikelihood of hiring people who do not fulfill the conditions established by labor legislation (Work-Related Sources), which is why point 1.10 of Table 3.5 was not included.

Generally, the experts believed that most of the criteria related to the Work Climate (1.11 to 1.15, Table 3.5) go beyond the effects of the construction stage, as these require a longer period of time to be effective. In keeping with the considerations of Valdés and

Klotz (2013), the experts believed in the importance of work teams being Aware of Sustainability when they create and plan a project.

From the experts' point of view, the conditions that affect the community's Human Capital are also affected by the design stage, because it is here that decisions are made that will impact the future surroundings (Valdés and Klotz 2013), and the operation stage is where those impacts become permanent (Gilchrist and Allouche 2005). According to the experts, this pattern can be likened to most Productive and Community Capital criteria. They also emphasized the effects on Private Property, i.e. expropriations or variation in the value of the building. In the latter case it tends to be significant prior to materialization, as a result of speculation on the variations in demand according to the experts and in fact previous case studies provide evidence of this (Egre and Senecal 2003; Lockie 2009).

According to the experts, Stimulation of the Senses and Cohesion and Identity are criteria affected by community and family interaction with the infrastructure in use, just as Vanclay (2002) also associated these criteria to habitability and family life indicators.

Macro-Social Activities are those with a regional economic impact through tax collection or commercialization, which is mainly significant during the use of the infrastructure, according to the expert's opinion and the results of Fernández-Sánchez and Rodríguez-López (2010). Other Macro-Social Activities recognized by the experts are the environmental practices more heavily associated with the construction stage, although the authors recommended their uniform monitoring during the infrastructure's life cycle (Fernández-Sánchez and Rodríguez-López 2010; Labuschagne and Brent 2008).

According to the experts, democratization implies that actors participate in an informed context (Provision of Information), which would allow relevant contributions from the stakeholders. Thus, the design and pre-demolition stages are crucial in terms of how the delivery of information and Consideration of Opinions (feedback) are handled; this idea is also highlighted in the study by Valdés and Klotz (2013). The experts believed that achieving democratization also requires Empowerment (or a commitment to involvement) throughout the development, this being consistent with other authors and policies (Fernández-Sánchez and Rodríguez-López 2010; ISO 2010). They all indicate the planning and design stage is the one where the decisions are made.

3.6 Conclusions

This article describes the process and results of the research conducted to select the criteria that contribute to social sustainability in the development of a civil infrastructure for public use in Chile. The contributions of this article focus on the criteria selected to contribute to the social sustainability of an infrastructure and will determine an order of relevance among the stages of the life cycle. The finding allow us to conclude that there are 20 criteria in the design stage, 29 in the construction stage, 33 in the operation stage and 27 in the demolition stage, which constitutes a maximum of 75.7% of all the evaluations of social sustainability to consider in the development of a public civil infrastructure.

According to the order of relevance of each criterion in the life cycle, the experts identified the contribution of an infrastructure's design stage over most of the criteria that incorporate the categories Stakeholder Participation and External Local Population. Similarly, the construction stage influences the criteria associated with Internal Human Resources and Macro-Social Action of Socio-Environmental Activities; operation puts at risk the Macro-Social Action of Socio-Economic Activities and demolition is significant in the categories Stakeholder Participation and Internal Human Resources.

Although finding are limited to Chile and public infrastructure, whose functioning dynamic; public-private interaction; diversity of community end users; and other orientations affect particularly the experts' responses to the study questions. The results may contribute to future studies, where the criteria are assessed, indicators specified, incidence factors deepened or methodological applications established to evaluate social sustainability in the development of public civil infrastructure in its early stage. Generally, the results of this study illustrate the opportunity to emphasize certain social sustainability criteria in order to intervene in an infrastructure's characteristics to guide their impact and objectify their measurement in specific study areas.

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3.7 References

Alarcón L. F., Ashley D.B., Sucre de Hanily A., Molenaar K.R. and Ungo R. (2011). Risk planning and management for the Panama Canal expansion program. J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000317.

Alarcón L. F., Pavez I., Bascuñan C. and Diethelm S. (2005). Organizational diagnostics of Chilean construction companies. Proc. 4th SIBRAGEC Brazilian Symposium on Economy and Management of the Construction, 24 to 26 October, Porto Alegre. Brasil.

Alshubbak A., Pellicer E., Catalá J. and Teixeira J.C. (2015). A model for identifying owner's needs in the building life cycle. J. Civ. Eng. Manag., 21(8), 1-15.

Anand S. and Sen A. (2000). Human development and economic sustainability. World Development, 28(12), 2029-2049.

Armour A. (1990). Integrating impact assessment into the planning process. Impact Assess. Bull., 8(1-2), 3 – 14.

Axelsson R., Angelstam P., Degerman E., Teitelbaum S., Andersson K., Elbakidze M. and Drotz M.K. (2013). Social and cultural sustainability: Criteria, indicators, verifier variables for measurement and maps for visualization to support planning. AMBIO., 42, 215–228.

Azapagic A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. J. Clean. Prod., 12, 639–662.

Bakht M. and El-Diraby T. (2015). Synthesis of decision-making research in construction. J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000984,04015027.

Boyle C., Mudd G., Mihelcic J.R., Anastas P., Collins T., Cilligan P., Edwards M., Gabe J., Gallagher P., Handy S., Krumdieck S., Kao J.J., Lyles L.D., Mason I., Mcdowall R., Pearce A., Riedy C., Russell J., Schnoor J., Trotz M., Venables R., Zimmerman J.B., Fuchs V., Miller S., Page S. and Reeder-Emery K. (2010). Delivering sustainable infrastructure that supports the urban built environment. Environmental Science and Technology, 44, 4836–4840.

Brent, A. C., and Labuschagne, C. (2006). "Social indicators for sustainable project and technology lifecycle management in the process industry." Int. J. Life-Cycle Assess., 11(1), 3–15.

Burdge R. (1995). A Community Guide to Social Impact Assessment. Social Ecology Press. Middleton (WI, USA).

Burdge R. (2004). A Community Guide to Social Impact Assessment. [3rd Ed.]. Social Ecology Press.Middleton (WI, USA).

CIB (Internacional Council for Research and Innovation in Building and Construction) (2002). Agenda 21 for Sustainable Construction in Developing Countries. Report Publication No. E0204, Pretoria, South Africa.

Cortés J.M., Pellicer E. and Catalá J. (2012). Integration of occupational risk prevention courses in engineering degree: Delphi study. J. Prof. Issues Eng. Educ. Pract., 138(1), 31-36, 10.1061/(ASCE)EI.1943-5541.0000076.

DESA (Department of Economic and Social Affairs) (2007). Indicators of Sustainable Development. Guideline and Methodologies [3rd Ed.]. United Nations, New York.

DGMA (Dirección General del Medio Ambiente) (2000a). Methodological Guidelines for the Preparation of Environmental Impact Studies: Roads and Railways [2nd Ed.]. Ministerio de Medio Ambiente, Madrid, Spain.

DGMA (Dirección General del Medio Ambiente) (2000b). Methodological Guidelines for the Preparation of Environmental Impact Studies: Large Dams. Ministerio de Medio Ambiente, Madrid, Spain.

Egre D. and Senecal P. (2003). Social impact assessments of large dams throughout the world: Lessons learned over two decades. Impact Assessment and Project Appraisal, 21(3), 215-224.

EPA (United States Environmental Protection Agency) (1969). National Environmental Policy Act. Washington DC, USA.

Fernández-Sánchez G. and Rodríguez-López F. (2010). A methodology to identify sustainability indicators in construction project management–Application to infrastructure projects in Spain. Ecol. Indic., 10,1193–1201.

Finsterbusch K. (1985). State of the art in social impact assessment. Environment and Behavior, 17 (2), 193-221.

Florez L., Castro-Lacouture D. and Medaglia A.L. (2013). Sustainable workforce scheduling in construction program management. J. Oper. Res. Soc., 64(8), 1169–1181.

Gilchrist A. and Allouche E.N. (2005). Quantification of social costs associated with construction projects: state-of-the-art review. Tunn. Undergr. SP Tech., 20, 89–104.

Government of Chile (2013). Towards a Public Policy Social Responsibility for Sustainable Development in Chile. Government of Chile, Decree Nº 60, Santiago, Chile.

Griffiths K., Browne V, Williams V and Elliott P, (2012). The changing face of engineering down under. Eng. Sustainability, 165 (3), 223–232.

GRI (Global Reporting Initiative). (2013). Sustainability Reporting Guidelines G4: Reporting Principles and Standard Disclosures. Amsterdam, Netherlands.

Hallowell M. and Gambatese, J. (2010). Application of the Delphi method to CEM research, J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000137.

Hill R. and Bowen P. (1997). Sustainable construction: principles and a framework for attainment. Construction Management and Economics, 15, 223–239.

Huang B., Yang H., Mauerhofer V. and Guo R. (2012). Sustainability assessment of low carbon technologies-case study of the building sector in China. J. Clean. Prod., 32, 244–250.

ICPGSIA (Interorganizational Committee on Principles and Guidelines for Social Impact Assessment) (1994). Guideline and principles for social impact assessment. Environmental Impact Assessment Review, 15(1), 11–43.

ICPGSIA (Interorganizational Committee on Principles and Guidelines for Social Impact Assessment) (2003). Principles and guidelines for social impact assessment in the USA. Impact Assessment and Project Appraisal. 21 (3), 231–250.

ILO (International Labour Organization) (2015). World Employment Social Outlook. International Labour Organization, Geneva, Switzerland.

ISO (International Stardardization Organization) (2010). Guidance on Social Responsibility: ISO 26000. Geneva, Switzerland.

Koo D.H, Ariaratnam S.T., and Kavazanjian E. (2009). Development of a sustainability assessment model for underground infrastructure projects. Can. J. Civ. Eng., 36, 765–776.

Koo D.H. and Ariaratnam S.T. (2008). Application of a sustainability model for assessing water main replacement options. J. Constr. Eng. Manage., 10.1061/(ASCE)0733-9364(2008)134:(563).

Labuschagne C. and Brent A.C. (2008). An industry perspective of the completeness and relevance of a social assessment framework for project and technology management in the manufacturing sector. J. Clean. Prod., 16(3), 253–258.

Labuschagne C., Brent A.C. and Van Erck R.P.G. (2005). Assessing the sustainability performance of industries. J. Clean. Prod., 13(4), 373–385.

Lang D., Scholz R.W., Binder C.R., Wiek A. and Stäubli B. (2007). Sustainability potential analysis (SPA) of landfills - a systemic approach: theoretical considerations a systemic. J. Clean. Prod., 15(17), 1628–1638.

Lehmann A., Zschieschang E., Traverso M., Finkbeiner M. and Schebek L. (2013). Social aspects for sustainability assessment of technologies—challenges for social life cycle assessment (SLCA). Int. J. Life-Cycle Ass., 18, 1581–1592.

Lockie S.F. (2009). Coal mining and the resource community cycle: A longitudinal assessment of the social impacts of the Coppabella coal mine. Environmental Impact Assessment Review, 29(5), 330–339.

Menendez J.R. (2003). Mantenimiento Rutinario de Caminos por Microempresas. International Labour Organization, Lima, Perú (in Spanish).

Naderpajouh N., Mahdavi A., Hastak M. and Aldrich D.P. (2014). Modeling social opposition to infrastructure development. J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000876.

Oñate N, Ramos L. and Díaz A. (1998). Utilización del método Delphi en la pronosticación: Una experiencia inicial. Economía Planificada, 3(4), 9–48 (in Spanish).

Pellicer E., Yepes V., Teixeira J.C., Moura H.P. and Catala J. (2014). Construction Management, Wiley-Blackwell, Cambridge, United Kingdom.

Rowe G. and Wright G. (1999). The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting, 15(4), 353–375.

Shen L.Y., Tam V.W.Y., Tam L. and Ji Y. (2010). Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice. J. Clean. Prod., 18(3), 254–259.

Siegel S. (1983). Nonparametric Statistics Applied to the Behavioral Sciences [2nd Ed.]. Ed. Trillas, México.

Singh R. Keil M. and Kasi V. (2009). Identifying and overcoming the challenges of implementing a project management office. Eur. J. Inform. Syst., 18, 409–427.

Slootweg R, Vanclay F. and van Schooten M. (2001). Function evaluation as a framework for the integration of social and environmental impact assessment. Impact Assessment and Project Appraisal, 19 (1), 19–28.

Sourani A. and Sohail M. (2015). The Delphi method: Review and use in construction management research. International Journal of Construction Education and Research, 11(1), 54-76.

Spangenberg J.H. (2002). Institutional sustainability indicators: An analysis of the institutions in Agenda 21 and a draft set of indicators for monitoring their effectivity. Sustainable Development., 10, 103–115.

Torres-Machí C., Chamorro A., Pellicer E., Yepes V. and Videla C. (2015). Sustainable pavement management: Integrating Economic, Technical, and Environmental Aspects in Decision Making. Transportation Research Record. Journal of the Transportation Research Board, 2523, 56–63. https://doi.org/10.3141/2523-07.

Torres-Machí C., Chamorro A., Yepes V. and Pellicer E. (2014). Models and actual practices in the economic and environmental evaluation for the sustainable management of pavements networks. Revista de la Construcción, 13(2), 51–58.

Ugwu O.O. and Haupt T.C. (2007). Key performance indicators and assessment methods for infrastructure sustainability—a South African construction industry perspective. Building and Environment, 42, 665–680.

Ugwu O.O., Kumaraswamy M.M., Wong A. and Ng S.T. (2006a). Sustainability appraisal in infrastructure projects (SUSAIP) Part 1. Development of indicators and computational methods. Automation in Construction, 15, 239–251.

Ugwu O.O., Kumaraswamy M.M., Wong A. and Ng S.T. (2006b). Sustainability appraisal in infrastructure projects (SUSAIP) Part 2: A case study in bridge design. Automation in Construction, 15, 229–238.

UNCED (1992). Agenda 21: Action Plan for the Next Century. United Nations Conference on Environment and Development. United Nations, Rio de Janeiro.

Valdés R. and Klotz L.E. (2013). Social sustainability considerations during planning and design: framework of processes for construction projects. J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000566.

Vallance S., Perkins H. and Dixon J. (2011). What is social sustainability? A clarification of concepts. Geoforum, 42, 342–348.

Vanclay F. (1999). Social impact assessment. In: J. Petts, Editor. Handbook of Environmental Impact Assessment, 1, 301–326, Blackwell, Oxford (United Kingdom).

Vanclay F. (2002). Conceptualising social impacts. Environmental Impact Assessment Review, 22(3), 183–211.

Vanclay F. (2003). International principles for social impact assessment. Impact Assessment and Project Appraisal, 21(1), 5–11.

Venegas J.A. (2003). Road map and principles for built environment sustainability. Environmental Science and Technology, 37, 5363–5372.

Wang B. (2004). A Taxonomy of Sustainability in Highway Construction. M.Sc. Thesis. Department of Civil Engineering, University of Toronto, Toronto (Canadá).

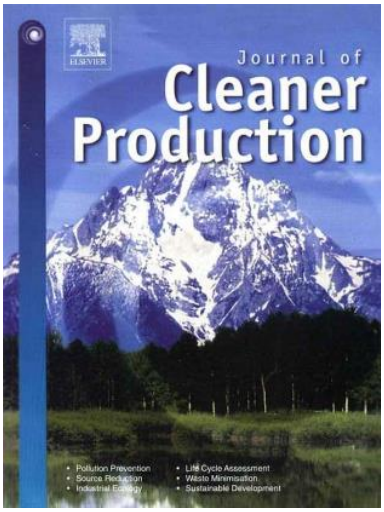
WCED (World Commission on Environment and Development) (1987). Our Common Future. Oxford University Press, Oxford (United Kingdom).

Yepes V., García-Segura T., Moreno-Jiménez J.M. (2015). A cognitive approach for the multi-objective optimization of RC structural problems. Archives of Civil and Mechanical Engineering, in press, 10.1016/j.acme.2015.05.001

CAPÍTULO 4

APPRAISAL OF INFRASTRUCTURE SUSTAINABILITY BY GRADUATE STUDENTS USING AN ACTIVE-LEARNING METHOD

Publicación



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Currently many university programs in the construction field do not take sustainability into account from a holistic viewpoint. This may cause a lack of sensitivity from future professionals concerning sustainability. Academics in construction must endeavor to instill a culture of sustainability in the curricula of their students. Therefore, this study proposes an active-learning method that allows graduate students in the construction field to take into consideration infrastructure sustainability from a variety of perspectives in a participatory process. The students applied an analytical hierarchical process to determine the appraisal degree of each criterion. A cluster statistical analysis was carried out, aiming to identify the profiles that influence decision-making. This method was applied to two classes of graduate students enrolled in the Master of Planning and Management in Civil Engineering at the Universitat Politècnica de València. This method identified a correlation between the profiles toward sustainability and the characteristics of the chosen infrastructure. It was also found that the method fulfills educational purposes: most of the students obtained more than 65% of the target learning outcomes. This approach promotes awareness and sensitivity to different points of view of the sustainability in a participatory context. It can be replicated in other contexts so as to obtain appraisals regarding various criteria that help enhance decision-making.

4.1 Introduction

The approach to sustainability has shifted the perspective of modern societies. Sustainability is associated with all practices that lead society to persist, survive and succeed in terms of environmental resources, economic development and quality of life to promote human development (Pappas et al., 2011). Phenomena such as global warming and social pressures, among others, are significant challenges that this generation must confront. Human activities are primarily responsible for these issues. Current development does not respond to existing needs without jeopardizing future generations' welfare. This is the core of the “sustainable development” paradigm (WCED, 1987).

Universities have a key role to play in creating a sustainable future. They educate professionals who are going to shape and manage the future society in the short term (Wright and Wilton, 2012). In the last decade, there has been growing interest in integrating sustainability into university curricula (Boks and Diehl, 2006; Wemmenhove and de Groot, 2001). Its introduction has been undertaken by adding content to existing courses, one-off workshops, or new courses that supplement current programs (Lozano and Young, 2013). Nonetheless, sustainability is a recent idea in modern society, which has not adequately permeated all university strata yet (Lozano, 2010; Lozano and Young, 2013).

Sustainability is composed of three equally important elements: social, economic and environmental (Labuschagne et al., 2005). However, according to Summers et al. (2004), only one-third of the public understands sustainability that way; the other two-thirds take into account only two out of the three aspects, always recognizing the centrality of the environmental component (García-Segura et al., 2014 ; Torres-Machí et al., 2014). In this line of thought, there are studies (Wright and Wilton, 2012; Watson et al., 2013) that affirm that sustainability is considered in higher education only when focused on the environment. While European experts in sustainability emphasize the sociological role of sustainability, most students focus on technology as a solution for environmental issues (Segalas et al., 2010). Additionally, Whitmer et al. (2010) emphasize a lack of successful learning models among the issues of sustainable education.

Aiming to overcome this challenge, Sipos et al. (2008) propose a transformative process that educates people in order to change their frames of reference and worldviews. In this regard, critical thinking processes are vital to boosting learning, rebuilding knowledge and producing new behaviors oriented toward sustainability (Sipos et al., 2008). The Higher Education Academy of the United Kingdom (HEA, 2006) also emphasizes the importance of social, environmental and economic integration, confrontation with real-life complexity, the promotion of critical judgment, professional and personal self-reflection and sustainability assessment. Specifically, some studies (Lozano, 2010; Lozano and Peattie, 2009) have examined the level of awareness in a student's decisions and actions that affect the environment and society. Kagawa (2007) claims that in some instances students are unfamiliar with sustainability, even though they consider it something positive. On the other hand, Byrne et al. (2013) indicate that engineering professionals associate certain concepts with sustainability according to the education they received.

Therefore, several studies (Segalas et al., 2010; Summers et al., 2004; Wright and Wilton, 2012) have identified students' understanding of sustainability. In comparison, other studies put forward the need for reflective analysis to create, correct or improve ways of thinking about sustainability and acting in accordance with its principles (Byrne et al., 2013; Lozano, 2010; Sipos et al., 2008). Some contributors (Sipos et al., 2008; Steinemann, 2003; Whitmer et al., 2010) point out the need to provide new active-learning methods that value judgments on the concept of integral sustainability: learning strategies focused on the student, the development of motivational and practical experiences, or participatory techniques, among others. Bucciarelli et al. (2000) propose project-based techniques to make students learn engineering design. Du et al. (2013) remark on the advantages of problem-based learning that consider the proposals for potential solutions from students. El-Adaway et al. (2015) introduce a hybrid method that combines different techniques, the results of which show that student performance and sense of responsibility increase. Unfortunately, learning strategies focused on infrastructure sustainability are scarce; among the few, Sieffert et al. (2014) propose a set of learning workshops through the design and construction of buildings using waste materials.

Regarding the design and construction of infrastructure, multiple criteria have to be considered in decision-making (Jato-Espino et al., 2014; Arroyo et al., 2015 ; Torres-Machí et al., 2015). In some cases, these include partial assessment of infrastructure sustainability (Kucukvar et al., 2014; Reyes et al., 2014). However, when these decisions affect sustainability, other opinions have to be considered, because different stakeholders can perceive sustainability according to different degrees of importance (Valdés-Vasquez and Klotz, 2013).

Therefore, there is still room for improvement regarding active-learning methods that value multiple criteria regarding sustainability, particularly those focused on construction. From this point of departure, this study proposes an active-learning method for graduate students to appraise infrastructure sustainability from every facet, considering the multiple preferences of stakeholders and their effect on decision-making. This method is applied to two classes of students enrolled in the Master of Planning and Management in Civil Engineering at the Universitat Politècnica de València (Spain). This paper is organized as follows. First, it presents the proposal. The next section details the selected reference criteria of sustainability. Then, the practical implementation of the prioritization process and the sensitivity analysis are explained. Finally, the formative process is evaluated, the results are discussed and the conclusions are highlighted.

4.2 Methods

The proposed method is based on active-learning. This approach provides for supporting knowledge conceptualization, development in uncertain contexts and collaborative work by the students (Bucciarelli et al., 2000; Prince, 2004; Sieffert et al., 2014). Furthermore, active-learning presents interesting features such as practical implementation in real-life scenarios, critical thinking and participatory action research, which are key elements in learning about sustainability (Du et al., 2013). These reasons motivate the use of an active-learning method in this research. This method was designed according to the layout shown in Figure 4.1which establishes the stages for project prioritization. This method is linked to the education process applied to two classes of graduate students in the construction field. The educational purpose of this method seeks to achieve learning outputs in terms of four aspects: (1) the appropriate interpretation of the integral sustainability criteria and the identification of indicators for case studies; (2) the application of a method that enables the evaluation of sustainability; (3) the identification of project characteristics that affect sustainability; and (4) the understanding of how preferences regarding sustainability (awareness, value judgment of interest and knowledge) influence the final decision-making process.

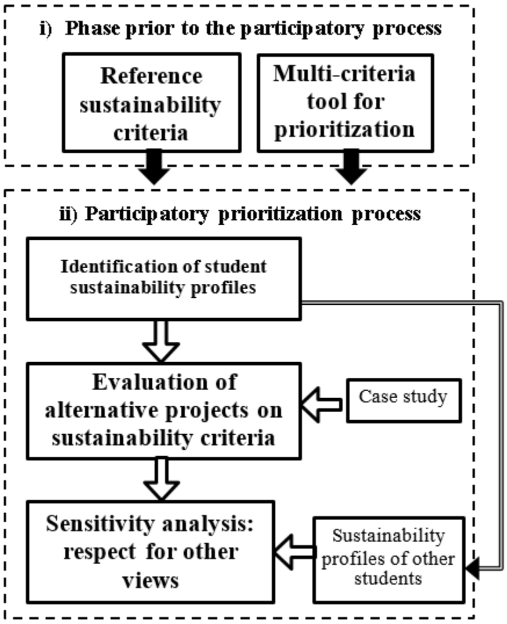


Figure 4.1: Development outline of the method

This method is based on the issue of prioritization of infrastructure projects regarding their contribution to sustainability; this prioritization is going to be assessed by students. Prior to the participatory process, criteria selection and the evaluation method must be referenced. The criteria are sustainability operating principles that can be identified as a result of the scientific, technical and legislative documentation review. They can also be identified by the experts and stakeholders involved during the infrastructure life-cycle (Kumar and Katoch, 2014). These criteria facilitate the correct understanding of the sustainability concept.

The prioritization of the project alternatives for the chosen criteria is developed using a multi-criteria decision-making tool (Jato-Espino et al., 2014), the purpose of which is to provide a rational and organized structure for the decision-making process. Prioritization starts with the identification of students' profiles regarding sustainability. This is done by using the analytic hierarchy process (AHP hereafter), according to the comparison of the importance each student places on the criteria (Medineckiene et al., 2010). A cluster analysis identifies groups of students according to the distance between their preferences (Lee et al., 2014). Thus, the preferences of multiple evaluators are represented by only one dataset. These data correspond to the student profile and are the result of an aggregation method, such as the arithmetic mean. This way, the students' views of sustainability can be grouped.

In the second instance, the specifications of project alternatives must be appraised by students based on the chosen criteria. Generally, the prioritized project is the result of the combined valorization between the profiles and appraisal of the project alternatives. There are subjective factors that might affect the outcome, which justifies a sensitivity analysis that aims to ascertain how the outcome could have been affected in light of a possible variation in the appraisals. The students apply a sensitivity analysis, which focuses on the variation of the criteria scores for each profile (Wolters and Mareschal, 1995). In this way, students analyze the possible changes in prioritization as a result of the different orientation profiles.

4.3 Selection of criteria for sustainability

Before starting the participatory process, a general framework for sustainability is needed to identify the best criteria for a certain case study. The sustainability criteria were identified through a literature review process that focused on international standards and consulted scientific papers. Given the considerations previously stated, a framework of sustainability can be proposed: (1) it takes into consideration impacts on the social, environmental and economic system; (2) it has been corroborated by international standards, such as the Global Reporting Initiative, the sustainable development framework of the United Nations and the Wuppertal Sustainability Indicators; and (3) their concepts have breadth and flexibility so that students can adapt the general framework and interrelate them with more specific indicators. This framework has been validated by experts (Labuschagne et al., 2005) and applied by different authors (Huang et al., 2012; Lang et al., 2007). In this way, Labuschagne et al. (2005) state the criteria of sustainability, presented in Table 4.1, which is used as an initial proposal in the practical implementation of this study.

Table 4.1: Reference criteria of sustainability used in implementing the method (Adapted from Labuschagne et al. 2005)

Economic Sustainability	Environmental Sustainability	Social Sustainability
Financial Health	Air Resources	Internal Human Resources
Economic Performance	Water Resources	External Population
Financial Potential	Land Resources	Stakeholder Participation
Trading Opportunities	Mined Abiotic Resources	Macro Social Performance

4.4 Practical implementation

The selection of the multi-criteria analysis tool was based on the following three considerations: (1) the simplicity of operation and comprehension for use by a group of students; (2) the compatibility with methods for identifying decision-making profiles; and (3) the evidence of its application in construction. On this point, Alarcón (2005) established the AHP as a technique that provides the best possible reliability compared to other multi-criteria techniques in the context of sustainability assessment and the selection of their factors. Furthermore, the findings of Jato-Espino et al. (2014) present the AHP as one of the most frequently used techniques in the construction field. These considerations led to the use of the AHP as a sustainability assessment tool in this case.

Based on the reference criteria for infrastructure sustainability assessment (Table 4.1) and the use of the AHP, participatory prioritization and a sensitivity analysis, separated into three stages, were carried out. In the first stage, the representative profiles of the participants were obtained. In the second stage, the investment alternatives were evaluated with respect to the preference of each profile. And in the third stage, a sensitivity analysis measured the variability of the result in terms of a change in the profiles' preferences. This way, graduate students, acting as participants, contrasted their technical, ethical and personal judgments on sustainability.

Table 4.2 represents the breakdown structure in seven steps of this practical implementation, grouped into three stages, using nine classroom hours guided by a facilitator. This process was put into practice by two classes of graduate students enrolled in the Project Feasibility course (2014 and 2015) included in the Master of Planning and Management in Civil Engineering; this MSc degree applies a holistic managerial approach to construction from both production and business standpoints (Jiménez et al., 2011; Yepes et al., 2012 ; Torres-Machi et al., 2013).

Table 4.3 shows the characterization of the students. The facilitator of the study was an instructor who has specialized in the assessment of construction projects and in sustainability, with six years of experience. He was also supervised by two senior professors. For both classes, the activity was graded according to a final report for each team, as well as a scoring rubric described later in section 4.5.

The implementation of the process that follows these steps is described next.

Step 1: The instructor acted as a facilitator who led the students during the early stages. The working dynamics involved the following activities:

- Basic concepts and the sustainability criteria regarding social, environmental and economic approaches (Table 4.1) were introduced.
- The general terms of the case study were explained. The students discussed and answered the following question: What are the sustainability criteria that best fit this case? The general focus of the sustainability criteria was analyzed. The students discussed possible additions or eliminations of these criteria.
- The multi-criteria analysis systems were presented. The methodological foundations of the AHP were deepened.
- Students carried out an example of the AHP implementation exercise, proposed and supervised by the facilitator.

Table 4.2: The participatory process layout

	Activity	Input	Agent	Class 2014	Class 2015
Profile identification	**1.** - Introduce the students to sustainability and AHP	1.1.-Presentations and example (AHP) 1.2. - Guide of sustainability reference criteria discussion and interpretation	1.1.Facilitator 1.2.Student	Tuesday 6May (120’)	Tuesday 14April (120’)
	2. - Assessment of sustainability criteria through AHP	Electronic Survey	Student	Tuesday 13May (90’)	Friday 17April (90’)
	3. - Apply analysis by cluster and report the results to students.	Software SPSS, version 21	Facilitator	Tuesday 13May (30’)	Tuesday 21April (30’)
Alternative assessment	**4.** - Analysis of the case study background respect to sustainability	Background of the case (I)	Student	Tuesday 20May (60’)	Tuesday 21April (60’)
	5. - Appraise the alternatives of the case through AHP in each sustainability criterion	Spreadsheets	Student	Tuesday 20^{th}May (60’) Tuesday 27May (120’)	Friday 24April (60’) Tuesday 28April (120’)
	6. - Apply a simple additive weighting between profiles preferences and alternative appraisal results	Spreadsheets	Student	Tuesday 3June (20’)	Tuesday 28April (20’)
Sensitivity analysis	**7.** - Apply sensitivity with a preference variation of profiles	Report of the Results (II)	Student	Tuesday 3June (40’)	Tuesday 5 May (40’)

Note: (I) The background of the case are released to students one week in advance, through virtual platform. The facilitator notifies students the need to review the background. (II) Preparation time results report by the students was a week.

Table 4.3: Background of the process participants

		Class of 2014	Class of 2015
Number of students		36	29
Age	[20 – 23]	11.1%	6.9%
	[24 - 28]	36.1%	41.4%
	[28 – 32]	25.0%	41.4%
	[32 – 36]	16.7%	6.9%
	[36 – 39]	11.1%	3.4%
Origin	Europe	50.0%	34.6%
	Americas	41.7%	62.0%
	Africa	8.3%	3.4%
Gender	Male	30.6%	62.1%
	Female	69.4%	37.9%

		Class of 2014			**Class of 2015**		
Profession	Civil Engineer	55.6%			79.3%		
	Architect	11.1%			3.5%		
	Construction Eng.	5.6%			10.3%		
	Building Engineer	25.5%			6.9%		
	Other	2.7%			---		
Years of Experience	[1 – 4]	69.4%			44.8%		
	[4 - 7]	2.8%			41.4%		
	[7 – 10]	11.1%			10.3%		
	[10 – 13]	13,9%			2.9%		
	[14 and more]	2.8%			--		
Sustainability		Field (I)			Field (I)		
		1	2	3	1	2	3
Prior Training	Part of a course	5	3	0	21	17	17
	Full course	10	2	0	1	1	1
	No training	50%			17.2%		
Experience	Yes	6	3	0	11	2	3
	No	77.8%			55.2%		

Note: (I): 1 environmental, 2 economic and 3 social.

Step 2: At this stage, each student acted as an expert and comparatively appraised the sustainability criteria. These appraisals comparatively assessed the AHP survey (Table 4.4). In this survey, the student was asked to appraise the sustainability criteria through hierarchical levels: first among the general sustainability dimensions and second among social, environmental and economic sustainability criteria, considered separately. The number of comparisons (*N*) to be carried out was determined by Equation 4.1 (Saaty, 1987) according to the number of criteria (*a*) subject to comparison within the same hierarchical cluster.

Equation 4.1

$$N = a\frac{(a-1)}{2}$$

The AHP assessment system evaluates the level of importance for one criterion versus another using Saaty's fundamental scale on a ranking of 1–9, in which "1" indicates equal importance and "9" indicates extremely important. This dynamic was used as an individual assessment, in which the student had to solve the survey and check the level of importance for sustainability criteria. The comparisons among hierarchical groups had to be coherent according to the consistency ratio established by Saaty (1987): from 5% to 10%.

Table 4.4: Extract of comparative appraisal survey (base don Saaty (1987)

Criteria Contrast	Assign an appraisal in the same order in which it is announced: the least important criterion is quantified as 1 —whereas the other is quantified up to 9, taking Saaty's scale into account (1987)
Social Sustainability versus Environmental Sustainability	/
Social Sustainability versus Economic Sustainability	/
Environmental Sustainability versus Social Sustainability	/
Internal Human Resources versus External Local Population …(I)	/
Air Resources versus Water Resources …(II)	/
Financial Health versus Economic Performance …(III)	/

Note: (I) comparison among the rest of the social sustainability criteria; (II) comparison among the rest of the environmental sustainability criteria; and (III) comparison among the rest of the economic sustainability criteria.

Step 3: At this stage, the activities leading to obtaining decision-making profiles were coordinated by the facilitator. Each survey was processed and a matrix for each group of criteria was comprised from the same hierarchical group, i.e., sustainability, economic sustainability, social sustainability and environmental sustainability. In each matrix, the intrinsic values were obtained, which corresponds to the partial weights each student confers on the criteria within its hierarchical cluster. Thus, the partial weight of each criterion on the second hierarchical level was weighted with the partial weight of the sustainability criterion from the first hierarchical level to which it belonged (social, economic and environmental level) in order to obtain the final weights of the sustainability criteria from each student (Saaty, 1987).

The resulting weights from each survey indicated the order of importance that each student attributed to the final sustainability criteria. Based on those weights, a cluster analysis was performed according to the Ward (1963) method, with a measuring interval of Euclidean distance to the square and the support of statistical software SPSS v. 21. In general terms, Ward's method (1963) groups elements hierarchically to minimize the intra-group variation of a structure. The intra-group quadratic addition (*IQA*) corresponds to the sum of the *IQA* of each k group; also, the *IQA* of group *k* corresponds to the addition of deviations in all the criteria (*m*) for all students (*nj*) within cluster k. The deviations are the result of the quadratic difference between the weight (*X*) of criterion *i* for each student *j* who belongs to group *k* and the average weight (*X*) of criterion *i* in group *k*, as reflected in Equation 4.2 (Ward, 1963).

Equation 4.2

$$IQA = \sum_{1}^{h} IQA_k \; ; \; IQA_k = \sum_{i=1}^{m} \sum_{j=1}^{n_k} \left(X_{ijk} - \bar{X}_{ik}\right)^2$$

The selection of the number of clusters was determined based on the number of manageable profiles that did not increase variability within the clusters (Vila-Baños et al., 2014). Accordingly, Figure 4.2 shows the Ward (1963) dendrogram: a layout that illustrates a squared Euclidean distance of five, confirming four groups for each case study with different orientations toward sustainability. For the 2014 class, the following profiles were identified: (1) social with an economic trend; (2) economic; (3) environmental with a social trend; and (4) environmental with an economic trend (Figure 4.2 left). Meanwhile, for the 2015 class, the following profiles were identified: (A) financial, i.e. the student prefers to guarantee funding throughout the project life-cycle; (B) environmental with a social trend; (C) economic, i.e., the student prefers to ensure the economic profitability of the project; and (D) social with an environmental trend (Figure 4.2 right). For both cases, the environmental trend is highlighted. The class of 2014 had a more homogeneous distribution than the 2015 class, because the environmental trend reached a differentiation (economic and social), whereas for the 2015 class, the economic dimension also reached a differentiation but in a more reduced group. The representative valuation of the sustainability criteria of each profile was the result of the arithmetic mean of the weights of the students that comprised each profile. The facilitator explained the analysis undertaken and the results obtained to the students, making public the profile to which each student belonged.

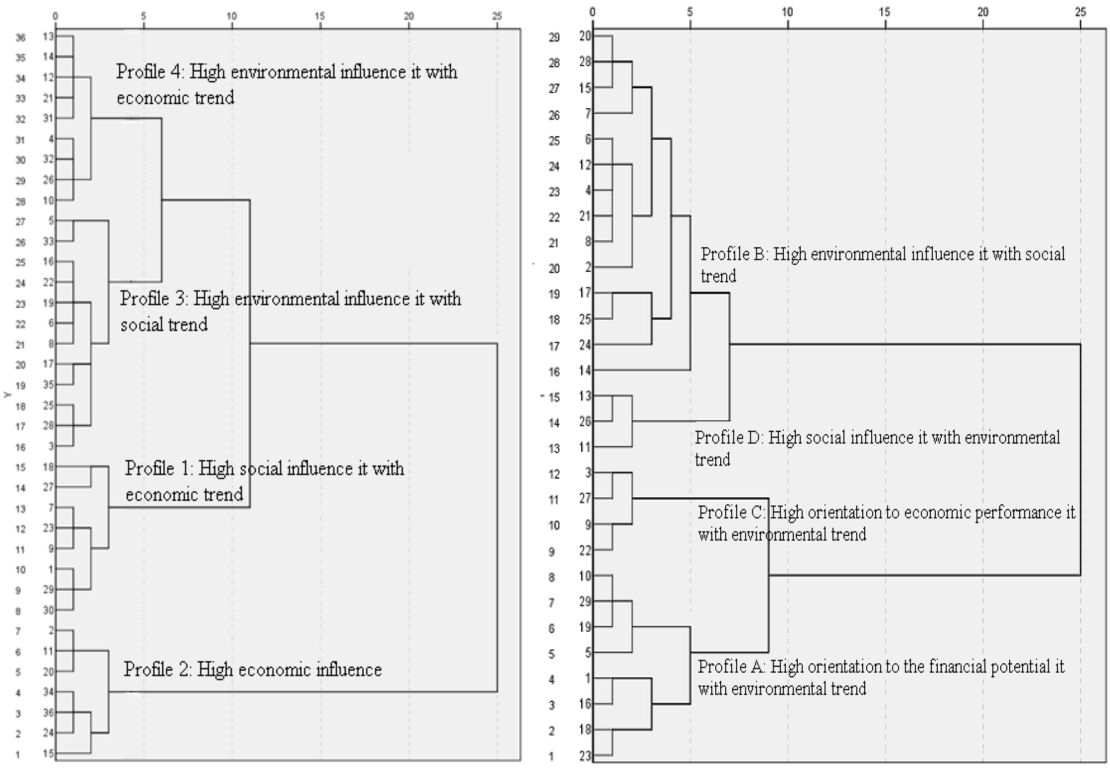


Figure 4.2: Identification of the trend on sustainability through the Ward dendrogram for the 2014 class (left) and the 2015 class (rigth)

Step 4: Students were given the background of a real case, consisting of the assessment of infrastructure projects, addressed in collaborative teams. The discussion that began in Step 1 was deepened in order to determine the quantitative and qualitative indicators that justify the assessment of each alternative. Two case studies were implemented during the academic years 2013–2014 (see Figure 4.3) and 2014–2015. Both cases considered the life-cycle assessment: not only design and construction, but also operation. The information from both case studies is shown in Table 4.5. The teams were organized taking into consideration: (a) the practicality of the activity according to a limited execution time, (b) the facilitator advisory capability, (c) the participation of the entire group, and (d) the representation of every team profile considering all or most of the profiles of the students on the team. Figure 4.2 shows the distribution of four profiles in each course. The distribution of profiles in collaborative teams is specified in

Table 4.6; the teams were configured according to the proximity of its members' preferences.

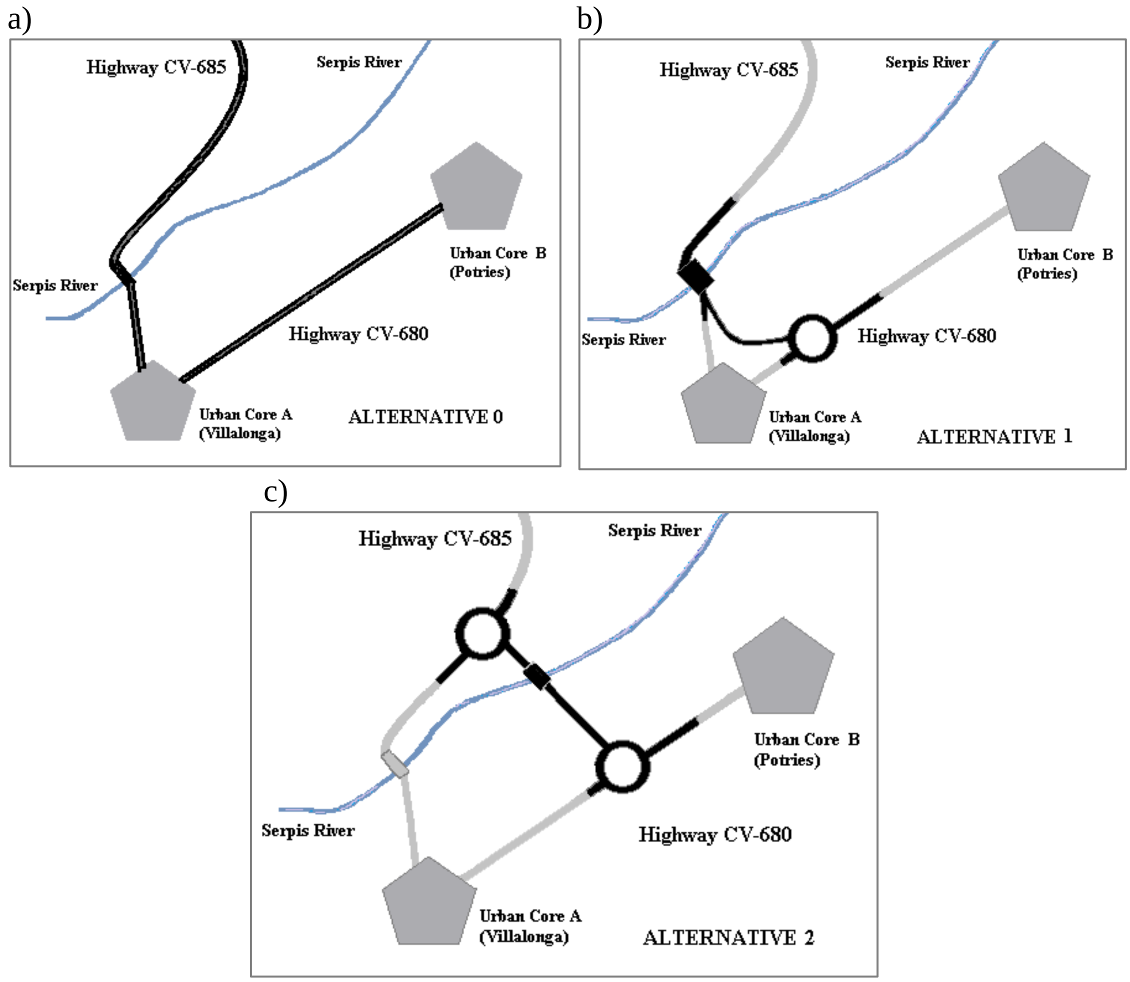


Figure 4.3: (a) Alternative 0 (no-project) for case study 1; (b) Alternative 1 for case study 1; (c) Alternative 2 for case study 1

Table 4.5: Background of case studies 1 and 2

Case Study 1 (Class 2014)	Case Study 2 (Class 2015)
Local Information. Town A has 4,350 inhabitants and an area of 43.3 km^2. It has a 10-year population growth of 0.7%. Its unemployment rate is 9.83%. Town B has 987 inhabitants and an area of 3.1 km^2. It has had no population growth in the last decade. Its unemployment rate is 8.51%. Both urban areas have civic spaces, cultural heritage buildings and basic education and health services. Their main economic activities are the agri-food industry, handmade ceramics and, to a lesser extent, rural tourism.	**Local Information.** The alternatives are located in mid-sized towns (around 20,000 people). The main productive activities are: food industry, agricultural and livestock transformation, crafts and cultural tourism. In the sector, the population growth rate does not exceed 0.9%.
Alternative 0: Minimum travel distance of 4.53 km and crosses Town A. Projected traffic: CV-685 2500 / CV680: 8000 vehicles/day. Average speed: CV-685: 45 km/hr. / CV680: 45 km/hr. Hazard index: CV-685: 13 / CV680: 7.1 Death rate: CV-685 0.7 / CV680 0.5 Operation costs (30 years): €623,749.00	**Alternative M1:** Project the retaining wall of 118 m long with a deadline of 5 months and an estimated hiring of 28 people. During construction, electrical and sanitation services need to be scheduled. The value of bidding reaches €252,129, with an allocation to health and safety costs of 1.05%. This finished in pigmented concrete, in line with the urban regulations of the residential area. 283 people were direct beneficiaries in the short-term.
Alternative 1: Minimum travel distance of 4.53 km Projected traffic CV-685 2500 / CV-680: 8000 vehicles/day. Average speed: CV-685: 75 km/hr. / CV-680: 90 km/hr. Hazard index: CV-685: 9.5 / CV-680: 7.1 Death rate: CV-685 0.55 / CV-680 0.5 Operation costs (30 years): €1,205,120.00	**Alternative M2:** Project the retaining wall of 86 m in length with a deadline of four months and an estimated hiring of 13 people. During construction, electrical services need to be intervened. The value of bidding reaches €78,476, with an allocation to health and safety costs of 0.57%. 166 people were direct beneficiaries in the short-term.
Alternative 2: Minimum travel distance of 2.4 km Projected traffic CV-685 2500 / CV-680: 10328 vehicles/day Average speed: CV-685: 75 km/hr. / CV-680 100 km/hr. Hazard index: CV-685: 7.1 / CV-680: 4.5 Death rate: CV-685 0.5 / CV-680: 0.4 Operation costs (30 years): €4,018,524.00	**Alternative M3:** Breakwater retaining wall 45 m in length, 6 m high with a deadline of 2 months and an estimated recruitment eight people. Their level of earthmoving reaches 1148 m^3 and considers reuse of excavation material. The value of bidding reaches €52,427, with an allocation to health and safety costs of 2.26%. The influence area covers a population of 510 people.

Step 5: In this step, students analyzed the alternatives according to the sustainability criteria agreed to in Step 1 as well as the indicators produced in Step 4. To this end, the team valued the relative level of importance for each of the alternatives based on a comparison by pairs that applied the Saaty scale. Each team presented a unique output of their appraisals through a comparison matrix for each sustainability criterion. The processing of the scores of each matrix provided the intrinsic value, which represents the relative weight of each alternative compared to the others for every sustainability criterion (Saaty, 1987). This exercise was applied to the construction and operation phases of the infrastructure life-cycle.

Step 6: This step was based on the output of the appraisal of sustainability criteria for each profile and the weights of the alternatives for every sustainability criterion. Each alternative was weighted by appraising the corresponding criteria, according to the profile assigned to each team. Thus, all contributions of this alternative to sustainability were added up. This way, the overall weight of each alternative was obtained, which included consideration of all criteria according to the background of alternatives and the students' value judgments

This exercise was applied to the construction and operation phases of each infrastructure life-cycle. In the construction phase of case study 1, the results of the nine teams gave higher overall weight to Alternative 0, while there was no clear second choice. Meanwhile, during the operation phase, the preferences were not uniform, and in some cases, the vagueness in the consideration of the project characteristics assessment made it difficult to differentiate among the alternatives. For both life-cycle phases in case study 2, prioritizations differed in accordance with each team's profile. The results for both classes are displayed in

Table 4.6. On the other hand, Table 4.7 shows the main considerations that students took into account in their decision-making process.

Table 4.6: Prioritized projects for the student teams

Team	**Case 1 (Class 2014)**			**Case 2 (Class 2015)**		
	Team members' profiles	**Alternative / Weight**		**Team members' profiles**	**Alternative / Weight**	
		Construction	**Operation**		**Construction**	**Operation**
1	4 members Profile 1	1st place Alt-0 (0.46) 2nd place Alt-2 (0.31)	1st place Alt-2 (0.41) 2nd place Alt-1 (0.38)	4 members Profile A	1st place Alt-M1 (0.42) 2nd place Alt-M2 (0.35)	1st place Alt-M2 (0.41) 2nd place Alt-M3 (0.34)
2	4 members Profile 1	1st place Alt-0 (0.44) 2nd place Alt-2 (0.30)	1st place Alt-2 (0.40) 2nd place Alt-1 (0.39)	4 members Profile A	1st place Alt-M1 (0.45) 2nd place Alt-M2 (0.36)	1st place Alt-M2 (0.43) 2nd place Alt-M3 (0.34)
3	4 members Profile 2	1st place Alt-0 (0.45) 2nd place Alt-1 (0.36)	1st place Alt-1 (0.47) 2nd place Alt-2 (0.35)	4 members Profile B	1st place Alt-M1 (0.33) 2nd place Alt-M2 (0.33)	1st place Alt-M2 (0.43) 2nd place Alt-M3 (0.38)
4	3 members Profile 2 and 1 member Profile 4	1st place Alt-0 (0.54) 2nd place Alt-1 (0.30)	1st place Alt-1 (0.50) 2nd place Alt-2 (0.35)	5 members Profile B	1st place Alt-M1 (0.36) 2nd place Alt-M2 (0.34)	1st place Alt-M2 (0.45) 2nd place Alt-M3 (0.38)
5	4 members Profile 3	1st place Alt-0 (0.59) 2nd place Indefinite	1st place Alt-2 (0.40) 2nd place Alt-0 (0.34)	4 members Profile B	1st place Alt-M1 (0.34) 2nd place Alt-M2 (0.32)	1st place Alt-M2 (0.43) 2nd place Alt-M1 (0.39)
6	4 members Profile 3	1st place Alt-0 (0.56) 2nd place Alt-1 (0.24)	1st place Alt-2 (0.36) 2nd place Indefinite	4 members Profile C	1st place Alt-M2 (0.44) 2nd place Alt-M1 (0.33)	1st place Alt-M1 (0.40) 2nd place Alt-M2 (0.35)
7	4 members Profile 3	1st place Alt-0 (0.58) 2nd place Alt-1 (0.27)	1st place Indefinite 2nd place Indefinite	1 member Profile B and 3 members Profile D	1st place Alt-M1 (0.47) 2nd place Alt-M2 (0.27)	1st place Alt-M3 (0.46) 2nd place Alt-M2 (0.40)
8	4 members Profile 4	1st place Alt-0 (0.61) 2nd place Alt-1 (0.24)	1st place Alt-1 (0.37) 2nd place Alt-2 (0.34)			
9	4 members Profile 4	1st place Alt-0 (0.60) 2nd place Alt-1 (0.24)	1st place Alt-1 (0.39) 2nd place Alt-2 (0.37)			

Table 4.7: The key considerations that students took into account

Case 1 (Class of 2014)	Case 2 (Class of 2015)
- Alternative 0 implies a lower operating cost, and does not generate institutional, environmental and social interventions. However, the operation is not a viable alternative that provides a solution in the long term.	The M1 alternative: - During construction, it supports recruitment in an area with higher unemployment - It strengthens the use of materials and hiring of services in the area - The project stems from a process of public consultation with public vote organized by the municipality. - Its construction is associated with an "Urban Rehabilitation" program with a construction subsidy of €151,732. - It is the alternative that means more economic movement and for a longer period. - It has a better use of public resources as a function of their maintenance costs and number of beneficiaries.
- Alternative 1 satisfies the need and is more profitable in the long term in terms of costs of operation and economic benefits for drivers. - The estimate of the set of energy contained and CO_2 generation for the construction of Alternative 1 is less than for Alternative 2 - Alternative 1 involves lower volume of earth moving and solid waste generation. -Alternative 1 has a smaller and mitigated impact on the Serpis riverbed. It modifies the existing using of the space that was intervened in the construction of the first bridge.	The M2 alternative: - It produces a lower volume of solid waste to be disposed of. - According to Spanish legislation and the level of impact, it does not require an environmental impact assessment. - The volume and type of project involve less use of alternative energy and mineral resources for its construction. - The risk of delayed construction payments associated with its promoter is the lowest among the three alternatives. This ensures compliance with financial commitments to suppliers involved in the project. - Maintenance activities are manual without the use of equipment that uses energy or water and without equipment that emits gases. - It boasts improved accessibility and connectivity of people, safety, the environment, rural tourism and other business relationships.
- The high level of recruitment and duration of Alternative 2 promote job stability during construction. - Alternative 2 provides a design with improved security to the user during operation. - Alternative 2 promotes traffic flow. This supports the local economy of industry and generates indirect employment, which is especially desirable when the economic crisis in Spain is considered. - Alternative 2 favors the decongestion of Town A, which means lower sensory impact on the population (noise and landscape) and safety of their urban environment. - Alternative 2 does not require expropriation. The lots are provided by the municipality.	The M3 alternative: - It encourages a reduced generation of CO_2 (less consumption of concrete) and lower water consumption. - Its location means lower impact on affected services and undesirable sensory stimuli. - The project is not associated with urban gardening works. Also, maintenance costs are lower and the use of water is required. - The wall supports the road that links the two rural locations. Its construction strengthens the safety of drivers. - It strengthens tourism between rural localities. - Its design in stone masonry is harmonious with the surroundings.

Step 7: The students analyzed the sensitivity of the decision-making with respect to the profile change. It was made through the variation in the weights of the criteria. Analogous to Step 6, each team incorporated the assessment criteria regarding the remaining three profiles to identify the possible differentiation in the preference for alternatives during the construction and operation phases. Students concluded their findings before they delivered the report on their results. These outputs were checked by the facilitator through Kendall's statistical test to identify the correlation of the teams regarding the prioritization of alternatives for each profile. During the construction phase, Alternative 0 was selected as the first priority by all teams in the 2014 class, whereas Alternative M1 was chosen by teams 6 and 7 in the 2015 class—its prioritization being significant according to the statistical test. As for the operation phase, Table 4.8 shows an important variability in the prioritization of alternatives, but the agreement at the 95% level of confidence remains significant.

Table 4.8: Sensitivity analysis per profile at the stage of operation of the infrastructure for both case studies

Operation Stage Class of 2014		**Alternative 0**	**Alternative 1**	**Alternative 2**	**W's Kendal**	**Asymptotic Sign.**
Profile 1	Prioritization Ranking [1st – 3rd]	3.00	1.89	**1.11**	.901	.000
Profile 2	Prioritization Ranking [1st – 3rd]	3.00	**1.00**	2.00	1.000	.000
Profile 3	Prioritization Ranking [1st – 3rd]	2.44	2.56	**1.00**	.753	.001
Profile 4	Prioritization Ranking [1st – 3rd]	3.00	**1.22**	1.78	.827	.001
Operation Stage Class of 2015		**Alternative M1**	**Alternative M2**	**Alternative M3**		
Profile A	Prioritization Ranking [1st – 3rd]	2.99	**1.03**	2.01	.810	.001
Profile B	Prioritization Ranking [1st – 3rd]	2.25	**1.21**	1.91	.650	.021
Profile C	Prioritization Ranking [1st – 3rd]	**1.14**	2.01	2.81	.863	.001
Profile D	Prioritization Ranking [1st – 3rd]	2.60	1.69	**1.30**	.827	.000

4.5 Assessment of the process

The assessment of the educational process was completed based on the development and application of two measuring instruments: a scoring rubric that assesses the level of achievement for each team and a survey to measure the overall effectiveness of the process. Both instruments were developed through a focus group composed of seven professors in the construction management field at the Universitat Politècnica de València, including the authors of this paper.

The scoring rubric was applied to each team's output. Examination and appraisal of this report involved four aspects with a corresponding score according to the level of efficiency achieved by each team:

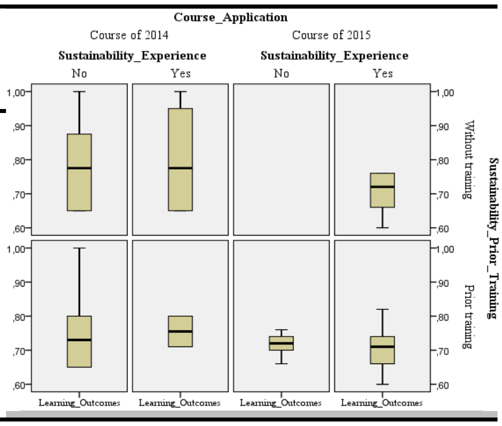
1. procedure and method (20%);
2. analysis of alternatives and their influence on sustainability (30%);
3. interpretation of the impact of human appraisal in decision-making and sensitivity analysis (30%); and
4. synthesis of the outcomes, as well as personal comments (20%).

The results of the weighting of these aspects show how achievement was reflected in each team. The learning outputs achieved by all students exceed 65% and 60% for the 2014 and 2015 classes, respectively. The best assessed aspect of the rubric is “means and methods”, whereas the “analysis of alternatives” and the association of qualitative indicators required more attention from the students. However, in every case, the items of the scoring rubric achieved more than 50% acceptance. Furthermore, the background of the students was compared with the learning outputs in order to identify any influence on the process. In each case, not significant correlations were identified.

Similarly, the background of the students was checked with the cluster. A statistically significant (95% confidence level) relationship was identified for the 2015 class between the previous training in sustainability and Profile B (environmental with social tendency). In this regard, Table 4.9 shows the measures of central tendency regarding the learning outputs for the students in both classes, which takes into account their previous experience and training in sustainability.

Table 4.9: Learning outcomes through the application of the assessment rubric

	Class of 2014		**Class of 2015**	
	Chi-squared	**P-value**	**Chi-squared**	**P-value**
Learning outcome x Sustainability prior training	6.716	.152	.752	.687
Learning outcome x Prior sustainability experience	.321	.852	.221	.638
Cluster x sustainability prior training	5.768	.450	14.122	.028
Cluster x prior sustainability experience	.413	.937	6.040	.110



On the other hand, the students were surveyed once the work was completed and the same day that the report was submitted for evaluation. They had to evaluate six statements based on a Likert scale from 1 (strongly disagree) to 10 (completely agree). The statements were grouped into two constructs, as follows:

Construct 1: Relevance of learning method for measuring sustainability in infrastructure:

P1. – The content and application of the method studied was significant for professional development.

P2. – The set of developed activities were adequate for achieving the learning.

P3. – The AHP method is an appropriate system in decision-making.

Construct 2: Compressibility of the interrelationship of human preferences and characteristics of the infrastructure in sustainable decision-making:

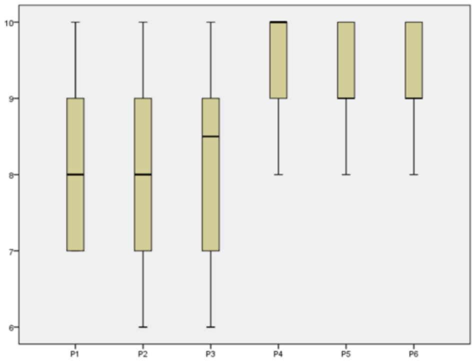
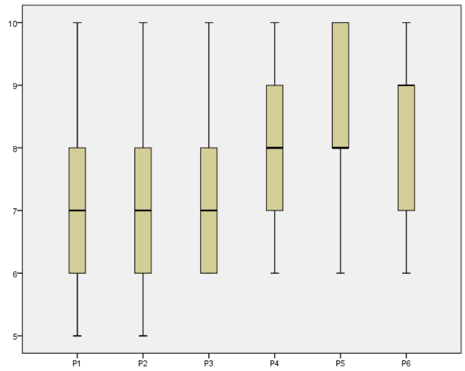
P4. – I understood how appraisal of human preferences affects sustainable decision-making.

P5. – I understood how the characteristics of a project interact with people's feelings and preferences.

P6. – I understood how the characteristics of a project influence sustainability.

To measure internal consistency, the reliability of each construct was determined by using Cronbach's alpha (Table 4.9). For each case, the alpha falls into the category of good (greater than 0.8) (George and Mallery, 2003). The results of the questionnaire applied to both classes are presented in Table 4.10.

Table 4.10: Results of the learning process through the applications of a survey

<table>
<tr><th rowspan="2"></th><th colspan="2">Cronbach's Alpha</th><th rowspan="2">Class 2014</th><th rowspan="2">Class 2015</th></tr>
<tr><th>Class 2014</th><th>Class 2015</th></tr>
<tr><td>Construct 1 (P1-P2-P3)</td><td>.853</td><td>.845</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Construct 2 (P4-P5-P6)</td><td>.863</td><td>.900</td></tr>
</table>

4.6 Discussion

Regarding the implementation of the process, it should be noted that the multi-criteria analysis technique (the AHP) was adequate according to the terms of practicality, simplicity of methodological management, comprehensibility and applicability according to the students' statements (Table 4.10); this concurs with the findings of Jato-Espino et al. (2014), who state that AHP is very suitable for decision-making problems involving economic, environmental, and social facets. The group structure of the course was appropriate for developing the educational process. The configuration of mixed teams (team 4 in class 2014 and team 7 in class 2015) did not reveal any differences in the alternative prioritization in relation to other teams whose profiles had a similar or equivalent association.

For the purposes of this paper, the method is suitable for identifying the profile of students in terms of their preference for the sustainability criteria; this method was developed using a cluster analysis, as successfully performed by Nelson et al. (2015) for identifying motivational profiles. In both the 2014 and 2015 classes, there was a clear differentiation between the economic profile and the rest of the profiles as well as an environmental trend (Figure 4.2). Previous research (Summers et al., 2004; Valdés-Vasquez and Klotz, 2011; Watson et al., 2013) has highlighted the fact that the environmental (Medineckiene et al., 2010) and economic (Levitt, 2007) facets of sustainability are more widely acknowledged. For the method proposed in this paper, however, it is not advisable to establish fewer than four profiles as doing so would increase the internal heterogeneity of preference in decision-making, and a number greater than four tends not to be very practical and in some cases is difficult to differentiate (Vila-Baños et al., 2014).

Concerning the influence of the profiles on decision-making, it was found that in the 2014 class, for the short term in the construction phase, the no-project alternative was preferred by all profiles because non-intervention is collectively the largest contributor option to the criteria of social, environmental and economic sustainability; this is consistent with other studies (Bilec et al., 2010; Sierra et al., 2015) that note a major impact of the construction phase on sustainability. In this stage, the enhancing Alternatives 1 and 2 do not yet provide evidence of their major contributions to sustainability. In the same sense, but in a second prioritization, employment prospects interact with the social Profile 1, assigning a higher preference to the project that contributes the most to this criterion (Alternative 2). For other cases, Alternative 1 is the second option. In the 2015 class, the construction phase of the alternative M1 satisfies the conditions of most of the teams. This has social characteristics that exceed the rest of the alternatives (procurement, socioeconomic contributions and citizen involvement); it attracts the preferences of profiles B and D. Furthermore, it has associated financial subsidies that attract Profile A. During the operation phase, Alternative M2 is preferred by Profile B because of its environmental potential, and by Profile A because of the indirect contribution to the local economy. On the other hand, the financial profitability and the contribution to the local community of Alternative M1 attract the preference of profiles C and D, respectively.

The main arguments from the students confirm the final selection. Table 4.7displays a sample of arguments according to the chosen alternative. Terms such as employability, quality of life, occupational safety and accidents are named by the teams with social focus (Labuschagne et al., 2005 Valdés-Vasquez and Klotz, 2011), whereas terms such as pollution, contained energy, waste, hydraulic resource or ecosystem are highlighted by the teams with an environmental tendency (Huang et al., 2012; Kucukvar et al., 2014). Furthermore, concepts such as net present value, cost, investment, maintenance, use of public resources and economic crisis are mentioned by teams with an economic focus (FHWA, 2003; Torres-Machí et al., 2014).

In the long term, different preference alternatives are detected in the operation phase. In the sensitivity analysis (Table 4.8) the statistical consistency of project priority according to the profile of preference was tested. Given the variation in the preference for sustainability, the consistency coefficients, for both classes, determine a significant correlation regarding the change in a sustainability profile. In this case, in general terms, profiles with some economic influence are inclined toward the alternative that involves greater influence on profitability (Alternative 1). Those profiles that feature some social influence focus on an alternative with a greater impact on community criteria (Alternative 2). This way, the characteristics of the alternatives lead to a preference for a specific alternative according to a given profile; for example, some authors (Dwyer and Byrne, 2010 ; Byrne et al., 2013) assert that engineers with more knowledge and skills in environmental facets identify attributes related to their jobs only in the environmental category.

When examining individual results in the operation phase, it was necessary in some teams to clarify the analysis of the appraisal of alternatives, especially in social sustainability criteria, in order to identify differences between alternatives (teams 2 and 7 in the 2014 class) as none of the 2014 students had undergone previous training in sustainability. Valdés-Vasquez and Klotz (2011) state that social sustainability is the dimension of sustainability least considered in engineering.

It is important to highlight that the assessment of the characteristics of the alternatives is not free of subjectivities despite the correct interpretation, due to the qualitative aspects and the relative precision of the Saaty scale (Arroyo et al., 2015). This produced close results that were difficult to differentiate in prioritization. However, some previous contributions emphasize that students should be challenged with ill-defined scenarios (Bucciarelli et al., 2000) or with self-defined learning goals (Steiner and Posch, 2006 ; Lehmann et al., 2008) during their academic career to be able to address the uncertainty of many real engineering problems, “particularly those in the social context” (Bucciarelli et al., 2000, p.142). The selection of a unique alternative in a participatory environment with different profiles is facilitated, considering that other alternatives are close to meeting the requirements and it is, therefore, easier to reach a consensus. In an educational scenario, this is normal because the students are not experts; thus, the role of the facilitator is key in guiding and contextualizing the case study to attain fruitful active learning (Prince, 2004; Boks and Diehl, 2006).

The evaluation system measured the quality of the processes developed by the students according to the scoring rubric; this same technique has been proposed by other authors (McCormick et al., 2015) to assess students' learning. Through this tool, 100% of the teams reached a level of achievement of learning outcomes over 60%. It is worth mentioning that, even though the class of 2014 did not undergo previous training in social sustainability, 67% of the students reached a level of learning above 70%. In this context, both classes corroborated the independence between the students' background and the level of learning achieved during implementation of the method. Meanwhile, the results of the student survey (Table 4.10) show the relevance of the AHP method in their profession and for successfully learning about sustainability. Approval fluctuated in the range of 6.0–9.0 at a 95% confidence level in an ascending approval scale from 1 to 10. At the higher levels of approval, students stated that the method allowed them to understand the interrelationship of human preferences and characteristics of an infrastructure for making sustainable choices. The approval level fluctuated in the range of 7.1–10.0 at a 95% confidence level. As stated previously, this finding aligns with previous research (Jato-Espino et al., 2014), which asserts that AHP is not only the most popular tool for decision-making but it is also the most robust and reliable.

Nonetheless, the authors have established some limitations of the method:

1. The study needs to guarantee a minimum level of professional maturity in the students, so they can understand the construction processes. To this point, other authors (Bucciarelli et al., 2000; Lehmann et al., 2008; Du et al., 2013) underline the relationship between academic and professional facets as a key factor for a sustainable education.
2. The study needs to guarantee a minimum number of students (at least 20) in order to form teams that are representative of the profiles regarding sustainability.
3. The facilitator must have in-depth knowledge about not only the construction processes but also the many facets of sustainability, as previously noted by Boks and Diehl (2006).
4. The AHP relates criteria that are under the dominance of each sustainability dimension (environmental, economic and social) and takes into account only the direct effect (first order) that each infrastructure exerts on each criterion. An extension of the method implies the use of a tool that allows the interaction of the criteria with high-order effects. This is possible by using an Analytical Neural Process (Saaty and Vargas, 2006). However, its implementation would require a technological background, more training time and work by the student on the activities involved.

4.7 Conclusions

Outcomes show that this proposal was appropriate for identifying the orientation in decision-making by graduate students regarding sustainability issues. Also, the need to clarify assessments of social criteria in alternative projects in order to generate significant differences in the contribution to sustainability was identified. Thus, the development of the case studies and their evaluation allowed the student to undertake a critical analysis and demonstrate an understanding how their personal values and sets of clusters influence the selection of a project.

In this context and according to the evidence of the results of these application cases, it was found that the profiles of evaluators or participants could influence the outcome of prioritization among a set of alternatives. In this sense, the method has promoted the learning of sustainability particularly, understanding the influence of the infrastructure characteristics and participant preferences in the results of the decisions made regarding sustainability.

The main limitations of the method are the need to train the facilitator in sustainability and construction processes, minimum previous professional experience of the students, as well as the considerations of only the direct impacts of infrastructure in the built environment. The transgression of these aspects does not guarantee the effectiveness of students' learning.

Future lines of research could focus on finding active-learning strategies that highlight the influence of the interaction between the criteria and the dimensions of sustainability regarding decision-making in an education environment. Furthermore, an extension of this method is the implementation of tools for decision-making among multi-stakeholders with different roles.

This paper provides a method that improves learning by using a simulated experience for decision-making, which focuses on the contribution of infrastructure to sustainability. The method considers the preference for sustainability given the initial conditions of awareness, interest and knowledge that a team of students has. In addition, the method has a rational and participatory approach that simulates multiple views from construction professionals regarding sustainability. This learning proposal can be replicated in every professional context that works with projects; of course, the case study would need to be adapted according to the field

Acknowledgments

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4.8 References

Alarcón, D.B., Aguado, A., (2005). Modelo integrado de valor para estructuras sostenibles. Ph.D. Disertation. Universitat Politècnica de Catalunya, Barcelona.

Arroyo, P., Tommelein, I. D., Ballard, G., (2015). Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. J. Constr. Eng. M. 141(1), 04014063. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000915.

Bilec, M.M., Ries, R.J., Matthews, H.S., (2009). Life-cycle assessment modeling of construction processes for buildings. Journal of Infrastructure Systems 16(3), 199–205. http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000022.

Boks, C., Diehl, J.C., (2006). Integration of sustainability in regular courses: experiences in industrial design engineering. J. of Clean. Prod. 14(9–11), 932–939. http://dx.doi.org/10.1016/j.jclepro.2005.11.038.

Bucciarelli, L.L., Einstein, H.H., Terenzini, P.T., Walser, A.D., (2000). ECSEL/MIT engineering education workshop ´99: A report with recommendations. J. Eng. Educ. 89(2), 141-150. http://dx.doi.org/10.1002/j.2168-9830.2000.tb00508.x.

Byrne, E.P., Desha C.J., Fitzpatrick, J.J., Hargroves, K., (2013). Exploring sustainability themes in engineering accreditation and curricula. Int. J. of Sustain. in High. Educ. 14(4), 384–403. http://dx.doi.org/10.1108/IJSHE-01-2012-0003.

Dwyer, B., Byrne, E., (2010). Practical skills and techniques for the transition to a sustainable future, a case study for engineering education. In: Proc. of the 3rd Int. Symp. for Engineering Education, ISEE2010, University College Cork, 30 June-2 July, pp. 326–333.

Du, X., Su, L., Liu, J., (2013). Developing sustainability curricula using the PBL method in a Chinese context. J. of Clean. Prod. 61, 80–88. http://dx.doi.org/10.1016/j.jclepro.2013.01.012.

El-Adaway, I., Pierrakos, O., Truax D., (2015). Sustainable construction education using problem-based learning and service learning pedagogies. J. Prof. Iss. Eng. Ed. Pr. 141(1), 05014002. http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.0000208.

FHWA, (2003). Economic analysis primer. Department of Transportation, FHWA, Office of Asset Management, Washington, D.C.

García-Segura, T., Yepes, V., Alcalá, J., (2014). Life-cycle greenhouse gas emissions of blended cement concrete including carbonation and durability. The International Journal of Life Cycle Assessment 19(1), 3-12. http://dx.doi.org/ 10.1007/s11367-013-0614-0

George D., Mallery P., (2003). SPSS for Windows step by step: a simple guide and reference. 11.0 Update (4th ed.). Allyn & Bacon, Boston, MA.

HEA, (2006). Sustainable development in higher education current practice and future development: progress report for senior managers in higher education. Higher Education Academy, Heslington, United Kingdom.

Huang, B., Yang, H., Mauerhofer, V., Gu, R., (2012). Sustainability assessment of low carbon technologies-case study of the building sector in China. J. of Clean. Prod. 32, 244–250. http://dx.doi.org/ 10.1016/j.jclepro.2012.03.031.

Jato-Espino, D., Castillo-López, E., Rodríguez-Hernández, J., Canteras-Jordana, J.C., (2014). A review of application of multi-criteria decision making methods in construction. Automat. in Construct. 45, 151–162. http://dx.doi.org/ 10.1016/j.autcon.2014.05.013.

Jiménez, J., Pellicer, E., Yepes, V., (2011). Teaching and learning using a case study: application to a master degree in construction management. Procedia – Soc. Behav. and Sci. 15(1), 696–702. http://dx.doi.org/ 10.1016/j.sbspro.2011.03.167.

Kagawa, F., (2007). Dissonance in students' perceptions of sustainability and sustainable development: implications for curriculum change. Int. J. of Sustain. in High. Educ. 8(3), 317–338. http://dx.doi.org/10.1108/14676370710817174.

Kucukvar, M., Noori, M., Egilmez, G., Tatari O., (2014). Stochastic decision modeling for sustainable pavement designs. Int. J Life Cycle Ass. 19(6), 1185–1199. http://dx.doi.org/10.1007/s11367-014-0723-4. http://dx.doi.org/ 10.1007/s11367-014-0723-4.

Kumar, D., Katoch, S.S., (2014). Sustainability indicators for run of the river (RoR) hydropower projects in hydro rich regions of India. Renew. and Sustain. Energy Reviews 35, 101–108. http://dx.doi.org/ 10.1016/j.rser.2014.03.048.

Labuschagne, C., Brent, A.C., van Erck, R.P., (2005). Assessing the sustainability performances of industries. J. of Clean. Prod. 13. 373–385. http://dx.doi.org/ 10.1016/j.jclepro.2003.10.007.

Lang, D., Scholz, R.W., Binder, C.R., Wiek, A., Staubli, B., (2007). Sustainability potential analysis (SPA) of landfills - a systemic approach: theoretical considerations a systemic. J. of Clean Prod. 15(17), 1628–1638. http://dx.doi.org/10.1016/j.jclepro.2006.08.004.

Lee, S., Kim, W., Kim, Y. M., Lee, H.Y., Oh, K.J., (2014). The prioritization and verification of IT emerging technologies using an analytic hierarchy process and cluster analysis. Technolog Forecast. and Soc. Change. 87, 292–304. http://dx.doi.org/ 10.1016/j.techfore.2013.12.029.

Lehmann, M., Christensen, P., Du, X.Y., Thrane, M., (2008). Problem-oriented and project based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. European Journal of Engineering Education 33 (3), 281–293. http://dx.doi.org/10.1080/03043790802088566.

Levitt, R.E., (2007). CEM research for the next 50 years: Maximizing economic, environmental, and societal value of the built environment. J. Constr. Eng. M. 133(9), 619–628. http://dx.doi.org/10.1061/(ASCE)0733-9364.

Lozano, R., (2010). Diffusion of sustainable development in universities' curricula: an empirical example from Cardiff University. J. of Clean. Prod. 18(7), 637–644. http://dx.doi.org/10.1016/j.jclepro.2009.07.005.

Lozano, R., Peattie, K., (2009). Developing a tool to audit curricula contributions to sustainable development. In: Sustainability at universities – opportunities, challenges and trends (vol. 31). Peter Lang Publishing Group, Frankfurt am Main, Germany.

Lozano, R., Young, W., (2013). Assessing sustainability in university curricula: exploring the influence of student numbers and course credits. J. of Clean. Prod. 49, 134–141. http://dx.doi.org/ 10.1016/j.jclepro.2012.07.032.

McCormick M., Lawyer K., Wiggins J., Swan C. W., Paterson K. G., Bielefeldt A. R., (2015). Sustainable engineering assessment using rubric-based analysis of challenge question responses. J. Prof. Iss. Eng. Ed. Pr. 141(2). http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.000021.

Medineckiene, M., Turskis, Z., Zavadskas, E.K., (2010). Sustainable construction taking into account the building impact on the environment. J. of Environ. Eng. and Landsc. Manage. 8(2), 118–127. http://dx.doi.org/ 10.3846/jeelm.2010.14.

Nelson, K. G., Shell, D. F., Husman, J., Fishman, E. J., Soh, L., (2015). Motivational and self-regulated learning profiles of students taking a foundational engineering course. J. Eng. Educ. 104(1), 74-100. http://dx.doi.org/10.1002/jee.20066.

Pappas, E., Nagel, R., Frazier, C., Hulleman, C., Benton, M., (2011). A contextual approach to researching and teaching sustainability. School of Engineering, James Madison University. Harrisonburg, VA.

Prince, M., (2004). Does active learning work? A review of the research. Journal of Engineering Education, 93(3), 223-231. http://dx.doi.org/ 10.1002/j.2168-9830.2004.tb00809.x.

Reyes, J.P., San-Jose, J.T., Cuadrado, J., Sancibrian, R., (2014). Health & safety criteria for determining the sustainable value of construction projects. Safety Science 62, 221–232. http://dx.doi.org/10.1016/j.ssci.2013.08.023.

Saaty, T.L., (1987). The analytic hierarchy process – What it is and how it is used. Math. Model. 9(3–5), 161–176. http://dx.doi.org/ 10.1016/0270-0255(87)90473-8.

Saaty, T.L., Vargas, L.G., (2006). Decision making with the analytic network process: economic, political, social and technological applications with benefits, opportunities, costs and risks. Springer, New York.

Segalas, J., Ferrer-Balas, D., Mulder, K.F., (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. J. of Clean. Prod. 18(3), 275–284. http://dx.doi.org/10.1016/j.jclepro.2009.09.012.

Sieffert, Y., Huygen, J.M., Daudon, D., (2014). Sustainable construction with repurposed materials in the context of a civil engineering architecture collaboration. J. of Clean. Prod. 67, 125–138. http://dx.doi.org/10.1016/j.jclepro.2013.12.018.

Sierra, L., Yepes, P., Pellicer, E., (2015). Social sustainability in the life cycle of Chilean public infrastructure. J. Constr. Eng. M., in press. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001099.

Sipos, Y., Battisti, B., Grimm, K., (2008). Achieving transformative sustainability learning: engaging heads, hands and heart. Int. J. of Sustain. in High. Educ. 9(1), 68–86. http://dx.doi.org/10.1108/14676370810842193.

Steiner, G., Posch, A., (2006). Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real world problems. J. of Clean. Prod. 14, 877–890. http://dx.doi.org/ 10.1016/j.jclepro.2005.11.054.

Summers, M., Corney, G., Childs, A., (2004). Student teachers' conceptions of sustainable development: the starting points of geographers and scientists. Educ. Res. 46(2), 163–182. http://dx.doi.org/10.1080/0013188042000222449.

Torres-Machi, C., Carrion, A., Yepes, V., Pellicer, E., (2013). Employability of graduate student in construction management. J. of Prof. Issues in Eng. Educ. and Pract. 139(2), 163–170. http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.0000139.

Torres-Machí, C., Chamorro, A., Pellicer, E., Yepes, V., Videla, C., (2015). Sustainable pavement management: Integrating economic, technical, and environmental aspects in decision making. Transportation Research Record, 2523, 56–63. https://doi.org/10.3141/2523-07

Torres-Machí, C., Chamorro, A., Yepes, V., Pellicer, E., (2014). Models and actual practices in the economic and environmental evaluation for the sustainable management of pavements networks. Revista de Construcción. 13(2), 49-56. http://dx.doi.org/10.4067/S0718-915X2014000200006

Valdés-Vasquez, R., Klotz, L., (2011). Incorporating the social dimension of sustainability into civil engineering education. J. Prof. Issues Eng. Educ. Pract. 137(4), 189–197. http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.0000066.

Valdés-Vasquez, R., Klotz, L., (2013). Social sustainability considerations during planning and design: framework of processes for construction projects. J. Constr. Eng. Manage. 139(1), 80–89. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000566.

Vila-Baños, R., Rubio-Hurtado, M., Berlanga Silvente, V., Torrado-Fonseca M., (2014). Cómo aplicar un análisis jerárquico en SPSS. Revista d' Innovació i Recerca en Educació. 7(1), 113–127. http://dx.doi.org/10.1344/ reire2014.7.1716.

Ward, J.H., (1963). Hierarchical grouping to optimize an objective function. J. of the Am. Stat. Assoc. 58, 236–244. http://dx.doi.org/10.1080/01621459.1963.10500845.

Watson, M.K., Lozano, R., Noyes, C., (2013). Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology. J. of Clean. Prod. 61, 106–116. http://dx.doi.org/10.1016/j.jclepro.2013.09.010.

Wemmenhove, R., de Groot, W.T., (2001). Principles for university curriculum greening. An empirical case study from Tanzania. Int. J. of Sustain. in High. Educ. 2(3), 267–283. http://dx.doi.org/10.1108/14676370110388354.

Whitmer, A., Ogden, L., Lawton, J., Sturner, P., Groffman, P.M., Schneider, L., Hart, D., Halpern, B., Schlesinger, W., Raciti, S., Bettez, N., Ortega, S., Rustad, L., Pickett, S.T.A., Killilea, M., (2010). The engaged university: providing a platform for research that transforms society. Front. in Ecol. and the Environ. 8(6), 314–321. http://dx.doi.org/10.1890/090241.

Wolters, W.T.M., Mareschal, B., (1995). Novel types of sensitivity analysis for additive MCDM method. Eur. J. of Oper. Res. 81, 281–290. http://dx.doi.org/ 10.1016/0377-2217(93)E0343-V.

World Commission on Environment and Development (WCED), (1987). Our common future. Oxford University Press, Oxford, United Kingdom.

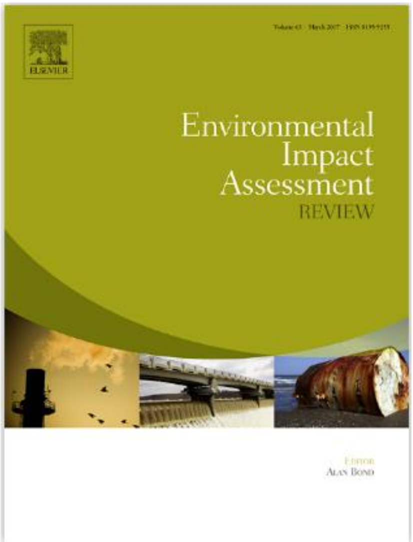
Wright, T.S.A., Wilton, H., (2012). Facilities management directors' conceptualizations of sustainability in higher education. J. of Clean. Prod. 31, 118–125. http://dx.doi.org/10.1016/j.jclepro.2012.02.030.

Yepes, V., Pellicer, E., Ortega, A.J., (2012). Designing a benchmark indicator for managerial competences in construction at the graduate level. J. of Prof. Issues in Eng. Educ. and Pract. 138(1), 48–54. http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.0000075.

CAPÍTULO 5

METHOD FOR ESTIMATING THE SOCIAL SUSTAINABILITY OF INFRASTRUCTURE PROJECTS

Publicación



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Nowadays, sustainability assessments tend to focus on the biophysical and economic considerations of the built environment. Social facets are generally underestimated when investment in infrastructure projects is appraised. This paper proposes a method to estimate the contribution of infrastructure projects to social sustainability. This method takes into account the interactions of an infrastructure with its environment in terms of the potential for short and long-term social improvement. The method is structured in five stages: (1) social improvement criteria and goals to be taken into account are identified and weighed; (2) an exploratory study is conducted to determine transfer functions; (3) each criterion is homogenized through value functions; (4) the short and long-term social improvement indices are established; and finally, (5) social improvement indices are contrasted to identify the socially selected alternatives and to assign an order of priority. The method was implemented in six alternatives for road infrastructure improvement. The results of the analysis show that the method can distinguish the contribution to social sustainability of different infrastructure projects and location contexts, according to early benefits and potential long-term equitable improvement. This method can be applied prior to the implementation of a project and can complement environmental and economic sustainability assessments.

KEYWORDS: Social Contribution, Social Improvement, Infrastructure, Method, Social Sustainability

5.1 Introduction

The sustainable contribution of an infrastructure has to be measured within its own context. Social facets are more influenced by context than environmental or economic ones. These social facets have to be considered in the short and long term and must be properly defined for each project investment (Valdés-Vásquez and Klotz 2013).

Infrastructure projects promote economic well-being, complement many social interventions and facilitate participation in sociopolitical processes (Asomani Boateng et al. 2015). An infrastructure by itself, however, may have a reduced impact on society (Gannon and Liu 1997, Van de Walle 2009). The assessment of the social impact that an infrastructure has on a region has been under-researched to date. Since the mid-20th century, monetization-based methods have been widely used to evaluate infrastructure projects (Mostafa and El-Gohary 2014). Nevertheless, some authors have introduced environmental aspects into this evaluation (Torres-Machi et al. 2014, 2015, Yepes et al. 2015a), with sustainability reaching beyond the analysis of monetary efficiency (Colantonio 2011). Mostafa and El-Gohary (2014) emphasize the limitations of these methods compared to equitable distribution and the assessment of non-economic aspects;

they also add the assumption that investment is inadequate if the benefits do not exceed the costs.

In the last decade, methods have been proposed to assess the sustainability of infrastructure projects, aiming to make sustainable development measurable. In Spain, the "Integrated Value Model for Sustainability Assessment" (MIVES in Spanish) can consider the social facet, even though it has been extensively used for the assessment of environmental and economic criteria (De la Cruz et al. 2015). The social facet can be assessed with a value function proportional to the average satisfaction of the experts. There is no evidence of a simultaneous treatment of different contexts considering the social facet. Nor is there a clear approach that maximizes the improvement of social need in the context of an infrastructure project.

The "Sustainability Appraisal in Infrastructure Projects" (SUSAIP) has been applied in the Chinese construction industry for bridges and viaducts (Ugwu et al. 2006a, b). This method assesses different types of designs considering their geographic context. Thirty percent of its indicators consider the social facet. However, the method assumes the same conditions for different contexts. Furthermore, there is only one decision-maker in the method.

The "Technical Sustainability Index" (TSI) has been applied in Canada for electrification infrastructures (Dasgupta and Tam 2005). This method takes into consideration a set of indicators applied to different stages of the assessment. Within the environmental indicators, the method deals with human indicators such as health, wealth and politics. Socially, the method is focused on long-term efficiency in a single context; short-term impact is not considered.

5.2 Point of departure

Colantonio (2011) establishes social sustainability as a condition and a process that improves a community's quality of life. Asomani and Boateng (2015) identify states of social development according to the extent of improvement after an intervention. Other authors associate social sustainability with the adequate distribution of well-being in the present and future (Valdes-Vasquez and Klotz 2013, Mostafa and El-Gohary 2014). Indeed, the social impact of infrastructure depends on its life cycle (design, construction, operation and disposal) (Sierra et al. 2016). Based on these assumptions, this study allows for the current (short-term) and future (long-term) states with respect to an infrastructure project.

In the short term, Valdes-Vasquez and Klotz (2013) consider that the context of the place, the user and the commitment and identification of the key stakeholders are aspects to take into account in the design and planning of an infrastructure project; in addition, a large part of the social impact depends on the pre-existing conditions or immediately added interventions (Van de Walle 2009). Short-term social improvement does not necessarily imply adequate distribution of the social benefits; in fact, in some cases it harms sectors in social need (Foth et al. 2013). Therefore, distribution mechanisms that include the most vulnerable population must be ensured (Mostafa and El-Gohary 2014) so those abilities are developed in conditions of social need. This is a process with long-term results.

An infrastructure project contributes to sustainability in the short and long term, which can be measured using social improvement criteria and goals, respectively. The criteria are requirements to an intervention that must be fulfilled to obtain a sustainability standard (Pavlovskaia 2013). Most of the social criteria cited from the 1990s have been addressed by Labuschange et al. (2005). On the other hand, the social improvement goals for a zone are more appropriate for a long-term approach. Specifically, the orientation of a social improvement goal is related to types of social indicators (Fulford et al. 2015); a social indicator is a measurement to monitor society's progress in terms of improvements in well-being over time, or the change in society with respect to evolving development goals (Noll 2013).

Therefore, according to what was set out in the previous points, the knowledge gap in the social sustainability assessment of infrastructure presents two aspects: (1) the social contribution in terms of how infrastructure interacts with its context (Gannon and Liu 1997, Van de Walle 2009, Asomani-Boateng et al. 2015), and (2) the potential benefit distribution effects on a long-term basis balanced with its short-term contribution (Colantonio 2011, Foth et al. 2013, Sierra et al 2016). These ideas are the point of departure for this study.

5.3 Objectives of the research

This article proposes a general method to assess the contribution of infrastructure projects to social sustainability in different geographic contexts simultaneously. This purpose is achieved with three specific goals that determine: (A) the estimation of social improvement produced by the infrastructure project in the short term; (B) the estimation of social improvement produced by the infrastructure project in the long term (or social development); and (C), the joint assessment of social improvement produced by the infrastructure project in the short and long term, prioritizing the different alternatives.

In order to accomplish these goals, this article is structured as follows: The first section contains the proposed method, based on multicriterion and multi-objective techniques, the Delphi method and systems theory. Next, the proposal is applied to a specific case so the reader can appreciate its practical implementation. Then the results are discussed. Finally, the contributions, recommendations, limitations and future lines of research are presented.

5.4 Proposed method

In order to fulfill the goals of this research, a general method is presented to evaluate an infrastructure's contribution to social sustainability. Its use supports the decision-making process in the early formulation phases of the project. This method is structured in three groups of processes, according to the three aforementioned specific goals. For each group of processes, the outcome is: (A) an index of short-term social improvement (*STSI*); (B) an index of long-term social improvement (*LTSI*); and (C) the multi-objective prioritization of different alternatives of an infrastructure investment. STSI identifies an infrastructure's contribution in interaction with the present context. In this study, the short term considers the social effects of infrastructure planning, design and construction for approximately three years from the start of the operation. On the other hand, in the long term, the distribution impact of the benefit considers the zones in social need. The long term considers the social effects on the type of tenure and preservation of the infrastructure. Once the social improvement for the different alternatives has been identified, these can then be prioritized according to their contribution to social sustainability.

Figure 5.1 illustrates the processes that intervene in the assessment method. In accordance with the previously established objectives, the processes labeled "A" intervene in social improvement in the short term. Comparably, the processes labeled "B" determine social improvement in the long term. Finally, processes "C" determine the prioritized solution of socially sustainable infrastructure projects and their stability. The dotted line shows the flow of information as well as the scoring steps of criteria and social goals. In the following sub-sections, each of the processes that compose the proposed method is explained according to the layout shown on the left side of Figure 5.1.

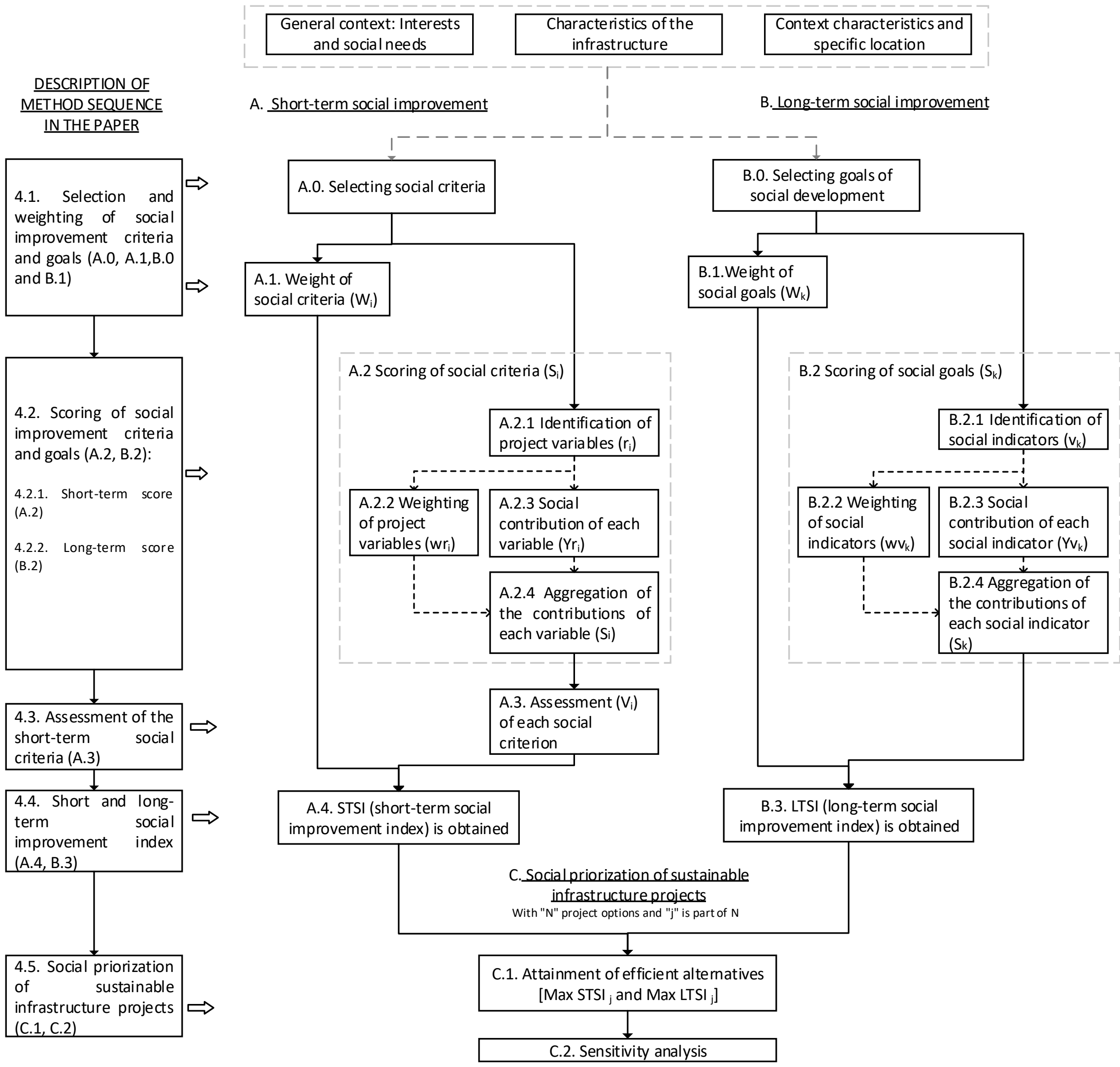

Figure 5.1 : Proposed method

5.4.1 *Selection and weighting of social criteria and goals (A0, A1, B0, B1)*

The specific criteria and goals of social improvement are selected from a pre-established set of criteria (Labuschagne et al. 2005) and national goals (UN 2015). The pre-selection takes into account: (1) the general interests for social improvement in the short and long term, and (2) incidence of characteristics of the type of public infrastructure being studied. Experts are needed to disclose their conformity or nonconformity with every aspect of the sample of criteria and goals, and may consider others to be relevant.

At least eight experts are required to obtain a consensus applying the Delphi method (Hallowell and Gambatese 2010), a qualitative structured communication technique developed as an interactive systematic method of prediction based on a panel of experts (Cortés et al. 2012, Alshubbak et al. 2015). Generally, the expert's profile must fulfill a minimum of four requirements from a list of 10 proposed by Hallowell and Gambatese

(2010) in order to guarantee the rigor of the method. These include university degree, membership in professional associations, minimum of professional experience, authorship of papers or book chapters, and so on. In particular, for the short term, experience in public infrastructure projects as well as specific knowledge of the region under study are desirable. Conversely, for the long term, institutional representation and socio-historical knowledge of the context can be required. Additionally, an interdisciplinary expert panel configuration is also necessary (Munda 2006) as a panel of experts should represent the interests of the stakeholders involved in the region.

Later, the experts are asked to provide a solution to the following question:

A.1. *Based on the greater contribution to short-term (or long-term) social improvement, compare the degree of importance between the different social criteria (or social improvement goals) for an infrastructure*.

The experts are asked to indicate on a pairwise-comparison questionnaire the importance of a criterion (or social improvement goal) compared to another by applying an analytic hierarchy process (AHP). The AHP is a technique that determines the weight of different aspects through the dual and consistent comparison of their importance on a scale from “1”, equal importance, to “9”, extremely important (Saaty 1987, Ahmadvand et al. 2011). Table 5.1: AHP questionnaire sample applied to the experts shows an excerpt from the questionnaire prepared for the experts’ responses. Thus, the criteria and goals are processed to obtain their relative weights. The process is iterative until a consensus is obtained or a number of rounds not less than three is reached (Hallowell and Gambatese 2010). According to Fernández-Sánchez and Rodríguez-López (2010), those aspects that concentrate 80% of the greatest importance are suitable for a methodological process. The results contain selected criteria “i” (or improvement goal “k”) and their relative weight. The relative weight of each criterion (or development goal) is normalized to the total weight of the selected criteria (or improvement goal). The new weights of the selected criteria or social improvement goals are called “Wi” or “Wk.”, respectively.

Table 5.1: AHP questionnaire sample applied to the experts

Based on the greater contribution to short-term (or long-term) social improvement, compare the degree of importance between the different social criteria (or social improvement goals) for an infrastructure In each comparison to register only the preference of more importance. Use the scale of importance from 1 until 9 (*)				
Pre-selected criteria of short–term				
“Employment”		vs		“Property and habitability”
“Employment”		vs		“Safe environmental”
…….		vs		……
“Communal cohesion and identity”		vs		“Citizen participation”
Pre-selected goals of long-term				
“Economy”		vs		“Health”
“Economy”		vs		“Education”
…….		vs		
“Education”		vs		“Innovation”

(*) Note:
1: The same importance; 3: Moderate importance; 5: Greater importance; 7: Very great importance; 9: Extreme importance;
Values 2,4,6 and 8 can be used for intermediate points

5.4.2 Scoring of social improvement criteria and goals (A.2, B.2)

For each social improvement criterion and goal, a score is given as the interrelation between the project characteristics and the social context. Social contexts can be viewed from a systemic approach. A social system can be considered as a set of dynamic processes adaptable to disruptions (Luhmann 1998, Dominguez-Gomez 2016). In this sense, social interrelation is a complex system that can be understood from its internal or external description (Xing et al. 2013). In general terms, an internal description structures the behavior of the system in terms of its variables and interdependence. Alternatively, an external description is considered a black box, displaying the functional relations of the system’s inputs and outputs. These functional relations translate into transfer functions that explain how the inputs are processed to produce the outputs (Le Moige 1990). In this field, the transfer functions are associated with a soft systems methodological and historical experience given by stakeholders for a specific context. In this vein, a complex system must be understood in relation to its context, which has an input gathering process (Xing et al. 2013). Based on a systems approach, the following paragraphs describe the process to determine the long and short-term scores.

5.4.2.1 Short-term score (A.2)

The scoring mechanism of a criterion depends on the contribution of the project within the context intervals, measured on a scale of 0 to 100. Assumptions to determine the score of each criterion are expressed in the following lines. In the short-term, the score values (S_i^{ST}) for an infrastructure’s contribution to each social criterion *i* could be assumed to be in a state of certainty. Therefore, the input of each social criterion is conditioned to the available and verifiable information. The formulation of S_i^{ST} takes four aspects into account: (1) the infrastructure variables *r* and their value X_{ir} that affect each social criterion *i* according to the infrastructure type and life cycle stage; (2) the weight the variables have in a social criterion ω_{ir}; (3) the vector of conditioning factors C_r regardless of the project and related to the context that impacts on the contribution of each variable r; and finally, (4) the transfer function $f_r(X_r, C_r)$ that explains the response Y_r^{ST} of an idle social system to the drive for development caused by the infrastructure for each variable r. Figure 5.2 illustrates the systemic process for determining a score for the social contribution of an infrastructure project. Equation 5.1 and Equation 5.2 represent the response of the transfer functions (Y_{ir}^{ST}) and the score (S_i^{ST}) of each social criterion with respect to an infrastructure project.

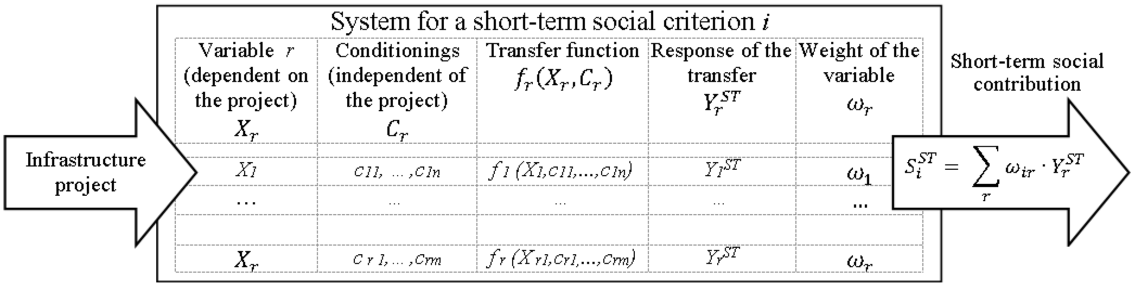

Figure 5.2: Intervening elements for scoring a social criterion in the short term

Equation 5.1

$$Y_{ir}^{ST} = f_{ir}(X_{ir}, C_{ir})$$

Equation 5.2

$$S_i^{ST} = \sum_r \omega_{ir} \cdot Y_{ir}^{ST} \quad ; \quad being \sum_{r=1}^{n} \omega_{ir} = 1 \quad and \quad S_i^{ST} \in [0 - 100]$$

Each short-term transfer function $f_{ir}(X_{ir}, C_{ir})$ is determined according to the type of infrastructure in its relation to the social environment. An example of transfer function with quantitative variables is shown in Equation 5.3. In this function the value of each variable X_{ir} is measured according to the type of project. The performance range can be identified through the conditioning factors $c_{ir\text{-}max}$ and $c_{ir\text{-}min}$. Variables such as hiring personnel, project deadlines or investment in safety and health could be modeled this way. Similarly, Alarcón et al. (2011) set out functions limited between maximum and minimum ranges to represent the contribution of buildings to economic and environmental sustainability.

Equation 5.3

$$f_{ir}(X_{ir}, c_{irmax}, c_{irmin}) = 100 \cdot \frac{[X_{ir} - C_{irmin}]}{[C_{irmax} - C_{irmin}]}; \quad being\ c_{irmin} \leq X_{ir} \leq c_{irmax}$$

In the case of qualitative variables or conditioning factors, the information X_{ir} or c_{ir} of each variable r can be defined according to the situation. For instance, the variable "safety during construction" could correspond to construction works alongside vehicular traffic and/or with direct access to main roads. The zonal conditioning factors can enhance or reduce the contribution of the infrastructure's variables. For example, high local unemployment increases the impact of the variable "employment" on the infrastructure in the zone. In these cases a transfer function can be the interaction of the variables of infrastructure and conditioning factors. Each interaction is valued according to the distribution of 100 points per variable consistent with the level of influence. In each infrastructure type and location context, determination of the variables, their weights, conditioning factors and transfer functions are the result of an exploratory study. Figure 5.3 shows a recommendation of techniques to use to perform this process. An expert consultation can be part of the process of exploratory research. Prior to any such consultation, however, a document review and field studies are recommended. In this regard, techniques are needed that provide greater reasoning (e.g. interviews and conceptual maps) and validation (e.g. surveys and Delphi method) of the variables, conditioning factors and their interaction.

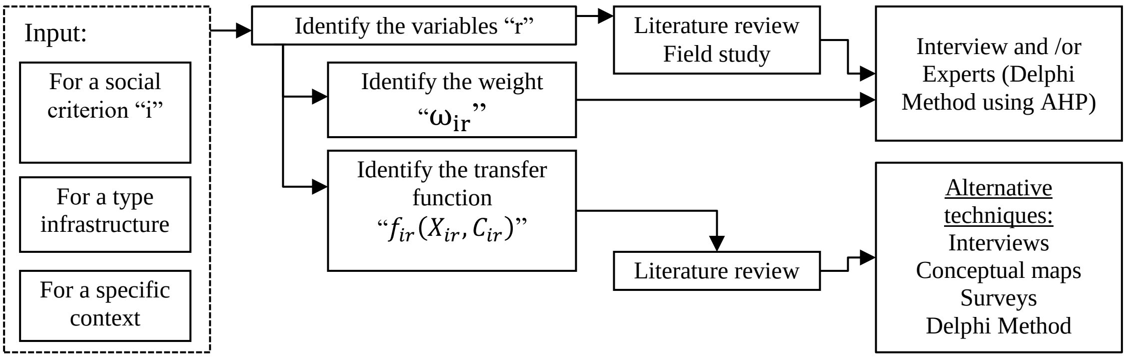

Figure 5.3: Determination of variables, weights and transfer functions

5.4.2.2 Long-term score (B.2)

The score for each social improvement goal k in the long-term (S_k^{LT}) depends on the ability of the project to satisfy social needs. Similarly, a systemic approach is illustrated in Figure 5.4to determine the score of the infrastructure long-term social improvement for a goal k. In this case, the response of each transfer function depends on the improvement of each zonal indicator that characterizes a goal k. In addition, an indicator must provide reliable information and represent the structural needs of the area. Given the uncertainty of this condition, field studies and expert consultations are recommended. Thus, the S_k^{LT} formulation takes five aspects into account: (1) the indicators v that represent each improvement goal and which have data available; (2) a vector of zonal conditioning factors C_v that characterize the present state of indicator v in the zone; (3) a vector of variables Z of the infrastructure that could affect the set of indicators; (4) the weight that the indicators have on a social improvement goal ω_{kv}; and finally, (5) the transfer function $f_v(Z, C_v)$, which explains the response Y_v^{LT} in the long term of the drive to develop motivated by the infrastructure. Equation 5.4 and Equation 5.5 represent the response of the transfer functions ($Y_{kv}{}^{LT}$) and the score ($S_k{}^{LT}$) of each social improvement goal with respect to an infrastructure project.

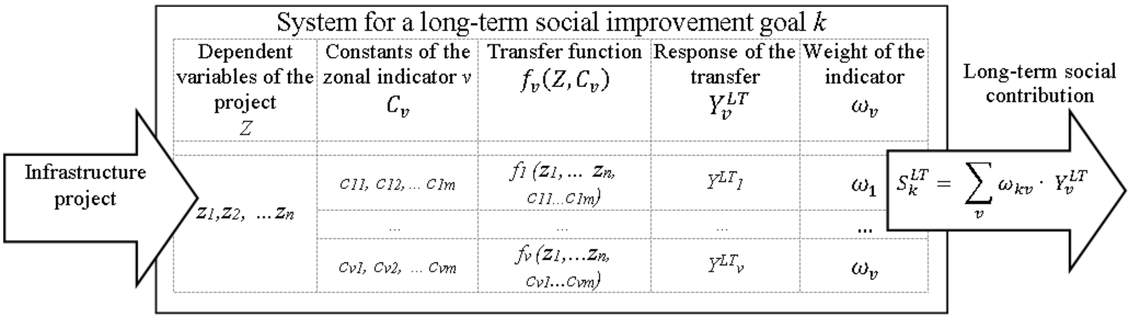

Figure 5.4: Intervening elements in the score contributing to a long-term social goal

Equation 5.4

$$Y_v^{LT} = f_v(Z, C_v)$$

Equation 5.5

$$S_k^{LT} = \sum_v \omega_{kv} \cdot Y_v^{LT} \quad ; \quad being \sum_{v=1}^{n} \omega_{kv} = 1 \quad and \ S_k^{LT} \in [1 - 25]$$

In this case, the transfer function $f_{kv}(Z, C_{kv})$ promotes the right distribution of the infrastructure's benefits according to the zone's initial social conditions (Esteves and Vanclay 2009, Fulford et al. 2015). For this, a systematic consultation with a panel of experts (equivalent to the panel in the B.1 process) is done until a consensus is reached. To do this, the panel is informed of the variables in project Z and the vector C_v of the current social indicators in the zone, their trend and position in the region. The process begins when the panel is asked to provide a solution to the following questions:

B.2.1. - According to the characteristics of the infrastructure project and on a scale of 1 (minimum benefit) to 5 (maximum benefit), identify the degree of long-term benefit that the project would generate for each social indicator.

B.2.2. - According to the current situation of the project location zone and on a graduating scale of 1 (minimum social need) to 5 (maximum social need), identify the degree of need in each project zone with respect to each social indicator.

If consensus cannot be reached, the experts are asked to reconsider their responses after feedback from the previous results. The response of the social transfer function (Y_v^{LT}) for each indicator v is the product of the degree of potential benefit from the infrastructure (B.2.1) and the degree of zonal need (B.2.2).

5.4.3 Assessment of the short-term social criteria (A.3)

The multi-attribute utility theory represents a structure of preferences by means of a function. Under a short-term approach in which a state of greater certainty is admitted, a value function is used (Mel et al. 2015). A generic value function is used to unify the scores (S_i^{ST}). This function is developed to estimate sustainability and has been applied to buildings (Alarcón et al. 2011) and to concrete structures (Gómez-Lopez et al. 2013). This function normalizes the tendencies of the criteria with demonstrated behavior and represents them through a unit of "value" (Gómez-Lopez 2013). This means that in concave functions that imply low social demand, high satisfaction is reached with few improvements. Convex functions implying high demand require large improvements in the criterion to achieve satisfaction. In a linear function the increase in satisfaction is constant with respect to the improvement. In addition, it is possible that the levels of demand for a criterion depend on the development in a region (Max-Neef 1995). Therefore, to promote the development of weak criteria, a strategic decision is to use concave curves. Convex curves are more appropriate for developed criteria where the desire is to obtain a high standard (Alarcón et al. 2011). Finally, Alarcón et al. (2011) recommend linear functions for decision making on criteria with no clear trend. Equation 5.6 represents the generic value function, with V being the value of each short-term social criterion i and the parameter S_i^{ST} the score of each criterion i. The parameters m_i, n_i, and A_i define the convex ($A_i \geq 2$, $m_i \leq 0.1$, $n_i \geq 45$), concave ($A_i \leq 0.75$, $m_i \geq 0.9$, $n_i \approx 100$), or linear form ($A_i \approx 1$, $m_i \approx 0$, $n_i \approx 15$) of the criterion (Manga 2005). K_i limits the result interval of the function of $V = 0$ ($S_i^{ST} = 0$) to $V = 1$ ($S_i^{ST} = 100$) (Alarcón et al. 2011).

Equation 5.6

$$V_i = K_i \cdot \left[1 - e^{-m_i \left(\frac{S_i^{ST}}{n_i} \right)^{A_i}} \right]$$

5.4.4 Short and long-term social improvement indices (A.5, B.4)

The short and long-term social improvement index is the result of the simple additive weighting of each criterion and social indicator. This technique provides an indicator equivalent to the weighted mean. The short-term social improvement (*STSI*) index varies on a scale from 0 to 1, and reflects the level of social contribution that an infrastructure project contributes to a context in the short term. The *STSI* index is obtained from the values V_i and normalized weights *Wi*. Each normalized weight is obtained by dividing each criterion chosen using the Delphi method by the total sum of the weights. Equation 5.7 illustrates the *STSI* index of an infrastructure project.

Equation 5.7

$$STSI = \sum_{i=1}^{n} W_i \cdot V_i$$

Likewise, the long-term social improvement (*LTSI*) index varies on a scale from 1 to 25 and reflects the reinforcement potential of the long-term social needs in areas with the greatest need. The *LTSI* index is obtained from the values S_k and normalized weights W_k. Equation 5.8shows the *LTSI* index of an infrastructure project.

Equation 5.8

$$LTSI = \sum_{k=1}^{n} W_k \cdot S_k^{LT}$$

5.4.5 Socially sustainable solutions (C.1, C.2)

Infrastructure project alternatives *j* are selected according to the simultaneous evaluation of *STSI* and *LTSI* indices. Figure 5.5 shows the sequence of activities to identify the eligible projects.

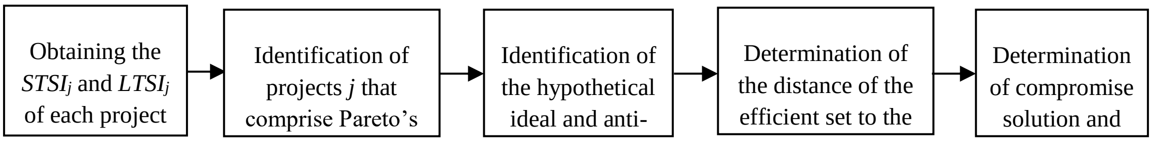

Figure 5.5: Sequence of activities to identify the elegible projects according to theirs contribution to social sustainability

Charting *STSI* vs. *LTSI*, the alternatives that comprise Pareto's border are identified. The efficient projects are those for which there is no other project alternative that improves one index without making the other worse (Garcia-Segura et al. 2015). In turn, the ideal solution is the best result of *STSI* and *LTSI* of the socially efficient set. Similarly, an anti-ideal solution corresponds to the worst result of *STSI* and *LTSI*. On this point, multi-objective compromise programming is used to reduce the efficient solutions. This subgroup of solutions is determined with respect to the shortest distance to an ideal solution. For two goals a compromise subgroup is limited by solutions with metric distances d_1 (Manhattan's distance) and d_∞ (Tchebychev's distance) (Yepes et al. 2015b). Equation 5.9 and Equation 5.10 represent the mathematical model of the subgroup of compromise solutions for this model. In these, d_∞ is the maximum individual distance of each objective and d_1 is the orthogonal sum. Then, projects with the minimum Manhattan and Chebyshev distances are eligible candidates. The $STSI_j$ and $LTSI_j$ represent the values of the indices of each j^{th} project. The λ_1 , λ_2 are the weights of the improvement goals;

the $STSI^*$ and $LTSI^*$ indices represent the ideal solution, and the $STSI_*$ and $LTSI_*$ the anti-ideal solutions for the short and long-term social improvement goals, respectively.

Equation 5.9

$$Min \quad d_\infty \quad ; \qquad d_{\infty j} = Max \left[\lambda_1 \cdot \left(\frac{STSI^* - STSI_j}{STSI^* - STSI_*}\right); \ \lambda_2 \cdot \left(\frac{LTSI^* - LTSI_j}{LTSI^* - LTSI_*}\right)\right]$$

Equation 5.10

$$Min \quad d_1 \quad ; \qquad d_{1j} = \lambda_1 \cdot \left(\frac{STSI^* - STSI_j}{STSI^* - STSI_*}\right) + \ \lambda_2 \cdot \left(\frac{LTSI^* - LTSI_j}{LTSI^* - LTSI_*}\right)$$

A sensitivity analysis is proposed from a set of solutions. The sensitivity analysis identifies the effect on the assessment of social sustainability for each infrastructure after the possible variation of the input elements. This analysis consists of the iteration of regular and independent variations of each input variable, susceptible to uncertainty, keeping the rest constant (Mel et al. 2015). The variation of the input elements determines the stability intervals of the solution.

5.5 Case study

A case study is presented to illustrate the method and its practical application. This case study is an adaptation of the project "Revitalization of Local Economies through Public Infrastructure" implemented in El Salvador. The project is led by the United Nations Development Program (UNDP) and El Salvador's Ministry of Public Works. The project aims to strengthen institutional capacities for planning and prioritizing public infrastructure. This objective takes into account the potential and integrated development of rural and intercity areas. Thus, a set of infrastructure projects in the national portfolio were analyzed by multisectoral experts and the research team. From this set, three contexts and two options of projects for rural and intercity roads were selected to illustrate the method. Key aspects and results of the application of the method are described in the following paragraphs.

5.5.1 Social improvement criteria and goals

An expert panel was formed according to the requirements explained in the above sub-section 5.4.1. Table 5.2 specifies the characteristics of the set of experts who participated in this case study. Three rounds were needed to reach consensus. Criteria and goals (short and long term, respectively) that reached more than 80% of importance are shown in

Figure 5.6. Furthermore, Figure 5.6 presents the variables of the infrastructure projects and their conditioning factors to illustrate the case study. These elements and their interactions stemmed from the review of similar projects in this context (literature review and field studies). A semi-structured interview with six experts concluded the exploratory study. Furthermore, the social indicators in the long term are also displayed in Figure 5.6. For each social goal, a quality review of the data available for the context indicators was performed. The field studies and interviews also helped to align the social indicators most representative of a social goal. A proposal of indicators, variables, conditioning factors and their relationships was validated by the panel of experts during the first round

Table 5.2: Characteristics of the expert panel of the case study "El Salvador"

Requirements		**Profile l** (15)	**Profile 2** (14)
A		26%	28%
B		30%	46%
C	1	--	7%
	2	27%	7%
	3	20%	--
	4	27%	36%
	5	13%	21%
	6	13%	7%
	7	--	14%
	8	--	14%
D	[5-15]	20%	7%
	[16-25]	33%	43%
	[26 or more]	47%	50%
E	BS	47%	29%
	MSc	46%	57%
	PhD	7%	14%
F	Social	20%	29%
	C.E. /Arq.	40%	29%
	Environmental	20%	14%
	Health	6%	7%
	Economy	13%	21%
G		53%	12.5%

Notes:
A: Author of peer-reviewed journal articles.
B: Invited to speak at a conference
C: Member of a nationally/regionally recognized committee or institution (1.Central government, 2Technical departments MOP, 3.Social Development Departments, 4 Universities, 5NGOs (UNDP, local foundations), 6 Public Health Institute, 7 Chamber of commerce and privates, 8 Regional delegate).
D: At least 5 years of professional expertise
E: Advanced degree in the field of civil engineering, CEM, or other related fields (minimum BS)
F: Knowledge Area (1. Social, 2 Engineering and Architecture, 3 Environmental, 4, 5 Economy and public management)
G: Professional registration
Profile 1: Members of the expert panel to evaluate short-term
Profile 2: Members of the expert panel to evaluate long-term

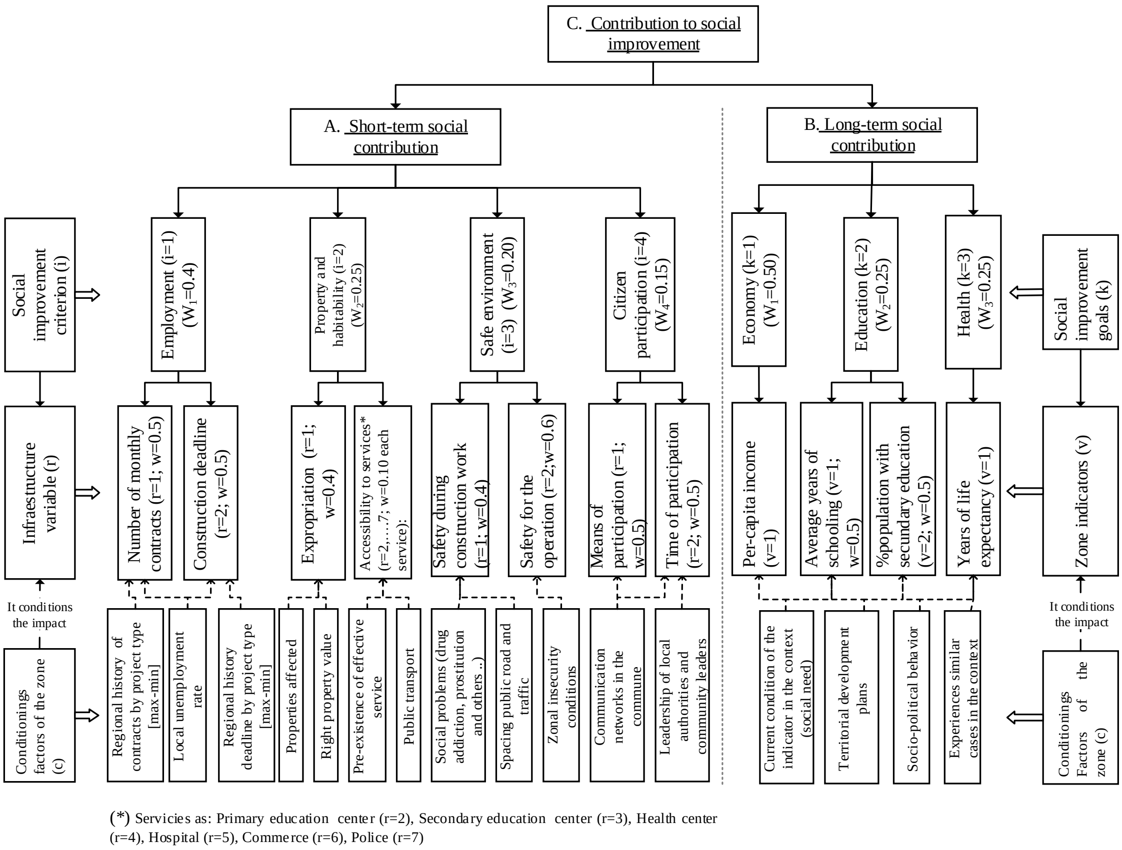

Figure 5.6: Decision-making structure of case study

5.5.2 *Description of the alternatives of infrastructure projects*

Currently, El Salvador is a developing country, after suffering through a 12-year Civil War (1980-1992). According to the DIGESTYC (2014), its poverty rate is 31.85%, its per-capita income is US 1742 per annum and its human development index is 0.67, one of the lowest in Central America. In this macro-context the public administration agency must prioritize the infrastructure alternatives. To do this, it wants to consider the contribution to social sustainability. The case study focuses on the analysis of six alternatives comprised for the combination of two options of road projects alternatively applied in three rural sectors of the country. The two road project options are technically applicable to all the identified sectors. Option A is a rehabilitation that includes works of transverse and longitudinal drainage, treatment of critical points and maintenance of a gravel road. In this case, the speed limit does not exceed 40 km/h. Option B involves an improvement and adds road widening work to a standard of 7 m and hydraulic concrete paving. As needed, this solution also incorporates the treatment of critical points and improvement of the drainage system. In this case, the speed limit does not exceed 90 km/h.

The general geographical context of each study zone is presented in Figure 5.7and is described next:

1. Zone 1: It presents highly deteriorated concrete and stone pavement. The road connects the seasonally isolated local area with a highly populated city. The project benefits 1,500 inhabitants. The annual mean daily traffic on the road is 800 vehicles. The intervention length is 7 km. The local economy is based on the agriculture industry.
2. Zone 2: It presents a rural road which connects five local areas. The road benefits 2,680 inhabitants. This is a gravel road which varies in width; it has difficult accessibility and a high accident rate in winter. The mean annual daily traffic is 500 vehicles and the intervention length is 15 km. The local economy is based on tourism, mainly in mountainous areas. The zone presents unexploited historic-cultural conditions.
3. Zone 3: It presents an intercity road which connects two local areas and one city. The zone has untapped port facilities. However, there are political and civic pressures for its early regularization and exploitation. The road has a gravel loose pebbles and a deteriorated drainage system. The project benefits 600 inhabitants. The annual mean daily traffic is 300 vehicles and the intervention length is 7 km. The zone is located in a coastal sector and has poor tourism development. The local economy is based mainly on agriculture and fishing.

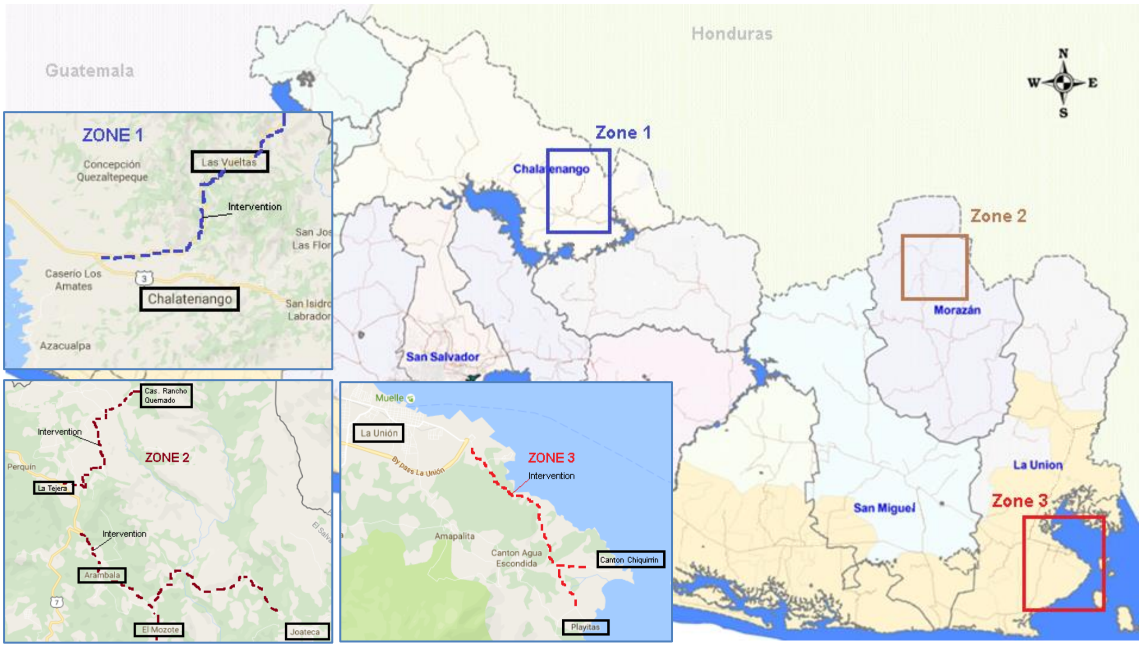

Figure 5.7: Geographical location of assessment contexts

Table 5.3 displays the main background used for the assessment of social improvement in the short term. Data were obtained from the review of projects, field studies, interviews with designers and statistical data (DIGESTYC 2014).

Table 5.3: Synthesis of the background of the alternatives for short-term evaluation

Social improvement criterion (*i*), variables (*r*) and constants (c_{ir})	**Project versus zone**					
	A1	**B1**	**A2**	**B2**	**A3**	**B3**
Employment (*i*=1)						
Number of monthly contracts (*r*=1)	*60 contracts*	*30 contracts*	*70 contracts*	*45 contracts*	*50 contracts*	*35 contracts*
Regional history of contracts by project type [c_{111}-c_{112}]	*[18-80]*		*[18-80]*		*[18-80]*	
Construction deadline (*r*=2)	*3 months plus 12 months of maintenance*	*4 months*	*4 months plus 12 months of maintenance*	*6 months*	*3 months plus 12 months of maintenance*	*4 months*
Regional history deadline by project type [c_{21}-c_{22}]	*[2-12 months plus 12 months of maintenance]*		*[2-12 months plus 12 months of maintenance]*		*[2-12 months plus 12 months of maintenance]*	
Local unemployment(c_{113}=c_{123}) Maximum and minimum national unemployment [c_{114}-c_{115}]= [c_{124}-c_{125}]	*6.01%; [4.1%-6.8%]*		*4.55%; [4.1%-6.8%]*		*5.78%; [4.1%-6.8%]*	
Property and habitability (*i*=2)						
Expropriation (*r*=1)	*no evidence*	*no evidence*	*no evidence*	*Right of way for 150,000US and 40 properties affected*	*no evidence*	*Right of way for 130,000US and 36 properties affected*
Max historic value paid for rights of way (c_{211})	*200,000US*	*200,000US*	*200,000US*	*200,000US*	*200,000US*	*200,000US*
Max tolerable affected properties (consensus) (c_{212})	*50*	*50*	*50*	*50*	*50*	*50*
*Current average accessibility (Without project) to : Primary education center (*r*=2); Secondary education center (*r*=3); Health center (*r*=4); Hospital (*r*=5); Commerce (*r*=6); Police (*r*=7)	*Rural health services, basic school, police are available in local area (6 km, 15' by car to the most disadvantaged population center); Secondary school, hospital, large retailers (15 km, 35' by car to the most disadvantaged population center).*		*Rural health services, basic school, police are available in local area (10 km, 45' by car to the most disadvantaged population center); Secondary school, hospital, large retailers (30 km, 135' by car to the most disadvantaged population center).*		*Rural health services, police, rural school available in local area (4 km, 13' by car to the most disadvantaged population center); Basic and secondary school, hospital, shops (15 km, 40' by car to the most disadvantaged population center).*	
Current frequency of public transport (c_{2r1})	*Public transportation 3 times per day.*		*Public transportation 6 times per day.*		*Public transportation 2 times per day*	
Safe environment (*i*=3)						
Safety during construction work (*r*=1)	*Work with machines and equipment with contiguous traffic. The roads access directly to a main way. There is strong evidence of alcoholism and crime*		*Work with machines and equipment with contiguous traffic*		*The roads access directly to a main way. There is strong evidence of alcoholism and crime*	
Safety in the operation of infrastructure (*r*=2)	---	*Flooding conditions will be reduced*	---	*Flooding conditions will be reduced. Improves safety on the layout of the track.*	---	---
Zonal insecurity conditions(C_{32Z})	*Zone for agricultural burning, animals and heavy transport and basic school next to road*		*Presence of cliffs and extreme climate*		*Number important of people walk on the road, zone of agricultural burning*	
Citizen participation (*i*=4)						
Means of participation (*r*=1)	*no evidence*	*Communal meeting*	*no evidence*	*Communal meeting, but just receives observations of leaders*	*no evidence*	*Publication in the local newspaper*
Time of participation(*r*=2)	*no evidence*	*During the design*	*no evidence*	*From conceptualization by initiative of the Mayor*	*no evidence*	*Interview with random group of the community during the conceptualization*
(*)Note: Improving accessibility (travel time) is determined according to the speed of operation of the infrastructure and the distance to each center (in this case does not change).						

Table 5.4 provides some of the information given to the experts for evaluation of potential long-term social improvement. In particular, this information was taken into account for assessing the extent of social needs in each area (question B2.1, sub-section 5.4.2.2). In addition, the background of each project and the Plan of Territorial Development of El Salvador 2021 was used. This information was used to assess the potential contribution of the infrastructure in the long term (question B2.2, sub-section 5.4.2.2).

Table 5.4: Synthesis of the zone's current situation for long-term evaluation

Social improvement goals (k) and indicators (v)	Background of context		
	Zone 1	**Zone 2**	**Zone 3**
Economy (*k*=1)			
Per capita income (v=1)	*450US/month*	*300US/month*	*285US/month*
Annual trend (10 years)	*+1.25%*	*+4%*	*+0.7%*
Position of the region in the country [1 worst -10 best]	*7*	*4*	*3*
Education (*k*=2)			
Average years of schooling (v=1)	*8*	*6*	*5*
Annual trend (10 years)	*+3.25%*	*+2%*	*+0.5%*
Position of the region in the country [1 worst -10 best]	*8*	*6*	2
% population with secondary education(v=2)	*75%*	*55%*	*35%*
Annual trend (10 years)	*+1.83%*	*+0.8%*	*+0.2%*
Position of the region in the country [1 worst -10 best]	*6*	*5*	2
Health (*k*=3)			
Years of life expectancy (v=1)	*73*	*74*	*68*
Annual trend (10 years)	*+0.25%*	*+0.4%;*	*+0.1%*
Position of the region in the country [1 worst -10 best]	*1*	*8*	*3*

Date source: Based on DIGESTYC (2014) Household Survey and purposes multiples-El Salvador (EHPM in Spanish)

5.5.3 Contribution to short-term social improvement

Some variables with social implications have been highlighted in other studies with respect to transport infrastructure projects. Regarding employment, Labuschagne et al. (2005) mention its incidence during construction and maintenance of infrastructures. Meanwhile the issue of expropriation is one of the greatest concerns and interests for communities. The higher the value and the greater the number of properties affected, the greater the social upheaval (Valentin and Bogus 2015). Moreover, Gannon and Liu (1997) and Van de Walle (2009) consider accessibility as a direct impact of road infrastructure on community services. Regarding safety, the road affects the area during construction and operation (Valdes-Vasquez and Klotz 2013, Sierra et al. 2016). In this sense, the conditions of work and transit, design and the safety hazards in the area are variables that influence the social impact. The criterion of stakeholder participation is also significant in the results of infrastructure planning and execution (O'Faircheallaigh 2010).

Based on the background mentioned and interviews with specialists, a set of project variables, zone conditioning factors and interrelations were defined. These inputs enabled the structuring of the most significant transfer functions that justify the contribution to a short-term social criterion. Table 5.5 illustrates the specific operation carried out to estimate the transfer functions of the variables: number of contracts (*i*=1, *k*=1), construction deadline (*i*=2, *k*=2), safety during construction work (*i*=3, *k*=1) and safety for the operation (*i*=3, *k*=2). In the first and second cases, the transfer functions were modeled quantitatively according to Equation 5.3; they interact with the zonal unemployment. In the third case, four qualitative variables of project and social issues of the context were related in a transfer function. In the fourth case, two sets of ten possible situations interacted: the variables of design *p* of the project and the conditions of risk *z* of the zone

Table 5.5: Transfer functions for "employment" and "safe environment" social criteria

i	***r***	$\boldsymbol{f_r(X_r, C_r)}$
1.- Employment	1Number of contracts	$Y_{11}^{ST} \cong \left[\frac{(X_{11} - c_{112})}{(c_{111} - c_{112})}\right] \cdot \left[\frac{c_{113} - c_{115}}{c_{114} - c_{115}}\right]$
	2 Construction deadline	$Y_{12}^{ST} \cong \left[\frac{(X_{12} - c_{122})}{(c_{121} - c_{122})}\right] \cdot \left[\frac{c_{123} - c_{125}}{c_{124} - c_{125}}\right]$
3.- Safe environmental	1 Safety during construction work	$Y_{31}^{ST} \cong \left[1 - \frac{X_{31\_1} \cdot X_{31\_2} \cdot (X_{31\_3} + X_{31\_4} + \sum_{q=1}^{5} c_{31q})}{24 \cdot 3 \cdot 7}\right]$ For: X_{31_1} : Project deadline until 24 months X_{31_2} : Interval of annual mean daily traffic➔(3) >1000; (2) [500-1000]; (1) [100-500]; (0) <100 X_{31_3} : Does it require direct access to main roads?➔(1) Yes; (0) No X_{31_4} : Is there use of machinery and work alongside vehicular traffic? ➔(1) Yes; (0) No c_{31q} : Social issues in the context, *q*ϵ[1 – 5]; If *q* fulfill ➔ c_{31q} = 1 , in other case c_{31q} = 0 *q*=1 alcoholism; *q*=2 crime; *q*=3 violence; *q*=4 drug; *q*=5 prostitution
	2 Safety in the operation of infrastructure	$Y_{32}^{ST} \cong \left[\frac{\sum_{p=1}^{10} X_{32\_p}}{m}\right] \cdot \left[1 - \sum_{z=1}^{10} \frac{c_{32z}}{10}\right]$ Design variables: If *p* fulfills a standard➔ $X_{32\_p} = 100$; If *p* does not fulfill and is required ➔ $X_{32\_p} = 0$ *m* is the number of design conditions according to the characteristics of the project, with *m* = [1 – 10] *p* in this case are: (p=1) road equipment, (*p*=2) road geometry, (*p*=3) intersections, (*p*=4) pavements, (*p*=5) drains, (*p*=6) margins, (*p*=7) vulnerable users, (*p*=8) solution to pre-existing flooding conditions, (*p*=9) solution to disintegration or undermining, and (*p*=10) improvement zones along the trajectory with high accident rates. Condition of risk: If *z* is present ➔ c_{32z}= 1, in other case c_{32z}= 0 "z" in this case are: (*z*=1) flooding not improved, (*z*=2) landslide not improved, (*z*=3) social conflict zone, (*z*=4) agricultural burning zone, (*z*=5) heavy load industrial zone, (*z*=6) animal zone, (*z*=7) cliff zone, (*z*=8) zone under extreme climatic conditions, (*z*=9) school zone or contiguous meeting points on the inter-city, and (*z*=10) wooded zone.

Table 5.6 presents the facts of each project variable and conditioning factors of zone, the interaction of which establishes the social contribution of the variable. These are taken into consideration in each transfer function. For this case, the contributions present a

proportionally increasing value according to the number of conditions involved on each variable.

Table 5.6: Aspects that determine the social contribution of the variable "r"

i	*r*	Variable *r* vs. conditioning factor	Reference
1	1.- Number of monthly contracts	Number of monthly contracts vs. Intervals of contracts max and min in the zone for project type Local unemployment rate and range of national unemployment rate	Labuschagne et al. 2005 Asomani-Boateng 2015 Sierra et al. 2016
	2.- Construction deadline	Construction deadline vs. Intervals of deadlines max and min for project type vs. Local unemployment rate and range of national unemployment rate	
2	1.- Expropriation	Range of properties affected vs. Intervals of market valuation of the property to be ceded	Valentin and Bogus 2015
	2 to 7.- Accessibility to services	Ranges of travel time reduction from the most socially disadvantaged population center to the service (2) primary education, (3) secondary education, (4) health clinic, (5) hospital, (6) commerce, (7) police, v.s Frequency intervals at which public transportation passes	Asomani-Boateng 2015
3	1.- Safety conditions of the works	Intervals of mean annual daily traffic in the zone, vs. Risk conditions during the work activities for the road user, surrounding community and project personnel, vs. Time limit range for work	Valdes-Vasquez and Klotz 2013 Valentín and Bogus 2015
	2.- Safety conditions of the operation	Design conditions, v.s Improvement in conditions of the *layout of the track* with evidence of accident risk Elements of lack of safety in the independent context of the project	Porter et al. 2012
4	1.- Means of participation	Means of information that only allow closed feedback, open feedback, or are not in evidence.	Labuschagne et al. 2005 O'Faircheallaigh 2010
	2.- Initial point of participation	From project genesis and conceptualization, during the design process, beginning of construction or is not shown, vs. Level of notice: Open call, community representatives, limited and random sample	Valdes-Vasquez and Klotz 2013 O'Faircheallaigh 2010

From the background of each alternative and the zonal context, the procedure described and the use of Equation 5.2, Equation 5.6and Equation 5.7followed. Table 5.7 shows the score results (*SIST*), assessment (V_i), and *STSI* for each alternative. The assessment V_i is determined by assuming the incentive of the practices that promote improvement of the criteria. This in turns makes it possible to differentiate alternatives with low scores. According to the previously described recommendations by Manga (2005), the parameters used to determine V_i are A_i =0.72, m_i=0.9, n_i=100 and K_i=1.69.

Table 5.7: Results of social improvement from short-term infrastructure alternatives

Alternative	*i*	S_i^{ST}	V_i	W_i	*STSI*
A1	1	**44.861**	0.670	0.400	0.603
	2	55.143	0.750	0.250	
	3	**53.095**	0.735	0.200	
	4	0.000	0.000	0.15	
A2	1	12.292	0.305	0.400	0.501
	2	80.000	0.905	0.250	
	3	57.365	0.765	0.200	
	4	0.000	0.000	0.150	
A3	1	34.441	0.577	0.400	0.590
	2	58.846	0.776	0.250	
	3	66.286	0.825	0.200	
	4	0.000	0.000	0.150	
B1	1	10.061	0.267	0.400	0.629
	2	68.952	0.841	0.250	
	3	73.460	0.868	0.200	
	4	83.333	0.922	0.150	
B2	1	5.144	0.170	0.400	0.605
	2	67.109	0.830	0.250	
	3	87.048	0.942	0.200	
	4	87.500	0.944	0.150	
B3	1	11.359	0.290	0.400	0.596
	2	51.875	0.726	0.250	
	3	86.048	0.936	0.200	
	4	54.167	0.743	0.150	

5.5.4 Contribution to long-term social improvement

From the review of local databases (DIGESTYC 2014), quality and representativeness for each context was checked. Then, a set of indicators was defined by experts to respond to the-needs of each long-term social goal in the region. Table 5.4presents the current state of the social indicators of each zone. The value of the social indicator, its trend and position of the zone within the region characterize each social indicator.

According to the procedure described, Table 5.8 shows the elements that determine the score S_k^{LT} for each social improvement goal. It displays the results of consensus on questions that identify the degree of potential benefit from the infrastructure (B.2.1) and the degree of zonal need (B.2.2). Additionally, Equation 5.8 is used to determine the *LTSI* index from the weights of each social improvement goal (Table 5.1) and its score.

Table 5.8: Results of long-term social improvement

Alt.	Social improvement goal *k*	Indicator *v*	B.2.1	B.2.2	Y_v^{LT}	w_v	S_k^{LT}	W_k	*LTSI*
A.1	Economic development *k*=1	Per capita income *v*=1	2	1	2	1	2	0.5	2.000
	Improvement in education *k*=2	Average years of schooling *v*=1	1	2	2	0.5	2	0.25	
		% population with secondary education *v*=2	1	2	2	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	1	2	2	1	2	0.25	
A.2	Economic development *k*=1	Per capita income *v*=1	3	3	9	1	9	0.5	6.375
	Improvement in education *k*=2	Average years of schooling *v*=1	2	2	4	0.5	3.5	0.25	

Alt.	**Social improvement goal *k***	**Indicator *v***	**B.2.1**	**B.2.2**	Y_v^{LT}	w_v	S_k^{LT}	W_k	***LTSI***
		% population with secondary education *v*=2	1	3	3	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	1	4	4	1	4	0.25	
A.3	Economic development *k*=1	Per capita income *v*=1	3	5	15	1	15	0.5	10.000
	Improvement in education *k*=2	Average years of schooling *v*=1	2	4	8	0.5	6	0.25	
		% population with secondary education *v*=2	1	4	4	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	1	4	4	1	4	0.25	
B.1	Economic development *k*=1	Per capita income *v*=1	4	1	4	1	4	0.5	4.750
	Improvement in education *k*=2	Average years of schooling *v*=1	2	2	4	0.5	5	0.25	
		% population with secondary education *v*=2	3	2	6	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	3	2	6	1	6	0.25	
B.2	Economic development *k*=1	Per capita income v=1	4	3	12	1	12	0.5	10.250
	Improvement in education *k*=2	Average years of schooling *v*=1	3	2	6	0.5	9	0.25	
		% population with secondary education *v*=2	4	3	12	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	2	4	8	1	8	0.25	
B.3	Economic development *k*=1	Per capita income *v*=1	5	5	25	1	25	0.5	18.500
	Improvement in education *k*=2	Average years of schooling *v*=1	3	4	12	0.5	12	0.25	
		% population with secondary education *v*=2	3	4	12	0.5			
	Improvement in health *k*=3	Years of life expectancy *v*=1	3	4	12	1	12	0.25	

5.5.5 Outcomes from the method

According to the described procedure illustrated in Figure 5.5, six alternatives are contrasted according to the value of their *LTSI* and *STSI* indices. The graph in Figure 5.8 represents the efficient solutions comprised of alternatives B1, B2 and B3. After application of compromise programming with $\lambda_1 = \lambda_\infty = 0.5$, the efficient set is prioritized in accordance with the shortest distance d_1 and d_∞. The ordered alternatives closest to the ideal point and farthest from the anti-ideal are B3, B2 and B1.

The stability of the response is presented in Table 5.9 based on the performance of a sensitivity analysis of the weights. For a variation at regular intervals of the variables W_i y W_k, there are no important fluctuations in the prioritization. From a change in the short-term criterion weight of "Employment" and "Participation", over +20% and under -30% respectively, the order of solution set changes significantly.

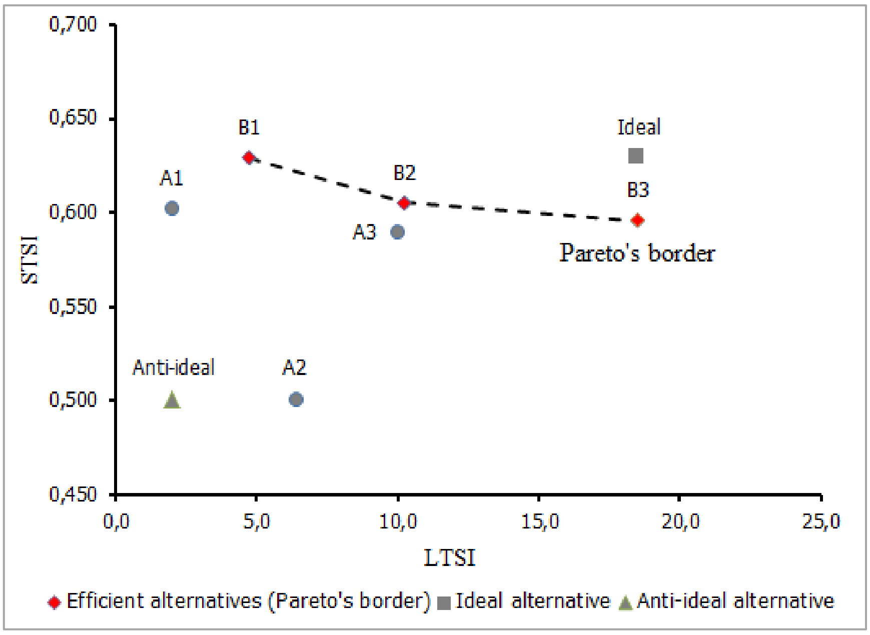

Figure 5.8: Socially sustainable solutions

Table 5.9: Stability of variables "Weight-Wi Wk" for the solution set

% variation of weight	W_i				W_k		
	Employment	**Property & ability**	**Safe environment**	**Participation**	**Economy**	**Education**	**Health**
+40	**B3,A3,A1**	B3,B2,B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
+30	**B3,A3,A1**	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
+20	**B3,A3,B1,A1**	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
+10	B3, (B2-A3), B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
0	**B3, B2, B1**	**B3, B2, B1**	**B3, B2, B1**	**B3, B2, B1**	**B3, B2, B1**	**B3, B2, B1**	**B3, B2, B1**
-10	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
-20	B3, B2, B1	B3, B2, B1	B3, B2, B1	B3, (B2-A3), B1	B3, B2, B1	B3, B2, B1	B3, B2, B1
-30	B3, B2, B1	B3, B2, B1	B3, B2, B1	**B3, A3, B1, A1**	B3, B2, B1	B3, B2, B1	B3, B2, B1
-40	B3, B2, B1	B3, B2, B1	B3, B2, B1	**B3, A3, A1**	B3, B2, B1	B3, B2, B1	B3, B2, B1

5.6 Discussion

The outcome of the method revealed that improvement projects B obtained better rates than rehabilitation projects "A". In particular, alternative B1 does not affect ownership and improve accessibility. These conditions raise its *STSI* index. In this respect, the high *LTSI* index of "B3" is the result of a potential improvement in the goal "economy". This is consistent with the need in the area and the existence of a harbor nearby that complements the project's contribution.

In this way the case study illustrates how the method prioritizes the current and future conditions of the context. In this vein, Esteves and Vanclay (2009) consider cumulative impacts as a result of interventions. Also, Valdés-Vasquéz and Klotz (2011) and Owgu et al. (2006) regard the experience as a means to understand the relationships of future impacts. This method employs experts to estimate the social benefit of a long-term project. It also looks at the social status of the area to promote a more equitable distribution. In this respect, Gannon and Liu (1997) highlighted infrastructure as a generator of long-term development in the areas of greatest need.

The proposed method also promotes multisectoral participation in decision-making. Munda (2006) suggests that considering different viewpoints addresses the representation of all interests in a society. In addition, the inclusion of decision-makers promotes social learning. In this regard, Pellicer et al. (2016) show different profiles learning in decision-making about a sustainable infrastructure. In the long term, this implies improvements and innovations in urban and rural development for public use. An example of this can be seen in the building sector, where the assessment and certification of sustainability was developed much earlier (Ugwu et al 2006). A case in point is the "Industrialization of sustainable housing" (INVISO in Spanish) project in Spain, which contributes to social change through modular solutions and the commitment of stakeholders who make up the life cycle of the housing (Queipo et al. 2009).

According to the above, the method provides a specific and necessary treatment to the social dimension of sustainability. However, phase prioritization can integrate economic and environmental dimensions of sustainability. This idea points to a non-compensatory multidimensional approach for estimating integral sustainability solutions (Garcia-Segura and Yepes 2016). Meanwhile, the exploration of the items of projects, context and interaction on social sustainability must be strengthened. Uncertainty is also typical of a process when assessment by people is involved (Mel et al. 2015). In this regard, the way to treat the uncertainty of the input and assessment mechanism is to further improve the method.

The method has a national strategic purpose, i.e., taking into account the regions of a nation and the projects that are socially suitable. In this vein, the decision-making process acts early and is adaptable to the geographical context and type of infrastructure.

5.7 Conclusions

The article proposes a method to select suitable infrastructure projects from the social sustainability point of view. This method emphasizes the interactions of the infrastructure with the environment and the consideration of social improvement in the short and long term. The method is structured in five stages that seek to identify: the improvement criteria and goals; the elements of infrastructure and environment and their interaction for social improvement; the assessment according to the level of regional development; the indices of social improvement in the short and long term; and the socially efficient alternatives. The method was illustrated through six alternatives of road infrastructure improvement in three different zones.

The implementation of the method distinguishes the contribution to social sustainability of different infrastructures and location contexts. The method identifies the efficiency of a social contribution in terms of the returns of early social benefits and a distribution adapted to the long term. This proposal supports early decision-making regarding infrastructure projects and their location from the point of view of social contribution. It takes into consideration current needs, as well as future strategies for a specific zone. In this sense, it can be a tool to support public agencies in charge of infrastructure investments to promote development in different geographic scenarios.

The method can be applied prior to the implementation of a project to select the infrastructure alternatives most pertinent to a context by virtue of its social sustainability. The results can complement environmental or economic sustainability assessments. This method can be replicated in any geographic context, adapting the elements of the model to the local, regional characteristics and to the type of infrastructure.

In the future, this proposal will be broadened so that the interactions with other sustainability dimensions can be identified and measured. The intention is also to investigate the transfer relations, considering the significant elements of the infrastructures that affect social sustainability criteria.

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5.8 References

Ahmadvand, M., Karami, E., Taghi, M. (2011). "Modeling the determinants of the social impacts of agricultural development projects", Environ. Impact Assess., 31(1):8-16, doi: 10.1016/j.eiar.2010.06.004

Alarcón, B., Aguado, A., Manga, R., Josa, A. (2011). "A value function for assessing sustainability: Application to industrial building", Sustainability, 3: 35-50, doi: 10.3390/su3010035

Alshubbak, A., Pellicer, E., Catalá, J., Teixeira, J.C. (2015). "A model for identifying owner's needs in the building life cycle", J. Civ. Eng. Manag., 21(8): 1-15, doi: 10.3846/13923730.2015.1027257

Asomani-Boateng, R., Fricano, R. J., Aderkwa, F. (2015). "Assessing the socio-economic impacts of rural road improvements in Ghana: A case study of transport sector program support (II)", Case Stud. Transp. Policy, 3(4): 355-366, doi: 10.1016/j.cstp.2015.04.006

Colantonio, A. (2011). "Social sustainability: exploring the linkages between research, policy and practice", European Research on Sustainable Development, 1: 35-57, doi: 10.1007/978-3-642-19202-9_5

Cortés J.M., Pellicer E., Catalá J. (2012). "Integration of occupational risk prevention courses in engineering degree: Delphi study", J. Prof. Issues Eng. Educ. Pract., 138(1), 31-36, 10.1061/(ASCE)EI.1943-5541.0000076

Dasgupta, S., Tam, E.K.L. (2005). "Indicators and framework for assessing sustainable infrastructure", Can. J.Civil Eng., 32: 30–44, doi: 10.1139/l04-101

De la Cruz, M. P., Castro, A., del Caño, A., Goméz, D., Lara, M. Cartelle, J.J. (2015). "Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1: The MIVES – Monte Carlo Method", Soft Computing Applications for Renewable Energy and Energy Efficiency, 69-106, doi: 10.4018/978-1-4666-6631-3.ch004

DIGESTYC – Dirección General de Estadísticas y Censos (2014). Encuesta de hogares y propósitos múltiples – San Salvador, El Salvador. In http://www.digestyc.gob.sv/index.php/temas/des/ehpm/publicaciones-ehpm.html (April 2016)

Dominguez-Gomez, J.A. (2016)."Four conceptual issues to consider in integrating social and environmental factors in risk and impact assessments", Environ. Impact Assess., 56 (1): 113 –119, doi: 10.1016 / j.eiar.2015.09.009

Esteves, A.M., Vanclay, F. (2009). "Social development needs analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry", Environ. Impact Assess., 29(2):137-145, doi: 10.1016 / j.eiar.2008.08.004

Fernández-Sánchez, G., Rodríguez-López, F. (2010). "A methodology to identify sustainability indicators in construction project management—Application to infrastructure projects in Spain", Ecol. Indic., 10(6): 1193-1201, doi: 10.1016/j.ecolind.2010.04.009

Foth, N., Manaugh, K., El-Geneidy, A. M. (2013). "Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006", J. Transp. Geogr., 29(1): 1-10, doi: 10.1016/j.jtrangeo.2012.12.008

Fulford, R.S., Smith, L.M., Harwell, M., Dantin, D., Russell, M., Harve, J. (2015). "Human well-being differs by community type: Toward reference points in a human well-being indicator useful for decision support", Ecol. Indic., 56(1):194-204, doi: 10.1016 / j.ecolind.2015.04.003

Gannon, C. A., Liu, Z. (1997). Poverty and Transport (No. TWU-30), Washington, DC: World Bank.

García-Segura, T., Yepes, V., Alcala, J., Pérez-López, E. (2015) "Hybrid harmony search for sustainable design of post-tensioned concrete box-girder pedestrian bridges", Engineering Structure, 92: 112-122, doi:10.1016/j.engstruct.2015.03.015.

García-Segura, T., Yepes, V. (2016) "Multiobjective optimization of post-tensioned concrete box-girder road bridges considering cost, CO2 emissions, and safety", Engineering Structure, 125: 325-336, doi: 10.1016/j.engstruct.2016.07.012.

Gómez-López, D., del Caño, A., de la Cruz, M. (2013). "Estimación temprana del nivel de sostenibilidad de estructuras de hormigón en el marco de la instrucción española EHE-08", Inf. Constr., 65(529): 65-76, doi: 10.3989/ic.11.123

Hallowell M., Gambatese, J. (2010). "Application of the Delphi method to CEM research", J. Constr. Eng. Manage., 136(1):99-107, doi:10.1061/(ASCE)CO.1943-7862.0000137

Labuschagne, C., Brent, A.C., van Erck, R.P.G. (2005). "Assessing the sustainability performance of industries", J. Clean. Prod., 13(4): 373–385, doi: 10.1016/j.jclepro.2003.10.007

Le Moigne, J.L.(1990). La Modélisation des Systems Complexes, Paris: Dunod.

Luhmann, N. (1998). Sistemas Sociales: Lineamientos para una Teoría General, Bogotá: Anthropos Editorial.

Manga, R. (2005). Una Nueva Metodología para la Toma de Decisión en la Gestión de Contratación de Proyectos. PhD Thesis, Barcelona: Universitat Politècnica de Catalunya.

Max-Neef, M. (1995). "Economic growth and quality of life: a threshold hypothesis", Ecol. Econ., 15(2): 115-118, doi: 10.1016/0921-8009(95)00064-x

Mel, J., Gómez, D., de la Cruz, P. (2015). "Análisis de sensibilidad y estudio crítico del modelo de evaluación de la sostenibilidad de la Instrucción Española de Hormigón Estructural", Inf. Const., 67(539), doi: 10.3989/ic.14.126

Mostafa, M., El-Gohary, N. (2014). "Stakeholder-sensitive social welfare–oriented benefit analysis for sustainable infrastructure project development", J. Constr. Eng. Manage., 140(9): 04014038, doi: 10.1061/(ASCE)CO.1943-7862.0000788.

Munda, G.(2006). "Social multi-criteria evaluation for urban sustainability policies", Land Use Policy 23(1): 86–94, doi:10.1016/j.landusepol.2004.08.012

Noll, H.H. (2013). "Subjective Social Indicators: Benefits and limitations for policy making—An introduction to this special issue", Soc. Indic. Res, 114(1): 1–11, doi: 10.1007/s11205-013-0379-7

O'Faircheallaigh C. (2010). "Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making", Environ. Impact Assess., 30(1): 19–27, doi: 10.1016/j.eiar.2009.05.001

Pavlovskaia, E. (2013). "Using sustainability criteria in law", International Journal of Environmental Protection and Policy, 1(4): 76–78, doi: 10.11648/j.ijepp.20150305.11

Pellicer, E., Sierra, L.A., Yepes, V. (2016). "Appraisal of infrastructure sustainability by graduate students using an active-learning method", J. Clean. Prod., 113(1): 884-896, doi:10.1016/j.jclepro.2015.11.010

Porter, R., Donnell, E., Mason, J. (2012). "Geometric design, speed, and safety", Transportation Research Record: Journal of the Transportation Research Board, 2309, 39-47, doi: 10.3141/2309-05

Queipo, J., Navarro, J.M., Izquierdo, M., Aguila, A., Guinea, D., Villamor, M., Vega.S., Neila, J. (2009). "Proyecto de Investigación INVISO: Industrialización de Viviendas Sostenibles", Informes de La Construcción 61(513): 73–86, doi:10.3989/ic.09.001.

Saaty, T.L., (1987). "The analytic hierarchy process – What it is and how it is used", Math. Model, 9(3–5), 161–176. doi:10.1016/0270-0255(87)90473-8

Sierra, L., Pellicer, E., Yepes, V. (2016). "Social sustainability in the life cycle of Chilean public infrastructure", J. Constr. Eng. Manage., 142(5), 05015020, doi: 10.1061/(ASCE)CO.1943-7862.0001099

Torres-Machi, C., Chamorro, A., Pellicer, E., Yepes, V., Videla, C. (2015). "Sustainable pavement management: Integrating economic, technical and environmental aspects in decision making", Transportation Research Record: Journal of the Transportation Research Board, 2523:56-63, doi: 10.3141/2523-07

Torres-Machí, C., Chamorro, A., Yepes, V., Pellicer, E. (2014). "Current models and practices of economic and environmental evaluation for sustainable network-level pavement management", Revista de la Construcción, 13(2): 49-56, doi: 10.4067/S0718-915X2014000200006

Ugwu, O.O., M.M. Kumaraswamy, A. Wong, S.T. Ng. (2006a). "Sustainability Appraisal in Infrastructure Projects (SUSAIP) Part 1: Development of indicators and computational methods", Automation in Construction 15 (2): 239–251. doi:10.1016/j.autcon.2005.05.006.

Ugwu, O.O., M.M. Kumaraswamy, A. Wong, S.T. Ng. (2006b). "Sustainability Appraisal in Infrastructure Projects (SUSAIP) Part 2: A case study in bridge design", Automation in Construction 15 (2): 229–238. doi:10.1016/j.autcon.2005.05.005.

UN (2015). Transforming our World: The 2030 Agenda for Sustainable Development, New York: United Nations Organization.

Valdés-Vásquez, R., Klotz L.E. (2013). "Social sustainability considerations during planning and design: framework of processes for construction projects", J. Constr. Eng. Manage., 139(1): 80-89, doi: 10.1061/(ASCE)CO.1943-7862.0000566

Valentin, V., Bogus, S. (2015). "Assessing the link between public opinion and social sustainability in building and infrastructures projects", J. Green Build., 10(3): 177-190. doi: 10.3992/jgb.10.3.177

Van de Walle, D. (2009). "Impact evaluation of rural road projects", Journal of Development Effectiveness, 1: 15-36, doi: 10.1080/19439340902727701

Xing, K., Ness, D., Lin, F. (2013). "A service innovation model for synergistic community transformation: integrated application of systems theory and product-service systems", J. Clean. Prod., 43(1): 93-102, doi: 10.1016/j.jclepro.2012.11.052

Yepes, V., Martí, J.V., García-Segura, T. (2015a). "Cost and CO2 emission optimization of precast-prestressed concrete U-beam road bridges by a hybrid glowworm swarm algorithm", Automat. Constr., 49: 123-134, doi: 10.1016/j.autcon.2014.10.013

Yepes, V., Garcia-Segura, T., Moreno-Jimenez, J.M. (2015b). "A cognitive approach for the multi-objective optimization of RC structural problems", Arch. Civil Mech. Eng., 15(4): 1024-1036, doi:10.1016/j.acme.2015.05.001

CAPÍTULO 6

ASSESSING THE SOCIAL SUSTAINABILITY CONTRIBUTION OF AN INFRASTRUCTURE PROJECT UNDER CONDITIONS OF UNCERTAINTY

Publicación

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Assessing the viability of a public infrastructure includes economic, technical and environmental aspects; however, on many occasions, the social aspects are not always adequately considered. This article proposes a procedure to estimate the social sustainability of infrastructure projects under conditions of uncertainty, based on a multicriteria deterministic method. The variability of the method inputs is contributed by the decision-makers. Uncertain inputs are treated through uniform and beta PERT distributions. The Monte Carlo method is used to propagate uncertainty in the method. A case study of a road infrastructure improvement in El Salvador is used to illustrate this treatment. The main results determine the variability of the short and long-term social improvement indices by infrastructure and the probability of the position in the prioritization of the alternatives. The proposed mechanism improves the reliability of the decision making early in infrastructure projects, taking their social contribution into account. The results can complement environmental and economic sustainability assessments.

KEYWORDS: Infrastructure; Multicriteria Decision-Making; Uncertainty; Social Sustainability

6.1 Introduction

The social dimension is a pillar of sustainable development together with the economic and environmental aspects. Yet the treatment of the social dimension is less evolved (Valdés-Vásquez and Klotz 2013, Dominguez-Gomez 2016). Several methods have focused on identifying the environmental and economic impacts of infrastructure projects, without explicitly considering their social approach (Ahmadwand and Karami 2009, Penades-Pla et al. 2016, Karami et al. 2017). Social assessment is an overarching framework that embodies the evaluation of all impacts on humans and on the ways in which people interact with their socio-cultural, economic and biophysical surroundings (Vanclay 2002, 2003). Specifically, Vanclay (2002) identifies seven categories social impacts that could be considered in an assessment: health and social well-being; liveability; economic and material well-being; cultural; family and community; institutional, political and equity; and gender relations.

In the last decade some initiatives have been proposed that take into account the assessment of the social contribution. In the MIVES (“Integrated Value Method for Sustainability Assessments”), a function proportional to the satisfaction of the beneficiaries deals with the social aspects (Gómez-López et al. 2013). In the SUSAIP (“Sustainability Appraisal in Infrastructure Projects”), the social aspects are treated homogenously in different regional contexts and the stakeholders are considered less in the decision-making (Ugwu et al. 2006). In the TSI (“Technical Sustainability Index”), the immediate impacts are not considered and aspects like health, wealth and politics are treated within a set of environmental indicators (Dasgupta and Tam 2005). In addition, some sustainability rating systems such as ENVISION, CEEQUAL or IS have included social aspects in their evaluations. However, these are more appropriate for developed countries, and they give less importance to the social aspects (Diaz-Sarachaga et al. 2016).

In most of these proposals, the social aspects have been interwoven with environmental assessment methods to measure sustainability. Moreover, the little familiarity and the difficulty in dealing with the social aspects mean they are taken less into consideration (Pope et al. 2004, Pellicer et al. 2016). The heterogeneity of regional development or the impossibility of standardizing an impact in different contexts are relativized aspects in the usual methods (Esteves and Vanclay 2009). Indeed, the interaction between infrastructure type and location context affects its social contribution. Normally, the contribution to social improvement in the short and long term justifies the decision-making of a public project. Yet the two approaches are not necessarily given simultaneously (Gannon and Liu 1997). In a short-term approach the early return of the social benefits of an infrastructure is only possible in a consolidated context. By contrast, a long-term approach concentrates on the contexts with the greatest social weaknesses and greater potential contribution to improvement (van de Walle, 2009).

A multicriteria deterministic method was recently proposed to assess social sustainability in infrastructure projects (Sierra et al. 2017). This method is structured in three processes that determine (a) a short-term social improvement index; (b) a long-term social improvement index; and (c) a multi-objective prioritization of the public infrastructure investment alternatives. Short-term social improvement identifies an infrastructure's contribution in interaction with the present context. In this study, the short term considers the social effects of infrastructure planning, design and construction up to approximately three years from the start of the operation. On the other hand, in the long term, the distribution impact of the benefit considers the zones with social need. The long term considers the social effects on the type of tenure and preservation of the infrastructure. Once the social improvement for the different alternatives has been identified, these can then be prioritized according to their contribution to social sustainability.

However, the social contribution requires an assessment of qualitative and quantitative aspects, the impact of which on well-being and social development is not predetermined (Valdés-Vásquez and Klotz 2013, Sierra et al. 2016, 2017). In this sense, the specific characteristics of a project have a high degree of uncertainty in the viability phase (Pan 2009, Cardenas and Halman 2016). In the design and construction phases of an infrastructure, contingencies arise, the determinist assessment of which is not reliable in the early stages (Gervásio and Da Silva 2012). Specifically, the local or regional sources of information make it possible to establish the variability of certain social aspects. The social databases related to infrastructures and particularly qualitative aspects, however, are still nascent (Labuschagne and Brent 2006, Sahely et al. 2005). Therefore, the experience of local experts can be a source of information that can be modeled to deal with the uncertainty (de la Cruz et al. 2015).

Therefore, in line with the previous points, the social aspects require adequate treatment in the evaluation of sustainability. In this vein, Sierra et al. (2017) proposed a deterministic evaluation method of the social sustainability of infrastructures in the short and long term. However, assessing the social aspects requires a procedure to deal with their uncertainty (Gervásio and Da Silva 2012, Cárdenas and Halman 2016). This is the starting point of the present study. Given the above, this paper proposes an additional treatment to estimate the contribution to the social sustainability of infrastructure projects under conditions of uncertainty.

The article debates, first of all, the techniques to treat uncertainty addressed in this work. Next the method for assessing the social sustainability of infrastructures as proposed by Sierra et al. (2017) is presented. Then the proposal to deal with the uncertain variables within the evaluation method is described step-by-step. The proposed treatment is illustrated through a case study. Finally, the contributions, limitations and future lines of research are presented in the conclusions.

6.2 Dealing with uncertainty

In the viability phase of the service life of a public project, different infrastructure alternatives are assessed. In this phase the social aspects are important due to their vagueness and uncertainty of their effects on society (Gervásio and Da Silva 2012). The uncertainty can be internal or external. The first takes into account the variability of the method to be used and the input data. External uncertainty refers to the lack of knowledge about a choice (Gervásio and Da Silva 2012).

Multicriteria decision-making requires consideration of the weights of each criterion and the assessment of these criteria for each alternative (Zamarron-Mieza et al. 2017). In each of these processes there are uncertain variables that can be defined by ranges of behavior expected according to a probability (Jato-Espino et al. 2014). When the amount of data available is not sufficient for a classic probabilistic adjustment, a discrete uniform distribution can be used (Gervásio and Da Silva 2012). In other cases, knowledge and experience can permit the maximum and minimum parameters and the mode that describes a triangular distribution to be known (de la Cruz et al. 2015). Alternatively, the parameters of a triangular distribution can be assimilated to a beta PERT distribution. This function allows a greater ease of use and a more real continuity in the adjustment of the turning points (Jato-Espino et al. 2014).

In addition, a method widely used to give functionality to the simultaneous propagation of uncertainty through decision-making processes is the Monte Carlo method (Gervásio and Da Silva 2012, de la Cruz et al. 2015). The Monte Carlo method can be used as a risk management tool that aims to elicit the probability of contributing a series of achievements for a certain alternative (Jato-Espino et al. 2014). Thus, from a set of random variables, with specific and iterative distributions, it is possible to control the uncertainty of the set of decision-making alternatives

6.3 Estimation method of the social sustainability of infrastructures

This method for estimating sustainability includes an approach for short and long-term social improvement and prioritization. The second and third column of Figure 6.1 illustrate the processes that intervene in the evaluation method. The processes called "A" and "B" intervene in short and long-term social improvement, respectively. The process "C" weighs the results of "A" and "B", and determines the prioritized solution of socially sustainable alternatives. In line with Sierra et al. (2017), the stages that determine the method are presented as follows.

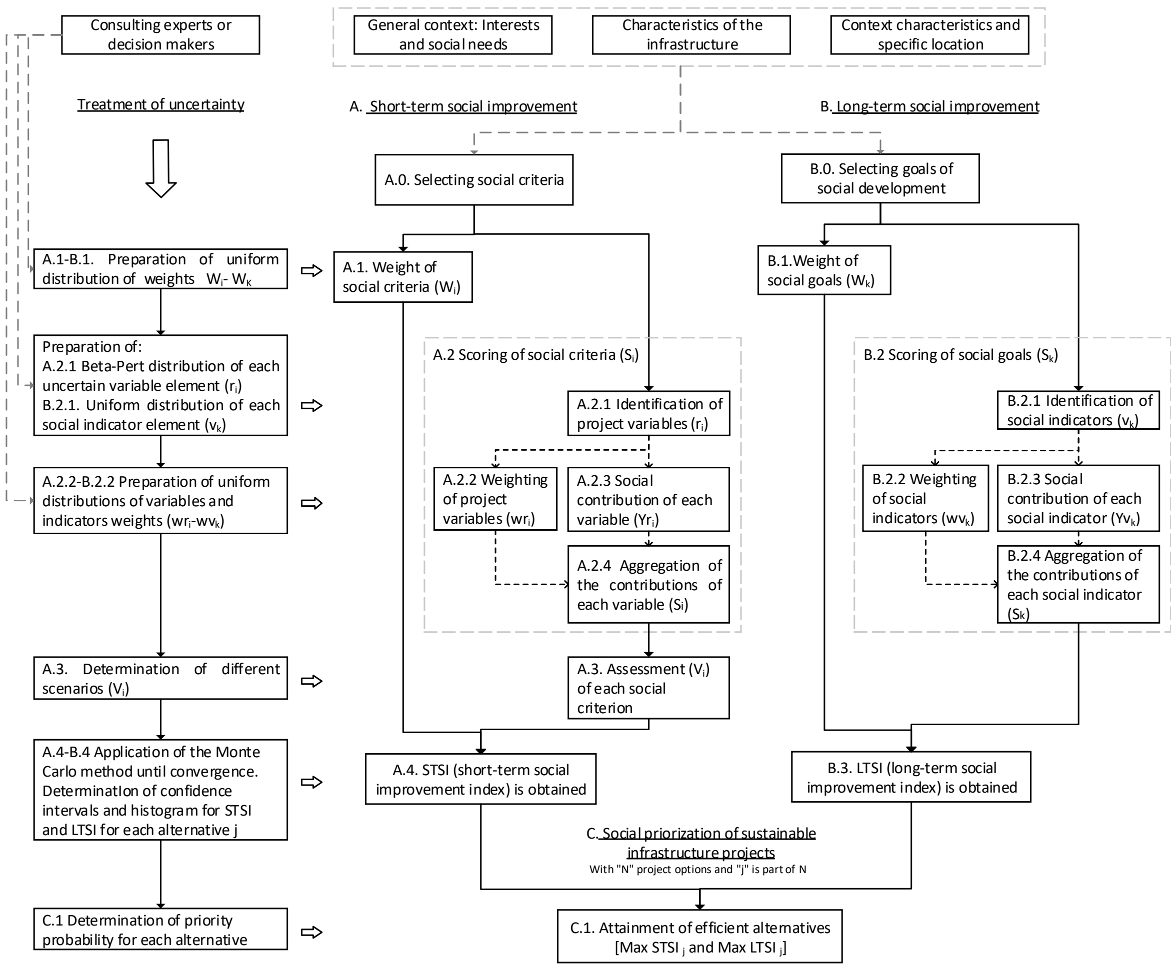


Figure 6.1: Method for estimating the social contribution considering the uncertainty (adapted from Sierra et al. 2017)

Stages A.0 and B.0: A set of multidisciplinary decision-makers selects the criteria and social goals according to the set of infrastructures and the context. To approximate a consensus the Delphi method is applied. The profile of the decision-makers is adjusted to the suggestions by Hallowell and Gambatese (2010) to guarantee the rigor of the method.

Stages A.1 and B.2: The set of decision-makers determines the weights of the criteria and social improvement objectives. The decision-makers compare the importance between pairs of criteria and among social goals through an Analytic Hierarchy Process (AHP) (Saaty 1987).

Stages A.2.1 and B.2.1: For each criterion *i* and objective *k* the project variables r_i and indicators of the zone v_k are identified, respectively. Both the variables and the indicators must potentially be influenced in the lifecycle of the infrastructure. In addition, the effect of each variable r_i is determined by conditioning factors of the zone c_{ir} that are identified. The selection of the variables r_i, the conditioning factors c_{ir} and the indicators v_k are the result of a field study and the consensus of the decision-makers.

Stages A.2.2 and B.2.2: The group of decision-makers determines the weights of the variables of the project w_{ri} and social indicators w_{kv}. The decision-makers compare dually the importance between criteria and indicators by applying the AHP method.

Stages A.2.3 and B.2.3: The project variable r_i and social indicator v_k determine the social contribution Y_{ir}^{st} and Y_{kv}^{lt}, respectively. For each project variable r_i and its conditioning factors from the zone c_{ir}, a transference function is formulated. The transference functions are interpolation functions. The functions transform the qualitative and quantitative inputs to a value Y_{ir}^{st} of 0 (no contribution) to 100 (maximum contribution). In turn, for each indicator v_k the degree of future benefit of the project Z_{kv} is determined, as well as the degree of current weakness of the zone C_{kv}. The values of Z_{kv} and C_{kv} are agreed upon by the decision-makers on a scale from 1 (minimum benefit/weakness) to 5 (maximum benefit/weakness). Thus, the value of Y_{kv}^{lt} is the product between Z_{kv} and C_{kv} for each indicator v_k.

Stages A.2.4 and B.2.4: The social contributions Y_{ir}^{st} and Y_{kv}^{lt} of a project are added to a score by criterion and social goal. The simple additive weight of the contributions Y_{ir}^{st} and Y_{kv}^{lt} determine a score by criterion S_i^{st} and social goal S_k^{lt}, respectively. The values of S_i^{st} are contained in the intervals of [0-100]. In turn, S_k^{lt} is contained in the interval [1-25].

Stage A.3: A function revalues the score of each short-term social criterion (S_i^{st}) according to what the context demands. Alarcón et al. (2011) and Gómez-López et al. (2013) developed a generic value function to estimate the satisfaction of attributes. This function can be used for different levels of social requirement. In effect, a concave shape represents a low demand, i.e., high satisfaction can be reached with few improvements. A convex shape represents a high demand, i.e., large improvements are required to reach a high level of satisfaction. A linear shape represents a moderate demand, i.e., satisfaction is proportional to the improvement. Equation 6.1 represents the value function indicated, with V_i being the value of each criterion *i*. The parameters m_i, n_i and A_i define the convex ($A_i \geq 2$, $m_i \leq 0.1$, $n_i \geq 45$), concave ($A_i \leq 0.75$, $m_i \geq 0.9$, $n_i \approx 100$), or linear ($A_i \approx 1$, $m_i \approx 0$, $n_i \approx 15$)

shape of the criterion. K_i limits the result interval of the function from 0 (S_i^{st} =0) to 1 (S_i^{st} =100) (Manga 2005)

Equation 6.1

$$V_i = K_i \cdot \left[1 - e^{-m_i\left(\frac{S_i^{st}}{n_i}\right)^{A_i}}\right]$$

Stages A.4, B.3: For each project, the values of V_i and S_k^{lt} are added to a short-term social improvement index (*STSI*) and long-term social improvement index (*LTSI*), respectively. The *STSI* and *LTSI* are the result of simple additive weight of V_i and S_k^{lt}, respectively. The *STSI* varies on a scale from 0 to 1, and reflects the integrated contribution of an infrastructure in the short term. The *LTSI* varies on a scale from 1 to 25 and reflects the potential strengthening of the social weaknesses in the long term.

Stage C.1: The optimization techniques have proven to be an efficient system to discriminate sustainable alternatives (Torres-Machi et al. 2017). In that case, the prioritization of the infrastructure projects derives from the multi-objective optimization that maximizes the *STSI* and *LTSI*. A compromise programming method that determines the smallest Chebyshev distance d_∞ to an ideal point establishes balanced solutions (Yepes et al. 2015). Equation 6.2 represents the formula of the compromise programming for this method. $STSI_j$, $LTSI_j$ represent the values of the indices of each j^{th} alternative. λ_1, λ_2 are the weighting of the improvement indices; $STSI^*$, $LTSI^*$ represent an ideal point and $STSI_*$, $LTSI_*$ the anti-ideal point of the short and long-term social improvement, respectively.

Equation 6.2

$$Min \;\; d_\infty \;; \qquad d_{\infty j} = Max \left[\lambda_1 \cdot \left(\frac{STSI^* - STSI_j}{STSI^* - STSI_*}\right);\ \lambda_2 \cdot \left(\frac{LTSI^* - LTSI_j}{LTSI^* - LTSI_*}\right)\right]$$

6.4 Treatment of uncertainty proposed for the assessment of social sustainability of infrastructures

Next, the treatment of the uncertainty incorporated into the method for estimating the social sustainability of infrastructure projects is detailed. This procedure makes it possible to control the risk in prioritizing a set of infrastructure projects. The distributions of the social improvement indices determine the probability of the order of priority of each project. The parameters dealt with according to this mechanism are: (1) all the weights involved in the method (W_i, w_{ir}, W_k, w_{kv}); (2) the variables of the project (r_i) and influential conditioning factors (c_{ir}) categorized as uncertain by the experts and (3) degree of potential benefit from the infrastructure (Z_{kv}) and the degree of zonal need (C_{kv}) for each long-term indicator. The first column in Figure 6.1shows the flow of the procedure to control the internal uncertainty in processes A, B and C of the method. The following paragraphs describe the treatment of the uncertainty in the method.

6.4.1 Distribution of the weights of the method (A.1, A.2.2, B.1, B.2.2)

The weights of the method refer to the importance that the decision-makers give to the short-term criteria (W_i), the project variables (w_{ir}), the social goals (W_k) and social indicators (w_{kv}). For these weights, a uniform probability distribution is derived from the variation of the decision-makers' results. The importance of each criterion and social goal is related to the rest of their set and must add up to 100%. For this reason, a correlation analysis can be incorporated into the distribution of the set. In this case the distribution of the set depends on the weight of greatest variability. Later, the resulting weights are standardized (Gervásio and Da Silva 2012). This way, the uniform accumulated distributions of each weight set are determined for a limited number of experts. In this case, the distribution represents the probable variation space of the weight to use for different random iterations

6.4.2 Preparation of the uncertain variables (ri) and indicators (vk) (A.2.1 – B.2.1)

The input data for the evaluation of each criterion and social goal are conditional upon the information from each project and its location context. In dealing with the uncertainty, the decision-makers intervene in three aspects: (1) they identify the state of uncertainty of each variable (r_i) or conditioning factor of the zone (c_{ir}); (2) they quantify the maximum, minimum and most probable value of each uncertain r_i or c_{ir}; and (3) they value the improvement potential of each indicator through Z_{kv} and C_{kv} per project.

From the uncertain values of r_i or c_{ir}, the parameters α and β can be determined, which in turn determine the beta PERT distribution of each uncertain element. Equation 6.3 and Equation 6.4 represent the parameters α and β of a beta PERT distribution for the maximum (X_{max}), minimum (X_{min}) and most probable (X_{mod}) values of each uncertain r_i or c_{ir} by project (Jato-Espino et al. 2014).

Equation 6.3

$$\alpha = \frac{2 \cdot (X_{max} + 4 \cdot X_{mod} - 5 \cdot X_{min})}{3 \cdot (X_{max} - X_{min})} \cdot \left[1 + 4 \cdot \frac{(X_{mod} - X_{min}) \cdot (X_{max} - X_{mod})}{(X_{max} - X_{min})^2}\right]$$

Equation 6.4

$$\beta = \frac{2 \cdot (5 \cdot X_{max} - 4 \cdot X_{mod} - X_{min})}{3 \cdot (X_{max} - X_{min})} \cdot \left[1 + 4 \cdot \frac{(X_{mod} - X_{min}) \cdot (X_{max} - X_{mod})}{(X_{max} - X_{min})^2}\right]$$

On the other hand, an accumulated uniform distribution may be associated with the discrete values given by the set of experts in each indicator, where the evolution of each indicator depends on the improvement potential because of project Z_{kv} and the current weakness of the indicator in the zone C_{kv}.

6.4.3 Assessment scenarios of the short-term social criteria (A.3)

The utility function of Equation 6.1 is used to re-assess the satisfaction level of the short-term criteria. Strategically, those criteria that one wishes to promote tend to use a low-demand curve (concave curve). In case of aspiring to criteria with a higher demand or with no clear trend, the convex or linear curves are more appropriate, respectively. Operationally, where there are project alternatives with similar conditions, high-demand curves facilitate the differentiation. Figure 6.2 illustrates three scenarios of smoothed V_i functions of high, moderate and low demand. These scenarios are used to estimate the sensitivity of the final decision-making method.

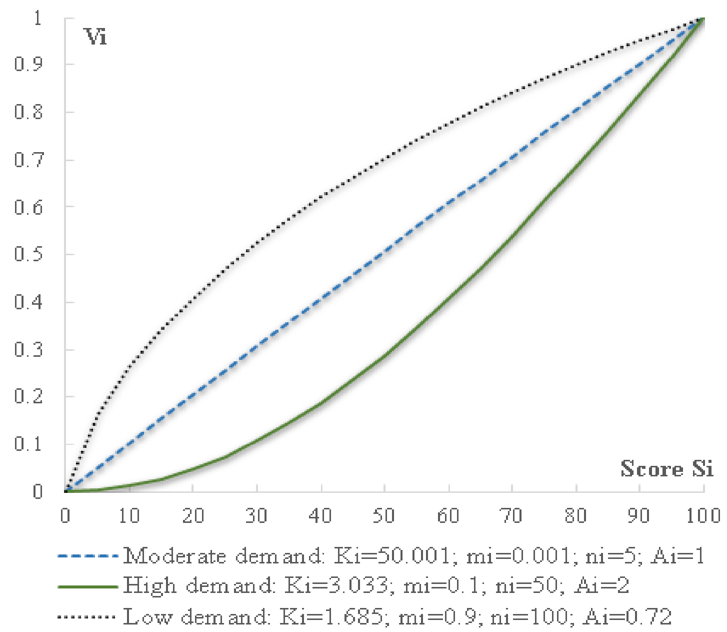


Figure 6.2: Curve of Vi value for high, moderate and low social requirement

6.4.4 Propagation of uncertainty in the method to obtain the social improvement indices (A.4, B.4)

STSI and *LTSI* are obtained from the values V_i and S_k^{lt} and from the weights of the criteria *Wi* and from the social goals W_k, respectively. The accumulated probability of the weights, variables and indicators must be determined. Then, the Monte Carlo method propagates the uncertainty in the processes of the method. This method generates pseudo-random probabilities according to the specific probability distribution of each uncertain element. This is to say, in each uncertain element a random value (0 to 1) is generated and a specific value is determined through the inverse of its accumulated probability. Thus, a sample of iterations of *STSI* and *LTSI* is generated with respect to the uncertainty associated with a project. After several tests for this model, it has been identified that with 5,000 iterations a significant convergence is already reached and with a low computing cost. The confidence intervals and histograms for each index are results obtained from this procedure.

6.4.5 Determination of probability of each prioritized alternative (C.1)

On this point, the infrastructure project alternatives *j* selected derive from the simultaneous evaluation of *STSI* and *LTSI*. The method optimizes projects *j* according to the smaller distance d_∞ through compromise programming (Equation 6.2). A set of *STSI* and *LTSI* values represents an infrastructure project. In ascending order from d_∞, the infrastructure projects are prioritized for each iteration. The projects selected in each position of the order of priority correspond to the mode of the iteration sample. On this point, the probability of each project selected is obtained in a position of the order of priority. High probabilities confer greater reliability on the decision-making of a project with a better social contribution. This procedure is repeated for each scene (high, moderate and low social requirement) established in point 6.4.3 of this article

6.5 Case study

A case study is presented to illustrate the method and its practical application. The case study is based on six alternatives that arise with two options to improve interurban roads applied in three regions of El Salvador. The two improvement options are technically applicable to all the location sectors. In this context, the public administration must prioritize the infrastructure alternatives during the viability phase of the life cycle. To do so, the social contribution of each alternative is taken into account. The following sub-sections present the decision-making structure, the background and the treatment of uncertainty for the case study. Other background of the application of the method in the case study can be consulted in Sierra et al. (2017).

6.5.1 Structure for decision-making

The selection of criteria (i), project variables (r_i), conditioning factors (c_{ri}), social goals (k) and indicators (v_k) forms the decision-making structure. This structure takes into account the incidence of the road infrastructure in the context of El Salvador. A field study as well as a review of projects, norms and the regional database were considered in the definition of the structure. The validation of the structure derives from the consensus of 29 multidisciplinary decision-makers. The background of the decision-makers and the exploratory study are set out in Sierra et al. (2017). The first five columns of Table 6.1show the short-term decision-making structure. Table 6.1 also presents the transference functions according to stage A.2.3 of the method. In the long term, three social goals are selected: socioeconomic (local level) ($k=1$), education ($k=2$) and health care ($k=3$). From these the per-capita income indicators (v_1), years of schooling (v_{2_1}), percentage of the population with secondary education (v_{2_2}) and life expectancy (v_3) are derived according to each social goal.

Table 6.1: Short-term decision-making structure of the case of study

i	Criterion	*R*	Variable	Interaction items		Nature[1]	Transference function (x10²)
1	Employment	1	Hiring	X_{11}	N° contracts	S	$Y_{11}^{cp} \cong \left[\frac{(X_{11}-c_{112})}{(c_{111}-c_{112})}\right]\cdot\left[\frac{c_{113}-c_{115}}{c_{114}-c_{115}}\right]$
				c_{111}	Max. hiring	D	
				c_{112}	Min. hiring	D	
				c_{113}	Local unemployment rate	S	
				c_{114}	Max regional unemployment rate	D	
				c_{115}	Min regional unemployment rate	D	
		2	Deadlines	X_{12}	Hiring months	S	$Y_{12}^{cp} \cong \left[\frac{(X_{12}-c_{122})}{(c_{121}-c_{122})}\right]\cdot\left[\frac{c_{123}-c_{125}}{c_{124}-c_{125}}\right]$
				c_{121}	Historic max. hiring period	D	
				c_{122}	Historic min. hiring period	D	
				c_{123}	Local unemployment rate	S	
				c_{124}	Max regional unemployment rate	D	
				c_{125}	Min regional unemployment rate	D	
2	Property and habitability	1	Rights of way	X_{21_1}	N° properties affected	D	$Y_{21}^{cp} \cong \left[1-\frac{(X_{21\_1}\cdot X_{21\_2})}{(c_{211}\cdot c_{212})}\right]$
				X_{21_2}	Right of way assessment	S	
				c_{211}	Max historic right of way assessment	D	
				c_{212}	Max historic N° properties affected (or by consensus)	D	
		2	Resettlements	X_{22_1}	N° vulnerable families	D	$Y_{22}^{cp} \cong \left[1-\frac{(X_{22\_1}\cdot X_{22\_3}+X_{22\_2}\cdot X_{22\_4})}{5\cdot c_{221}}\right]$
				X_{22_2}	N° non-vulnerable families	D	
				X_{22_3}	Degree of mitigation of vulnerable families[3]	D	
				X_{22_4}	Degree of mitigation of non-vulnerable families[3]	D	
				c_{221}	Max historic N° resettled families (or by consensus)	D	
		3 to 8	Accessibility to services	X_{2r_1}	% travel time reduction limited to 75%	S	If $X_{2r\_2} \leq (c_{2r3}-c_{2r2})$ & $(c_{2r3}>c_{2r2})$ then $Y_{2r}^{cp} \cong \left[\frac{X_{2r\_1}\cdot c_{2r1}}{75\cdot 3}\right]\cdot\left[1-\frac{X_{2r\_2}}{(c_{2r3}-c_{2r2})}\right]$;
				X_{2r_2}	Absolute increase demand service year 2	S	
				c_{2r1}	Frequency existing public transport[2]	D	In other cases $Y_{2r}^{cp} \cong 0$
				c_{2r2}	Current demand for service	D	
				c_{2r3}	Capacity of the service	D	Con: r=3 Primary ed.; r=4 Secondary ed.; r=5 Health unit; r=6 Hospital; r=7 Commercial area; r=8 Police and emergency.
3	Safety of the Environment	1	Safety during construction	X_{31_1}	Months construction of the project, fewer than 24	S	$Y_{31}^{cp} \cong \left[1-\frac{X_{31\_1}\cdot X_{31\_2}\cdot(X_{31\_3}+X_{31\_4}+\sum_{q=1}^{5}c_{31q})}{24\cdot 3\cdot 7}\right]$
				X_{31_2}	Mean annual daily traffic interval[4]	D	
				X_{31_3}	The work requires direct access to the main road[5]	D	
				X_{31_4}	Use of machines with contiguous traffic[5]	D	
				c_{31q}	Preexistence of social problems in the context; q∊[1 – 5][5, 6]	D	
		2	Safety in operati	X_{32_p}	Verification of applicable design conditions; p∊[1 – 10][7, 8]	D	$Y_{32}^{cp} \cong \left[\frac{\sum_{p=1}^{10}X_{32\_p}}{m}\right]\cdot\left[1-\sum_{z=1}^{10}c_{32z}\right]$

				c_{32z}	Danger of the context; $z\epsilon[1-10]$[5, 9]	D	With "m" applicable design conditions.
4	Participation	1	Means of participation	X_{41_1}	Existence of information medium[5]	D	$Y_{41}^{cp} \cong \left[\frac{(X_{41\_1}+\frac{X_{41\_1}}{2})}{2}\right]\cdot\frac{X_{41\_3}}{c_{411}}$
				X_{41_2}	Type of feedback[10]	D	
				X_{41_3}	Participation rate invitations regarding the project.	S	
				c_{411}	Local participation rate in democratic votes	D	
		2	Point of participation	X_{42_1}	Point of participation[11]	D	$Y_{42}^{cp} \cong \left[\frac{(X_{42\_1}\cdot X_{41\_2})}{9}\right]\cdot\frac{X_{42\_3}}{c_{421}}$
				X_{42_2}	Type of invitation[12]	D	
				X_{42_3}	Participation rate invitations regarding the project.	S	
				c_{421}	Local participation rate in democratic votes	D	

(1)	S Stochastic; D Deterministic	(2)	(3) Frequent; (2) Little; (1) Null.
(3)	(5) Vulnerable family: there are no mitigation measures for occupants or economic compensation is allocated to the owners according to the state of the property. (4) Non-vulnerable family: economic compensation is allocated according to the current state of the property. (3) Vulnerable and non-vulnerable family: aid in relocation and allocation of a new house with conditions of equivalent habitability. (2) Non-vulnerable family: aid in relocation and allocation of a new house with significantly better conditions of habitability on the property. (1) Vulnerable family: aid in relocation and allocation of a new house with significantly better conditions of habitability on the property. (0) Not applicable.		
(4)	(3) >1000; (2) [500-1000]; (1) [100-500]; (0) <100.	(5)	(1) Complies; (0) Does not comply.
(6)	q=1 alcoholism; q=2 delinquency; q=3 violence; q=4 drug addiction; q=5 prostitution	(7)	(1) Complies; (0) Does not comply; (NA) Not applicable.
(8)	p=1 Road equipment; p=2 Geometry of the road; p=3 Intersections; p=4 Pavements; p=5 Drainages; p=6 Margins; p=7 Vulnerable user; p=8 Improvement in flooding conditions of the road; p=9 Improvement in risks of erosion/crumbling; p=10 Improves points with high risk of accident.		
(9)	z=1 Zones with flooding cycles; z=2 Landslide zone; z=3 Social conflict zone; z=4 Forest fire zone; z=5 Heavy load industrial zone; z=6 Animal zone; z=7 Cliff zone; z=8 Extreme weather zone; z=9 School or meeting zone; z=10 Forest zone.		
(10)	(0) No evidence; (1) Closed Feedback; (2) Open feedback.	(11)	(0) No evidence; (1) During construction; (2) During the design; (3) During the conceptualization.
(12)	(0) No evidence; (1) Random limited sample; (2) To representatives; (2) Open.		

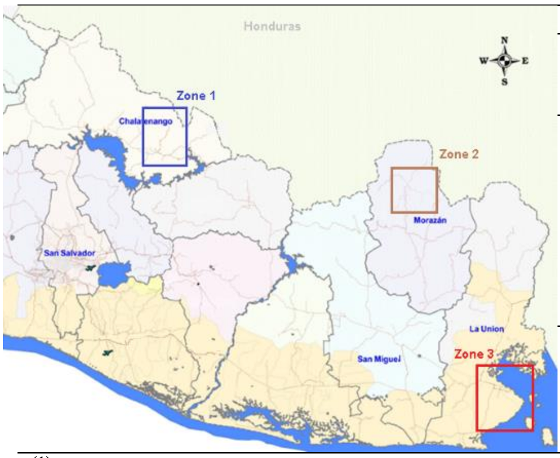
6.5.2 Description of the alternatives of infrastructure projects

The improvement of road network infrastructures in El Salvador is currently at a crucial stage of its plan to revitalize local economies (UNDP 2010). To illustrate this study, two intervention options were selected. Option A is a partial improvement with works of transverse, longitudinal drainage and permanent maintenance of the stone platforms or patching the existing pavement; in this case, the operating speed does not exceed 40 km/h. Option B involves an overall improvement and incorporates road widening works to a standard of 7 m and paving in hydraulic concrete; in this case, the operating speed does not exceed 90 km/h. The improvement options can be applied on the base lines of each zone represented in Table 6.2 and characterized in the following:

1. Zone 1: There is currently an inter-city road paved in concrete with a high level of deterioration. The road connects a highly developed city and a local town with a high population and which is seasonally isolated (winter). The improvement benefits 1,500 inhabitants. The mean annual daily traffic on the road is 800 vehicles. The length to improve is 7 km. The local economy depends on the agro-fishery industry.

2. Zone 2: The rural road connects five local areas and involves a benefit for 2,680 inhabitants. The road varies in width, with a gravel platform, difficult accessibility and a high accident rate in winter. The mean annual daily traffic is 500 vehicles and the length to improve is 15 km. The local economy is based on the tourist potential in the mountain zone. The zone presents unexploited historico-cultural conditions.
3. Zone 3: It is an interurban road that connects two local areas and a city of average development. In the medium term already existing harbor facilities will begin operating. The road has loose pebbles and a deteriorated drainage system. The improvement involves a benefit for 600 inhabitants. The mean annual daily traffic is 300 vehicles and the length to improve is 7 km. The zone is located in the coastal sector with a low tourist development. The local economy is based on agriculture and fishing.

Table 6.2: Location background of assessment contexts



k	Indicators[1]	Zone 1	Zone 2	Zone 3
1	Per capita income (v=1)	450US	300US	285US
	Annual trend [2]	+1.25%	+4%	+0.7%
	Position in the country[3]	7	4	3
2	Average years of schooling (v=1)	8.3	6.4	5.1
	Annual trend[2]	+3.25%	+2%	+0.5%
	Position of the country[3]	8	6	2
	% population with secondary education (v=2)	75%	55%	35%
	Annual trend[2]	+1.83%	+0,8%	+0.2%
	Position in the country[3]	6	5	2
3	Years of life expectancy (v=1)	73	74	68
	Annual trend[2]	+0.25%	+0.4%	+0.1%
	Position in the country [3]	7	8	3

(1) Based on DIGESTYC (2014) Household Survey and purposes multiples- El Salvador (EHPM in Spanish);
(2) To 10 years;
(3) 1 (worst) to 10 (best)

Table 6.3 presents the background for the evaluation of each short-term alternative. The background derives from a review of the project documentation, field studies, a review of comparable infrastructure projects and interviews with experts. The value of the uncertain elements comes from the consultation with the expert decision-makers with respect to each alternative.

Table 6.3: Synthesis of the background of the alternatives for short-term evaluation with uncertain criteria

Inputs *i*, *r* and c_{ir}	**Project versus zone**					
	A_1	**B_1**	**A_2**	**B_2**	**A_3**	**B_3**
Employment (*i*=1)						
Number of monthly contracts (r=1)	*max 66, min 54, mode 60 contracts*	*max 36, min 24, mode 30 contracts*	*max 77, min 63, mode 70 contracts*	*max 54, min 36, mode 45 contracts*	*max 55, min 45, mode 50 contracts*	*max 42, min 28, mode 35 contracts*
Regional history of contracts by project type [c_{111}-c_{112}]	*[18-80]*		*[18-80]*		*[18-80]*	
Construction deadline (r=2)	*min 2, max 12 (includes maintenance), mode 3 months*	*min 3, max 6, mode 4 months;*	*min 3, max 12 (includes maintenance), mode 4 months*	*min 5, max 8, mode 6 months*	*min 2, max 12 (includes maintenance), mode 3 months*	*min 3, max 6, mode 4 months.*

Inputs *i*, *r* and c_{ir}	**Project versus zone**					
	A_1	**B_1**	**A_2**	**B_2**	**A_3**	**B_3**
Regional history deadline by project type [c_{121}-c_{122}]	*[2-24]*		*[2-24]*		*[2-24]*	
Local unemployment (c_{113}=c_{123}) Max and min national unemployment [c_{114}-c_{115}]= [c_{124}-c_{125}]	*max 6.53%, min 5.53%, mode 6.01%;* *[4.1%-6.8%]*		*max 5.82%, min 4.21%, mode 4.55%;* *[4.1%-6.8%]*		*max 5.85 min 4.98%, mode 5.78%;* *[4.1%-6.8%]*	
Property and habitability (*i*=2)						
Rights of way (*r*=1)	*no evidence*	*no evidence*	*no evidence*	*Right of way for min 100, max 200; mode 150 mil US and 40 properties affected*	*no evidence*	*Right of way for min 45, max 80, mode 60 mil US and 25 properties affected*
Max historic value paid for rights of way (c_{211})	*1 mill.US*	*1 mill.US*	*1 mill.US*	*1 mill.US*	*1 mill.US*	*1 mill.US*
Max tolerable affected properties (consensus) (c_{212})	*250*	*250*	*250*	*250*	*250*	*250*
Resettlements (*r*=2)	*no evidence*	*no evidence*	*no evidence*	*4 vulnerable families; Assists in relocation under equal conditions*	*no evidence*	*no evidence*
Max consensus of resettled families (c_{221})	*50*	*50*	*50*	*50*	*50*	*50*
[1]Current accessibility to community services (*r_1*): Primary education center (*r*=3); Secondary education center (*r*=4); Health center (*r*=5); Hospital (*r*=6); Commerce (*r*=7); Police (*r*=8)	*Rural health services, elementary school, police are available in local area at 6 km; (min 7', mode 9' max 15'); Secondary school, hospital, major commerce at 15 km; (min 18', mode 23', max 35') by car to the most disadvantaged core population that uses the road*		*Rural health services, elementary school, police are available in local area at 10 km; (min 11', mode 15' max 15'); Secondary school, hospital, major commerce at 30 km; (min 40', mode 45', max 50') by car to the most disadvantaged core population*		*Rural health services, elementary school, police are available in local area at 4 km; (min 4', mode 6' max 10'); Secondary school, hospital, commerce at 30 km; (min 40', mode 45', max 50') by car to the most disadvantaged core population*	
Current frequency of public transport (c_{2r1})	*Public transportation 2 times per day.*		*Public transportation 6 times per day.*		*Public transportation 2 times per day*	
Increased demand for r service due to the project (*r_2*): (max, mode, min)	*r=3 (20, 15, 5 registrations); r=4 (25,20, 5 registrations); r=5 (13,10, 0 consultations/day); r=6 (20, 10, 0 beds); r=7 (20,15, 5 events)*	*r=3 (50, 40,20 registrations); r=4 (15,10, 0 registrations); r=5 (40,25,10 consultations/day); r=6 (40, 30, 10 beds); r=7 (50,30, 10 events)*	*r=3 (60, 50,40 registrations); r=4 (40,20, 5 registrations); r=5 (25,15,5 consultations/day); r=6 (10, 5, 0 beds); r=7 (30,20, 5 events)*	*r=3 (85,80,75 registrations); r=4 (55,45, 30 registrations); r=5 (90,70,50 consultations/day); r=6 (35,25,5 beds); r=7 (100,50,20 events)*	*r=3 (75, 70,50 registrations); r=4 (15,10, 0 registrations); r=5 (25,20,5 consultations/day); r=6 (20, 10, 0 beds); r=7 (30,25, 5 events)*	*r=3 (180, 150,100 registrations); r=4 (55,45, 30 registrations); r=5 (40,30,10 consultations/day); r=6 (50,40, 30 beds); r=7 (70,50,15 events)*
Current service demand (c_{2r2}):	*Primary Sch.(305 registrations); Secondary Ed. (2500 registrations); Health unit (385 consultations/day); Hospital (250 camas); Police (2100 events)*		*Primary Sch.(850 registrations); Secondary Ed. (800 registrations); Health unit (100 consultations/day); Hospital (150 camas); Police (2000 events)*		*Primary Sch.(415 registrations); Secondary Ed. (2350 registrations); Health unit (550 consultations/day); Hospital (110 camas); Police (1500 events)*	
Projected service capacity (c_{2r3}):	*Primary Sch.(500 registrations); Secondary Ed. (3000 registrations); Health unit (400 consultations/day); Hospital (250 beds); Police (2300 events)*		*Primary Sch.(1200 registrations); Secondary Ed. (850 registrations); Health unit (200 consultations/day); Hospital (200 beds); Police (2000 events)*		*Primary Sch.(550 registrations); Secondary Ed. (2500 registrations); Health unit (600 consultations/day); Hospital (150 beds); Police (1800 events).*	

Inputs *i, r* and c_{ir}	**Project versus zone**					
	A_1	**B_1**	**A_2**	**B_2**	**A_3**	**B_3**
Safe environment (*i*=3)						
Safety during construction work (*r=1*)	*Work with machines and equipment with contiguous traffic. The roads access directly to a main way. There is strong evidence of alcoholism and crime*		*Work with machines and equipment with contiguous traffic*		*The roads access directly to a main way. There is strong evidence of alcoholism and crime*	
Safety in the operation of infrastructure (*r*=2)	---	*Flooding conditions will be reduced*	---	*Flooding conditions will be reduced. Improves safety on the layout of the track.*	---	---
Zonal insecurity conditions(c_{32Z})	*Zone for agricultural burning, animals and heavy transport*		*Presence of cliffs and extreme climate*		*Number important of people walk on the road*	
Citizen participation (*i*=4)						
Means of participation (*r*=1)	*no evidence*	*Communal meeting with leaders*	*no evidence*	*Communal meeting with leaders*	*no evidence*	*Diffusion by broadcasting station*
Time and rate of participation of the area of direct influence (*r*=2) (min, mode, max)	*no evidence*	*During the design; (1, 8, 10%)*	*no evidence*	*Conception Initiative of the Mayor and communal leaders (5, 8, 12%)*	*no evidence*	*Construction started (5, 10, 20%)*
Regional democratic participation rate (c_{411}=c_{421})	*45.0%,*		*40.1%,*		*55.1%.*	

(1) Note: Improving accessibility (travel time) is determined according to the speed of operation of the infrastructure and the distance to each center.

6.5.3 Treatment of uncertainty in the case study

The following paragraphs describe the development of the evaluation of the case study in the same sequence as the items explained in section 6.4 of this article. The code was written using Matlab (R2015b 64 bit) language for its flexibility and capacity in the development of algorithms

6.5.3.1 Weight distribution for the case study (Stages A1, A2.2, B1, B2.2)

Section 6.3 presents the procedure to determine the weights of the decision-making structure of the case study. A discrete uniform distribution of weights W_i, w_{ir}, W_k and w_{kv} derives from the importance determined by the 29 decision-makers. Section 6.4.1 sets forth this procedure. Figure 6.3 shows the interquartile variations of the criteria and social goal weights of the decision-makers. The correlation coefficients are determined for each weight set from the same branch. For example, Table 6.4 presents the correlation coefficients of the criteria (*i*) of the decision-making structure. The correlation coefficients condition and ensure a comparative trend in the weight distribution of a branch. For example, for an increase in the criterion *i*=1, the criteria *i*=2, *i*=3, and *i*=4 decrease in correlation. Then the criteria are standardized to guarantee 100% all together. Figure 6.4 represents the accumulated uniform distribution of criterion *i*=1 (employability) and social goal *k*=1 (socioeconomic). This form of distribution in all the weight sets facilitates the subsequent application of the Monte Carlo method.

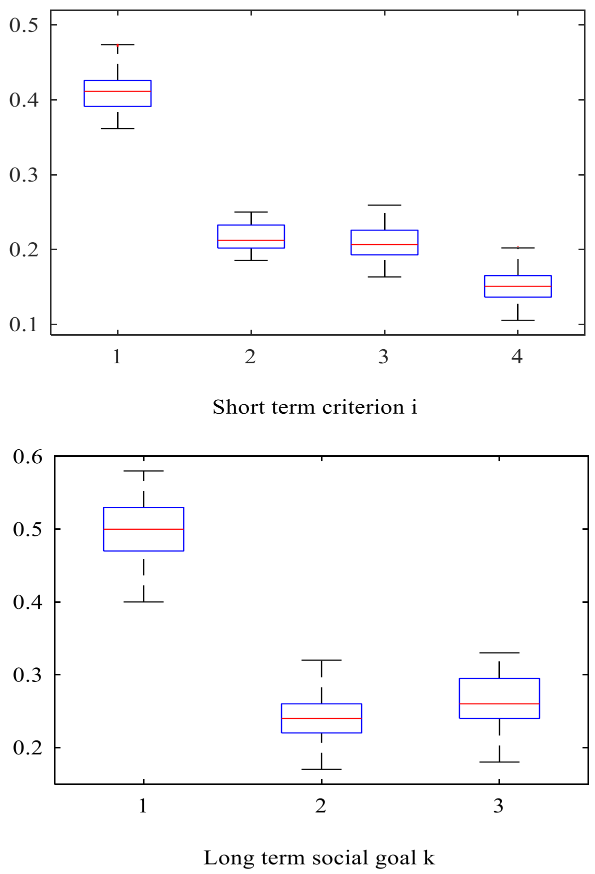


Figure 6.3: Variation of weights obtained in consultation with decision-makers

Table 6.4: Correlation of short-term social criterion weights

	i=1	*i=2*	*i=3*	*i=4*
i=1	1	-0.3052	-0.6076	-0.1860
i=2		1	-0.2197	-0.2488
i=3			1	-0.3730
i=4				1

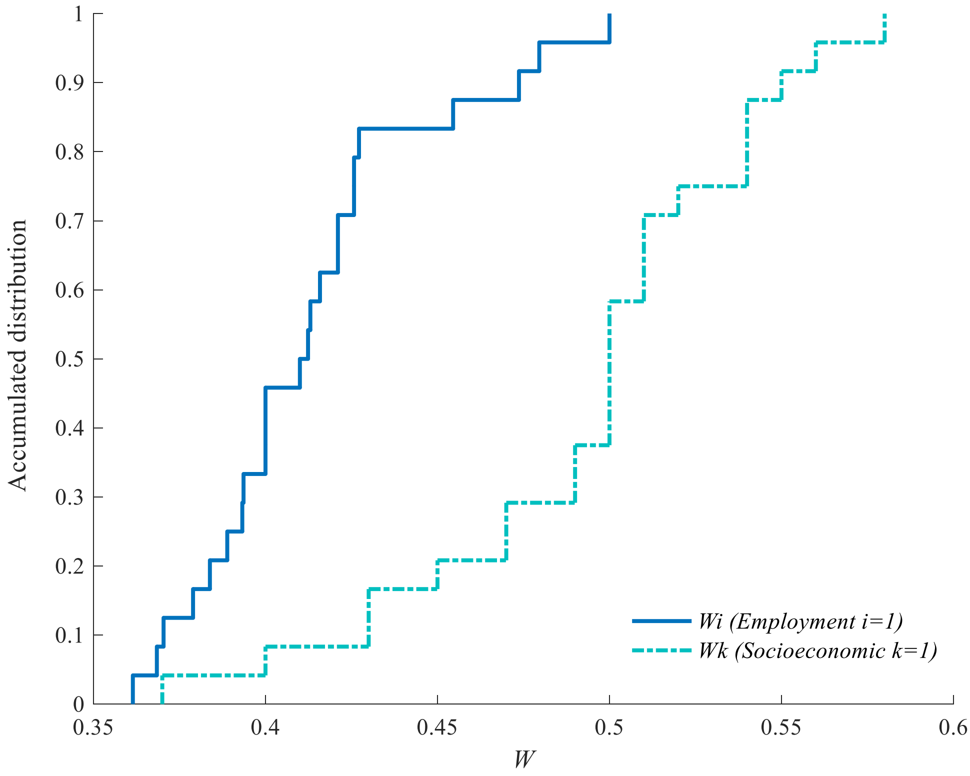


Figure 6.4: Accumulated uniform distribution of employment (i=1) and socioeconomic (k=1)

6.5.3.2 Preparation of the uncertain variables and indicators in the case study (Stages A2.1, B2.1)

The values of r_i and c_{ri} considered uncertain by the decision-makers were identified in column six of Table 6.1. The uncertain values of r_i or c_{ri} come from the consultation with the decision-makers or the regional database (DIGESTYC 2014) depending on availability. The maximum (X_{max}), minimum (X_{min}) and most probable (X_{mod}) values were collected for each uncertain item. According to the procedure in section 6.4.2, Equation 6.3 and Equation 6.4 determine the parameters of the beta PERT probability distribution. The values Z_{kv} and C_{kv} derived from the evaluation of the 29 decision-makers as part of stage B2.3 of the proposed method. Z_{kv} and C_{kv} are discrete values obtained for each project and indicator *v*. Analogous to Figure 6.3, the evaluations of the 29 decision-makers are grouped in an accumulated uniform distribution

6.5.3.3 Assessment scenario for the case study (Stage A3)

In this case, three homogenous scenes of social requirement are described (high, moderate and low demand). Each scenario comes from the use of the value function of Equation 6.1according to the parameters proposed in Figure 6.2. The propagation of uncertainty in the short-term evaluation process was applied to the three social requirement scenarios.

6.5.3.4 Propagation of uncertainty in the evaluation of the case study (Stages A4, B3)

When propagating uncertainty, the Monte Carlo method acted in a pseudo-random way; that is to say, in each iteration a random number from 0 to 1 determines the value of the inverse accumulated distribution corresponding to each uncertain element. In this case, each project alternative was evaluated through 5,000 iterations. In other words, 5000 *STSI* and *LTSI* constituted the variation space of a project alternative.

6.5.3.5 Case study analysis and results (Stage C.1)

The variation space of the *STSI* and *LTSI* for the six alternatives is shown in Figure 6.5. For higher levels of demand, the short-term social improvement tended to be smaller and more concentrated. Visually the best simultaneous short and long-term contributions are produced by alternatives B2 and B3. Additionally, the high social requirement scenario facilitated differentiation of the best alternatives. Analytically, for each iteration and project alternative Equation 6.2 determined a position within an order of priority. Table 6.5: Order of priority of infrastructure alternatives indicates the order of priority of the set of alternatives for the three decision-making scenarios. In all the cases the first option was alternative B3 with a reliability over 90%.

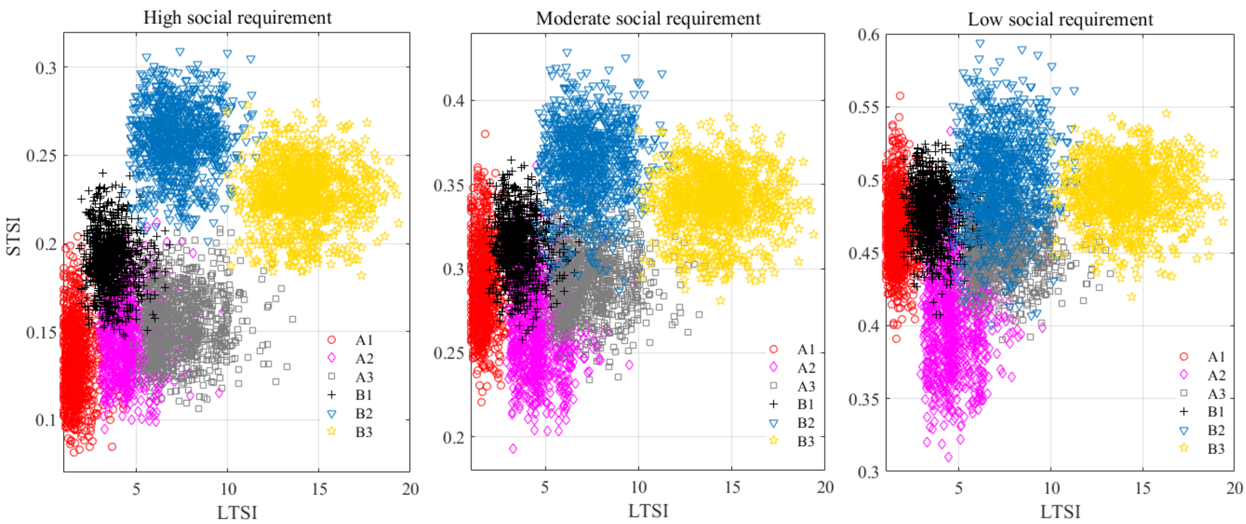


Figure 6.5: Contribution to the social improvement of the infrastructure alternatives in three social requirement scenarios

Table 6.5: Order of priority of infrastructure alternatives

Order of priority		1st	2nd	3rd	4th	5th	6th
High demand	Alternative	**B3**	**B2**	A3	A2	A2	A1
	Probability	**97.7**	**93.7**	52.9	35.1	40.4	79.9
Moderate demand	Alternative	**B3**	B2	A3	B1	A1	A2
	Probability	**94.7**	78.3	57.6	72.3	83.3	74.3
Low demand	Alternative	**B3**	B2	A3	B1	A1	A2
	Probability	**92.6**	62.9	48.8	79.9	94.9	82.5

The partial results are also important in the analysis of the decision-making. Figure 6.6(left) shows a significant impact of the B3 project on the socioeconomic objective. This result is partly derived from the weight that is greater than that of the other long-term objectives (Figure 6.3). Otherwise, there were no significant differences observed between the effect of B2 and B3 in the long term. Figure 6.6(right), however, shows a smaller difference between B2 and B3 in the short term. With respect to the criteria of property-habitability and participation, B.2 stood out over B3. Nevertheless, the long-term socioeconomy and short-term employment presented a heavy weight on the part of the decision-makers. This determined the inclination to alternative B3 over B2.

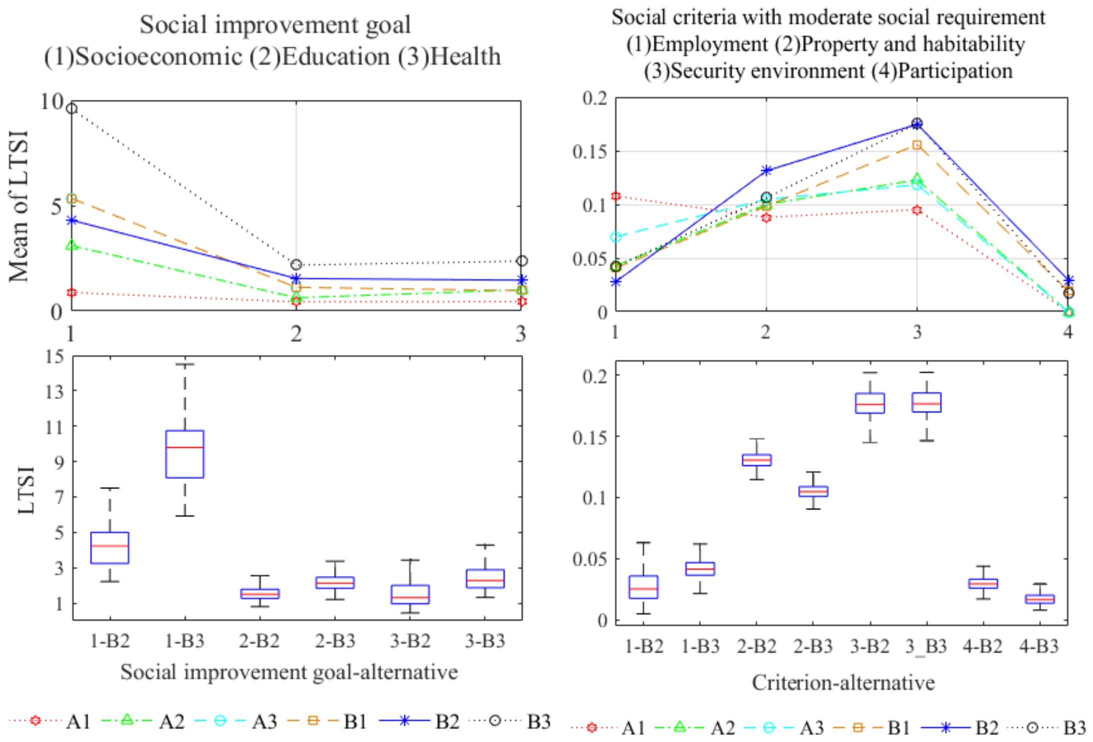


Figure 6.6: Improvement of long-term social goals (left) and short-term criteria (right) by infrastructure

6.6 Conclusions

The present article proposes a treatment of the uncertainty that complements the method to assess the social contribution of infrastructure projects. Thus, the method emphasizes the interactions of the infrastructure with the environment, short/long-term social improvement and the treatment of uncertainty in the decision-making. In its development the article focuses on the probabilistic treatment of the weights and uncertain evaluation items of the projects, the propagation of uncertainty in the method and the determination of the reliability of different social requirement scenarios.

The treatment of uncertainty is illustrated using a case study that proposes six alternatives to improve road infrastructure in different location contexts. Under this scheme the method was able to differentiate the social contribution of each alternative. In addition, a control of the uncertainty allowed the decision-makers to consider the reliability of the prioritization of an alternative. The degree of reliability is evidence of the repercussion of bias in the estimation of social values. The method was developed in a participatory manner. The treatment of uncertainty made it possible to integrate the opinion of various decision-makers. Thus, it is a support mechanism for the public investment agencies responsible for promoting regional development.

The adequate functioning of this proposal is limited to a suitable range of uncertainty in order to obtain results with an acceptable probability. Moreover, a suitable selection of decision-makers is advisable. If not, the reliability of the decision-making may be affected.

The proposed method is a possible estimation tool for use in the viability phase of the service life of the infrastructure. The results can complement environmental or economic sustainability assessments. This method can be applied in any geographic context, adapting the decision-making structure to the characteristics of the zone and the type of infrastructure. In the future, the intention is to investigate the transference functions and the significant elements of different infrastructures that affect the social contribution.

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6.7 References

Ahmadvand, M., Karami, E. (2009). “A social impact assessment of the floodwater spreading project on the Gareh-Bygone plain in Iran: a causal comparative approach”. *Environ. Impact Assess.*, 29(2), 126-136, doi: 10.1016/j.eiar.2008.08.001.

Alarcón, B., Aguado, A., Manga, R., Josa, A. (2011). “A value function for assessing sustainability: Application to industrial building”, *Sustainability*, 3, 35-50, doi: 10.3390/su3010035.

Cárdenas, C., Halman, J.I.M. (2016). “Coping with uncertainty in environmental impact assessments: Open techniques”, *Environ. Impact Assess.*, 60, 24-39, doi: 10.1016/j.eiar.2016.02.006.

Dasgupta, S., Tam, E.K.L. (2005). "Indicators and framework for assessing sustainable infrastructure", *Can. J. Civil Eng.*, 32, 30–44, doi: 10.1139/l04-101.

De la Cruz, M.P, Castro, A., del Caño, A., Gómez, G., Lara, M., Cartelle, J.J. (2015). "Comprehensive methods for dealing with uncertainty in assessing sustainability. Part 1: The MIVES – Monte Carlo Method", *Soft Computing Applications for Renewable Energy and Energy Efficiency*, 69-106, doi: 10.4018/978-1-4666-6631-3.ch004.

Diaz-Sarachaga, J.M., Jato-Espino, D., Alsulami, B., Castro-Fresno, D. (2016). "Evaluation of existing sustainable infrastructure rating systems for their application in developing countries". *Ecol. Indic.*, 71, 491–502, doi:10.1016/j.ecolind.2016.07.033.

Dirección General de Estadísticas y Censos (DIGESTYC) (2014). Encuesta de Hogares y Propósitos Múltiples (EHPM), Gobierno de la República de El Salvador, Ministerio de Economía-El Salvador.

Dominguez-Gómez, J.A. (2016)."Four conceptual issues to consider in integrating social and environmental factors in risk and impact assessments", *Environ. Impact Assess.,* 56 (1), 113 –119, doi: 10.1016 / j.eiar.2015.09.009.

Esteves, A.M., Vanclay, F. (2009). "Social development needs analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry", *Environ. Impact Assess.,* 29(2),137-145, doi: 10.1016 / j.eiar.2008.08.004.

Gannon, C. A., Liu, Z. (1997). Poverty and Transport (No. TWU-30), World Bank, Washington, DC.

Gervásio, H., Da Silva, L.S. (2012) "A probabilistic decision-making approach for the sustainable assessment of infrastructures", *Expert Systems with Applications*, 39(8), 7121-7131, doi:10.1016/j.eswa.2012.01.032.

Gómez-López, D., del Caño, A., de la Cruz, M. (2013). "Estimación temprana del nivel de sostenibilidad de estructuras de hormigón en el marco de la instrucción española EHE-08", *Inf. Constr*., 65(529), 65-76, doi: 10.3989/ic.11.123.

Hallowell M., Gambatese, J. (2010). "Application of the Delphi method to CEM research", *J. Constr. Eng. Manage*., 136(1), 99-107, doi:10.1061/(ASCE)CO.1943-7862.0000137.

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V.C., Ballester-Muñoz, F. (2014) "A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements", *Expert Systems with Applications*, 41(15), 6807-6817, doi:10.1016/j.eswa.2014.05.008.

Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). "System dynamic simulation: A new method in social impact assessment (SIA)", *Environ. Impact Assess.*, 62(1), 25-34, doi: 10.1016/j.eiar.2016.07.009.

Labuschagne, C., Brent, A.C., (2006). "Social indicators for sustainable project and technology life cycle management in the process industry", *Int. J. Life Cycle Assessment*, 11, 3–15, doi:10.1065/lca2006.01.233.

Manga, R. (2005). Una Nueva Metodología para la Toma de Decisión en la Gestión de Contratación de Proyectos. PhD Thesis, Universitat Politècnica de Catalunya, Barcelona.

Pan, N.F. (2009) "Selecting an appropriate excavation construction method based on qualitative assessments", *Expert Systems with Applications*, 36(3), 5481-5490, doi: 10.1016/j.eswa.2008.06.097

Pellicer, E., Sierra, L.A., Yepes, V. (2016). "Appraisal of infrastructure sustainability by graduate students using an active-learning method", *J. Clean. Prod.*, 113(1), 884-896, doi:10.1016/j.jclepro.2015.11.010.

Penades-Pla, V., Garcia-Segura, T., Marti, J.V., Yepes, V. (2016). "A review of multi-criteria decision making methods applied to the sustainable bridge design", *Sustainability*, 8(12), 1295, doi:10.3390/su8121295.

Pope, J., Annandale, D., Morrison-Saunders A. (2004). "Conceptualising sustainability assessment", *Environ. Impact Assess*., 24(6), 595- 616, doi: 10.1016/j.eiar.2004.03.001.

Saaty, T.L., (1987). "The analytic hierarchy process – What it is and how it is used", *Math. Model.*, 9(3-5), 161–176, doi:10.1016/0270-0255(87)90473-8.

Sahely, H.R., Kennedy, C., Adams, B.J., (2005). "Developing sustainability criteria for urban infrastructure systems", *Can. J. Civ. Eng.*, 32, 72–85, doi:10.1139/l04-072.

Sierra, L., Pellicer, E., Yepes, V. (2016). "Social sustainability in the life cycle of Chilean public infrastructure", *J. Constr. Eng. Manage.*, 142(5), doi: 10.1061/(ASCE)CO.1943-7862.0001099.

Sierra, L., Pellicer, E., Yepes, V. (2017). "Method for estimating the social sustainability of infrastructure projects", *Environ. Impact. Asses.*, accepted (in press).

Torres-Machi, C., Pellicer, E., Yepes, V., Chamorro, A. (2017). "Towards a sustainable optimization of pavement maintenance programs under budgetary restrictions", *J. Clean. Prod.*, 148(1), 90-102, doi: 10.1016/j.jclepro.2017.01.100.

Ugwu, O.O., Kumaraswamy, M.M., Wong, A., Ng, S.T. (2006). "Sustainability appraisal in infrastructure projects (SUSAIP): Part 1. Development of indicators and computational methods", *Automation in Construction*, 15(2), 239-251, doi: 10.1016/j.autcon.2005.05.006.

United Nations Development Programme - UNDP (2010). Project: Revitalize Local Economies Through the Development and Reconstruction of Public Infrastructure, Code 00074250, San Salvador – El Salvador. http://www.sv.undp.org/content/el_salvador/es/home/operations/projects/human_development/programa-de-modernizacion-y-gestion-de-los-activos-de-CEPA11.html (In November 2015).

Valdés-Vásquez, R., Klotz L.E. (2013). "Social sustainability considerations during planning and design: framework of processes for construction projects", *J. Constr. Eng. Manage.*, 139(1), 80-89, doi: 10.1061/(ASCE)CO.1943-7862.0000566.

Van de Walle, D. (2009). "Impact evaluation of rural road projects". *J. Dev. Eff.*, 1, 15–36. doi:10.1080/19439340902727701.

Vanclay, F., (2003). "International Principles for Social Impact Assessment". *Impact Assess. Proj. Apprais*. 21(1), 5–11, doi:10.3152/147154603781766491

Vanclay, F., (2002). "Conceptualising social impacts". *Environ. Impact Assess. Rev*. 22(1), 183–211, doi:10.1016/S0195-9255(01)00105-6

Yepes, V., Garcia-Segura, T., Moreno-Jimenez, J.M. (2015). "A cognitive approach for the multi-objective optimization of RC structural problems", *Arch. Civil Mech. Eng.*, 15(4), 1024-1036, doi:10.1016/j.acme.2015.05.001.

Zamarron-Mieza, I., Yepes, V., Moreno-Jimenez, J.M. (2017). "A systematic review of application of multi-criteria decision analysis for aging-dam management". *J. Clean. Prod.*, 147, 217-230, doi: 10.1016/j.jclepro.2017.01.092.

CAPÍTULO 7

BAYESIAN NETWORK METHOD FOR MAKING DECISIONS ABOUT SOCIAL SUSTAINABILITY OF INFRASTRUCTURE PROJECTS

Publicación

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Nowadays, sustainability assessment tends to focus on the biophysical and economic aspects of the built environment. The social aspects are generally overestimated during an infrastructure evaluation. This study proposes a method to optimize infrastructure projects by assessing their social contribution. This proposal takes into account the infrastructure's interactions with the local environment in terms of its potential contribution in the short and long-term. The method is structured in three stages: (1) preparation of a decision-making model, (2) formulation of the model, and (3) implementing the model through optimization of infrastructure projects from the social sustainability viewpoint. The theory of Bayesian reasoning and a harmony search optimization algorithm are used to carry out the research. The paper presents the application to a case study of a set of alternatives for road infrastructure projects in El Salvador. The results show that the method can distinguish socially efficient alternatives. The method can be employed in the infrastructure formulation and prioritization phases and complemented with economic and environmental sustainability assessments.

KEYWORDS: Bayesian networks; infrastructure; multiple criteria; optimization algorithm; social sustainability.

7.1 Introduction

Sustainable development makes the economy, society and the environment compatible without jeopardizing either development or future generations (WCED 1987). In the last 30 years of the 20th century, the discussion centered on ecology. Only at the end of the century did the international community begin to understand the importance of enhancing human capabilities (Colantonio 2011). In particular, the evaluation of social sustainability has been intertwined with assessment methods to make sustainable development measurable (Torres-Machi et. al 2015, Pellicer et al. 2016). Environmental assessments incorporate this condition; however, the social aspect is not taken sufficiently into account (Valdes-Vasquez and Klotz 2013, Dendena and Corsi et al. 2015). In addition, social aspects have limitations to being evaluated the same way as other sustainability dimensions. Social and cultural heterogeneity drives the divergence of measurement criteria (Vanclay 2002, Colantonio 2011). Moreover, the estimation of social sustainability also requires the assessment of qualitative aspects.

Infrastructure projects promote economic well-being, and they may complement many social interventions as well. For example, early maintenance investments improve the social contribution of services that require infrastructures (Schwarz et al. 2016). Thus, a complete life-cycle analysis is crucial to assessing the impacts of an infrastructure (Sierra et al. 2016, Zastrow et al. 2017). However, the social characteristics of a project have a high degree of uncertainty (Delgado and Romero 2016). This is especially noticeable in the early stages of a project's development, prior to its construction (Gervásio and Da Silva 2012, Mel et al. 2015). Furthermore, the social contribution of an infrastructure project depends heavily on its interaction with the contextual conditions (Mostafa and El-Gohary 2014, Dendena and Corsi 2015). In this sense, contextual conditions refer to the development level of an area, such as the level of employability, public transport services, health and education services, and so forth.

Investment in public infrastructure should be justified by the social contribution in the short and long-term. In a short-term approach, the early return of the social benefits of an infrastructure will only be possible in a developed geographical context (Gannon and Liu 1997). By contrast, a long-term approach will promote the social development in those contexts lacking in opportunities. In order to clarify these two terms (short and long-term), two real examples are used. First, the second Penang Bridge, with a length of 24 km, connects Batu Kawan on mainland Malaysia to Batu Maung on Penang Island (Yadollahi et al. 2015); after commissioning (short-term) there was evidence of accident reduction and the decrease of noise-level in the area which previously had high traffic congestion; in the long-term, there was an improvement in equity accessing and using city services and the surrounding area flourished economically. Second, the Dam “Urra 1” (Egre and Senecal 2003), which affects 350 km along the Sinú River in the northwestern part of Colombia, impacts a local area with low public investment. In the short-term there were impacts on the activities of the fishermen and ethnic conflicts; in the long-term the area improved the quality of life due to the greater private investment, leading to social segregation and a change in lifestyle and identity. It is likely that the short and long-term approaches will not be simultaneous; i.e., the projects that involve early efficiency do not necessarily benefit the population groups that require major development. In this sense the distribution of public benefits should aim to achieve equality in society (Foth et al. 2013, Delgado and Romero 2016). In light of this, governments must consider the initial local conditions that interact with the project's characteristics in the prioritization of infrastructure projects. Accordingly, it is necessary to identify a series of infrastructure project alternatives which have an early return on social well-being and create development opportunities (Foth et al. 2013).

The literature regarding the social sustainability of infrastructure projects is limited. Valdes-Vasquez and Klotz (2013) propose a range of aspects to consider during the planning of an infrastructure project: user-centered design, environmental safety elements, communication with stakeholders, and contextual conditions, among others. In global terms, social criteria have been more clearly defined since the 1990s; the most prevalent criteria are the ones proposed by Labuschagne et al. (2005), comprising a social sustainability framework. Furthermore, a criterion requires the determination of certain attributes of the infrastructure and its location context defined as decision variables (Gervásio and Da Silva 2012). In particular, the social contribution of a set of decision variables will depend on the type of infrastructure and the contextual condition.

Technically, the number of decision variables and evaluation criteria may be too high. The problem is daunting when there are several possible states for each variable and criterion. Given the computer time and resources required, a conventional multi-criteria analysis by itself does not provide a solution to the problem domain. Using the techniques of Bayesian reasoning, a decision-making model can be generated by experts (Chen and

Pollino 2012, Mkrtchyan et al. 2016). Bayesian networks have been applied to predict the industrial energy consumption and the salinity risks of soils by experts (Rahman et al. 2015, Nannapaneni et al. 2016). In addition, other participatory approaches have already employed Bayesian networks in sustainable decisions-making (Bertone et al. 2016, Mkrtchyan et al. 2016).

In this case, a model can represent the relations among the variables of the infrastructure and the location context, the evaluation criteria and the short and long-term social contribution (Gannon and Liu 1997, Labuschagne et al. 2005, Foth et al. 2013). The decision-making model can be used to determine a number of alternatives for infrastructure projects (Chen and Pollino 2012). Through optimization, the decision-makers can concentrate on the best alternatives from the social sustainability viewpoint. These alternatives will be the most likely to satisfy social improvement in the short and long-term. These considerations are the point of departure for this study. The research reported in this paper proposes a method to optimize infrastructure projects by assessing their social contribution; this proposal takes into account the infrastructure's interactions with the local environment in terms of its potential contribution in the short and long-term.

This paper is organized in the following way: It begins with the introduction of the techniques of Bayesian reasoning. Then, it follows a description of the proposed method in order to prepare the decision-making model, to evaluate its connections and to apply an optimization algorithm in the multiple-criteria model. The sequence of the Bayesian network development model is established through a case study. Finally, the conclusions of the paper are presented.).

7.2 Bayesian network applied to decisión-making

Bayesian networks are a well-established graphical representation for encoding conditional probabilistic relationships among uncertain variables using Bayes' theorem (Chen and Pollino 2012). A model of multi-criteria decision-making based on a Bayesian network can include: (1) the decision variables that depend on the decision-makers; (2) the result variables that express the system's exit expectation; and (3) the interconnection variables between the decision and the result variables. The model is made up of a set of interconnected nodes that represent each variable and its relation. Each relation involves a probability distribution that identifies the decision-makers' experience (Mkrtchyan et al. 2016). Once the model is built, the Bayesian reasoning method can help identify the likely impact given a set of decision elements.

Thus, a directed acyclic graph represents the probabilistic dependencies and independencies between each node. At this point, Bayesian networks can define a factorization of joint probability distribution on the related nodes (Pearl 2009). Certain conditional probability distributions can be approximated by a causal independence model. In this sense, one widely used technique is the "Noisy-OR" (Pearl 2009; Mkrtchyan et al. 2016). Studies by Diez and Druzdel (2007) have demonstrated the effectiveness of this application even with non-Boolean variables. A Noisy-OR assumes that each cause (parent node) is capable in itself of causing an effect, and that this capability is not affected by the presence or absence of other active causes (Lemmer and Gossink 2004). Thus, a conditional probability distribution is represented according to the Equation 7.1, in which v_o and v_p are the states of a child and parent node, respectively; and p_i is the conditional probability of the effect of each state of a parent node *i* on a child node "o"(Diez and Druzdel 2007).

Equation 7.1

$$P(v_0|v_P) = 1 - \prod_i (1 - p_i)$$

Noisy-OR models can favorably reduce the quantification of the p_i (Pearl 2009, Mkrtchyan et al. 2016). For example, for the application of a Bayesian network the number of p_i would correspond to m^{n+1}, with *n* being the number of parent nodes and *m* the number of states of each parent and child nodes. However, a Noisy-OR model only requires a number of $m^2 \cdot n$ conditional probabilities to define the model. In this line, a Noisy-OR model is adequate for intuitive interpretation and estimation of conditional probabilities tables by experts (Mkrtchyan et al. 2016). On this point, a survey makes it possible to estimate a conditional probability value p_i after rounds of questions with feedback and a consensus.

A Noisy-OR model assumes that all causes (of an effect) are independent of each other. Thus, the Noisy-OR model is limited for the capture of notions as synergy or interference between the causes. Furthermore, the possible value of parent variables not explicitly represented is dismissed (Lemmer and Gossink 2004). In this case, additional questions to the experts would be required, which would hinder obtaining the model and quantification of parameters. Recursive functions and leaky models can respond to these issues (Diez and Druzdel 2007). However, formulation of functions with more than three causes is more complex, bordering on unapproachable.

7.3 Proposed method

As stated earlier, this research paper proposes a method to optimize infrastructure projects assessing their social contribution; it takes into consideration the infrastructure's interactions with the local environment in terms of its potential social contribution in the short and long-term. In order to achieve this goal, it uses four basic techniques:

1. Document review regarding regional infrastructure design standards as well as current projects in the region.

2. Delphi technique: experts (at least eight) are required with experience in the fields of public infrastructure and social development; the Delphi method is applied according to the guidelines of Hallowell and Gambatese (2010) in order to reach a consensus (further details of the application of this technique are provided in sub-section 7.3.1).
3. Bayesian reasoning and the Noisy-OR techniques (using the software Matlab R2015b 64 bit) to estimate the social contribution of each infrastructure project in the multi-criteria model.
4. Multi-objective harmony search algorithm (Garcia-Segura et al. 2015) to determine the socially optimal infrastructure projects also using the software Matlab (R2015b 64 bit).

The proposed method is structured in three stages (see Figure 7.1): (1) preparation of a decision-making model, (2) formulation of the model, and (3) implementing the model through optimization of infrastructure projects from the social sustainability viewpoint. In the first stage, the variables, relations and occurrence probabilities must be established according to regional needs; the Delphi technique is applied here. On this point, an infrastructure project alternative is a combination of the states of the decision variables that contribute to social sustainability. The decision variables come from the contextual condition and from the infrastructure design and planning. In the second stage, the short and long-term social contribution assesses the alternatives using the Bayesian reasoning method. Finally, a set of infrastructure and contextual conditions is determined using the harmony search algorithm. The specific description of each of the stages is described sequentially in the following sub-sections.

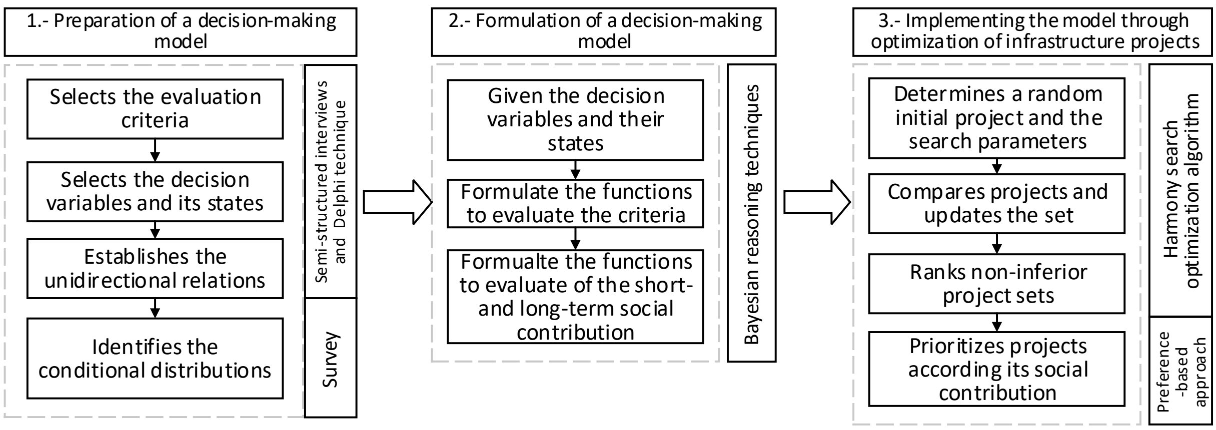

Figure 7.1: Stages of the proposed method

7.3.1 Preparation of the decision-making model (Stage 1)

Preparation of the decision-making model requires that four elements affecting the decision-making be determined (see Figure 7.1): (1) the social sustainability assessment criteria and their states; (2) the decision variables and the possible states that characterize an infrastructure project and its location context; (3) the unidirectional relations that identify the causality of the decision variables for each evaluation criterion; and (4) a conditional probability table for each relation in the network.

Determination of social sustainability assessment criteria in infrastructure life cycle is currently not clearly defined (Valdés-Vásquez and Klotz 2013; Pellicer et al. 2016; Zastrow et al 2017). Therefore, a set of criteria must be established to measure the contribution of an infrastructure in the short and long-term. For their part, the decision variables correspond to the aspects of the infrastructure project and its area of influence that affect the realization of an evaluation criterion. For each decision variable, the possible states of response must be identified. Indeed, certain decision variables and their states will depend on the type of infrastructure and the availability of information about the surroundings. In addition, determining the relations of the variables that affect each criterion and the criteria that affect the short and long-term social contribution defines all the causalities of the decision-making network.

Thus, in order to identify the criteria, the decision variables and their relations, a panel of experts is required to gain a consensus through the application of semi-structured interviews and the Delphi method (Hallowell and Gambatese 2010, Cortes et al. 2010, Alshubbak et al. 2015). The Delphi method is a qualitative technique of structured communication, developed as an interactive systematic method of prediction based on a panel of experts (Cortes et al. 2010, Alshubbak et al. 2015). Generally, the profile of the experts must fulfill the minimum requirements suggested by Hallowell and Gambatese (2010) in order to guarantee the rigor of the method. In particular, experience in the development of public infrastructure and institutional representation is required. Initially, a literature review (Labuschagne et al. 2005, Sierra et al. 2016) and the semi-structured interview with the experts will allow a frame of reference for the criteria, decision variables and their states of action to be identified. From there, the process is carried out by asking the panel of experts to provide a solution to three consecutive questions, after consensus of the previous question:

Q.1.- According to the short and long-term social contribution for the region, assess the respective importance of each social evaluation criterion.

Q.2.- According to each social evaluation criterion for the region, assess the importance and applicability of the following decision variables of the infrastructure project and its area of influence.

Q.3.- According to each decision variable of the infrastructure project and its area of influence, identify whether you "agree" or "disagree" with the states that represent the levels of action and influence.

Consultation with the experts is formalized through a questionnaire containing a set of alternative responses to be assessed. Also, each expert can incorporate other alternatives that are not included. Each item can be described on a scale of 1 (least importance/applicability) to 5 (greatest importance/applicability). In case of consensus, the alternatives of greatest importance (described with 4 and 5) are selected. Otherwise, the distribution of the responses is fed back to the panel for reconsideration and must continue until a consensus is reached. The specific sequence of steps for the Delphi method is illustrated in Figure 7.2.

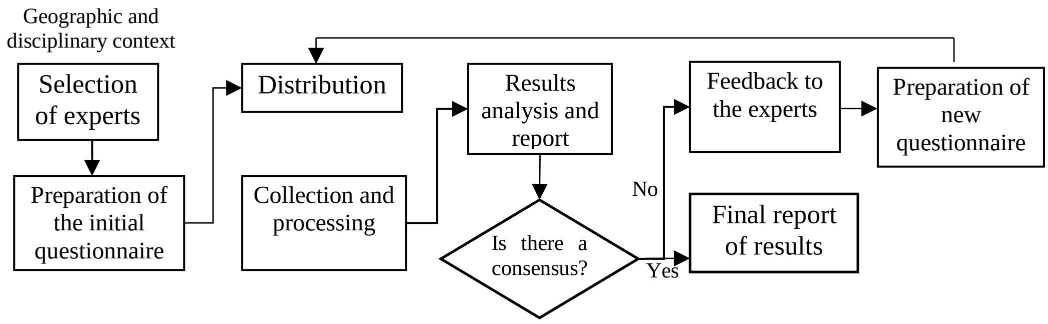

Figure 7.2: Process for the identification of criteria, decision variables and their causal connection

After structuring the Bayesian network, the next step is to configure the probabilistic relations through a conditional probability table for each relation. A conditional probability table is expressed in the form of a probability distribution that contains the statistical information of the decision-makers' experience (Mkrtchyan et al. 2016). As shown in Figure 7.3, this is performed by administering a survey to the panel of experts, in which each identifies the probable distribution of impact of a child node as a result of each possible occurrence state of a parent node. The consultation is conducted according to the relevance of the profile with the extent of each relation. This means that the consultations with reference to the short and long-term levels of social contribution (nodes *ST* and *LT*) with respect to a criterion (node *C*) are aimed at institution representatives and opinion leaders. Conversely, the selection of the level of impact of the criteria (node *C*) with respect to the state of each decision variable (*D* node) is an issue posed to the technical professionals in infrastructure development. Once the experts have been consulted, the selection is added and transferred to a conditional probability table. This aggregate part is the average of the distribution of each expert for each state of a parent node. Figure 7.3 exemplifies the consultation with an expert, in which it has been noted that a reduction in travel time over 50% would have a high impact on accessibility to local health centers, whereas for other states of time reduction the impact would be low.

For each state of “reduction in travel time” distribute 100 points according to the probable impact (high, medium, low) on the “Accessibility to local health centers”

		Child node (e.g. Accessibility to local health centers)		
Parent node (e.g. reduction in travel time)		High	Medium	Low
	More than 50%	100	0	0
	[26-50%]	55	45	0
	[10-25%]	0	60	40
	Less than 10%	0	25	75

Figure 7.3: Selection of the level of impact of a child node with respect to the state of a parent node

7.3.2 Formulation of the decision-making model (Stage 2)

With the elements from stage 1, Bayesian reasoning can be applied to solve the decision-making problem. Figure 7.4 illustrates a Bayesian network structure, where each of its nodes have been previously identified. The set of nodes is classified and defined corresponding to: (1) the decision variables D_N (N= [1,…, n]), (2) evaluation criteria C_K (K= [1,…k]), and (3) short and long-term social contribution, $ST – LT$ respectively. Also, the possible states of each node are represented according to the coding in small letters of the type of variable to which it is associated; for example: d_{N1} is the first state of the node $D_{N},$ c_{K1} is the first state of the node C_K and, analogously, st_1 and lt_1 are the first states of nodes ST and LT, respectively.

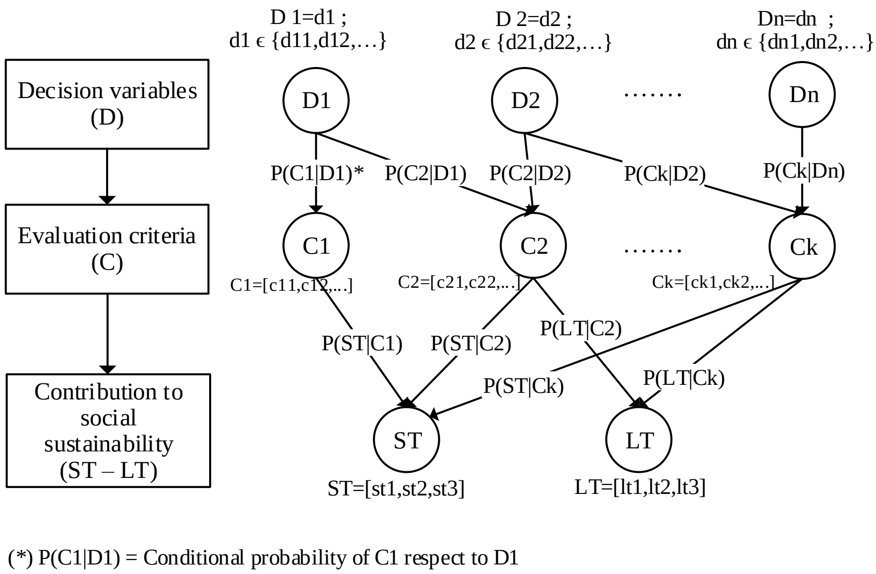

Figure 7.4: Multiple criteria decision-making model of "n" decision variables, "k" criteria and two joint probability variables ST (short-term) and LT (long-term).

After assigning a value set for the decision variables ($d_1, d_2,..., d_n$) that characterize an infrastructure project and its location context, Bayesian networks and a Noisy-OR can be applied. With this the most probable values for the short and long-term social contribution can be deduced step-by-step in the direction of impact propagation. Thus, the conditional probabilities of the nodes C_2 and *LT* can be determined specifically by Equation 7.2 and Equation 7.3 in agreement with what is expressed by Equation 7.1. Through Equation 7.4 it is expected that *LT* will correspond to the specific state lt_1 and Equation 7.5 will determine the most probable level of social contribution for *LT* according to the value of each state a. For qualitative states of high, moderate and low social contribution, these are associated with a score of 9, 5 and 1, respectively. Similarly, the probable level of social contribution for *ST* and for each criterion can be obtained.

Equation 7.2

$$P(C_{2=}c_{21}|D_1 = d_1;\ D_2 = d_2) = 1 - P(C_{2=}c_{21}|D_1 \neq d_1) \cdot P(C_{2=}c_{21}|D_2 \neq d_2)$$
$$= \ 1 - [1 - P(C_{2=}c_{21}|D_1 = d_1)] \cdot [1 - P(C_{2=}c_{21}|D_2 = d_2)]$$

Equation 7.3

$$P(LT = lt_1|C_2 = c_{21};\ C_k = c_{k1}) = 1 - P(LT = lt_1|C_2 \neq c_{21}) \cdot P(LT = lt_1|C_k \neq c_{k1})$$
$$= \ 1 - [1 - P(LT = lt_1|C_2 = c_{21})] \cdot [1 - P(LT = lt_1|C_k = c_{k1})]$$

Equation 7.4

$$P(LT = lt_1) = \sum_{c_{2i}} \sum_{c_{kt}} P(LT = lt_1|C_2 = c_{2i};\ C_k = c_{kt})$$

Equation 7.5

$$E(LT) = \sum_{a} lt_a \cdot P(LT = lt_a)$$

These steps can determine the short and long-term social contribution value in one of each infrastructure project alternative in a specific location context.

7.3.3 Optimization of infrastructure projects (Stage 3)

Optimal alternatives from the social sustainability viewpoint are determined based on the application of the harmony search optimization algorithm. Harmony search algorithm was proposed by Geem and Kim (2001) to find optimal alternatives based on the search for the perfect musical harmony. Then, Xu et al. (2010) proposed a multiobjective version of the HS algorithm. Ricart et al. (2011) studied two proposals of the multiobjective harmony search (MOHS) and compared them to a popular algorithm called NSGA-II (non-dominated sorting genetic algorithm II). Results indicated that MOHS is competitive in comparison with NSGA-II. The algorithm is calibrated according to three parameters that determine the random selection, memory consideration, and pitch adjustment. These are the harmony memory size (*HMS*), the harmony memory considering rate (*HMCR*) and the pitch adjusting rate (*PAR*). Additionally, the maximum number of improvisations without improvement (*IWI*) determines the stopping criterion. This paper uses the second proposal of Ricart et al. (2011) and adds a selection based on the crowding distance.

The algorithm begins by assigning the algorithm parameters. Secondly, a harmony memory matrix (*HM*) is filled with *HMS* vectors formed by random values. Each vector is a set of decision variables that displays a feasible alternative. Then, new harmony vectors are improvised following the Equation 7.6 and Equation 7.7. The values of the decision variables are chosen from a set of possible states with the probability equal to (1-*HMCR*). Otherwise, the new alternative is chosen from the *HM* with a probability of *HMCR*. In this case, the value is modified one position up or down with a probability of *PAR*.

Equation 7.6

$$X_i' \in \{x_i^1, x_i^2, \dots, x_i^{HMS}\}\ with\ probability\ HMCR$$

Equation 7.7

$$X_i' \in X_i\ with\ probability\ (1 - HMCR)$$

After improvising *HMS* solutions, the *HM* is updated with the lowest ranking alternative. The ranking is determined according to the method illustrated by Garcia-Segura (2015). The alternatives with the lowest ranking are transferred to *HM* until the number of alternatives with the last ranking is larger than the space of HM. In this case, the alternatives with the highest crowding distance are chosen. The crowding distance metric improves the diversity of the alternatives. The procedure finishes when the number of sequential improvisations without improvement reaches *IWI*.

The application of this algorithm generates a set of optimal alternatives for a contribution to social sustainability in the short and long-term. However, it is often difficult to decide on a large set of non-inferior alternatives (i.e., one in which an improvement in one goal requires degradation of another). Using a preference-based approach (Yepes et al. 2015), an equivalent preference can be assigned to the short and long-term social contribution. This enables a unique social contribution composite indicator to be established, which is the result of the arithmetic mean of the short and long-term states. Thus, the non-inferior alternatives can be prioritized according to the mean of their social contribution.

7.4 Case study

The proposed method was applied to prioritize infrastructure projects according to its contribution to short and long-term of social sustainability. Each project is defined by decision variables determined by the design, planning and location conditions. The case study is contextualized in the Eastern region of El Salvador, Central America. Decisions with regard to infrastructure investments in El Salvador are made mainly by the Ministry of Public Works and Transport, supported by the United Nations Development Program. Specifically, the case study focuses on four Departments. The backgrounds of each Department are specified in Figure 7.5.

Adapted from Wikimedia Commons (2007)

Department	IDH [1]	Population [2]	Poverty rate [2]	Per-capita income[2] $	Illiteracy rate[2]
La Unión	0.598	263092	36.90	1422.6	21.89
Usulután	0.640	367871	38.40	1477.2	15.50
Morazán	0.594	199021	48.06	1216.68	20.21
San Miguel	0.637	489546	34.45	1664.64	15.20
Country	0.672	6459911	34.84	1762.80	10.84

Note: (1) IDH: Human Development Index; Human Development Report - El Salvador (UNDP 2013)
(2) Ministry of Economy, DYGESTIC (2015), Household Survey and multiple purposes

Figure 7.5: Background of context of the case study

The projects involve opening or improving secondary roads in the study area. In addition, projects include roads that are currently made of gravel, have a high deterioration in paving, or it is non-existent; however, their improvement is necessary and it is also technically feasible. Every intervention involves hydraulic concrete paving. As needed, this solution also incorporates the treatment of critical points and improvement of the drainage system. In this case the operating speed does not have to exceed 75 km/h. Other specific improvements depend on the area location.

7.4.1 Preparation of the decisión-making model for the case study

El Based on experience, knowledge and availability, a sample of 31 experts was selected. The competencies of the experts focused on transport infrastructure development and the application of public policies. Table 7.1 identifies the characteristics of the selected experts.

Table 7.1: Characteristics of selected experts

Requirements	**% full expert panel (31)**			**Group A** (32.3%)	**Group B** (67.7%)
A	25.8			30.0%	23.8%
B	41.9			70.0%	28.6%
C	41.9			100.0%	14.3%
D	[10-15]	=	35.5	40.0%	33.3%
	[15-20]	=	16.1	20.0%	14.3%
	[>20]	=	48.4	40.0%	52.4%
E	19.4			40.0%	9.52%
F	BS	=	61.3	30.0%	76.2%
	MSc	=	32.3	50.0%	23.8%
	PhD	=	6.45	20.0%	--
G	70.1			70.0%	71.4%

Notes:
A: Primary or secondary author of at least 3 peer-reviewed journal articles
B: Invited to speak at a conference
C: Member or chair of a nationally recognized committee
D: At least 10 years of professional expertise
E: Faculty member at an accredited institution of higher learning
F: Advanced degree related to their field of work (minimum BS)
G: Professional registration
Group A: Experience and training in public policy and social development
Group B: Experience and training in transport infrastructure

According to the procedure described in Section 7.3.1, Figure 7.6 represents the steps for the implementation of Stage 1. In steps 1 and 2 a literature review and eight semi-structured interviews were conducted to establish a frame of reference for the criteria, decision variables and decision states. At this point, the "high, moderate and low" states were set for each social contribution and evaluation criteria. In steps 3, 4 and 5 the experts in Group A answered question Q.1 and then the experts in Group B answered questions Q.2 and Q.3, in each case with a consensus on the previous question. The consensus was achieved through the Delphi method according to the process displayed in Figure 7.2. In this case in steps 3 and 4, two rounds were required. In step 5 the consensus was achieved in three rounds. Regarding steps 4 and 5, the experts modified some aspects. For example, the decision variable “life expectancy in the area” was changed to “population attended by health professional” because it is a more appropriate indicator for local areas. In addition, experts pointed out contextual conditions that redefined decision states. For instance, lack of rural access to the Internet as a means for participation meant that face-to-face meetings had greater importance. Frequency of public transportation was another case that needed adjustments. Thus, as not all the experts’ opinions were identical, with an agreement over 75%, 13 criteria were selected, considering 21 decision variables for the case study (see Table 7.2).

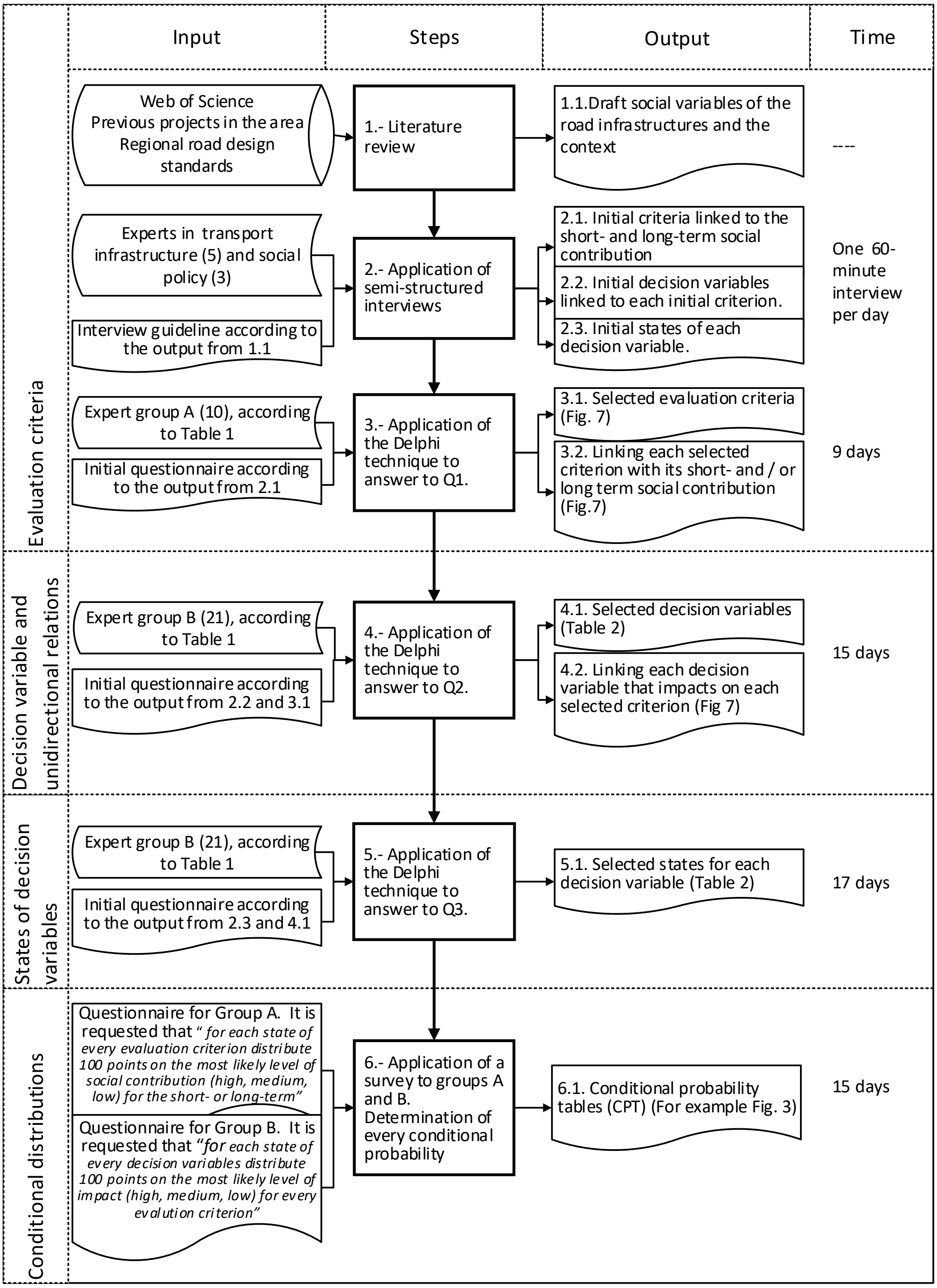

Figure 7.6: Steps for the preparation of decision-making model

Table 7.2: Decision variables of the road project and context that contribute to social sustainability

Node	Decision items	Type[1]	Alternative states
D1	Existence of public transport	C	1) Frequent (more than two round trips per day), 2) Scarce (two or less round trips per day), 3) Null
D2	Reduction in travel time	DP	1) Less than 10%, 2) [10-25%], 3) [26-50%], 4) More than 50%
D3	Population attended by health professional	C	1) High: >60%, 2) Moderate: [30-60%], 3) Low: <30% of the population affected by a health problem
D4	School attendance in the zone	C	1) High: >80%, 2) Moderate: [40-80%], 3) Low: <40% of the annual enrollment rate
D5	Commerce, services and industry in the zone	C	SI: Sales index (difference of the percentage of companies with increase and reduction in annual economic activity): 1) High: SI>30, 2) Moderate: SI= [15-30]; 3) Reduced: SI= [1-15]; 4) Non-existent or limited: SI<1.0
D6	Affected real estate	DP	1) Less than 5, 2) [5-20], 3) [21-50], 4) More than 50 properties
D7	Valuation of the affected real estate	C	(Vs= Local land value by hectare; Vsmax=Maximum land value for the zone; Vsmin= Minimum land value for the zone): 1) (Vs- Vsmin)/(Vsmax-Vsmin)≤0.50; 2) (Vs- Vsmin)/(Vsmax-Vsmin)>0.50
D8	Medium of citizen participation	DP	1) Mass media (radio, TV, print media); 2) Virtual media (web, e-mail); 3) Face-to-face (meetings, interviews)
D9	Citizen participation in democratic processes.	C	RCI: Rate of community involvement (number of people registered on councils or municipal or neighborhood committees divided by the local active population): 1) RCI<0.20; 2) RCI= [0.20-0.35]; 3) RCI=[0.35-0.50]; 4) RCI>0.50
D10	Level of projected mobility services	DP	Mobility services envisaged as required in each case: a) Capacity of the road to cover the projected traffic 20 years; b) Equipment and infrastructure for integration in the context (footbridges, bus stops, underpasses) 1) Comply; 2) Do not comply with necessary requirements
D11	Emergency conditions in zonal mobility	C	1) Geographic isolation: there is a single interrupted access; 2) Risky access: access risky due to state of the road; 3) Risk conditions do not apply
D12	Integrated systems of ecological mobility	DP	1) Promotes only motorized transport; 2) Promotes motorized, pedestrian transport and/or bicycle paths
D13	Safety of the design for the context	DP	1) Fully complies: 100% of the design elements fulfill the safety requirements of the context; 2) Partially complies: with more than 50% of the design elements account for safety in the context but not totally; 3) Does not comply: none of the above
D14	Unsafe conditions and accident rate of the zone	C	1) High: > 20 deaths/100000 inhabs. year, due to unsafe conditions along the route; 2) Medium: 10-20 deaths/100,000 inhabs per year; 3) Low: in other cases
D15	Local unemployment	C	1) High, > 8.5%; 2) Moderate: [8.5 – 7.0%]; 3) Low: <7.0% unemployment rate
D16	Type of road	DP	1) Tertiary road; 2) Intermediate between secondary roads; 3) Communicates directly to primary road
D17	Impact on architectural / cultural heritage	C-DP	1) Temporary (it affects an item for a limited period after which returns to its normal condition without external intervention); 2) Recoverable or mitigable (the condition of the affected items recovered or reduced through an external intervention); 3) Irrecoverable /the normal condition of the affected items may not be recovered or reduced)
D18	Design consistent with the environment and social context	DP	Design consistency implies characteristics of the infrastructure that aligns with the culture of the context, the colors and/or shapes of the ecosystem 1) Partially (between 25 and 50% of equipment); 2) Mainly (more than 50% of equipment); 3) Not considered
D19	Connectivity of sectors	DP	1) Minor: < 5 sectors; 2) Moderate: [5-15]; 3) High: > 15 sectors
D20	State of local connectivity	C	1) Pre-existing communication with large cities with populations of low-density; 2) Pre-existing communication between populations of low-density; 3) No communication with other urban centers with more services
D21	Segregation due to route	DP	1) Segregates without mitigation; 2) Segregates with mitigation; 3) Does not cause segregation

Note: (1) C: Variable coming from context localization ; DP: Variable coming from design and planning of road projects

A decision-making model, as shown in Figure 7.8, was established at the end of step 5. The model identifies the incidence relations on the evaluation criteria and the short and long-term social contribution goals. For example, in this case accessibility to a health center can be influenced by such decision-making variables as the existence of public transport (*D1*), the reduction in travel time (*D2*) or zonal population attended by a health professional (*D3*). In addition, the figure shows which evaluation criteria affect the social contribution goals. A short-term social contribution depends on those criteria that can be achieved during the infrastructure design, construction or start-up. Thus, community involvement, the immediate contribution to road safety, the integration of the mobility service, the participation of stakeholders, the right of property and accessibility to health centers, schools and businesses are criteria that would be made clear early on. On the other hand, a long-term contribution depends on the assessment of criteria that would be made clear after the development of certain social skills. These criteria require a future visualization according to the zonal guidelines and the contribution of the road infrastructure. In this context, reduction of the accident rate, community identity and improvement of health and education, and local employability are criteria with a future projection for this case study.

After structuring the decision-making model, step 6 (see Figure 7.7) configured the conditional probability table for each relation. This way, the experts in Group A were consulted about the short and long-term social contribution (high, moderate, or low) of every state of the criteria that correspond to it. For their part, Group B was asked about the impact on each criterion (high, moderate, low) with respect to every state of the decision variables that correspond to it. Thus, Figure 7.3 exemplifies the way of consulting experts. The average of every of the experts' distributions determined each conditional probability table. Accordingly, a decision variable can be grounds for two different criteria but with opposite preference. For example, taking as a reference the relation from Figure 7.7 and data obtained from Table 7.3, the pre-existence of a high rate of school enrollment in the zone (node *D4*) favors the short-term assessment (node *ST*) as the infrastructure achieves accessibility to schools (node *C3*). However, the pre-existence of a favorable rate of school enrollment (node 4) does not guarantee a great improvement in the education of the zone (*C4* node) in the long-term (node *LT*). In this case, given the existence of children without accessibility to local schools and with a low enrollment rate, the project contributes to further improvement of education in the long-term.

Table 7.3: Conditional probability of "Accessibility to schools" and "Improvement in education" with respect to "School attendance"

D4.-School attendance (x100)	C3.- Accessibility to local schools			C4.- Improvement of education in the zone		
	High	Medium	Low	High	Medium	Low
1.- High	0.76	0.17	0.07	0.00	0.20	0.80
2.- Moderate	0.15	0.50	0.35	0.40	0.50	0.10
3.- Low	0.05	0.30	0.65	0.95	0.05	0.00

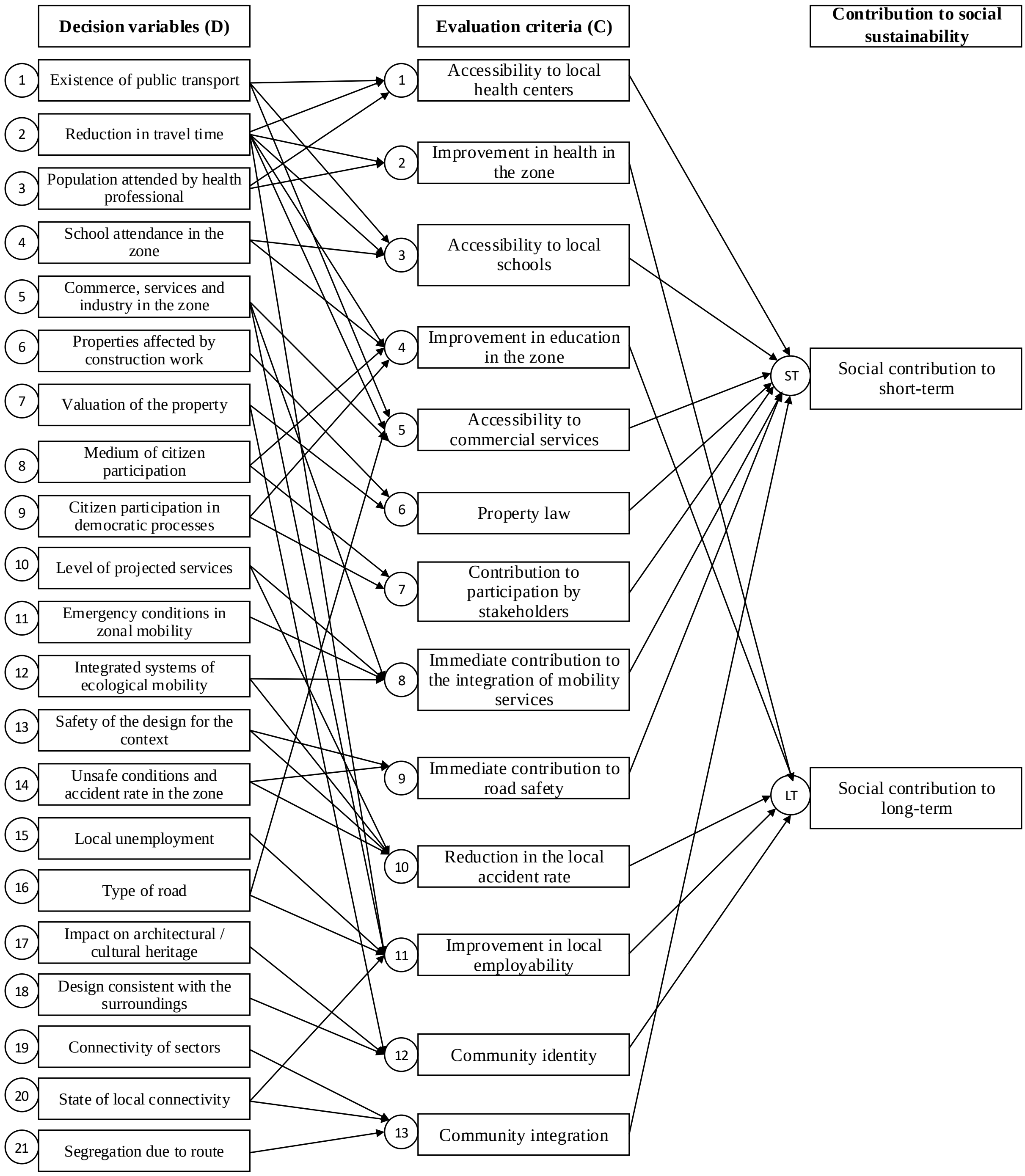

Figure 7.7: Decision-making model for the case study

7.4.2 Formulation of the decision-making model for the case study

Stage 2 of the method was developed according to the guidelines in section 7.3.2. The technique of Bayesian reasoning and the Noisy-OR were applied to the model. The code sets a function that determines the levels of social contribution to the short and long-term on a scale of 1 (low contribution) to 9 (high contribution). The model was formulated in three steps that determine: (1) the impact of the decision variables on the evaluation criteria; (2) the impact of the evaluation criteria on social contributions; and (3) the level of social contribution to the short and long-term. Steps 1 and 2 were coded according to the guidelines of Equation 7.2 and Equation 7.3 respectively. Step 3 required Equation 7.4 to estimate the probability of high, medium or low impact on each social contribution. Finally, social contribution levels were inferred from Equation 7.5 and scores for high (9), medium (5) and low (1). The code was written using Matlab (R2015b 64 bit) language for its flexibility and capacity in the development of algorithms.

7.4.3 Optimization of road projects

In this case Stage 3 of the method optimized the model using Matlab language (R2015b 64 bit). Considering 21 decision variables and each of their possible states (Table 7.2), the number of possible road projects (or combinations of decision variables states) exceeds $7.427e^{21}$ theoretical projects. Consequently, it would be difficult for the decision-maker to determine a reasonable set of alternatives with the best contribution to short and long-term social sustainability simultaneously. This way, the harmony search optimization algorithm aimed to find the optimum combination of states of decision variables that maximizes the short and long-term social contribution according to the code of the decision-making model (Figure 7.6). Sub-section 7.4.3 explains the steps followed to find the optimal projects (i.e. projects with greater social contribution at short and long-term simultaneously). The algorithm parameters were selected according to the design of experiments methodology proposed by García-Segura et al. (2015). Furthermore, IWI is adjusted by stopping the procedure when the convergence criterion is achieved. The calibration recommended: *HMS*=200, *HMCR*=0.7, *PAR*= 0.4, and *IWI*=50000. According to the principle of non-inferior alternatives a set of projects was ranked.

Figure 7.8a shows the set of project alternatives that define the social contribution limit, which are integrated by non-inferior alternative of road projects or close to them. In light of the foregoing, Figure 7.8b shows a ranking of 1st, 2nd and 3rd place for the road project set. In this instance, the alternative set is composed of 47 alternatives in 1st place (non-inferior), 45 alternatives in 2nd place, and 49 alternatives in 3rd place. Considering the number of preselected road projects, Figure 7.8c represents the social contribution mean of each one. Finally, Table 7.4 shows the values of decision variables that represent the 20 road project alternatives with the highest social contribution mean (>5.5). Thus, the decision variables tend toward long-term social contribution according the model set. From the analysis of Table 7.4, the alternatives 9 and 18 present the less short-term social contribution. Some states of decision variables can explain this situation. For example, the low commerce index in the area (*D5*), the low impact of type of road (*D16*) or the low connectivity with more developed towns (*D20*). By contrast, a high social contribution in the long-term is feasible given the low school attendance (*D4*), the low access to health professionals (*D3*) and the adequate performance of infrastructure variables (e.g. *D2, D8, D10, D12*). The last one is only feasible provided there are health-care and education centers in the area.

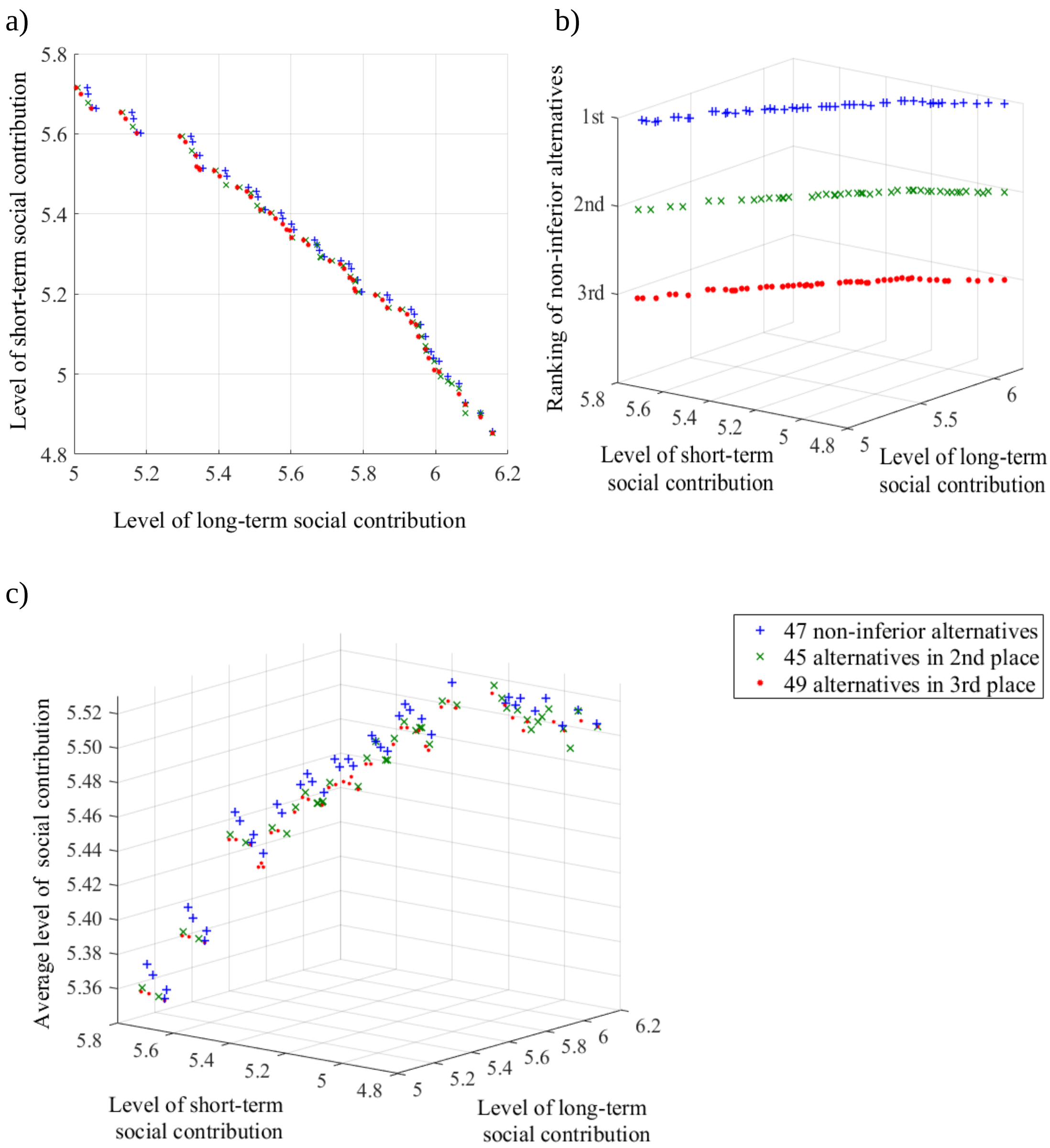

Figure 7.8: Analysis of eligible alternatives: (a) social contribution limit, (b) ranking of non-inferior alternatives, (c) behavior of the social contribution mean

Table 7.4: Sample of non-inferior alternatives with higher social contribution mean

N°	Social contribution level			States of each decision variable (*D*)																				
	ST	*LT*	Mean	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	5.162	5.933	5.547	1	4	3	3	1	1	1	3	4	1	1	2	1	1	1	3	1	2	3	1	3
2	5.150	5.940	5.545	1	4	3	3	1	1	1	3	4	1	1	2	1	1	1	2	1	2	3	1	3
3	5.123	5.959	5.541	1	4	3	3	1	1	1	3	4	1	1	2	1	1	1	1	1	2	3	1	3
4	5.095	5.971	5.533	1	4	3	3	2	1	1	3	4	1	1	2	1	1	1	1	1	2	3	1	3
5	5.198	5.866	5.532	1	4	3	2	1	1	1	3	4	1	1	2	1	1	1	3	1	2	3	1	3
6	5.186	5.873	5.529	1	4	3	2	1	1	1	3	4	1	1	2	1	1	1	2	1	2	3	1	3
7	5.056	5.986	5.521	1	4	3	3	2	1	1	3	4	1	1	2	1	1	1	2	1	2	3	2	3
8	5.032	6.009	5.521	1	4	3	3	2	1	1	3	4	1	1	2	1	1	1	1	1	2	3	2	3
9	4.976	6.064	5.520	1	4	3	3	3	1	1	3	4	1	1	2	1	1	1	1	1	2	3	2	3
10	5.061	5.974	5.518	1	4	3	3	1	1	1	3	4	1	1	2	1	1	1	1	1	2	3	2	3
11	5.275	5.760	5.518	1	4	3	1	1	1	1	3	4	1	1	2	1	1	1	3	1	2	3	1	3
12	5.039	5.994	5.517	1	4	3	3	3	1	1	3	4	1	1	2	1	1	1	1	1	2	3	1	3
13	5.263	5.766	5.514	1	4	3	1	1	1	1	3	4	1	1	2	1	1	1	2	1	2	3	1	3
14	4.903	6.124	5.514	1	4	3	3	3	1	1	3	4	1	1	2	1	1	1	1	1	2	3	3	3
15	4.994	6.033	5.513	1	4	3	3	3	1	1	3	4	1	1	2	1	1	1	2	1	2	3	2	3
16	5.284	5.738	5.511	1	4	3	3	1	1	2	3	4	1	1	2	1	1	1	3	1	2	3	1	3
17	5.234	5.785	5.510	1	4	3	1	1	1	1	3	4	1	1	2	1	1	1	1	1	2	3	1	3
18	4.857	6.156	5.506	1	4	3	3	4	1	1	3	4	1	1	2	1	1	1	1	1	2	3	3	3
19	4.929	6.082	5.506	1	4	3	3	4	1	1	3	4	1	1	2	1	1	1	1	1	2	3	2	3
20	5.205	5.796	5.501	1	4	3	1	2	1	1	3	4	1	1	2	1	1	1	1	1	2	3	1	3
21	5.335	5.666	5.500	1	4	3	3	1	1	1	3	4	1	1	2	1	3	1	3	1	2	3	1	3

7.5 Discussion

Each alternative is a combination of states of 21 decision variables representing the road characteristics and location context. Table 7.4 identifies project alternatives with greater social contribution simultaneously in the short and long-term, i.e., the method obtained characteristics of roads more compatible with some context conditions. Furthermore, according to the model configuration, certain decision variables are more sensitive (Mel et al. 2015). For example, the variable *D16* “Type of road" or *D4* “School attendance in the zone" have greater variability according to the state of the remaining variables.

Stages 1 and 2 of this method were used to model and evaluate the social contribution of a road project. Through Stage 3, alternatives of infrastructure projects were estimated to support the planning process and the decision-making from the social viewpoint. Operationally, Bayesian reasoning techniques and the Noisy-OR model have given functionality of the decision-making model. With these techniques were treated the uncertainty of variables according on experts’ experience (Chen and Pollino 2012, Mkrtchyan et al. 2016). Moreover a multi-objective approach allowed treating opposite aspects of the valuation (Yepes et al. 2015). In this case short-term social welfare does not always contribute to equitable development in the long-term (Mostafa El-Gohary 2014). Particularly the roads located in contexts with weak states of decision variables are more likely to have a high long-term social contribution. Conversely, favorable current states of the decision variables are more likely high social contribution in the short-term.

The proposed method can be replicated in any geographic context and type of infrastructure. For this, an appropriate set of experts with experience in the study area must be selected. Furthermore, the variables, their states and relationships of the model must adapt to the conditions of the area and type of infrastructure. Thus, the locations must share similar development strategies to be evaluated under the same decision-making model. In addition, the correct determination of the conditional probability tables is a laborious but necessary task for the method to work. This method does not take synergy and interference between causes into consideration. To this additional questions put to the experts and a more complex formulation of the Bayesian network using a recursive Noisy-OR (Lemmer and Gossink 2004) should be required. All these considerations are needed to guarantee an appropriate interpretation of the results.

The prioritization of infrastructure projects from a social sustainability viewpoint can support the political and strategic decisions on a region. In this sense, the method promotes the systematic participation of experts and the agreement to build a knowledge-based system. Aspects such as learning capability, self-organization, diversity, trust and common sense are key elements to promote social sustainability through participatory models (Missimer et al. 2017). Thus, the method establishes a decision-making model which is adjustable over time according to society's needs).

7.6 Conclusions

This paper proposes a method to optimize infrastructure projects and their location contexts from the social sustainability point of view. This method emphasizes the interaction between the infrastructure and the contextual conditions to estimate the infrastructure's short and long-term social contribution. The method is structured in three stages: preparation of the decision-making model, formulation of the model and an optimization process.

The method was applied in a real context for the prioritization of potential infrastructure projects of roads in various geographic areas of El Salvador. The implementation of the method made it possible to distinguish the contributions to social sustainability of different road projects. A project is represented through a specific combination of characteristics of planning, design and location context. Additionally, the experience in the context and the uncertainty of the decision-making was also taken into account. Thus, it was possible to classify in degrees of priority the best set of alternatives of infrastructure projects with simultaneous short and long-term social contributions.

This proposal supports early decision-making to prioritize and determine the characteristics of an infrastructure project from the point of view of social sustainability.

It is a support tool for the public entities to formulate and prioritize investment in infrastructure. The method promotes experts' participation to build an evaluation system based on knowledge. This way, the method can be aligned with a region's development strategies.

The results of this method can be complemented with assessments of the economic and environmental dimension of sustainability. Thus, it can also be replicated in any geographic context and type of infrastructure once the elements of the decision network have been adapted. In the future, this proposal could integrate all the elements of sustainability taking into account the conditions of synergy and interference between causes.

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7.7 References

Alshubbak, A., Pellicer, E., Catalá, J., Teixeira, J.C. (2015). A model for identifying owner's needs in the building life cycle. J. Civ. Eng. Manag. 21(8), 1-15, doi:10.3846/13923730.2015.1027257.

Bertone, E., Sahin, O., Richards, R., Roiko, A. (2016). Extreme events, water quality and health: A participatory Bayesian risk assessment tool for managers of reservoirs. J. Clean. Prod. 135, 657-667, doi: 10.1016/ j.jclepro.2016.06.158

Chen, S.H., Pollino, C.A. (2012). Good practice in Bayesian network modelling. Environ. Model. Softw. 37(1), 134-145, doi: 10.1016/j.envsoft.2012.03.012.

Colantonio, A. (2011). Social sustainability: exploring the linkages between research, policy and practice. European Research on Sustainable Development, 1, 35-57, doi: 10.1007/978-3-642-19202-9_5.

Cortés J.M., Pellicer E., Catalá J. (2012). Integration of occupational risk prevention courses in engineering degree: Delphi study. J. Prof. Issues Eng. Educ. Pract. 138(1), 31-36, doi: 10.1061/(ASCE)EI.1943-5541.0000076.

Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. Environ. Model. Softw. 77(1), 108-121, doi: 10.1016 / j.envsoft.2015.12.011.

Dendena, B., Corsi, S. (2015). The Environmental and Social Impact Assessment: a further step towards an integrated assessment. J. Clean. Prod. 108, 965-977, doi: 10.1016/j.jclepro.2015.07.110

Diez, F. J., Druzdrel, M. J. (2007). "Canonical probabilistic models for knowledge engineering" Technical Rep. CISIAD-06-01, Universidad Nacional de Educacion a Distancia, Madrid, Spain, ⟨http://www.ia.uned.es/~fjdiez/papers/canonical.pdf⟩ (Feb. 01, 2016).

DIGESTYC. (2015). Encuesta de hogares y propósitos múltiples – San Salvador. Dirección General de Estadísticas y Censos. El Salvador. http://www.digestyc.gob.sv/index.php/temas/des/ehpm/publicaciones-ehpm.html (April. 02, 2016)

Egre D., Senecal P. (2003). Social impact assessments of large dams throughout the world: Lessons learned over two decades. Impact. Assess. Project Appraisal 21(3), 215-224, doi: 10.3152/147154603781766310.

Foth, N., Manaugh, K., El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. J. Transp. Geogr. 29(1), 1-10, doi: 10.1016/j.jtrangeo.2012.12.008.

Gannon, C. A., Liu, Z. (1997). Poverty and Transport (No. TWU-30), World Bank, Washington, DC.

García-Segura, T., Yepes, V., Alcala, J., Pérez-López, E. (2015). Hybrid harmony search for sustainable design of post-tensioned concrete box-girder pedestrian bridges. Eng. Struct. 92, 112-122, doi:10.1016/j.engstruct.2015.03.015.

Geem, Z.W., Kim, J.H.,. Loganathan, G. V. (2001). A new heuristic optimization algorithm: Harmony search. Simulation. 76(2), 60–68. doi: 10.1177/003754970107600201.

Gervásio, H., Da Silva. L. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Syst. Appl. 39(8), 7121–7131, doi: 10.1016/j.eswa.2012.01.032.

Hallowell M., Gambatese, J. (2010). Application of the Delphi method to CEM research. J. Constr. Eng. Manage.136(1), 99-107, doi:10.1061/(ASCE)CO.1943-7862.0000137.

Labuschagne, C., Brent, A.C., van Erck, R.P.G. (2005). Assessing the sustainability performance of industries, J. Clean. Prod. 13(4), 373–385, doi: 10.1016/j.jclepro.2003.10.007.

Lemmer, J. F., Gossink, D. E. (2004). Recursive Noisy OR- A ruler for estimating complex probabilistic interactions. IEEE T. Syst. Man Cyb. 34(6), 2252-2261, doi: 10.1109/TSMCB.2004.834424.

Mel, J., Gómez, D., de la Cruz, P. (2015). Análisis de sensibilidad y estudio crítico del modelo de evaluación de la sostenibilidad de la Instrucción Española de Hormigón Estructural. Inf. Const. 67(539), doi: 10.3989/ic.14.126.

Mkrtchyan, L., Podofillini, L., Dang, V.N. (2016). Methods for building conditional probability tables of Bayesian belief networks from limited judgment: An evaluation for human reliability application. Reliab. Eng. Syst. Saf. 151(1), 93-112, doi: 10.1016/j.ress.2016.01.004.

Missimer, M., Robèrt, K-H., Broman, G. (2017). A strategic approach to social sustainability – Part 1: exploring the social system. J. Clean. Prod. 140, 32-41, doi: 10.1016/j.jclepro.2016.03.170

Mostafa, M., El-Gohary, N. (2014). Stakeholder-sensitive social welfare–oriented benefit analysis for sustainable infrastructure project development, J. Constr. Eng. Manage. 140(9), 04014038, doi: 10.1061/(ASCE)CO.1943-7862.0000788.

Nannapaneni, S., Mahadevan, S., Rachuri, S. (2016). Performance evaluation of a manufacturing process under uncertainty using Bayesian networks. J. Clean. Prod. 113, 947-959, doi: 10.1016/j.jclepro.2015.12.003

Pellicer, E., Sierra, L., Yepes, V. (2016). Appraisal of infrastructure sustainability by graduate students using an active-learning method, J. Clean. Prod. 113(1), 884-896, doi:10.1016/j.jclepro.2015.11.010.

Pearl, J. (2009). Causality: Models, Reasoning and Inference (2nd Ed.). Cambridge University Press, Cambridge.

Rahman, M. M., Hagare, D., Maheshwari, B. (2015). Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian Belief Network. J. Clean. Prod. 105, 406-419, doi: 10.1016/j.jclepro.2014.04.068

Ricart, J., Hüttemann, G., Lima, J., Barán, B. (2011). Multiobjective harmony search algorithm proposals, Electron. Notes Theor. Comput. Sci. 281 (1), 51–67, doi:10.1016/j.entcs.2011.11.025.

Schwarz, N., Flacke, J., Sliuzas, R. (2016). Modelling the impacts of urban upgrading on population dynamics. Environ. Model. Softw. 78, 150-162, doi: 10.1016/j.envsoft.2015.12.009.

Sierra, L., Pellicer, E., Yepes, V. (2016). Social sustainability in the life cycle of Chilean public infrastructure. J. Constr. Eng. Manage. 142(5), 05015020, doi: 10.1061/(ASCE)CO.1943-7862.0001099.

Torres-Machi, C., Chamorro, A., Pellicer, E., Yepes, V., Videla, C. (2015). Sustainable pavement management: Integrating economic, technical and environmental aspects in decision making. Transport. Res. Rec. 2523, 56-63, doi: 10.3141/2523-07.

UNDP (2013). Informe sobre Desarrollo Humano El Salvador 2013. United Nations Development Programme, San Salvador, El Salvador.

Valdés-Vásquez, R., Klotz L.E. (2013). Social sustainability considerations during planning and design: framework of processes for construction projects, J. Constr. Eng. Manage. 139(1), 80-89, doi: 10.1061/(ASCE)CO.1943-7862.0000566.

Vanclay, F. 2002. Conceptualising social impacts. Environ. Impact Assess. 22(3), 183–211, doi: 10.1016/S0195-9255(01)00105-6.

WCED (1987). Our Common Future. World Commission on Environment and Development. Oxford University Press, Oxford.

Wikimedia Commons (2007). File:Departments of El Salvador named.svg. Retrieved from. https://commons.wikimedia.org/wiki/File:Departments_of_El_Salvador_named.svg.

Xu, H., Gao, X.Z., Wang, T., Xue, K. (2010). Harmony Search Optimization Algorithm: Application to a Reconfigurable Mobile Robot Prototype. In Z. W. Geem (Ed.), Recent Advances In Harmony Search Algorithm (Vol. 270, pp. 11–22). Berlin: Springer-Verlag Berlin Heidelberg, doi:10.1007/978-3-642-04317-8_2.

Yadollahi, M., Ansari, R., Majid, M. Z. A., Yin C.H. (2015). A multi-criteria analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia. Struct. Infrastruct. Eng. 11(5), 638-654, doi:10.1080/15732479.2014.893002.

Yepes, V.,Garcia-Segura, T., Moreno-Jimenez, J.M. (2015). A cognitive approach for the multi-objective optimization of RC structural problems. Arch. Civil Mech. Eng. 15(4), 1024-1036, doi: 10.1016/j.acme.2015.05.001.

Zastrow, P., Molina-Moreno, F., Garcia-Segura, T., Martí, J., Yepes, V. (2017). Life cycle assessment of cost-optimized buttress earth-retaining walls: a parametric study. J. Clean. Prod. 140,1037-1048, doi: 10.1016/j.jclepro.2016.10.085.

CAPÍTULO 8

DISCUSION GENERAL DE LOS RESULTADOS

Este capítulo discute los principales resultados de la investigación. Para una mejor comprensión del lector en la primera sección se presenta la estructura general de los resultados de la investigación; continuando en la sección siguiente con la discusión de la pregunta general.

8.1 Estructura general de los resultados de investigación

Cada capítulo intermedio desarrolla los objetivos secundarios enunciados en el capítulo 1, los cuales apuntan al objetivo principal de la investigación. En concordancia con la estructura de la investigación del capítulo 1, la Figura 8.1 expone los principales resultados que dan respuesta a los objetivos secundarios de esta investigación y especifica los capítulos involucrados.

Se han desarrollado estudios específicos cuyos resultados satisfacen el objetivo general de la investigación: *Evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones.*

Los estudios expuestos evidencian el tratamiento que se ha dado al concepto de la sostenibilidad social en la evaluación de proyectos de infraestructuras, y a su vez incorporan los resultados en el proceso de priorización. La implementación de los estudios fue realizada a través de:

- Simulaciones con los estudiantes de dos cursos del Master en Planificación y Gestión en Ingeniería Civil (Universitat Politècnica de València, España).
- Consultas (mediante el método Delphi) a especialistas interdisciplinarios de Chile respecto del desarrollo de su infraestructura.
- La aplicación de dos de los métodos propuestos en infraestructuras viarias de El Salvador.

A partir de la identificación de las necesidades de mejora de la evaluación de la sostenibilidad social (objetivo del capítulo 2), los estudios de la investigación avanzan hasta alcanzar la integración de los tratamientos necesarios de la equidad intergeneracional, el aprendizaje social, la interacción con el contexto y los criterios sociales trascendentes, la participación y finalmente de la incertidumbre. El desarrollo de estos conceptos se han producido, en forma implicita, en los métodos propuestos como resultado de los objetivos secundarios de los capítulos 3 al 7. Es decir, en una primera aproximación se contextualizan los criterios sociales para infraestructuras chilenas (objetivo del capítulo 3). Estos resultados identifican en cómo se ha articulado la participación, y verifican la consistencia de los criterios sociales trascendentes con los propuestos en el capítulo 1. Posteriormente, se proponen tres métodos:

1. Un primer método verifica el logro del aprendizaje social de la sostenibilidad a través de la evaluación de las infraestructuras (objetivo del capítulo 4);
2. Un segundo método evalúa la sostenibilidad social de proyectos de infraestructuras en fase de diseño y a partir de alternativas discretas, las prioriza (objetivo del capítulo 5). Complementariamente, el mismo método se mejora asignando un tratamiento a la incertidumbre de los datos (objetivo del capítulo 6); y
3. El tercero evalúa y determina las características generales y compatibles de infraestructuras tipo y de contextos, para apoyar una planificación territorial socialmente sostenible (objetivo del capítulo 7).

Los resultados de los objetivos de los capítulos 5, 6 y 7 (métodos 2 y 3) incluyen los mecanismos para integrar la evaluación de la sostenibilidad social en el proceso de toma de decisión. En la sección siguiente, se discuten los tratamientos para la evaluación de la sostenibilidad social y los mecanismos adoptados para integrarla en la toma de decisiones.

	Objetivo secundario	Método de investigación	Principales resultados
Capítulo 2	Explorar los aspectos sociales y su tratamiento en la evaluación multicriterio de proyectos de infraestructuras	Revisión de la literatura 1995 – 2017. Indaga en base de datos WOS y seguimiento de referencias y citaciones.	Mejorar los métodos que evalúan aspectos sociales, tal que: - incorporen procesos de aprendizaje social - implementen la equidad inter-generacional - traten la incertidumbre de los datos - contextualicen e interaccionen con la información local - participen representantes de todos los sectores y disciplinas - no se limite los criterios sociales trascendentes del contexto
Capítulo 3	Contextualizar los criterios sociales trascendentes en el ciclo de vida de una infraestructura	Estudio de caso: emplea el método Delphi; una prueba binomial; coeficiente de Kendall; entrevista	- En un contexto especifico el método Delphi contextualizó los criterios en el ciclo de vida para la evaluación social de infraestructuras - Se introduce la participación multidisciplinar en la aplicación del método Delphi para definir criterios trascendentes. - Los resultados generales del caso de estudios son consistentes con los criterios propuestos en cap. 2
Capítulo 4	Plantear un método de aprendizaje social de la sostenibilidad a través de la evaluación participativa y multicriterio de proyectos de infraestructuras	Diseña un método de aprendizaje-activo a través de análisis multi-criterio AHP, análisis de clúster y un caso de estudio.	La evaluación multicriterio de infraestructuras promueve el aprendizaje social de: -el aporte de las infraestructuras a la sostenibilidad integral -la influencia de la preferencia sostenible del evaluador en la su toma de decisión. -el tratamiento de lo social en la sostenibilidad integral de infraestructuras.

Figura 8.1: Estructura generales de resultados de investigación

	Objetivo secundario	Método de investigación	Principales resultados
Capítulo 5	Proponer un método para evaluar la contribución de proyectos de infraestructuras a la sostenibilidad social, que permita la toma de decisión entre alternativas predefinidas	Emplea Delphi, AHP, MIVES y una programación por compromiso	Se propone un método determinista de evaluación sostenibilidad social de infraestructuras que: -considera la equidad intergeneracional y no compensa las contribuciones sociales de corto y largo plazo. -emplea funciones de interacción proyecto-contexto con datos locales y complementa con estudios de campo -considera una método para definir los criterios sociales adecuados al contexto. -promueve la participación multidisciplinar y multisectorial en la mayor parte del proceso. -Integra la evaluación social (cualitativa y cuantitativa) en la priorización de alternativas de infraestructuras

A través del método

	Objetivo secundario	Método de investigación	Principales resultados
Capítulo 6	Formular un tratamiento de la incertidumbre en el proceso de evaluación multicriterio de la sostenibilidad social de proyectos de infraestructuras	Emplea un tratamiento probabilístico y método de Montecarlo	Se incorpora al método del capitulo 5 el tratamiento de la incertidumbre, lo cual: - integra las opciones de todos los participantes aunque no coincidan con la mayoría, en pesos y evaluaciones de largo plazo. - otorga flexibilidad y contextualiza los al tratar con datos históricos locales y consulta especialistas del contexto. -identifica la confiabilidad de la priorización.
Capítulo 7	Plantear un método multicriterio que determine las características generales de una infraestructura y del contexto (sin que existan alternativas predefinidas) que mejor contribuyan a la sostenibilidad social	Emplea la teoría de redes bayesianas, Noise-OR y un algoritmo de búsqueda armónica	Se propone un método que determina las atributos generales de infraestructuras y de contextos para la planificación territorial socialmente sostenible, a través de una estructura causa-efecto y una muestra poblacional, lo cual: -considera la equidad intergeneracional a través de la contribuciones de corto y largo plazo, no compensable, -evalúa un modelo causa efecto en que interaccionan variables del proyecto y contexto, -aplica un método para determinar criterios trascendentes a través de la participación multidisciplinar, -trata la incertidumbre a través de probabilidades condicionales dadas por la experiencia en el contexto, -integra la contribución social en la priorización de atributos de infraestructuras y contextos.

Figura 8.1: Estructura generales de resultados de investigación (continuación)

8.2 Discusión general de los resultados de investigación.

En esta sección se discute los métodos de evaluación propuestos como resultado de los objetivos de los capítulos 5, 6 y 7. En estos capítulos se presentan dos métodos que permiten integrar la evaluación de la sostenibilidad social en la toma de decisión en el ámbito de infraestructuras. En este sentido se revisa la configuración de los métodos desde la determinación de la estructura conceptual de la sostenibilidad social, su evaluación y la priorización de alternativas. Estudios de Bueno et al. (2105) y Jato-Espino et al. (2016) destacan estas fases en la configuración de los métodos multicriterios que apoyan la toma de decisiones. En particular, se propone una metodología para definir un conjunto de criterios, indicadores y relaciones que conforman una estructura conceptual de la sostenibilidad social. La evaluación de la estructura converge en dos índices que determinan la contribución social de cada alternativa al corto y largo plazo. Esto facilita la comparación del desempeño de cada alternativa (proyectos de infraestructura en el capítulo 5 y conjunto de características generales de infraestructura y contexto en el capítulo 7) dentro de un territorio.

En primer lugar se propone una metodología para modelar la estructura conceptual de la sostenibilidad social de acuerdo con un tipo de infraestructuras y su contexto. En efecto estudios de Vanclay (2002) y Valdés-Vásquez y Klotz (2013) enfatizan que no hay listas preestablecidas de criterios sociales que sean válidas para todos los contextos, y las que existan solo pueden ser empleadas como una referencia. Otros estudios orientan la evaluación hacia aspectos sociales cuantificables, lo que limita la representación (Gervásio y Da Silva 2012, 2013, Di Cesare et al. 2016). En esta línea, Munda (2004), Delgado y Romero (2016) y Díaz- Sarachaga et al. (2016) exponen que los aspectos de evaluación deben ser trascendentes para el contexto, ya sean cualitativos o cuantitativos, incorporando técnicas que permitan simularlos. En los capítulos 5 y 7, el método Delphi contextualiza, en forma multidisciplinar, los criterios sociales derivados del desarrollo de infraestructuras viarias en El Salvador. En esta línea, estudios de Munda (2004, 2006), Resendez et al. (2014) y Soltani et al. (2015) recomiendan la participación multidisciplinar, ante la imposibilidad de la participación directa de la comunidad. Esteves y Vanclay (2009) y Vilchés et al. (2014) anticipan la dificultad de la implementación de iniciativas sostenibles centradas en la capacidad reflexiva de las personas. En efecto, bajo este enfoque es necesario al menos tres rondas Delphi para lograr un consenso y entender el problema del contexto. Además otras técnicas como entrevistas semiestructuradas (capítulos 3, 5 y 7) o estudios de campo (capítulos 5) definen las propuestas iniciales, identifican las relaciones y verifican de los resultados. Siguiendo a Vanclay (2002) y Karami et al. (2017) las técnicas cualitativas permiten delinear la lógica de impacto de las intervenciones sobre los criterios sociales. Operativamente una reorganización del panel multidisciplinar facilita la construcción de las estructuras de sostenibilidad social. Es decir, especialistas con experiencia en la implementación de proyectos responden con mayor claridad a la cuestión de qué indicadores del proyecto y del contexto inciden sobre los criterios sociales. De esta forma los elementos de las funciones de transferencia (capítulo 5) o de las variables de decisión (capítulo 7) las determinan especialistas con ese perfil. Por su parte, los impactos generales sobre los criterios y oportunidades a largo plazo son identificados por los cargos directivos. En este sentido, Curiel-Esparza (2016) y Hallowell y Gambatese (2010) muestran estudios en que la consistencia entre las preguntas y la experiencia del evaluador determina una respuesta robusta. Las estructuras propuestas en los capítulos 5 y 7 son consistentes con la equidad intergeneracional. Esto es que definen un marco general para la satisfacción social a corto plazo y al desarrollo de oportunidades sociales a largo plazo. En el caso de países en desarrollo, Díaz-Sarachaga et al. (2016, 2017) expone la necesidad de preestablecer criterios que aborden más allá de las preferencias actuales centradas en lo socioeconómico, como por ejemplo, la tasa de empleo o el ingreso familiar. En efecto, de no considerar necesidades futuras como educación o salud, el alcance de la sostenibilidad social será limitado. Complementariamente, Colantonio (2011) y Hyard (2012) plantean la posibilidad de un desarrollo de oportunidades y capacidades a largo plazo a partir de intervenciones planificadas. De este modo, los enfoques a corto y largo plazo simultáneos se observan como dos resultados a los que converge la contribución de la infraestructura a través de múltiples aspectos sociales. De acuerdo a lo anterior las Figuras Figure 5.6 y Figure 7.7 muestran dos estructuras de sostenibilidad social jerárquica y en red para infraestructuras viarias en El Salvador.

En segundo lugar, se proponen dos mecanismos para evaluar la contribución social multicriterio de una infraestructura, una para la etapa de diseño (capitulo 5) y otra para la planificación territorial (capitulo 7). Las estructuras de sostenibilidad social se evalúan a través de dos índices de mejora social a corto y largo plazo. Ambos índices no son compensables y dependen del estado actual de las condiciones del contexto. Munda (2004, 2006) y Gervásio y Da Silva (2012) exponen que la compensación completa en un sistema de evaluación de aspectos sociales limita a lo éticamente correcto. Es decir, debería existir un cuestionamiento sobre si una necesidad futura es menos importante que una necesidad actual. Además, Gannon y Liu (2001) consideran que la sola evaluación basada en la eficacia de la satisfacción de la población es insuficiente para alcanzar la sostenibilidad. En particular, en el método propuesto en los capítulos 5 y 6 el índice de la mejora social a corto plazo se obtuvo a través de funciones de transferencia, una función valor y una adición ponderada simple. Los dos primeros mecanismos interaccionan el aporte del proyecto con las condiciones del contexto y su nivel de desarrollo. En algunos estudios la interacción ocurre al normalizan indicadores cuantitativos de acuerdo con la capacidad máximo-mínimo de un contexto (Dasgupta y Tam 2005, Ramani et al. 2011). En otros, funciones discretas estiman el impacto social de variables cualitativas de acuerdo a la condición del contexto (Koo et al. 2008, 2009 y Resendez et al. 2014). El método propuesto integra ambos enfoques, tratando a la vez variables cualitativas y cuantitativas a través de funciones de trasferencia por cada criterio social. En esta línea, Oppio et al. (2017) han propuesto indicadores compuestos para la toma de decisiones territoriales, aunque no integran a la infraestructura en el modelo. De esta forma, las funciones de transferencia integran factores condicionantes del contexto e indicadores del proyecto para estimar un impacto positivo de 0 a 100. En efecto, este mecanismo se aproxima a un enfoque de teoría de sistemas blando implementado en un contexto social (Luhmann 1998, Hong et al. 2011, Xing et al. 2013). Estas funciones se construyen a través de la experiencia de especialistas del contexto. Munda (2004, 2006) expone que la evaluación de intervenciones sociales debe considerar la información de la comunidad.

De hecho, las bases de datos locales de aspectos sociales son incipientes respecto del desarrollo de infraestructuras (Labuschagne y Brent 2006, Chow et al. 2014, Bueno et al. 2015). En estos casos y en consistencia con otros estudios, se emplean técnicas cualitativas para facilitar la implementación (Karami et al. 2017, Delgado y Romero 2016).

En la evaluación de lo social otro elemento del contexto a considerar es el nivel de desarrollo; el cual afecta el grado de satisfacción de corto plazo. En el capítulo 5, se adapta una función de valor para considerar escenarios de exigencia social de acuerdo al nivel de desarrollo para cada criterio. En otros ámbitos, Jato Espino et al. (2014) y De la Cruz et al. (2015) emplean la función de valor para normalizar indicadores medioambientales enmarcados en el método MIVES. El enfoque propuesto es compartido por estudios de Max-Neef (1995) y Missimer et al (2017), en que los *satisfactores* se ajustan al nivel de desarrollo tecnológico o cultural de cada contexto. Por lo tanto, los parámetros de la función de valor se condicionan para fomentar proyectos que mejoran criterios sociales débiles (menor exigencia social) o exigen un estándar mayor para zonas desarrolladas.

Por su parte, en el capítulo 5, el índice de mejora social de largo plazo se obtiene de la ponderación aditiva simple del aporte a los objetivos sociales del territorio. El valor del aporte de cada objetivo social es el producto del grado de debilidad actual de la zona y del potencial beneficio futuro del proyecto. En este sentido, Van de Walle (2002) y Asomani-Boeteng et al. (2015) muestran que intervenciones adecuadas realizadas en zonas con vulnerabilidad alcanzan mejoras sociales significativas de largo plazo. Tanto el grado de debilidad de la zona como el beneficio del proyecto, resultan del consenso de los especialistas multidisciplinares. Otros casos como Dasgupta y Tam (2005) también emplean la opinión de expertos para estimar los efectos de infraestructuras de energía sobre la esperanza de vida o la mejora socioeconómica de la sociedad. Similarmente, Vanclay et al. (2015) emplea estrategias participativas para la evaluación de los impactos sociales acumulativos dada una intervención. Dado esto, el método propuesto en el capítulo 5 usa el método Delphi como un medio de control de la incertidumbre y de consenso en la evaluación a largo plazo. En efecto, Munda (2004, 2006) y Delgado y Romero (2016, 2017) advierten de la dispersión de la valoración humana sin un medio de control de la incertidumbre. Complementariamente al método propuesto, el capítulo 6 propone un tratamiento de la incertidumbre, a través de un enfoque probabilístico y el método de Montecarlo. Estas técnicas se han abordado en estudios que han controlado la incertidumbre en criterios con disponibilidad de datos (Bonsall y Kelly 2005, Gervásio y Da Silva 2012, 2013). Sin embargo, estudios de De la Cruz (2015), Ramani et al (2011) y Munda (2004) muestran que cuando los datos no están disponibles pueden ser sustituidos por la consulta especializada en el contexto. Incluso agregan que es más pertinente que la extrapolación a contextos con distinto nivel de desarrollo. En el método propuesto las bases de datos locales y las consultas a expertos de la zona permitieron la construcción de distribuciones de probabilidad Beta-Pert. Las funciones Beta-Pert presentan cambio suaves que simulan de mejor manera un criterio real y requieren solo de los valores máximo, mínimo y el más probable para modelarlas (Jato-Espino et al. 2014). Se emplearon además funciones de probabilidad discretas. En consistencia con las experiencias de Su et al. (2006), las funciones de probabilidad discretas permitieron la integración de las opiniones de los expertos. Esta condición mejora la representación de los participantes y legitima los resultados de los índices a corto y largo plazo.

En el capítulo 7, la evaluación e interacción con el contexto se representa en un diagrama causa-efecto, en el cual las características generales del contexto y de un tipo de infraestructura (ambos definidos como variables de decisión) se entrelazan para impactar a cada criterio social. Cada conjunto posible de características es parte de un conjunto poblacional de combinaciones, para las cuales se evalúa el aporte a la sostenibilidad social a corto y largo plazo. La técnica de razonamiento Bayesiano y el operador Noise-OR dan operatividad al método. Las redes Bayesianas se han empleado con éxito en diferentes ámbitos, aunque limitan en el número de elementos que la componen (Rahman et al. 2015, Nannapaneni et al. 2016). En este sentido el método está condicionado a brindar orientaciones generales que apoyen el ordenamiento territorial de infraestructuras.

Además, el método trata la incertidumbre de acuerdo a la experiencia de los especialistas en el contexto. Es decir, los especialistas del contexto aportan las probabilidades condicionales en que cada causa (características de la infraestructura o del contexto) puede afectar a un criterio social y a la contribución a corto o largo plazo. Sin embargo estudios de Mkrtchyan et al. (2016) evidencian que la obtención de las probabilidades condicionales por parte de cada especialista es una tarea laboriosa que dificulta la implementación. Esto confirma la limitación en el número de variables y criterios que conforman la estructura de la sostenibilidad social. Además, las interacciones del metodo están limitadas a un efecto simple. Es decir, los estudios de Lemmer y Gossink (2004) destacan que la sinergia e interferencia entre las características generales requiere de una reformulación del operador Noise-OR. Esta condición implica un mayor número de preguntas a los participantes y un operador recursivo que requiere de un mayor tiempo computacional.

Por su parte, dentro del proceso de evaluación, los capítulos 5 y 7 promueven el aprendizaje de los participantes. Además, se espera la aplicación cíclica de los métodos como parte de un proceso institucional. Esto coincide con los estudios de Santos et al. (2010) y Griffiths et al. (2012) que identifican a las actuaciones sistemáticas de múltiples participantes como un factor para el ajuste de prioridades. Sin embargo, en estos estudios se implementó una sola evaluación. Dado lo anterior, se desarrolla un estudio que verifica el aprendizaje social de la sostenibilidad a través de la evaluación multicriterio de infraestructuras (objetivo del capítulo 4). El resultado se basó en dos casos, aplicados con infraestructuras distintas, y estudiantes de cursos diferentes; lográndose en todos los estudiantes un aprendizaje con un 60% de exigencia. Específicamente, se detectaron debilidades en las condiciones de entrada respecto del tratamiento de la sostenibilidad social. De hecho Watson et al. (2013) anticipan que el entendimiento de los estudiantes respecto de la sostenibilidad está centrado en los aspectos medioambientales. Además, en consistencia con el perfil del estudiante hacia la sostenibilidad, fueron seleccionados los tipos de infraestructuras (Table 4.8). En efecto Byrne et al. (2013) plantean que la actuación sostenible de los profesionales es consistente con las ideas preconcebidas a través de su formación. De esta forma el método de aprendizaje-activo propuesto ayuda a comprender la influencia de la valoración humana en la toma de decisiones sostenibles en la gestión de proyectos.

Finalmente, se integra la evaluación de la sostenibilidad social en la toma de decisión en el ámbito de infraestructuras. En base a los índices de mejora social de corto y largo plazo, en los capítulos 5, 6 y 7 se aplican optimizaciones multiobjetivo para priorizar las soluciones de infraestructuras para un territorio. Este método reduce la compensación de los enfoques de corto y largo plazo, resguardando la equidad intergeneracional de los resultados. En efecto, esta propuesta es consistente con la definición de desarrollo sostenible de *satisfacer las necesidades actuales sin comprometer la satisfacción de las necesidades del desarrollo futuro* (WCED 1987). En particular, los capítulos 5 y 6 emplean una programación por compromiso para asignar un orden de priorización. En este sentido, Yepes et al. (2015) identifican la distancia en norma "d∞" como aquella que brinda soluciones más equilibradas y adecuadas para una optimización entre los dos enfoques. Además, el tratamiento de la incertidumbre del capítulo 6 determina un nivel de confiabilidad para la priorización de proyectos de infraestructura. En contextos poco estructurados, con alta incertidumbre de los participantes y de los datos, la confiabilidad del resultado será menor. En estos casos, los estudios de campo más específico pueden mejorar la calidad de los datos (Karami et al. 2017). De otra forma, Hallowell y Gambatese (2010) y Curiel-Esparza et al. (2016) emplean el método Delphi para reducir la incertidumbre del juicio entre los participantes.

Por su parte el capítulo 7 utiliza un algoritmo de búsqueda armónica para priorizar un conjunto de características de infraestructura. Otros estudios destacan el uso del algoritmo de búsqueda armónica por su mayor diversificación con muestras poblacionales y pocos parámetros de calibración (Garcia-Segura et al. 2015, 2017, Molina-Moreno et al. 2017).

De acuerdo con los resultados del capítulo 5, la zona priorizada es una de las más pobres del país a pesar de contar con infraestructuras portuarias cercanas. En este sentido, el resultado es consistente con las declaraciones de especialista que apuntan a la falta de conectividad en la zona y acciones que potencien las labores portuarias (Ferrufino et al. 2005). Además, el contexto incide en las alternativas priorizadas. Es decir, proyectos ubicados en contextos con condiciones sociales adecuadas presentan una mayor contribución a corto plazo (B.1 de la Figure 5.8); mientras que infraestructuras en contextos con condiciones sociales débiles tienen una mayor contribución a largo plazo (B.3 de la Figure 5.8). En estos términos, Gannon y Liu (2001) y Vilchés et al. (2014) plantean que la equidad de la sostenibilidad social debe fortalecer un estilo de desarrollo que no profundice la pobreza, ni la exclusión social en la toma de decisiones. Dado los argumentos expuestos cabe aclarar que esta investigación no aspira al logro la sostenibilidad de un solo ámbito, sino a contribuir al adecuado tratamiento de la sostenibilidad integral, a través del estudio de la dimensión menos considerada en la actualidad en la toma de decisiones: el aspecto social.

8.3 Referencias

Asomani-Boateng, R., Fricano, R. J., Adarkwa, F. (2015). Assessing the socio-economic impacts of rural road improvements in Ghana: A case study of Transport Sector Program Support (II). Case Studies on Transport Policy. https://doi.org/10.1016/j.cstp.2015.04.006

Byrne, E.P., Desha C.J., Fitzpatrick, J.J., Hargroves, K. (2013). Exploring sustainability themes in engineering accreditation and curricula. Int. J. of Sustain. in High. Educ. 14(4): 384–403, doi: 10.1108/IJSHE-01-2012-0003.

Bonsall, P., Kelly, C. (2005). Road user charging and social exclusion: The impact of congestion charges on at-risk groups. Transport Policy, 12(5): 406–418, doi: 10.1016/j.tranpol.2005.06.007

Bueno, P.C., Vassallo, J.M., Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods. Transp. Rev. 35(5): 622–649, doi:10.1080/01441647.2015.1041435

Chow, J.Y.J., Hernandez, S. V., Bhagat, A., McNally, M.G. (2014). Multi-Criteria Sustainability Assessment in Transport Planning for Recreational Travel. Int. J. Sustain. Transp. 8(2): 151–175. doi:10.1080/15568318.2011.654177

Colantonio, A. (2011). Social Sustainability: Exploring the Linkages Between Research, Policy and Practice. In C. C. Jaeger, J. D. Tàbara, J. Jaeger (Eds.), European Research on Sustainable Development Volume 1: Transformative Science Approaches for Sustainability, pp. 35–57. Berlin, Heidelberg: Springer, doi: 10.1007/978-3-642-19202-9

Curiel-Esparza, J., Mazario-Diez, J.L., Canto-Perello, J., Martin-Utrillas, M., (2016). Prioritization by consensus of enhancements for sustainable mobility in urban areas. Environ. Sci. Policy 55(1): 248–257. doi:10.1016/j.envsci.2015.10.015

Dasgupta, S., Tam, E.K. (2005). Indicators and framework for assessing sustainable infrastructure. Can. J. Civ. Eng. 32(1): 30–44, doi: 10.1139/l04-101

De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J., (2015). Chapter 4 Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1 : The MIVES - Monte Carlo Method, in: Corona, C., Arredondo, A., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 69–106. doi:10.4018/978-1-4666-6631-3.ch004

Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. Environ. Model. Softw. 77(1): 108-121, doi: 10.1016 / j.envsoft.2015.12.011.

Delgado, A., Romero, I., (2017). Integrating Social Impact Assessment and Environmental Conflict Analysis on a Hydrocarbon Exploration Project in Spain. Int. J. Eng. Technol. 8(6): 2403–241, doi:10.21817/ijet/2016/v8i6/160806402

Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D. (2017). Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study. Environ. Sci. Policy. 69(1): 73–80. doi:10.1016/j.envsci.2016.12.011

Di Cesare, S., Silveri, F., Sala, S., Petti, L. (2016). Positive impacts in social life cycle assessment: state of the art and the way forward. International Journal of Life Cycle Assessment, In Press, 1–16. https://doi.org/10.1007/s11367-016-1169-7

Esteves, A. M., Vanclay, F. (2009). Social Development Needs Analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry. Environmental Impact Assessment Review, 29(2): 137–145, doi: 10.1016/j.eiar.2008.08.004

Ferrufino, C. E., Gutiérrez, S., Zeledón, A. (2005). Plan nacional de ordenamiento y desarrollo territorial (PNODT): una lectura desde la sociedad civil. Fundación Nacional para el Desarrollo. San Salvador.

Hallowell M., Gambatese, J. (2010). Application of the Delphi method to CEM research. J. Constr. Eng. Manage. 136(1): 99-107, doi: 10.1061/(ASCE)CO.1943-7862.0000137.

Hong, Y., Liyin, S., Tan, Y., Jianli, H. (2011). Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. Automation in Construction Journal, 20(1): 1060–1069, doi: 10.1016/j.autcon.2011.04.007

Hyard, A. (2012). Cost-benefit analysis according to Sen: An application in the evaluation of transport infrastructures in France. Transportation Research Part A: Policy and Practice, 46(4), 707–719. https://doi.org/10.1016/j.tra.2012.01.002

Gannon, C., Lui, Z. (2001). Transporte : Infraestructura y servicios. Washington, D.C.: The World Bank. Retrieved from www.worlbank.org

García-Segura, T., Yepes, V., Alcalá, J., Pérez-López, E. (2015). Hybrid harmony search for sustainable design of post-tensioned concrete box-girder pedestrian bridges. Engineering Structures, 92(1): 112–122, doi:10.1016/j.engstruct.2015.03.015

García-Segura, T., Yepes, V., Frangopol, D.M. (2017). Multi-objective design of post-tensioned concrete road bridges using artificial neural networks. Struct. Multidiscip. Optim. 1–12, doi: 10.1007/s00158-017-1653-0

Gervásio, H., Da Silva. L.S. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Syst. Appl. 39(8): 7121–7131, doi: 10.1016/j.eswa.2012.01.032.

Gervásio, H., Da Silva, L.S. (2013). Life-cycle social analysis of motorway bridges. Structure and Infrastructure Engineering. 9(10): 1019–1039, doi: 10.1080/15732479.2011.654124

Griffiths, K., Browne, V., Williams, V., Elliott, P. (2012). The changing face of engineering down under. Eng. Sustain. 165 (ES3): 223–232, doi:10.1680/ensu.10.00037

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V. C., Ballester-Muñoz, F. (2014). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. Expert Systems with Applications, 41(15): 6807–6817, doi: 10.1016/j.eswa.2014.05.008

Jato-Espino, D., Blanco-Fernandez, E., Carpio-García, J., Castro-Fresno, D., (2016). Decision aid system founded on nonlinear valuation, dispersion-based weighting and correlative aggregation for wire rope selection in slope stability cable nets. Expert Systems with Applications, 54(1):148–154, doi: 10.1016/j.eswa.2016.01.023

Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). System dynamic simulation: A new method in social impact assessment (SIA). Environ. Impact Assess. Rev. 62(1): 25–34. doi:10.1016/j.eiar.2016.07.009

Koo, D.-H., Ariaratnam, S. T. (2008). Application of a Sustainability Model for Assessing Water Main Replacement Options. Journal of Construction Engineering and Management, 134(1):563–574, doi: 10.1061/(ASCE)0733-9364(2008)134:8(563)

Koo, D.-H., Ariaratnam, S. T., Kavazanjian, E. (2009). Development of a sustainability assessment model for underground infrastructure projects. Canadian Journal of Civil Engineering, 36(5):765–776, doi: 10.1139/L09-024

Labuschagne, C., Brent, A.C. (2006). Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry. Int. J. Life Cycle Assess. 11(1): 3–15, doi: 10.1065/lca2006.01.233

Lemmer, J. F., Gossink, D. E. (2004). Recursive Noisy OR- A ruler for estimating complex probabilistic interactions. IEEE T. Syst. Man Cyb. 34(6): 2252-2261, doi: 10.1109/TSMCB.2004.834424.

Luhmann, N. (1998). Sistemas sociales. Lineamientos para una teoría general. (Anthropos, Ed.) (2da ed.). Bogotá.

Max-Neef, M. (1995). Economic growth and quality of life: A threshold hypothesis. Ecological Economics, 15(1): 115–118, doi:10.1016/0921-8009(95)00064-X

Mkrtchyan, L., Podofillini, L., Dang, V.N. (2016). Methods for building conditional probability tables of Bayesian belief networks from limited judgment: An evaluation for human reliability application. Reliab. Eng. Syst. Saf. 151(1): 93-112, doi: 10.1016/j.ress.2016.01.004.

Missimer, M., Robert, K. H., Broman, G. (2017). A strategic approach to social sustainability - Part 1: exploring social system. Journal of Cleaner Production, 140(1): 32–41, doi: 10.1016/j.jclepro.2016.03.170

Molina-Moreno, F., García-Segura, T., Martí, J. V., Yepes, V. (2017). Optimization of buttressed earth-retaining walls using hybrid harmony search algorithms. Engineering Structures. 134(1): 205–216, doi: 10.1016/j.engstruct.2016.12.042

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. Eur. J. Oper. Res. 158(3): 662–677, doi:10.1016/S0377-2217(03)00369-2

Munda, G. (2006). Social multi-criteria evaluation for urban sustainability policies. Land use policy. 23(1): 86–94. doi:10.1016/j.landusepol.2004.08.012

Nannapaneni, S., Mahadevan, S., Rachuri, S. (2016). Performance evaluation of a manufacturing process under uncertainty using Bayesian networks. J. Clean. Prod. 113(1): 947-959, doi: 10.1016/j.jclepro.2015.12.003

Oppio, A., Corsi, S., Torrieri, F., Mattia, S., (2017). Infrastructure Development and Territorial Vulnerability. The Role of Composite Indicators for Addressing Siting Decisions, in: Stanghellini, S., Morano, P., Bottero, M., Oppio, A. (Eds.), Appraisal: From Theory to Practice. Springer, pp. 277–290, doi: 10.1007/978-3-319-49676-4

Rahman, M. M., Hagare, D., Maheshwari, B. (2015). Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian Belief Network. J. Clean. Prod. 105(1): 406-419, doi: 10.1016/j.jclepro.2014.04.068

Ramani, T.L., Zietsman, J., Knowles, W.E., Quadrifoglio, L. (2011). Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement. J. Transp. Eng. 137(6): 404–415. doi:10.1061/(ASCE)TE.1943-5436.0000255.

Resendez, L., Dueñas-Osorio, L., Padgett, J.E. (2014). Social Sustainability in Economic, Social and Cultural Context. The international journal of social sustainability in Economic, social and cultural context. 11(1): 25–38.

Santos, G., Behrendt, H., Maconi, L., Shirvani, T., Teytelboym, A. (2010). Part I: Externalities and economic policies in road transport. Res. Transp. Econ. 28(1): 2–45, doi: 10.1016/j.retrec.2009.11.002

Soltani, A., Hewage, K., Reza, B., Sadiq, R. (2015). Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Manag. 35(1): 318–328. doi:10.1016/j.wasman.2014.09.010

Su, C. W., Cheng, M. Y., Lin, F. B. (2006). Simulation-enhanced approach for ranking major transport projects. Journal of Civil Engineering and Management, 12(4): 285–291, doi: 10.1080/13923730.2006.9636405

Van de Walle, D. (2002). Choosing Rural Road Investments to Help Reduce Poverty. World Dev. 30(1): 575–589, doi: 10.1016/S0305-750X (01)00127-9

Vanclay, F. (2002). Conceptualising social impacts. Environmental Impact Assessment Review, 22(3): 183–21, doi: 10.1016/S0195-9255(01)00105-6

Vanclay, F., Esteves, A.M., Aucamp, I., Franks, D.M. (2015). Social Impact Assessment: Guidance for assessing and managing the social impacts of projects. Fargo ND, USA: Internaional Associaion for Impact Assessment.

Valdés-Vásquez, R., Klotz L.E. (2013). Social sustainability considerations during planning and design: framework of processes for construction projects, J. Constr. Eng. Manage. 139(1): 80-89, doi: 10.1061/(ASCE)CO.1943-7862.0000566.

Vilchés, A., Gil Pérez, D., Toscano, J.C., Macías, O. (2014). Ciencia de la Sostenibilidad. Organización de Estados Iberoamericanos. Artículo en línea obtenido de http://www.oei.es/decada/accion.php?accion=24 [Fecha de consulta: 15/05/2017].

Watson, M.K., Lozano, R., Noyes, C. (2013). Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology. J. of Clean. Prod. 61(1):106–116, doi: 10.1016/j.jclepro.2013.09.010.

WCED (1987). Our Common Future. World Commission on Environment and Development. Oxford University Press, Oxford.

Xing, K., Ness, D., Lin, F. R. (2013). A service innovation model for synergistic community transformation: Integrated application of systems theory and product-service systems. Journal of Cleaner Production, 43, 93–102. https://doi.org/10.1016/j.jclepro.2012.11.052

Yepes, V., García-Segura, T., Moreno-Jiménez, J. M. (2015). A cognitive approach for the multi-objective optimization of RC structural problems. Archives of Civil and Mechanical Engineering, 15(4): 1024–1036, doi: 10.1016/j.acme.2015.05.001

CAPÍTULO 9

CONCLUSIONES

En este capítulo se resumen los principales aportes y limitaciones de esta investigación. Los estudios propuestos han permitido alcanzar los objetivos definidos. La discusión del logro de los objetivos se ha presentado en el capítulo 8 y se han resumido en la Figura 8.1. A partir de este punto, se exponen las contribuciones derivadas de la pregunta general de investigación. Luego se presentan las recomendaciones para la implementación de los métodos en los procesos de evaluación de infraestructuras. A continuación se reconocen las limitaciones metodológicas de la investigación. Por último, se sugieren las líneas de trabajo futuro.

9.1 Contribución de la investigación

En los siguientes apartados se exponen las contribuciones derivadas de los capítulos intermedios en relación a la pregunta general de la investigación *¿Es posible evaluar la sostenibilidad social de las infraestructuras integrándola en la toma de decisiones?* Esta pregunta busca indagar en la implementación de tratamientos para evaluar la sostenibilidad social de infraestructuras y que permiten integrarla en la toma de decisión para la planificación de un territorio.

Los estudios propuestos consiguen integrar la evaluación de la sostenibilidad social en la toma de decisión a través de indicadores de mejora social. Estos indicadores han permitido, en un estudio, la priorización de la mejor infraestructura, y en otro la determinación de sus características para la planificación. Esto fue posible dado un tratamiento simultáneo de la sostenibilidad social, basado en:

- La equidad intergeneracional a través de una estructura de evaluación que considera la mejora social a largo plazo de contextos vulnerables, y un sistema de toma de decisión que no lo compensa con las necesidades actuales.
- El aprendizaje social de la sostenibilidad a través del proceso de evaluación de infraestructuras.
- La interacción con los elementos del contexto y el nivel de desarrollo.
- Una propuesta de criterios sociales generales adaptables a un contexto y etapas del ciclo de vida de una infraestructura.
- La participación multidisciplinar y multisectorial en el proceso de evaluación, que represente a los actores de interés.
- El control de la incertidumbre de los datos que resguarda la robustez de la priorización.

De esta forma, la investigación propone tratamientos específicos a través de un enfoque multicriterio. Esta contribución mejora y aporta herramientas para la planificación temprana de infraestructuras de un modo consistente con las propuestas de desarrollo territorial. Los resultados de esta investigación benefician a los organismos encargados de la priorización de infraestructuras públicas. En los siguientes puntos se especifica cada tratamiento de la sostenibilidad social que forma parte de la contribución de la investigación:

- Se propone una estructura de evaluación que diferencie la contribución social de infraestructuras al desarrollo de corto y largo plazo. De esta forma, la toma de decisión no solo considera infraestructuras que fortalecen zonas económicamente activas, sino también aquellas con necesidades sociales que tienen un potencial de mejora de largo plazo. La consideración simultánea y no compensatoria de estos enfoques permitieron identificar infraestructuras que aporten a la equidad intergeneracional de un territorio.
- Se consigue un aprendizaje de la sostenibilidad a través de la evaluación de infraestructuras. Esta investigación expone los efectos de la formación, experiencias y las prioridades de los evaluadores en la toma de decisión de infraestructuras sostenibles. A partir de esto, se propone que los sistemas de evaluación sean un medio de aprendizaje social de la sostenibilidad. Las evaluaciones cíclicas de los sistemas propuestos buscan alcanzar un estado de madurez de los evaluadores respecto de las necesidades del contexto para alcanzar un estado sostenible.
- Se consigue diferenciar la contribución social de una infraestructura dentro de un territorio. Los estudios desarrollados proponen un enfoque de indicadores compuestos, que representan la interacción entre los aportes del proyecto y las condiciones del contexto, para cada criterio social. Los indicadores compuestos son implementados a través de funciones de transferencia y un modelo de causa-efecto. Además, de acuerdo al nivel de desarrollo de cada contexto se adapta una función de valor para promover alternativas que potencien criterios sociales débiles. De esta forma, el enfoque de teoría de sistemas blandos, basado en el conocimiento del contexto, pudo incorporarse en la evaluación de la sostenibilidad social de los proyectos de infraestructuras.
- Se determinan un conjunto de 23 de criterios sociales con alcance local, regional y nacional, influenciados por diferentes infraestructuras públicas y etapas del ciclo de vida. Estos criterios pueden ser empleados como una referencia para la contextualización más específica de un tipo de infraestructura y lugar. Otras categorizaciones están orientadas al ámbito de responsabilidad social corporativa, o bien son específicas de un contexto, o no se adaptan al impacto de las infraestructuras públicas.
- Se consigue integrar la participación multidisciplinar y multisectorial para: contextualizar los criterios sociales de una infraestructura; determinar la estructura de evaluación; y participar en los procesos de evaluación. Otros

enfoques se han basado solo en expertos en infraestructuras o bien no consideran el adecuado tratamiento del resto de los aspectos sociales.

- Se consigue integrar el control de la incertidumbre junto con los demás tratamientos para la sostenibilidad social. Ante la falta de datos, la información basada en especialistas permitió obtener distribuciones y probabilidades condicionales adecuadas al contexto. Además, las funciones de probabilidad discretas permitieron integrar los juicios independientes de cada evaluador. De esta forma, se obtiene un nivel de confiabilidad que condiciona la robustez de la priorización. Estas condiciones del proceso y resultado otorgan una mayor legitimidad a la vista de los participantes.

9.2 Recomendaciones

A partir de la implementación de los estudios de la investigación se identifican medidas para incorporar a los procesos de evaluación de infraestructuras que consideren aspectos sociales. De esta forma se presentan recomendaciones en los siguientes ámbitos:

Para la participación:

- ✓ Los procesos participativos en los métodos de evaluación deben tener en cuenta a la población local afectada. La consideración de la comunidad local ayuda a determinar el problema y las necesidades; sin embargo, la obtención de resultados concluyentes también requieren de la participación académica o especializada. Por lo tanto, la participación a través de representantes multidisciplinares es una opción válida para interpretar la información de la comunidad local. Además, se recomienda que los integrantes cumplan con ciertas condiciones académicas y de disponibilidad que produzcan una toma de decisiones basada en la argumentación y la evidencia.
- ✓ La conformación del panel multidisciplinar debe ser menor de ocho personas y el proceso de implementación del método Delphi debiese requerir al menos de tres rondas. Esto permite la diversidad de puntos de vista para la reflexión y el aprendizaje de los participantes hasta alcanzar un acuerdo.
- ✓ También se recomienda que las consultas se ajusten al ámbito laboral del grupo. Es decir, los participantes que están en contacto habitual con las comunidades y con el desarrollo de proyectos identifican con mayor facilidad las variables específicas del proyecto y el contexto que inciden sobre los criterios sociales. Por su parte, los líderes de opinión y los representantes institucionales tienen una visión más global y distinguen mejor las líneas de desarrollo a largo plazo.

Para la contextualización (o interacción con el contexto):

- ✓ Los datos locales no siempre tienen la calidad y disponibilidad para considerar el contexto. Dado lo anterior, los estudios de campo son una opción para complementar la información local. Una triangulación por medio de entrevistas, revisión de proyectos ejecutados en el contexto y visitas de campo son una herramienta válida y confiable localmente. Esto permite tomar en cuenta los rangos de valores más adecuados para el contexto.
- ✓ En los países en desarrollo el estado actual de los criterios sociales tienden a presentar debilidades. En estos casos, y de acuerdo con el estudio del capítulo 5, se recomienda adoptar un nivel de satisfacción de baja exigencia, a través de la función de valor. Esta condición eleva la satisfacción, técnicamente representa de mejor forma la diferencia entre proyectos y promueve infraestructuras que aporten más en las áreas socialmente débiles.

Para el aprendizaje social:

- ✓ El aprendizaje social en los procesos de evaluación tiene un efecto a largo plazo y obedece a un proceso sistemático propuesto desde la primera implementación. Los métodos de evaluación deben considerar un proceso cíclico, una retroalimentación, tras cada revisión, y un alto compromiso institucional y de los participantes.
- ✓ Además, en el proceso de implementación, el uso de una plataforma virtual facilita la comunicación y el aprendizaje en un entorno participativo. Específicamente, el uso de documentos compartidos, la captura y el procesamiento automático de encuestas de AHP, o las vinculaciones que geo-referencian y especifican las alternativas de evaluación, se han empleado con éxito.
- ✓ En un ambiente de aprendizaje en aula (capítulo 4), también se recomienda permitir a los estudiantes adaptar una estructura de evaluación de acuerdo a los casos de estudio para contextualizar el problema y enriquecer la reflexión. De igual manera, las condiciones preestablecidas y exactas de los casos de estudio, alejadas de la realidad, no son recomendables.
- ✓ Por su parte, para los casos propuestos, se identifica la necesidad de mejorar la integración de la dimensión social de la sostenibilidad en los currículos de formación relacionados con la construcción. Específicamente, el tratamiento de variables cualitativas y la interpretación de los impactos sociales son más difíciles de abordar que los aspectos económicos o ambientales.

Para la estimación social de largo plazo (equidad intergeneracional):

- ✓ Para una evaluación de la contribución social a largo plazo, se recomienda informar a los participantes sobre los planes estratégicos territoriales que influyen en el desarrollo de las alternativas de infraestructuras. Así también, los indicadores locales y su posición respecto del territorio deben ser conocidos por los evaluadores. Esta información, más a la experiencia en el contexto y especialidad de cada participante, orienta el juicio que se lleva a un consenso posteriormente.

Para tratar la incertidumbre de los datos:

- ✓ De acuerdo al estudio del capítulo 6, para reducir el tiempo computacional se recomienda identificar los indicadores (variables de proyectos y factores condicionantes del contexto) que efectivamente presentan incertidumbre e influyen en el resultado de la priorización. Los especialistas del contexto pueden identificar los indicadores inciertos y sus valores probables (máximo, mínimo y moda). Por su parte, un análisis de sensibilidad previo identifica la influencia que cada indicador tiene sobre la priorización.
- ✓ De acuerdo al estudio del capítulo 6, se recomienda la consideración de resultados con una confiabilidad superior o igual al 90%. De otra forma, se requiere una mayor precisión de los antecedentes de entrada. Cuando la información proviene de la consulta a especialistas la aplicación previa del método Delphi ayuda a reducir la incertidumbre.

Para la implementación práctica:

- ✓ Las agencias públicas encargadas de la formulación de los proyectos deben mantener formatos estandarizados que incorporen los aspectos sociales para facilitar el proceso de implementación del método. En esta línea, se pueden implementar plantillas electrónicas que faciliten la organización y procesamiento de la información.
- ✓ De acuerdo con los estudios del capítulo 5, para una mayor facilidad y comparación del desempeño de las infraestructuras es adecuado modelar la respuesta de las funciones de transferencia en un escala de 0 a 100 o equivalente. Esto permite normalizar desde un principio los efectos de la interacción de los indicadores del proyecto (variables del proyecto) y del contexto (factores condicionantes). Además, para una mayor facilidad, las funciones de transferencias pueden configurarse a través de una interpolación (escalas artificiales para variables cuantitativas), por sistemas de puntuación discretos (para variables cualitativas) o una mezcla de ambos.
- ✓ En consideración con el capítulo 7, los estados de medición de las variables de decisión deben definirse claramente. Se aconseja un número menor de cuatro estados de medición. En caso contrario existe un incremento notorio en el tiempo computacional requerido para el procesamiento del método.

9.3 Limitaciones

Los estudios llevados a cabo en esta investigación proponen métodos para conseguir un adecuado tratamiento de la sostenibilidad social de infraestructuras e incorporarla en la toma de decisión. Estos resultados se deben ver a la luz de las siguientes limitaciones presentes en la investigación.

Limitaciones de la revisión del estado del arte:

- ✓ Los resultados de la revisión de la literatura están limitados a un proceso de revisión entre 1995 y enero de 2017, considerando los métodos de evaluación multicriterio de infraestructuras y los aspectos sociales.

Condiciones metodológicas para la implementación:

- ✓ Al considerar el AHP en cualquiera de los métodos, solo se consideran los efectos directos de primer orden que cada infraestructura ejerce sobre cada criterio. Una extensión del método requeriría emplear herramientas que permiten la interacción entre criterios con impactos de orden superior. Esto es posible a través de un proceso analítico en red (Analytic Network Process, ANP en inglés). Sin embargo su implementación requiere de mayor preparación de los participantes y un mayor tiempo de implementación.
- ✓ Los resultados de los métodos (capítulos 4, 5 y 6) están condicionados al desempeño de un conjunto específico de proyectos de infraestructuras. La introducción o exclusión de alguna alternativa puede alterar el resultado de la priorización.
- ✓ Las variables de decisión (capítulo 7) o factores condicionantes (capitulo 5) que interactúan sobre los criterios sociales deben ser independientes entre sí. Esta condición permite el empleo de la técnica de razonamiento Bayesiano a través del operador Noise-OR (capítulo 7) y permite no alterar los resultados de las funciones de transferencia.
- ✓ Las interacciones del modelo del capítulo 7 no consideran las condiciones de sinergia o interferencias de las variables de decisión sobre los criterios sociales, ni tampoco de los criterios sobre las contribuciones sociales a corto y largo plazo. La implementación de esta condición requiere de un número importante de preguntas adicionales a los participantes y una operatoria más compleja de razonamiento bayesiano (Noise-OR recursivo).

Limitaciones para la definicion de la estructura de evaluación de la sostenibilidad social con un enfoque multidisciplinario:

- ✓ Los resultados de la contextualización de los criterios sociales trascendentes en el ciclo de infraestructuras están limitados a la opinión de 24 especialistas multidisciplinarios chilenos (capítulo 3), y 29 y 31 especialistas multidisciplinarios de El Salvador para los estudios de los capítulos 5 y 7 respectivamente.
- ✓ Se han considerado únicamente infraestructuras civiles de uso público, interurbanas y con impactos predecibles de acuerdo a la experiencia compartida de los especialistas.
- ✓ En países en desarrollo con una limitada coordinación de las acciones ministeriales, las líneas de desarrollo regional son poco claras. Es decir, internamente las necesidades de mejora y los objetivos regionales futuros no están preestablecidos. En estos casos, la implementación del método (capítulos 5 y 7) requiere un mayor

esfuerzo en el consenso de los elementos que componen la estructura de toma de decisión. En estos casos, solo después de procesos cíclicos de evaluación y el logro del aprendizaje se espera un ajuste de los elementos a considerar por los participantes.

- ✓ Respecto de los elementos del modelo de evaluación del capítulo 7, un alto número de variables de decisión, de sus estados de medición o del número de criterios incrementa exponencialmente el tiempo computacional requerido para obtener los resultados optimizados. En este sentido, el modelo sólo debe incorporar los elementos y relaciones imprescindibles para orientar la planificación y diseño de la infraestructura socialmente sostenibles.

Limitaciones para el tratamiento de la incertidumbre:

- ✓ Cuanto más avanzada es la formulación de los proyectos, la incertidumbre de la información requerida para la implementación del método es menor. Los proyectos pueden ser sometidos a evaluación, incorporando estudios de campo en el contexto que adicionan la información más probable para ese tipo de proyecto.
- ✓ Proyectos de infraestructura con atributos sociales similares puede tener una baja confiabilidad en la priorización del método de los capítulos 5 y 6. Esta condición limita la utilidad del resultado general a la consideración de alternativas con algún grado de diferenciación. En estos casos, es necesaria una revisión de los resultados parciales de los desempeño de los criterios para considerar si existen más de una alternativa elegible simultáneamente.
- ✓ El proceso participativo para la evaluación a largo plazo en el método del capítulo 5 requiere un tratamiento previo a través del método Delphi para reducir la incertidumbre inherente a la valoración humana. Esto permite legitimar el proceso ante los participantes y obtener niveles de confiabilidad aceptables.
- ✓ En el método del capítulo 7, la determinación de las tablas de probabilidades condicionales por cada uno de los participantes es una tarea laboriosa pero necesaria para dar operatividad al modelo. En este sentido, los modelos más reducidos mejoran la implementación.

Condiciones para el aprendizaje en el proceso de evaluación:

- ✓ El logro del aprendizaje de la sostenibilidad de las infraestructuras a través de la evaluación multicriterio está sujeto al cumplimiento de las siguientes condiciones:
  - Se requiere que los participantes cuenten con un mínimo nivel de desarrollo profesional en el área de la construcción.
  - Para un caso controlado en aula, se requiere un mínimo número de estudiantes (al menos 20) para conformar equipos de trabajo que representen los perfiles de la sostenibilidad.

- El facilitador debe contar con conocimiento y experiencia en el área de la construcción y la sostenibilidad.

Limitaciones generales para la implementación institucional:

- ✓ Los métodos (capítulos 5 y 7) requieren de un ente coordinador que administre los procesos. Como todo proceso participativo y activo, la implementación requiere una planificación y tiempo para su desarrollo. Para una administracion adecuada, las plantillas de cálculo y el Matlab permiten agilizar el procesamiento de la información. Además, se requieren datos organizados derivados de la formulación completa de proyectos de infraestructuras. En otros casos el ordenamiento y recopilación de la información dificulta la implementación del proceso de evaluación.
- ✓ Actualmente el método (especialmente del capítulo 5) considera procesos adaptables a cualquier territorio pudiendo ser difícil de implementar por un organismo sin una previa preparación. Por lo tanto, además de un entrenamiento, es deseable simplificar la operatividad de los procesos. Esto puede lograrse contextualizando el método a específicos tipos de infraestructura y alcances geográficos dentro de un determinado país o región.

9.4 Futuras líneas de investigación

1. Se pueden proponer métodos para la implementación de la equidad y procesos de aprendizaje social de la sostenibilidad en los sistemas de evaluación multicriterio de infraestructuras. De acuerdo a la situación actual la cantidad de estudios que aborda estos aspectos no supera el 17%. Además, no se han evidenciado procesos de implementación de la equidad intergeneracional en contextos reales.

2. Respecto del desarrollo de métodos de aprendizaje de la sostenibilidad en aula, se visualizan las siguientes líneas de desarrollo futuro:
   - Proponer estrategias o métodos de aprendizaje de la sostenibilidad que distingan la interacción de los impactos de orden superior, dada la intervención de una infraestructura.
   - Además, es necesario una revisión de las actividades formativas y sus efectos sobre la integración de la dimensión social de la sostenibilidad en los currículos de formación de la construcción.
   - En este sentido también es deseable identificar los factores que inciden en el comportamiento del profesional del área de la construcción respecto de la sostenibilidad, y la incidencia de los procesos de formación.

3. Para mejorar la implementación se sugiere simplificar los métodos propuestos a través de la adaptación a tipos específicos de infraestructuras y zonas geográficas. La simplificación permite mejorar condiciones de transparencia en un proceso participativo y mejorar la legitimidad de la toma de decisión. Una simplificación respecto del método del capítulo 5 puede requerir el estudio de los contextos para establecer factores condicionantes y sus relaciones con las variables de un tipo de infraestructura para definir específicas funciones de transferencia. Complementariamente, se necesita estudiar las variables que requieren un tratamiento de la incertidumbre de cada contexto y tipo de infraestructura. Análogamente, en el método del capítulo 7, es necesario precisar para otros contextos e infraestructuras las variables de decisión, sus estados de medición, los criterios sociales y sus interacciones sobre las contribuciones a la mejora social a corto y largo plazo.

4. En el proceso contextualización también es necesario un tratamiento para la participación de personas no expertas. La simplificación del método mejora las condiciones para la participación y la legitimidad de las personas no expertas. En estos casos marcos de objetivos sociales de corto y largo plazo deben estar previamente definidos para centrar la atención en los aspectos locales

5. Alternativamente, el desarrollo de una herramienta virtual, en red y en un entorno amigable es necesaria para facilitar la definición de las estructuras de evaluación en un entorno participativo. Esta herramienta permitiría ampliar el alcance de participación, del aprendizaje y, además, facilitaría la tarea reflexiva del evaluador para lograr estructuras de evaluación más robustas y legítimas durante la implementación de los métodos.

6. Es posible ampliar el alcance de los métodos (capítulos 5, 6, y 7), incorporando las dimensiones ambientales y económicas de la sostenibilidad y sus interacciones. Esta nueva consideración requiere del modelado y procesamiento de una estructura de evaluación de criterios en red.

7. También se puede proponer un sistema metodológico para establecer las áreas de influencia de cada proyecto de infraestructura en consideración de las implicancias sociales sobre el territorio. El desarrollo de esta línea permitiría una mejor aproximación de las contribuciones sociales de un proyecto de infraestructura.

8. Es factible realizar un tratamiento integrado al método (capítulo 5 y 7) para distribuir el aporte de la mejora social a corto plazo entre los actores de interés. Este aporte permite determinar la equidad en la distribución de los beneficios de la infraestructura a corto plazo. Este enfoque requiere un mecanismo para tratar los beneficios compartidos y una clasificación estandarizada y transversal de los actores de interés.

9. El procesamiento de la incertidumbre puede mejorarse para identificar proyectos múltiples elegibles que contribuyan de manera similar a la mejora social, sin que ello implique un resultado de menor confiabilidad en la priorización final. Para ello se requiere una presentación de los resultados más extensa, que permita un análisis de los resultados parciales. Además, las relaciones que determinen una prioridad combinada pueden ser interesantes para identificar un nuevo estado de confiabilidad.

10. Respecto al método propuesto en el capítulo 7, se pueden incorporar las condiciones de sinergia e interferencia en las interacciones del modelo de toma de decisión. Esto requiere del planteamiento de preguntas adicionales a los participantes y una formulación a través de un operador Noise-OR recursivo.

CONCLUSIONS

In this chapter the main contributions and limitations of this study are summarized. The proposed studies have made it possible to reach the defined goals. Discussion of the achievement of the objectives presented in chapter 8 is summarized in Figure 8.1. From this point, the contributions derived from the general research question are set out. Then, the recommendations for implementing the methods in the infrastructure evaluation processes are presented. Next, the methodological limitations of the study are outlined. Finally, future lines of research are suggested.

9.1 Research contributions

In the following sections the contributions derived from the intermediate chapters are presented in relation to the general research question, Is it possible to evaluate the social sustainability of infrastructures by integrating it into the decision-making? This question seeks to delve into the implementation of treatments to assess the social sustainability of infrastructures and whether such treatments make it possible to integrate social sustainability into the decision-making for planning a territory.

The proposed studies are able to integrate the social sustainability assessment into the decision-making through social improvement indicators. These indicators have allowed, in one study, the prioritization of the best infrastructure, and in another one the determination of its characteristics for planning. This was possible given a simultaneous treatment of social sustainability based on:

- Intergenerational equity through an assessment structure that considers the long-term social improvement of vulnerable contexts, and a system of decision-making that does not compensate it with current needs.
- The social learning of sustainability through a process of infrastructure assessment.
- Interaction with the elements of context and level of development.
- A proposal of general social criteria adaptable to a context and the life cycle stages of an infrastructure.
- A multidisciplinary and multi-sector participation in the assessment process that represents the stakeholders.
- Control of the uncertainty of the data that safeguards the robustness of the prioritization.

Therefore, the study offers specific treatments through a multicriteria approach. This contribution improves and provides tools for the early planning of infrastructures in a manner consistent with the territorial development proposals. The results of this study benefit the entities in charge of prioritizing public infrastructures. The following points specify each social sustainability treatment that makes up the contribution of the study:

- An assessment structure is suggested that differentiates the social contribution of infrastructures from short and long-term development. This way, the decision-making not only includes infrastructures that strengthen economically active zones, but also those with social needs that have a potential for long-term improvement. The simultaneous and non-compensatory consideration of these approaches aids in identifying infrastructures that contribute to the intergenerational equity of a territory.
- The social learning of sustainability is achieved through a process of infrastructure assessment. This investigation sets out the effects of the evaluators' training, experiences and priorities in making decisions about sustainable infrastructures. On this basis, it is proposed that the assessment systems should be a means of social learning about sustainability. The cyclical evaluations of these systems seek to reach a state of maturity in the evaluators with respect to the needs of the context to achieve a sustainable state.
- The social contribution of an infrastructure within a territory can be distinguished. The studies conducted propose an approach of composite indicators that represent the interaction between the project contributions and the contextual conditions for each social criterion. The composite indicators are implemented through transfer functions and a cause-effect model. In addition, according to the level of development of each context, a value function is adapted to promote alternatives that bolster weak social criteria. Thus, the soft systems theory approach, based on knowledge of the context, could be incorporated into the social sustainability assessment of infrastructure projects.
- A set of 23 social criteria with local, regional and national reach was determined, which are influenced by different public infrastructures and life cycle stages. These criteria can be used as a reference for the most specific contextualization of a type of infrastructure and place. Other categorizations are oriented to the area of corporate social responsibility, or are context-specific, or they do not adapt to the impact of public infrastructures.
- The multidisciplinary and multi-sector participation is successfully integrated in order to contextualize the social criteria of an infrastructure, to determine the assessment structure, and to participate in the assessment processes. Other approaches have been based solely on infrastructure experts or do not include the adequate treatment of the remaining social aspects.
- The control of uncertainty is successfully integrated along with the other treatments for social sustainability. Where there is a lack of data, the information based on specialists made it possible to obtain conditional distributions and probabilities suited to the context. In addition, the discrete probability functions permitted the integration of each evaluator's independent judgments. Thus, a level of reliability is obtained that conditions the robustness of the prioritization. These

conditions of process and result provide greater legitimacy that the participants can see.

9.2 Recommendations

From the implementation of the studies in the investigation, measures are identified to incorporate the infrastructure assessment processes that include social aspects. Recommendations are presented in the following areas:

For participation:

- ✓ The participatory processes in the assessment methods must include the local population affected. Consideration of the local community helps determine the problem and the needs; however, obtaining conclusive results also requires academic or specialized participation. Therefore, participation through multidisciplinary representatives is a valid option to interpret the information from the local community. In addition, it is recommended that the members fulfill certain academic and availability conditions that produce decision-making based on argumentation and evidence.
- ✓ The make-up of the multidisciplinary panel must be less than eight people and implementation of the Delphi method should require at least three rounds. This allows for the diversity of points of view for the reflection and learning of the participants until an agreement is reached.
- ✓ It is also recommended that the consultations be adjusted to the group's work environment, i.e., the participants who are in regular contact with the communities and the project development more easily identify the specific variables of the project and the context that affects the social criteria. For their part, opinion leaders and representatives have a more global view and can better distinguish the lines of long-term development.

For contextualization (or interaction with the context):

- ✓ The local data do not always have the quality and availability to consider the context. Therefore, field studies are an option to complement local information. A triangulation by means of interviews, review of projects executed in the context and field visits are a valid and reliable tool locally. This can then take into account the most suitable value ranges for the context.
- ✓ In developing countries the current state of social criteria tends to present weaknesses. As such, and according to the study in chapter 5, it is recommended that a low level of satisfaction be adopted via the value function. This condition increases the satisfaction; technically it best represents the difference between projects and promotes infrastructures that contribute more in socially weak areas.

For social learning:

- ✓ Social learning in the assessment processes has a long-term effect and obeys a systematic process proposed from the first implementation. The assessment methods must include a cyclical process, feedback after each review, and a strong commitment from the institution and the participants.
- ✓ In addition, in the implementation process, the use of a virtual platform ensures communications and learning in a participatory environment. Specifically, the use of shared documents, the capture and automatic processing of AHP surveys, or the links that georeference and specify the assessment alternatives have all been used successfully.
- ✓ In an atmosphere of classroom learning (chapter 4), it is also recommended that the students be permitted to adapt an assessment structure according to the case studies so as to contextualize the problem and enhance reflection. Likewise, it is not advisable to have pre-established and exact conditions for the case studies, removed from reality.
- ✓ Additionally, for the proposed cases, the need to improve the integration of the social dimension of sustainability in construction-related training curricula is identified. Specifically, the treatment of qualitative variables and the interpretation of the social impact are more difficult to address than the economic or environmental aspects.

For long-term social assessment (intergenerational equity):

- ✓ For an assessment of the social contribution in the long term, it is recommended that the participants be informed about territorial strategic plans that influence the development of the infrastructure alternatives. Thus, the local indicators and their position with respect to the territory must also be known by the evaluators. This information, more than each participant's experience in the context and specialty, guides the judgment that will lead to a consensus.

Treating the uncertainty of the data:

- ✓ According to the study in chapter 6, to reduce the computer time it is recommended that the indicators be identified (project variables and conditioning factors of the context) that effectively present uncertainty and influence the result of the prioritization. The context specialists can identify the uncertain indicators and their likely values (maximum, minimum and mode). On the other hand, a prior sensitivity analysis identifies the influence that each indicator has on the prioritization.
- ✓ According to the study in chapter 6, consideration of results with a reliability equal to or greater than 90% is recommended. Otherwise, greater accuracy of the input data is required. When the information comes from the consultation with specialists, prior application of the Delphi method helps reduce the uncertainty.

For the practical implementation:

- ✓ The public agencies responsible for the formulation of projects must maintain standardized formats that incorporate the social aspects so as to facilitate the implementation of the method. In this vein, electronic templates can be created to facilitate data organization and processing.
- ✓ According to the studies in chapter 5, for greater ease and comparison of the performance of infrastructures, it is appropriate to model the response of the transfer functions on a scale from 0 to 100 or equivalent. This makes it possible to standardize the effects of the interaction of the project indicators (project variables) and the context (conditioning factors) right from the beginning. Also for greater ease, the transfer functions can be configured through an interpolation (artificial scales for quantitative variables), through discrete scoring systems (for qualitative variables), or a mixture of the two.
- ✓ Considering chapter 7, the measurement modes of the decision variables must be clearly defined. A number less than four measurement modes is advised. Otherwise, there is a sharp increase in the computer time required to process the method.

9.3 Limitations

The studies conducted in this investigation offer methods to secure adequate treatment of the social sustainability of infrastructures and incorporate it into the decision-making. These results should be seen in the light of the following limitations present in the investigation.

Limitations of the review of the state of the art:

- ✓ The results of the literature review are limited to a review process between 1995 and January 2017, considering the multicriteria assessment of infrastructures and the social aspects.

Methodological conditions for the implementation:

- ✓ When the AHP is considered in any of the methods, only the direct first-order effects that each infrastructure exerts on each criterion are considered. An extension of the method would require using tools that take interaction between criteria with higher-order impacts into account. This is possible through an analytic network process (ANP). Nevertheless, its implementation requires greater preparation from the participants and a longer implementation time.
- ✓ The results of the methods (chapters 4, 5 and 6) are dependent on the performance of a specific set of infrastructure projects. The introduction or exclusion of an alternative may alter the prioritization outcome.
- ✓ The decision variables (chapter 7) or conditioning factors (chapter 5) that interact on the social criteria must be independent of one another. This condition makes possible

the use of Bayesian reasoning through the noisy-OR gate (chapter 7) and prevents the results of the transfer functions from being altered.

- ✓ The interactions of the model in chapter 7 do not consider the synergy or interferences of the decision variables on the social criteria, nor of the criteria on the short and long-term social contributions. The implementation of this condition requires that an important number of additional questions be put to the participants and a more complex Bayesian reasoning operation (recursive noisy OR).

Limitations to the definition of the social sustainability assessment structure with a multidisciplinary approach:

- ✓ The results of the contextualization of the important social criteria in the life cycle infrastructures are limited to the opinion of 24 Chilean multidisciplinary specialists (chapter 3), and 29 and 31 multidisciplinary specialists in El Salvador for the studies in chapters 5 and 7, respectively.
- ✓ Only civil infrastructures of public use, intercity and with predictable effects according to the shared experience of the specialists have been considered.
- ✓ In developing countries with a limited coordination of ministerial actions, the lines of regional development are unclear. This is to say, the future needs for improvement and regional objectives are not pre-established internally. In such cases, the implementation of the method (chapters 5 and 7) requires a greater effort in the consensus of the elements that make up the decision-making structure. In these cases, only once the cyclical assessment processes and learning have been achieved can an adjustment of the elements to be considered by the participants be expected.
- ✓ With respect to the elements of the assessment model in chapter 7, a high number of decision variables, their measurement modes or the number of criteria exponentially increases the computer time required to obtain the optimized results. In this sense, the model must only incorporate the elements and relationships essential to orienting the planning and design of the socially sustainable infrastructure.

Limitations to the treatment of uncertainty:

- ✓ The more advanced the formulation of the projects, the lower the uncertainty of the information required for the implementation of the method. The projects can be subjected to evaluation, incorporating contextual field studies that add the most likely information for that type of project.
- ✓ Infrastructure projects with similar social attributes can have low reliability in the prioritization of the method in chapters 5 and 6. This condition limits the usefulness of the general result to the consideration of alternatives with some degree of differentiation. In these cases, the partial results of the performance of the criteria must be reviewed in order to consider whether there is more than one eligible alternative simultaneously.

- ✓ The participatory process for the long-term assessment in the method in chapter 5 requires a previous treatment through the Delphi method to reduce the uncertainty inherent to human assessment. This legitimizes the process to the participants and reaches acceptable levels of reliability.
- ✓ In the method in chapter 7, determination of the conditional probability tables by each of the participants is an arduous but necessary task to operationalize the model. In this sense, the most reduced models improve the implementation.

Conditions for learning in the assessment process:

- ✓ The achievement of learning about the sustainability of infrastructures through the multicriteria evaluation is subject to fulfillment of the following conditions:
  - The participants must have a minimum level of professional development in the area of construction.
  - For a controlled case in the classroom, a minimum number of students is required (at least 20) to form working groups that represent the sustainability profiles.
  - The facilitator must have knowledge and experience in the area of construction and sustainability.

General limitations for institutional implementation:

- ✓ The methods (chapters 5 and 7) require a coordinating body to administer the processes. Like every participatory and active process, implementation requires planning and time for its development. For suitable administration, the spreadsheets and Matlab expedite the data processing. In addition, organized data derived from the full formulation of infrastructure projects are required. In other cases the ordering and compilation of the information make it difficult to implement the assessment process.
- ✓ Currently, the method (especially in chapter 5) considers processes adaptable to any territory, and it can be difficult for any entity to implement them without previous preparation. Therefore, in addition to training, it is advisable to simplify the operability of the processes. This can be done by contextualizing the method to specific types of infrastructure and geographic ranges within a certain country or region.

9.4 Future lines of research

1. Methods can be proposed for the implementation of equity and social learning processes for sustainability in the multicriteria assessment systems of infrastructures. According to the current situation, the number of studies that addresses these aspects

does not exceed 17%. In addition, no implementation processes of intergenerational equity have been demonstrated in real-life contexts.

2. With respect to the development of methods for learning about sustainability in the classroom, the following future lines of development are envisioned:
   - To propose strategies or methods for learning about sustainability that distinguish the interaction of higher-order effects, given the intervention of an infrastructure.
   - Additionally, a review is needed of the training activities and their effects on the integration of the social dimension of sustainability in the training curricula in construction.
   - In this sense, it would also be useful to identify the factors that affect the behavior of professionals in the area of construction in terms of sustainability, and the incidence of the training processes.

3. In order to improve the implementation, it is suggested that the methods proposed be simplified by adapting to specific types of infrastructures and geographic areas. Simplification would improve the conditions of transparency in a participatory process and improve the legitimacy of the decision-making. A simplification with respect to the method in chapter 5 may involve studying the contexts to establish conditioning factors and their connections to the variables of a type of infrastructure to define specific transfer functions. Furthermore, the variables that require a treatment of the uncertainty of each context and type of infrastructure must be studied. Similarly, in the method in chapter 7, it is necessary to specify for other contexts and infrastructures the decision variables, their measurement modes, social criteria and their interactions with the contributions to short and long-term social improvement.

4. In the contextualization process also a treatment for the participation of non-expert people is necessary. The simplification of the method improves the conditions for participation and the legitimacy of non-expert people. In these cases, short- and long-term social objectives frameworks should be previously defined to focus attention on local aspects

5. Alternatively, the development of a networked virtual tool in a friendly environment is needed to facilitate the definition of the assessment structures in a participatory environment. This tool would make it possible to extend the scope of participation, learning and, in addition, it would facilitate the reflective task of the evaluator to

obtain more robust and legitimate assessment structures during implementation of the methods.

6. It is possible to extend the range of the methods (chapters 5, 6, and 7) by incorporating the environmental and economic dimensions of sustainability and their interactions. This new consideration requires the modeling and processing of a networked criteria assessment structure.

7. A methodological system can also be proposed to establish the areas of influence of each infrastructure project, considering the social implications on the territory. The development of this line would allow a better approach to the social contributions of an infrastructure project.

8. It is feasible to perform a treatment integrated into the method (chapter 5 and 7) to distribute the contribution of short-term social improvement among the stakeholders. This contribution can determine the equity in the distribution of the benefits of the infrastructure in the short term. This approach requires a mechanism to deal with the shared benefits and a standardized and cross-sectional classification of the stakeholders.

9. Processing the uncertainty can be improved in order to identify eligible multiple projects that contribute similarly to social improvement, without implying a less reliable result in the final prioritization. To do this, a more extensive presentation of the results is required, which enables an analysis of the partial results. In addition, the relationships that determine a combined priority may be interesting to identify a new state of reliability.

10. With respect to the method proposed in chapter 7, the conditions of synergy and interference in the interactions of the decision-making model can be incorporated. This requires asking the participants additional questions and a formulation through a recursive noisy-OR gate.

REFERENCIAS

Abu Dabous, S., Alkass, S. (2008). Decision support method for multi-criteria selection of bridge rehabilitation strategy. Construction Management and Economics, 26(786929861), 883–893. https://doi.org/10.1080/01446190802071190

Aghdaie, M. H., Zolfani, S. H., Zavadskas, E. K. (2012). Prioritizing constructing projects of municipalities based on AHP and COPRAS-G: A case study about footbridges in Iran. The Baltic Journal of Road and Bridge Engineering, 7(2), 145–153. https://doi.org/10.3846/bjrbe.2012.20

Ahmadvand, M., Karami, E. (2009). A social impact assessment of the floodwater-spreading project on the Gareh-Bygone plain in Iran: A causal comparative approach. Environmental Impact Assessment Review, 29(2), 126–136. https://doi.org/10.1016/j.eiar.2008.08.001

Ahmadvand, M., Karami, E., Iman, M. T. (2011). Modeling the determinants of the social impacts of agricultural development projects. Environmental Impact Assessment Review, 31(1), 8–16. https://doi.org/10.1016/j.eiar.2010.06.004

Alarcón, B., Aguado, A., Manga, R., Josa, A. (2010). A Value Function for Assessing Sustainability: Application to Industrial Buildings. Sustainability, 3(1), 35–50. https://doi.org/10.3390/su3010035

Alarcón, D. B. (2005). Modelo integrado de valor para estructuras sostenibles. Universitat Politècnica de Catalunya.

Alarcón, L. F., Ashley, D. B., de Hanily, A. S., Molenaar, K. R., Ungo, R. (2011). Risk Planning and Management for the Panama Canal Expansion Program. Journal of Construction Engineering and Management, 137(10), 762–771. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000317

Alarcón, L. F., Pavez, I., Bascuñan, C., Diethelm, S. (2005). Diagnóstico Organizacional de Empresas Constructoras Chilenas. In Simpósio Brasileiro de Gestão e Economia da Construção. IV SIBRAGEC. Porto Alegre.

Alshubbak, A., Pellicer, E., Catalá, J., Teixeira, J. M. C. (2015). A model for identifying owner's needs in the building life cycle. Journal of Civil Engineering and Management, 21(8), 1046–1060. https://doi.org/10.3846/13923730.2015.1027257

Anand, S. Sen, A. (2000). Human Development and Economic Sustainability. World Development, 28(12), 2029–2049. https://doi.org/10.1016/S0305-750X(00)00071-1

Armour, A. (1990). Integrating impact assessment in the planning process. Impact Assessment, 8(1–2), 3–14. https://doi.org/10.1080/07349165.1990.9726024

Arroyo, P., Tommelein, I. D., Ballard, G. (2014). Comparing AHP and CBA as Decision Methods to Resolve the Choosing Problem in Detailed Design. Journal of Construction Engineering and Management, 141(Mcdm), 4014063. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000915

Asomani-Boateng, R., Fricano, R. J., Adarkwa, F. (2015). Assessing the socio-economic impacts of rural road improvements in Ghana: A case study of Transport Sector Program Support (II). Case Studies on Transport Policy. https://doi.org/10.1016/j.cstp.2015.04.006

Axelsson, R., Angelstam, P., Degerman, E., Teitelbaum, S., Andersson, K., Elbakidze, M., Drotz, M. K. (2013). Social and cultural sustainability: Criteria, indicators, verifier variables for measurement and maps for visualization to support planning. Ambio, 42(2), 215–228. https://doi.org/10.1007/s13280-012-0376-0

Azapagic, A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. Journal of Cleaner Production, 12(6), 639–662. https://doi.org/10.1016/S0959-6526(03)00075-1

Bakht, M. N., El-Diraby, T. E. (2015). Synthesis of decision-making research in construction. Journal of Construction Engineering and Management, 141(9), 4015027. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000984

Balali, V., Mottaghi, A., Shoghli, O., Golabchi, M. (2014). Selection of Appropriate Material, Construction Technique, and Structural System of Bridges by Use of Multicriteria Decision-Making Method. Transportation Research Record: Journal of the Transportation Research Board, 2431, 79–87. https://doi.org/10.3141/2431-11

Bertone, E., Sahin, O., Richards, R., Roiko, A. (2016). Extreme events, water quality and health: A participatory Bayesian risk assessment tool for managers of reservoirs. Journal of Cleaner Production, 135, 657–667. https://doi.org/10.1016/j.jclepro.2016.06.158

Bilec, M. M., Ries, R. J., Matthews, H. S. (2010). Life-Cycle Assessment Modeling of Construction Processes for Buildings. Journal of Infrastructure Systems, 16(3), 199–205. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000022

Boks, C., Diehl, J. C. (2006). Integration of sustainability in regular courses: experiences in industrial design engineering. Journal of Cleaner Production, 14(9–11), 932–939. https://doi.org/10.1016/j.jclepro.2005.11.038

Bonsall, P., Kelly, C. (2005). Road user charging and social exclusion: The impact of congestion charges on at-risk groups. Transport Policy, 12(5), 406–418. https://doi.org/10.1016/j.tranpol.2005.06.007

Boyle, C., Mudd, G., Mihelcic, J.R., Haven, N., Collins, T., Edwards, M., Handy, S., Lyles, L.D., Riedy, C., Reeder-emery, K. (2010). Delivering Sustainable Infrastructure that Supports the Urban Built Environmental Science Technology, 44(13), 4836–4840. https://doi.org/10.1021/es903749d

Boz, M. A., El-adaway, I. H. (2015). Creating a Holistic Systems Framework for Sustainability Assessment of Civil Infrastructure Projects. Journal of Construction Engineering and Management, 141(2), 4014067–1. https://doi.org/10.1061/(ASCE)CO .1943-7862.0000911

Bröcker, J., Korzhenevych, A., Schürmann, C. (2010). Assessing spatial equity and efficiency impacts of transport infrastructure projects. Transportation Research Part B: Methodological, 44(7), 795–811. https://doi.org/10.1016/j.trb.2009.12.008

Bucciarelli. L.L., Einstein, H., Terenzini, P., Walser, A. (2000). ECSEL / MIT Engineering Education Workshop’ 99 : A Report with Recommendations. Journal of Engineering Education, 141–150. https://doi.org/10.1002/j.2168-9830.2000.tb00508.x

Bueno, P. C., Vassallo, J. M. (2015). Setting the weights of sustainability criteria for the appraisal of transport projects. Transport, 30(3), 298–306. https://doi.org/10.3846/16484142.2015.1086890

Bueno, P. C., Vassallo, J. M., Cheung, K. (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods. Transport Reviews, 35(5), 622–649. https://doi.org/10.1080/01441647.2015.1041435

Burdge, R. J. (1995). A Community Guide to Social Impact Assessment. (Social Ecology Press, Ed.). Middleton.

Burdge, R. J. (2004). A Community Guide to Social Impact Assessment. Social Ecology Press (3rd Ed.). Middleton (WI, USA).

Byrne, E. P., Desha, C. J., Fitzpatrick, J. J., Hargroves, K. (2013). Exploring sustainability themes in engineering accreditation and curricula. International Journal of Sustainability in Higher Education, 14(4), 384–403. https://doi.org/10.1108/IJSHE-01-2012-0003

Caliskan, N. (2006). A decision support approach for the evaluation of transport investment alternatives. European Journal of Operational Research, 175(3), 1696–1704. https://doi.org/10.1016/j.ejor.2005.02.035

Cardenas, I. C., Halman, J. I. M. (2016). Coping with uncertainty in environmental impact assessments: Open techniques. Environmental Impact Assessment Review, 60, 24–39. https://doi.org/10.1016/j.eiar.2016.02.006

CEEQUAL ltd. (2010). The Assessment and Awards Scheme for improving sustainability in civil engineering and the public realm. Assessment Manual for Projects in the UK and Ireland (No. ver. 4.1). United Kingdom. Retrieved from www.ceequal.com

Chen, S. H., Pollino, C. A. (2012). Good practice in Bayesian network modelling. Environmental Modelling and Software, 37, 134–145. https://doi.org/10.1016/j.envsoft.2012.03.012

Chen, S., Leng, Y., Mao, B., Liu, S. (2014). Integrated weight-based multi-criteria evaluation on transfer in large transport terminals: A case study of the Beijing South Railway Station. Transportation Research Part A: Policy and Practice, 66(1), 13–26. https://doi.org/10.1016/j.tra.2014.04.015

Chow, J. Y. J., Hernandez, S. V., Bhagat, A., McNally, M. G. (2014). Multi-Criteria Sustainability Assessment in Transport Planning for Recreational Travel. International Journal of Sustainable Transportation, 8(2), 151–175. https://doi.org/10.1080/15568318.2011.654177

CIB (Internacional Council for Research and Innovation in Building and Construction) (2002). Agenda 21 for Sustainable Construction in Developing Countries. Report Publication No. E0204, Pretoria, South Africa.

Colantonio, A. (2011). Social Sustainability: Exploring the Linkages Between Research, Policy and Practice. In C. C. Jaeger, J. D. Tàbara, J. Jaeger (Eds.), European Research on Sustainable Development Volume 1: Transformative Science Approaches for Sustainability (pp. 35–57). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-19202-9

Cortés, J. M., Pellicer, E., Catalá, J. (2012). Integration of occupational risk prevention courses in engineering degrees: Delphi study. Journal of Professional Issues in Engineering Education and Practice, 138(1), 31–36. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000076

Curiel-Esparza, J., Mazario-Diez, J. L., Canto-Perello, J., Martin-Utrillas, M. (2016). Prioritization by consensus of enhancements for sustainable mobility in urban areas. Environmental Science and Policy, 55, 248–257. https://doi.org/10.1016/j.envsci.2015.10.015

Dasgupta, S., Tam, E. K. (2005). Indicators and framework for assessing sustainable infrastructure. Canadian Journal of Civil Engineering, 32(1), 30–44. https://doi.org/10.1139/l04-101

De la Cruz, M. P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J. J. (2015). Chapter 4 Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1 : The MIVES - Monte Carlo Method. In C. Corona, A. Arredondo, M. Cascales (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency (pp. 69–106). IGI Global. https://doi.org/10.4018/978-1-4666-6631-3.ch004

De la Cruz, M. P., Castro, A., del Caño, A., Gómez, D., Lara, M., Gradaille, G. (2015). Chapter 5: Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 2: The Fuzzy-MIVES Method. In C. Corona, J. Lozano, M. Cascales (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency (pp. 107–140). IGI Global. https://doi.org/10.1017/CBO9781107415324.004

Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method : A case study of a mining project in Peru. Environmental Modelling and Software, 77, 108–121. https://doi.org/10.1016/j.envsoft.2015.12.011

Delgado, A., Romero, I., (2017). Integrating Social Impact Assessment and Environmental Conflict Analysis on a Hydrocarbon Exploration Project in Spain. Int. J. Eng. Technol. 8(6), 2403–2417. https://doi.org/10.21817/ijet/2016/v8i6/160806402

Dendena, B., Corsi, S. (2015). The Environmental and Social Impact Assessment (ESIA): a further step towards an integrated assessment process. Journal of Cleaner Production, 108, 965–977. https://doi.org/10.1016/j.jclepro.2015.07.110

DESA (Department of Economic and Social Affairs). (2007). Indicators of Sustainable Development : Guidelines and Methodologies (3rd.Ed). New York: United Nations. https://doi.org/10.1016/j.cirpj.2010.03.002

DGMA (Dirección General del Medio Ambiente). (2000a). Methodological Guidelines for the Preparation of Environmental Impact Studies: Large Dams. Madrid, Spain.

DGMA (Dirección General del Medio Ambiente). (2000b). Methodological Guidelines for the Preparation of Environmental Impact Studies: Roads and Railways (No. 2nd Ed). Madrid, Spain.

Di Cesare, S., Silveri, F., Sala, S., Petti, L. (2016). Positive impacts in social life cycle assessment: state of the art and the way forward. International Journal of Life Cycle Assessment, In Press, 1–16. https://doi.org/10.1007/s11367-016-1169-7

Diaz-Sarachaga, J. M., Jato-Espino, D., Alsulami, B., Castro-Fresno, D. (2016). Evaluation of existing sustainable infrastructure rating systems for their application in developing countries. Ecological Indicators, 71, 491–502. https://doi.org/10.1016/j.ecolind.2016.07.033

Diaz-Sarachaga, J. M., Jato-Espino, D., Castro-Fresno, D. (2017a). Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC). Environmental Science and Policy, 69(1), 65–72. https://doi.org/10.1016/j.envsci.2016.12.010

Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D. (2017b). Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study. Environ. Sci. Policy. 69(1): 73–80. doi:10.1016/j.envsci.2016.12.011

Diez, F. J., Druzdrel, M. J. (2007). "Canonical probabilistic models for knowledge engineering" Technical Rep. CISIAD-06-01, Universidad Nacional de Educacion a Distancia, Madrid, Spain, ⟨http://www.ia.uned.es/~fjdiez/papers/canonical.pdf⟩ (Feb. 01, 2016).

DIGESTYC – Dirección General de Estadísticas y Censos. (2014). Encuesta de Hogares y Propósitos Múltiples 2014. Dirección General de Estadística y Censos. El Salvador, San Salvador. Retrieved from http://www.digestyc.gob.sv/index.php/temas/des/ehpm/publicaciones-ehpm.html

Domínguez-Gómez, J. A. (2016). Four conceptual issues to consider in integrating social and environmental factors in risk and impact assessments. Environmental Impact Assessment Review, 56, 113–119. https://doi.org/10.1016/j.eiar.2015.09.009

Du, X., Su, L., Liu, J. (2013). Developing sustainability curricula using the PBL method in a Chinese context. Journal of Cleaner Production, 61, 80–88. https://doi.org/10.1016/j.jclepro.2013.01.012

Dwyer, B., Byrne, E. P. (2010). Practical skills and techniques for the transition to a sustainable future, a case study for engineering education. In University College Cork (Ed.), 3rd International Symposium for Engineering Education ISEE2010, Educating Engineers for a Changing World - Leading transformation from an unsustainable global society (pp. 326–333). Ireland. Retrieved from http://portal.acm.org/citation.cfm?doid=1773814.1773817

Égré, D., Senécal, P. (2003). Social impact assessments of large dams throughout the world: lessons learned over two decades. Impact Assessment and Project Appraisal, 21(3), 215–224. https://doi.org/10.3152/147154603781766310

El-Adaway, I., Pierrakos, O., Truax, D. (2015). Sustainable Construction Education Using Problem-Based Learning and Service Learning Pedagogies. Journal of Professional Issues in Engineering Education and Practice, 141(1). https://doi.org/10.1061/(ASCE)EI.1943-5541.0000208

Esteves, A. M., Vanclay, F. (2009). Social Development Needs Analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry. Environmental Impact Assessment Review, 29(2), 137–145. https://doi.org/10.1016/j.eiar.2008.08.004

Fernández-Sánchez, G., Rodríguez-López, F. (2010). A methodology to identify sustainability indicators in construction project management - Application to infrastructure projects in Spain. Ecological Indicators, 10(6), 1193–1201. https://doi.org/10.1016/j.ecolind.2010.04.009

Ferrufino, C. E., Gutiérrez, S., Zeledón, A. (2005). Plan nacional de ordenamiento y desarrollo territorial (PNODT): una lectura desde la sociedad civil. Fundación Nacional para el Desarrollo. San Salvador.

FHWA- Federal Highway Administration. (2003). Economic Analysis Primer (Department of Transportation, FHWA, Office of Asset Management). Washington, D.C.

Finsterbusch, K. (1985). State of the Art in Social Impact Assessment. Environment and Behavior, 17(2), 193–221. https://doi.org/10.1177/0013916585172002

Florez, L., Castro-Lacouture, D., Medaglia, A. L. (2013). Sustainable workforce scheduling in construction program management. Journal of the Operational Research Society, 64(8), 1169–1181. https://doi.org/10.1057/jors.2012.164

Foth, N., Manaugh, K., El-Geneidy, A. M. (2013). Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006. Journal of Transport Geography, 29, 1–10. https://doi.org/10.1016/j.jtrangeo.2012.12.008

Fulford, R. S., Smith, L. M., Harwell, M., Dantin, D., Russell, M., Harvey, J. (2015). Human well-being differs by community type: Toward reference points in a human well-being indicator useful for decision support. Ecological Indicators, 56, 194–204. https://doi.org/10.1016/j.ecolind.2015.04.003

Gannon, C., Liu, Z. (1997). Poverty and Transport (No. TWU-30). Washington, D.C.: The World Bank.

Gannon, C., Lui, Z. (2001). Transporte : Infraestructura y servicios. Washington, D.C.: The World Bank. Retrieved from www.worlbank.org

García-Segura, T., Yepes, V. (2016). Multiobjective optimization of post-tensioned concrete box-girder road bridges considering cost, CO2 emissions, and safety. Engineering Structures, 125, 325–336. https://doi.org/10.1016/j.engstruct.2016.07.012

García-Segura, T., Yepes, V., Alcalá, J. (2014). Life cycle greenhouse gas emissions of blended cement concrete including carbonation and durability. The International Journal of Life Cycle Assessment, 19(1), 3–12. https://doi.org/10.1007/s11367-013-0614-0

García-Segura, T., Yepes, V., Alcalá, J., Pérez-López, E. (2015). Hybrid harmony search for sustainable design of post-tensioned concrete box-girder pedestrian bridges. Engineering Structures, 92, 112–122. https://doi.org/10.1016/j.engstruct.2015.03.015

Gardner, J. (1989). Decision making for sustainable development: selected approaches to environmental assessment and management. Environmental Impact Assessment Review, 9, 337–366. https://doi.org/10.1016/0195-9255(89)90028-0

Geem, Z. W., Kim, J. H., Loganathan, G. V. (2001). A new heuristic optimization algorithm: Harmony search. SIMULATION, 76(2), 60–68. https://doi.org/10.1177/003754970107600201

George, D., Mallery, P. (2003). SPSS for Windows Step by Step: A Simple Guide and Reference Fourth Edition (11.0 update) (4th Ed). Boston: Allyn Bacon.

Gervásio, H., Da Silva, L.S. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Systems with Applications, 39(8), 7121–7131. https://doi.org/10.1016/j.eswa.2012.01.032

Gervásio, H., Da Silva, L.S. (2013). Life-cycle social analysis of motorway bridges. Structure and Infrastructure Engineering. 9(10), 1019–1039. https://doi.org/10.1080/15732479.2011.654124

Gilchrist, A., Allouche, E. N. (2005). Quantification of social costs associated with construction projects: State-of-the-art review. Tunnelling and Underground Space Technology, 20(1), 89–104. https://doi.org/10.1016/j.tust.2004.04.003

Gilmour, D., Blackwood, D., Banks, L., Wilson, F. (2011). Sustainable development indicators for major infrastructure projects. Proceedings of the Institution of Civil Engineers-Municipal Engineer, 164(1), 15–24. https://doi.org/10.1680/muen.800020

Gómez-López, D., Del Caño, A., De la Cruz, M. P. (2012). Estimación temprana del nivel de sostenibilidad de estructuras de hormigón, en el marco de la instrucción española EHE-08. Informes de La Construcción, 65(529), 65–76. https://doi.org/10.3989/ic.11.123

Goodland, R. (1995). The Concept of Environmental Sustainability. Annual Review of Ecology and Systematics, 26(1), 1–24. https://doi.org/10.1146/annurev.es.26.110195.000245

Government of Chile. Towards a Public Policy Social Responsibility for Sustainable Development in Chile. (2013). Santiago, Chile, Chile: Decree No 60.

GRI - Global Reporting Initiative. (2013). Sustainability Reporting Guidelines G4: Reporting Principles and Standard Disclosures. Amsterdam, Netherlands.

Griffiths, K., (2016). Sustainability rating tools for infrastructure - an in-depth review of tool practice and design. IPWEA Conference: Sustainability in Public Works, At Melbourne, Australia.

Griffiths, K., Browne, V., Williams, V., Elliott, P. (2012). The changing face of engineering down under. Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 165(3), 223–232. https://doi.org/10.1680/ensu.10.00037

Hallowell, M. R., Gambatese, J. A. (2010). Qualitative research: application of the Delphi method to CEM research. Journal of Construction Engineering and Management, 136(1), 99–107. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000137

HEA-Higher Education Academy. (2006). Sustainable development in higher education Current practice and future developments A progress report for Senior Managers in higher education. Sustainable Development. Heslington, United Kingdom.

Hill, R. C., Bowen, P. A. (1997). Sustainable construction: principles and a framework for attainment. Construction Management and Economics, 15(3), 223–239. https://doi.org/10.1080/014461997372971

Hong, Y., Liyin, S., Tan, Y., Jianli, H. (2011). Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. Automation in Construction Journal, 20, 1060–1069. https://doi.org/10.1016/j.autcon.2011.04.007

Huang, B., Yang, H., Mauerhofer, V., Guo, R. (2012). Sustainability assessment of low carbon technologies–case study of the building sector in China. Journal of Cleaner Production, 32, 244–250. https://doi.org/10.1016/j.jclepro.2012.03.031

Hyard, A. (2012). Cost-benefit analysis according to Sen: An application in the evaluation of transport infrastructures in France. Transportation Research Part A: Policy and Practice, 46(4), 707–719. https://doi.org/10.1016/j.tra.2012.01.002

Institute for Sustainable Infrastructure. (2015). ENVISION Rating System for Sustainable Infrastructure. Washington, DC 20005. Retrieved from www.sustainableinfrastructure.org

International Labour Organization-ILO. (2015). World Employment and Social Outlook-Trend 2015. Geneva, Switzerland.

International Stardardization Organization -ISO. (2010). Guidance on Social Responsibility: ISO 26000. Geneva, Switzerland.

Interorganizational Committee on Guidelines and Principles for Social Impact Assessment. (1995). Guidelines and principles for social impact assessment. Environmental Impact Assessment Review, 15(1), 11–43. https://doi.org/10.1016/0195-9255(94)00026-W

Interorganizational Committee on Guidelines and Principles for Social Impact Assessment. (2003). Principles and guidelines for social impact assessment in the USA. Impact Assessment and Project Appraisal, 21(3), 231–250. http://dx.doi.org/10.3152/147154603781766293

ISCA Infrastructure Sustainable Council of Australia. (2012). Infrastructure Sustainable (IS) Overview. Retrieved April 8, 2017, from http://www.isca.org.au

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., Canteras-Jordana, J. C. (2014). A review of application of multi-criteria decision-making methods in construction. Automation in Construction, 45, 151–162. https://doi.org/10.1016/j.autcon.2014.05.013

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V. C., Ballester-Muñoz, F. (2014). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. Expert Systems with Applications, 41(15), 6807–6817. https://doi.org/10.1016/j.eswa.2014.05.008

Jato-Espino, D., Blanco-Fernandez, E., Carpio-García, J., Castro-Fresno, D., (2016). Decision aid system founded on nonlinear valuation, dispersion-based weighting and correlative aggregation for wire rope selection in slope stability cable nets. Expert Systems with Applications, 54(1), 148–154. https://doi.org/10.1016/j.eswa.2016.01.023

Jeon, C. (2010). Incorporating Uncertainty into Transportation Decision Making: Sustainability-Oriented Approach. Transportation Research Record: Journal of the Transportation Research Board, 2174(1), 58–67. https://doi.org/10.3141/2174-09

Jeon, C. M., Amekudzi, A. a., Guensler, R. L. (2010). Evaluating Plan Alternatives for Transportation System Sustainability: Atlanta Metropolitan Region. International Journal of Sustainable Transportation, 4, 227–247. https://doi.org/10.1080/15568310902940209

Jeon, C.M., Amekudzi, A.A., Guensler, R.L. (2013). Sustainability assessment at the transportation planning level: Performance measures and indexes. Transport Policy 25(1), 10–21. https://doi.org/dx.doi.org/10.1016/j.tranpol.2012.10.004

Jeong, J. S., García-Moruno, L., Hernández-Blanco, J. (2014). Un modelo web para la asistencia en la toma de decisiones en la integración de las construcciones rurales mediante planificación espacial multi-criterio. Informes de La Construcción, 66(533), 1–10. https://doi.org/dx.doi.org/10.3989/ic.13.001

Jiménez, J., Pellicer, E., Yepes, V. (2011). Teaching and learning using a case study: application to a master degree in construction management. Procedia - Social and Behavioral Sciences, 15, 696–702. https://doi.org/10.1016/j.sbspro.2011.03.167

Kagawa, F. (2007). Dissonance in students' perceptions of sustainable development and sustainability. International Journal of Sustainability in Higher Education, 8(3), 317–338. https://doi.org/10.1108/14676370710817174

Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). System dynamic simulation: A new method in social impact assessment (SIA). Environmental Impact Assessment Review, 62, 25–34. https://doi.org/10.1016/j.eiar.2016.07.009

Koo, D.-H., Ariaratnam, S. T. (2008). Application of a Sustainability Model for Assessing Water Main Replacement Options. Journal of Construction Engineering and Management, 134(1), 563–574. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:8(563)

Koo, D.-H., Ariaratnam, S. T., Kavazanjian, E. (2009). Development of a sustainability assessment model for underground infrastructure projects. Canadian Journal of Civil Engineering, 36(5), 765–776. https://doi.org/10.1139/L09-024

Kucukvar, M., Gumus, S., Egilmez, G., Tatari, O. (2014a). Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision making method. Automation in Construction, 40(1), 33–43. https://doi.org/10.1016/j.autcon.2013.12.009

Kucukvar, M., Noori, M., Egilmez, G., Tatari, O. (2014b). Stochastic decision modeling for sustainable pavement designs. The International Journal of Life Cycle Assessment, 19(6), 1185–1199. https://doi.org/10.1007/s11367-014-0723-4

Kumar, D., Katoch, S. S. (2014). Sustainability indicators for run of the river (RoR) hydropower projects in hydro rich regions of India. Renewable and Sustainable Energy Reviews, 35, 101–108. https://doi.org/10.1016/j.rser.2014.03.048

Labuschagne, C., Brent, A. C. (2006). Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry. International Journal of Life Cycle Assessment, 11(1), 3–15. https://doi.org/10.1065/lca2006.01.233

Labuschagne, C., Brent, A. C. (2008). An industry perspective of the completeness and relevance of a social assessment framework for project and technology management in the manufacturing sector. Journal of Cleaner Production, 16(3), 253–262. https://doi.org/10.1016/j.jclepro.2006.07.028

Labuschagne, C., Brent, A. C., van Erck, R. P. G. (2005). Assessing the sustainability performances of industries. Journal of Cleaner Production, 13(4), 373–385. https://doi.org/10.1016/j.jclepro.2003.10.007

Lang, D. J., Scholz, R. W., Binder, C. R., Wiek, A., Stäubli, B. (2007). Sustainability Potential Analysis (SPA) of landfills – a systemic approach: theoretical considerations. Journal of Cleaner Production, 15(17), 1628–1638. https://doi.org/10.1016/j.jclepro.2006.08.004

Le Moigne, J. (1990). La modélisation des systèmes complexes. Droit et Société, 15(1), 236.

Lee, S., Kim, W., Kim, Y. M., Lee, H. Y., Oh, K. J. (2014). The prioritization and verification of IT emerging technologies using an analytic hierarchy process and cluster analysis. Technological Forecasting and Social Change, 87, 292–304. https://doi.org/10.1016/j.techfore.2013.12.029

Lehmann, A., Zschieschang, E., Traverso, M., Finkbeiner, M., Schebek, L. (2013). Social aspects for sustainability assessment of technologies—challenges for social life cycle assessment (SLCA). The International Journal of Life Cycle Assessment, 18(8), 1581–1592. https://doi.org/10.1007/s11367-013-0594-0

Lehmann, M., Christensen, P., Du, X., Thrane, M. (2008). Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. European Journal of Engineering Education, 33(3), 283–295. https://doi.org/10.1080/03043790802088566

Lemmer, J. F., Gossink, D. E. (2004). Recursive Noisy OR—A Rule for Estimating Complex Probabilistic Interactions. IEEE Transactions on Systems, Man and Cybernetics, Part B (Cybernetics), 34(6), 2252–2261. https://doi.org/10.1109/TSMCB.2004.834424

Levitt, R. E. (2007). CEM Research for the Next 50 Years: Maximizing Economic, Environmental, and Societal Value of the Built Environment. Journal of Construction Engineering and Management, 133(September), 619–628. https://doi.org/10.1061/(ASCE)0733-9364(2007)133:9(619)

Li, D., Hui, E. C. M., Xu, X., Li, Q. (2012). Methodology forassessing the sustainability ofmetro Systems based on emergy analysis. Journal of Management in Engineering, 28(1), 59–69. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000092.

Lockie, S., Franettovich, M., Petkova-Timmer, V., Rolfe, J., Ivanova, G. (2009). Coal mining and the resource community cycle: A longitudinal assessment of the social impacts of the Coppabella coal mine. Environmental Impact Assessment Review, 29(5), 330–339. https://doi.org/10.1016/j.eiar.2009.01.008

Lozano, R. (2010). Diffusion of sustainable development in universities' curricula: an empirical example from Cardiff University. Journal of Cleaner Production, 18(7), 637–644. https://doi.org/10.1016/j.jclepro.2009.07.005

Lozano, R., Peattie, K. (2009). Developing a Tool to Audit Curricula Contributions to Sustainable Development. (W. Leal Filho, Ed.), Sustainability at Universities – Opportunities, Challenges and Trends (Vol. 31). Frankfurt am Main, Germany: Peter Lang Publishing Group.

Lozano, R., Young, W. (2013). Assessing sustainability in university curricula: Exploring the influence of student numbers and course credits. Journal of Cleaner Production, 49, 134–141. https://doi.org//10.1016/j.jclepro.2012.07.032

Luhmann, N. (1998). Sistemas sociales. Lineamientos para una teoría general. (Anthropos, Ed.) (2da ed.). Bogotá.

Lupano, J. A. (2013). La infraestructura de transporte sostenible y su contribución a la igualdad en Ámerica Latina y el Caribe (Comisión Económica para América Latina y el Caribe - CEPAL). Santiago de Chile.

MacAskill, K., Guthrie, P. (2013). Risk-based approaches to sustainability in civil engineering. Engineering Sustainability, 166(ES4), 181–190. https://doi.org/10.1680/ensu.12.00001

Delgado, A., Romero, I., 2017. Integrating Social Impact Assessment and Environmental Conflict Analysis on a Hydrocarbon Exploration Project in Spain. Int. J. Eng. Technol. 8, 2403–2417. doi:10.21817/ijet/2016/v8i6/160806402

Ricart, J., Hüttemann, G., Lima, J., Barán, B., 2011. Multiobjective harmony search algorithm proposals. Electron. Notes Theor. Comput. Sci. 281, 51–67. doi:10.1016/j.entcs.2011.11.025

Manga, R. (2005). Una Nueva Metodología para la Toma de Decisión en la Gestión de Contratación de Proyectos. PhD Thesis, Barcelona: Universitat Politècnica de Catalunya.

Maturana, H., Varela, F. (1997). De máquinas y seres vivos. Autopoiesis: La organización de lo vivo. (Editorial Universitaira S.A, Ed.). Santiago de Chile.

Max-Neef, M. (1995). Economic growth and quality of life: A threshold hypothesis. Ecological Economics, 15(1), 115–118. https://doi.org/10.1016/0921-8009(95)00064-X

McCormick, M., Lawyer, K., Wiggins, J., Swan, C. W., Paterson, K. G., Bielefeldt A. R. (2015). Sustainable Engineering Assessment Using Rubric-Based Analysis of Challenge Question Responses. Journal of Professional Issues in Engineering Education and Practice, 141(2). https://doi.org/10.1061/(ASCE)EI.1943-5541.0000211.

McKenzie, S. (2004). Social sustainability: Towards some definitions (No. 27). Hawke Research Institute Working Paper Series. Australia. Retrieved from http://www.hawkecentre.unisa.edu.au/institute/

Medineckiene, M., Turskis, Z., Zavadskas, E. K. (2010). Sustainable construction taking into account the building impact on the environment. Journal of Environmental Engineering and Landscape Management, 18(2), 118–127. https://doi.org/10.3846/jeelm.2010.14

Mel, J., Gómez, D., de la Cruz, P., Del Caño, A. (2015). Análisis de sensibilidad y estudio crítico del modelo de evaluación de la sostenibilidad de la Instrucción Española de Hormigón Estructural. Informes de La Construcción, 67(539). https://doi.org/10.3989/ic.14.126

Menéndez, J. R. (2003). Mantenimiento Rutinario de Caminos con Microempresas- Manual técnico. Lima.

Missimer, M., Robert, K. H., Broman, G. (2017). A strategic approach to social sustainability - Part 1: exploring social system. Journal of Cleaner Production, 140(1), 32–41. https://doi.org/10.1016/j.jclepro.2016.03.170

Mkrtchyan, L., Podofillini, L., Dang, V. N. (2016). Methods for building Conditional Probability Tables of Bayesian Belief Networks from limited judgment: An evaluation for Human Reliability Application. Reliability Engineering and System Safety, 151, 93–112. https://doi.org/10.1016/j.ress.2016.01.004

Mostafa, A., El-Gohary, N. M. (2014). Stakeholder-Sensitive Social Welfare-Oriented Benefit Analysis for Sustainable Infraestructure Project Development. Journal of Construction Engineering and Management, 140(9). https://doi.org/10.1061/ (ASCE)CO.1943-7862.0000788

Muench, S., Anderson, J., Hatfield, J., Koester, J. R., Soderlund, M. (2011). Greenroads Manual v1. 5. (J. L. Anderson, C. D. Weiland, S. T. Muench, Eds.). Seattle, WA: University of Washington

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. European Journal of Operational Research, 158(3), 662–677. https://doi.org/10.1016/S0377-2217(03)00369-2

Munda, G. (2006). Social multi-criteria evaluation for urban sustainability policies. Land Use Policy, 23(1), 86–94. https://doi.org/10.1016/j.landusepol.2004.08.012

Naderpajouh, N., Mahdavi, A., Hastak, M., Aldrich, D. P. (2014). Modeling Social Opposition to Infrastructure Development. Journal of Construction Engineering and Management, 140(8), 1–10. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000876.

Nannapaneni, S., Mahadevan, S., Rachuri, S. (2016). Performance evaluation of a manufacturing process under uncertainty using Bayesian networks. Journal of Cleaner Production, 113, 947–959. https://doi.org/10.1016/j.jclepro.2015.12.003

National Environmental Policy Act of 1969-NEPA, 4 § (1969). Washington, USA.

Nelson, K. G., Shell, D. F., Husman, J., Fishman, E. J., Soh, L.K. (2015). Motivational and Self-Regulated Learning Profiles of Students Taking a Foundational Engineering Course. Journal of Engineering Education, 104(1), 74–100. https://doi.org/10.1002/jee.20066

Nishijima, K., Straub, D., Havbro Faber, M. (2007). Inter-generational distribution of the life-cycle cost of an engineering facility. Journal of Reliability of Structures and Materials, 1(3), 33–46.

Noll, H.-H. (2013). Subjective Social Indicators: Benefits and Limitations for Policy Making—An Introduction to this Special Issue. Social Indicators Research, 114(1), 1–11. https://doi.org/10.1007/s11205-013-0379-7

O'Faircheallaigh, C. (2010). Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making. Environmental Impact Assessment Review, 30(1), 19–27. https://doi.org/10.1016/j.eiar.2009.05.001

Oñate, N., Ramos, L., Díaz, A. (1998). Utilización del Método Delphi en la pronosticación: Una experiencia inicial. Cuba. Economía Planificada, 3(4), 9–48.

Oppio, A., Corsi, S., Torrieri, F., Mattia, S., (2017). Infrastructure Development and Territorial Vulnerability. The Role of Composite Indicators for Addressing Siting Decisions, in: Stanghellini, S., Morano, P., Bottero, M., Oppio, A. (Eds.), Appraisal: From Theory to Practice. Springer, pp. 277–290. https://doi.org/10.1007/978-3-319-49676-4

Pan, N.F. (2008). Fuzzy AHP approach for selecting the suitable bridge construction method. Automation in Construction, 17(8), 958–965. https://doi.org/10.1016/j.autcon.2008.03.005

Pan, N.F.(2009). Selecting an appropriate excavation construction method based on qualitative assessments. Expert Systems with Applications, 36(3), 5481–5490. https://doi.org/10.1016/j.eswa.2008.06.097

Pappas, E., Nagel, R., Pappas, J., Benton, M., Frazier, C., Hulleman, C. (2011). A Contextual Approach to Researching and Teaching Sustainability. School of Engineering, James Madison University, Harrisonburg, VA, United States.

Pavlovskaia, E. (2013). Using Sustainability Criteria in Law. International Journal of Environmental Protection and Policy, 1(4), 76–78. https://doi.org/10.11648/j.ijepp.20130104.15

Pearl, J. (2009). Causality: Models, Reasoning and Inference (2nd Ed). Cambridge: Cambridge University Press.

Pellicer, E., Sierra, L. A., Yepes, V. (2016). Appraisal of infrastructure sustainability by graduate students using an active-learning method. Journal of Cleaner Production, 113(1), 884–896. https://doi.org/10.1016/j.jclepro.2015.11.010

Pellicer, E., Yepes, V., Teixeira, J. Moura, H., Catala, J. (2014). Construction Management. Cambridge, United Kingdom: Wiley Blackwell.

Penadés-Plà, V., García-Segura, T., Martí, J., Yepes, V. (2016). A Review of Multi-Criteria Decision-Making Methods Applied to the Sustainable Bridge Design. Sustainability, 8(12), 1295. https://doi.org/10.3390/su8121295

Polese, M., Stren, R. (2000). The Social Sustainability of Cities: Diversity and the Management of Change Paperback – (1st Ed). Toronto: University of Toronto Press, Scholarly Publishing Division.

Pope, J., Annandale, D., Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. Environmental Impact Assessment Review, 24(6), 595–616. https://doi.org/10.1016/j.eiar.2004.03.001

Porter, R., Donnell, E., Mason, J. (2012). Geometric Design, Speed, and Safety. Transportation Research Record: Journal of the Transportation Research Board, 2309(1), 39–47. https://doi.org/10.3141/2309-05

Prince, M. (2004). Does Active Learning Work ? A Review of the Research. Journal of Engineering Education, 93(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Queipo, J., Navarro, J. M., Izquierdo, M., Del Águila, A., Guinea, D., Villamor, M., Vega.S., Neila, J. (2009). Proyecto de investigación INVISO: industrialización de viviendas sostenibles. Informes de La Construcción, 61(513), 73–86. https://doi.org/10.3989/ic.09.001

Rahman, M. M., Hagare, D., Maheshwari, B. (2015). Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian Belief Network. Journal of Cleaner Production, 105, 406–419. https://doi.org/10.1016/j.jclepro.2014.04.068

Ramani, T. L., Zietsman, J., Knowles, W. E., Quadrifoglio, L. (2011). Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement. Journal of Transportation Engineering, 137(6), 404–415. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000255.

Resendez, L; Dueñas-Osorio, L. P., Padgett, J.E. (2014). Social Sustainability in Economic, Social, and Cultural Context. The international journal of social sustainability in Economic, social and cultural context. 11(1), 25-38.

Reyes, J. P., San-José, J. T., Cuadrado, J., Sancibrian, R. (2014). Health Safety criteria for determining the sustainable value of construction projects. Safety Science, 62, 221–232. https://doi.org/10.1016/j.ssci.2013.08.023

Reza, B., Sadiq, R., Hewage, K. (2014). Emergy-based life cycle assessment (Em-LCA) for sustainability appraisal of infrastructure systems: A case study on paved roads. Clean Technologies and Environmental Policy, 16(2), 251–266. https://doi.org/10.1007/s10098-013-0615-5

Ricart, J., Hüttemann, G., Lima, J., Barán, B. (2011). Multiobjective harmony search algorithm proposals. Electronic Notes in Theoretical Computer Science, 281, 51–67. https://doi.org/10.1016/j.entcs.2011.11.025

Rowe, G., Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting, 15(4), 353–375. https://doi.org/10.1016/S0169-2070(99)00018-7

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. Mathematical Modelling, 9(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty, T. L. (2004). Decision-making — the Analytic Hierarchy and Network Processes (AHP/ANP). Journal of Systems Science and Systems Engineering, 13(1), 1–35. https://doi.org/10.1007/s11518-006-0151-5

Saaty, T. L., Vargas, L. G. (2006). Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Cost and Risks. Springer's International Series. https://doi.org/10.1007/978-1-4614-7279-7

Sahely, H. R., Kennedy, C. a, Adams, B. J. (2005). Developing sustainability criteria for urban infrastructure systems. Canadian Journal of Civil Engineering, 32(1), 72–85. https://doi.org/10.1139/l04-072

Santos, G., Behrendt, H., Maconi, L., Shirvani, T., Teytelboym, A. (2010). Part I: Externalities and economic policies in road transport. Res. Transp. Econ. 28(1), 2–45. https://doi.org/10.1016/j.retrec.2009.11.002

Schwarz, N., Flacke, J., Sliuzas, R. (2016). Modelling the impacts of urban upgrading on population dynamics. Environmental Modelling Software, 78, 150–162. https://doi.org/10.1016/j.envsoft.2015.12.009

Segalàs, J., Ferrer-Balas, D., Mulder, K. F. (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. Journal of Cleaner Production, 18(3), 275–284. https://doi.org/10.1016/j.jclepro.2009.09.012

Shang, J. S., Tjader, Y., Ding, Y. (2004). A unified framework for multicriteria evaluation of transportation projects. IEEE Transactions on Engineering Management, 51(3), 300–313. https://doi.org/10.1109/TEM.2004.830848

Shen, L., Tam, V. W. Y., Tam, L., Ji, Y. (2010). Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice. Journal of Cleaner Production, 18(3), 254–259. https://doi.org/10.1016/j.jclepro.2009.10.014

Shen, L. Y., Wu, Y. Z., Chan, E. H. W., Hao, J. L. (2005). Application of system dynamics for assessment of sustainable performance of construction projects. Journal of Zhejiang University: Science, 6 A(4), 339–349. https://doi.org/10.1631/jzus.2005.A0339

Shen, L. Y., Wu, Y., Zhang, X. (2011). Key Assessment Indicators for the Sustainability of Infrastructure Projects. Journal of Construction Engineering and Management, 137(6), 441–541. https://doi.org/10.1061/(ASCE)CO.1943-7862 .0000315

Shiau, T.-A., Huang, M.-W., Lin, W.-Y. (2015). Developing an Indicator System for Measuring Taiwan's Transport Sustainability. International Journal of Sustainable Transportation, 9(2), 81–92. https://doi.org/10.1080/15568318.2012.738775

Sieffert, Y., Huygen, J. M., Daudon, D. (2014). Sustainable construction with repurposed materials in the context of a civil engineering–architecture collaboration. Journal of Cleaner Production, 67, 125–138. https://doi.org/10.1016/j.jclepro.2013.12.018

Siegel, S. (1983). Nonparametric Statistics Applied to the Behavioral Sciences. (Ed.Trillas, Ed.) (2nd Ed). México.

Sierra, L. A., Pellicer, E., Yepes, V. (2016). Social Sustainability in the Lifecycle of Chilean Public Infrastructure. Journal of Construction Engineering and Management, 142(5), 5015020–1. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001099.

Sierra, L. A., Pellicer, E., Yepes, V. (2017). Method for estimating the social sustainability of infrastructure projects. Environmental Impact Assessment Review, 65(1), 41–53. https://doi.org/10.1016/j.eiar.2017.02.004

Singh, R., Keil, M., Kasi, V. (2009). Identifying and overcoming the challenges of implementing a project management office. European Journal of Information Systems, 18(5), 409–427. https://doi.org/10.1057/ejis.2009.29

Sipos, Y., Battisti, B., Grimm, K. (2008). Achieving transformative sustainability learning: engaging head, hands and heart. International Journal of Sustainability in Higher Education, 9(1), 68–86. https://doi.org/10.1108/14676370810842193

Slootweg, R., Vanclay, F., van Schooten, M. (2001). Function evaluation as a framework for the integration of social and environmental impact assessment. Impact Assessment and Project Appraisal, 19(1), 19–28. https://doi.org/10.3152/147154601781767186

Soltani, A., Hewage, K., Reza, B., Sadiq, R. (2015). Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Management, 35(1), 318–328. https://doi.org/10.1016/j.wasman.2014.09.010

Sourani, A., Sohail, M. (2015). The Delphi method: Review and use in construction management research. International Journal of Construction Education Research, 11(1), 54.

Spangenberg, J. H. (2002). Institutional sustainability indicators: An analysis of the institutions in Agenda 21 and a draft set of indicators for monitoring their effectivity. Sustainable Development, 10(2), 103–115. https://doi.org/10.1002/sd.184

Steiner, G., Posch, A. (2006). Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real-world problems. Journal of Cleaner Production, 14(9–11), 877–890. https://doi.org/10.1016/j.jclepro.2005.11.054

Su, C. W., Cheng, M. Y., Lin, F. B. (2006). Simulation-enhanced approach for ranking major transport projects. Journal of Civil Engineering and Management, 12(4), 285–291. https://doi.org/10.1080/13923730.2006.9636405

Summers, M., Corney, G., Childs, A. (2004). Student teachers' conceptions of sustainable development: the starting-points of geographers and scientists. Educational Research, 46(2), 163–182. https://doi.org/10.1080/0013188042000222449

Temper, L., Bene, D., Martinez-Alier, J. (2015). Mapping the frontiers and frontlines of global environmental justice: the EJAtlas. Journal of Political Ecology, 22, 255–278.

Thomopoulos, N., Grant-Muller, S. (2013). Incorporating equity as part of the wider impacts in transport infrastructure assessment: An application of the SUMINI approach. Transportation, 40(2), 315–345. https://doi.org/10.1007/s11116-012-9418-5

Thomopoulos, N., Grant-Muller, S., Tight, M. R. (2009). Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology. Evaluation and Program Planning, 32(4), 351–359. https://doi.org/10.1016/j.evalprogplan.2009.06.013

Torres-Machí, C., Carrión, A., Yepes, V., Pellicer, E. (2013). Employability of Graduate Students in Construction Management. Journal of Professional Issues in Engineering Education and Practice, 139(2), 163–170. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000139

Torres-Machí, C., Chamorro, A., Pellicer, E., Yepes, V., Videla, C. (2015). Sustainable Pavement Management: Integrating Economic, Technical, and Environmental Aspects in Decision Making. Journal of the Transportation Research Board, 2523, 56–63. https://doi.org/10.3141/2523-07

Torres-Machí, C., Chamorro, A., Yepes, V., Pellicer, E. (2014). Models and actual practices in the economic and environmental evaluation for the sustainable management of pavements networks. Revista de La Construcción, 13(2), 49-56. http://dx.doi.org/10.4067/S0718-915X2014000200006

Torres-Machi, C., Pellicer, E., Yepes, V., Chamorro, A. (2017). Towards a sustainable optimization of pavement maintenance programs under budgetary restrictions. Journal of Cleaner Production, 148(1), 90–102. https://doi.org/10.1016/j.jclepro.2017.01.100

Tudela, A., Akiki, N., Cisternas, R. (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investment. Transportation Research Part A: Policy and Practice, 40(5), 414–423. https://doi.org/10.1016/j.tra.2005.08.002

Ugwu, O., Haupt, T. (2007). Key performance indicators and assessment methods for infrastructure sustainability: South-african construction industry perspective. Building and Environment, 42(2), 665–680. https://doi.org/10.1016/j.buildenv.2005.10.018

Ugwu, O. O., Kumaraswamy, M. M., Wong, A., Ng, S. T. (2006a). Sustainability appraisal in infrastructure projects (SUSAIP). Automation in Construction, 15(2), 239–251. https://doi.org/10.1016/j.autcon.2005.05.006

Ugwu, O. O., Kumaraswamy, M. M., Wong, A., Ng, S. T. (2006b). Sustainability appraisal in infrastructure projects (SUSAIP): Part 2: A case study in bridge design. Automation in Construction, 15(2), 229–238. https://doi.org/10.1016/j.autcon.2005.05.005

Umer, A., Hewage, K., Haider, H., Sadiq, R. (2016). Sustainability assessment of roadway projects under uncertainty using Green Proforma: An index-based approach. International Journal of Sustainable Built Environment, In Press. https://doi.org/10.1016/j.ijsbe.2016.06.002

UN United Nations (2015). Transforming our World: The 2030 Agenda for Sustainable Development. New York.

UNCED- United Nations Conference on Environment and Development. (1992). Agenda 21: Action Plan for the Next Century. Rio de Janeiro. Retrieved from http://www.un.org/esa/sustdev/documents/agenda21/english/Agenda21.pdf

UNDP United Nations Development Programme. (2010). Project: Revitalize Local Economies Through the Development and Reconstruction of Public Infrastructure, Code 00074250. Retrieved from http://www.sv.undp.org/content/el_salvador/es/home/operations/projects/human_development/prog rama-de-modernizacion-y-gestion-de-los-activos-de-CEPA11.html

UNDP United Nations Development Programme. (2013). Informe sobre Desarrollo Humano El Salvador 2013. Imaginar un nuevo país. Hacerlo posible. Diagnóstico y propuesta. San Salvador, El Salvador.

Valdés-Vásquez, R., Klotz, L. (2011). Incorporating the Social Dimension of Sustainability into Civil Engineering Education. Journal of Professional Issues in Engineering Education Practice, 137(4), 189–197. https://doi.org/10.1061/(asce)ei.1943-5541.0000066

Valdés-Vásquez, R., Klotz, L. E. (2013). Social Sustainability Considerations during Planning and Design: Framework of Processes for Construction Projects. Journal of Construction Engineering and Management, 139(1), 80–89. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000566

Valentin, V., Bogus, S. M. (2015). Assessing the Link between Public Opinion and Social Sustainability in Building and Infrastructure Projects. Journal of Green Building, 10(3), 177–190. https://doi.org/10.3992/jgb.10.3.177

Vallance, S., Perkins, H. C., Dixon, J. E. (2011). What is social sustainability? A clarification of concepts. Geoforum, 42(3), 342–348. https://doi.org/10.1016/j.geoforum.2011.01.002

Van de Walle, D. (2009). Impact evaluation of rural road projects. Journal of Development Effectiveness, 1(1), 15–36. https://doi.org/10.1080/19439340902727701

Van de Walle, D. (2002). Choosing Rural Road Investments to Help Reduce Poverty. World Development, 30(4), 575–589. https://doi.org/10.1016/S0305-750X(01)00127-9

Vanclay, F. (1999). Social impact assessment. In Handbook of Environmental Impact Assessment (Vol. 1, pp. 301–326). United Kingdom: Blackwell, Oxford.

Vanclay, F. (2002). Conceptualising social impacts. Environmental Impact Assessment Review, 22(3), 183–211. https://doi.org/10.1016/S0195-9255(01)00105-6

Vanclay, F. (2003). International Principles for Social Impact Assessment. Impact Assessment and Project Appraisal, 21(1), 5–11. https://doi.org/10.3152/147154603781766491

Vanclay, F., Esteves, A.M., Aucamp, I., Franks, D.M. (2015). Social Impact Assessment: Guidance for assessing and managing the social impacts of projects. Fargo ND, USA: Internaional Associaion for Impact Assessment.

Vanegas, J. A. (2003). Road map and principles for built environment sustainability. Environmental Science Technology, 37(23), 5363–5372. https://doi.org/10.1021/es030523h

Vilà-Baños, R., Rubio-Hurtado, M., Berlanga-Silvente, V., Torrado-Fonseca, M. (2014). Cómo aplicar un análisis jerárquico en SPSS. Revista d'Innovació I Recerca En Educació, 7(1), 113–127. https://doi.org/10.1344/ reire2014.7.1716.

Vilchés, A., Gil Pérez, D., Toscano, J.C., Macías, O. (2014). Ciencia de la Sostenibilidad. Organización de Estados Iberoamericanos. Artículo en línea obtenido de http://www.oei.es/decada/accion.php?accion=24 [Fecha de consulta: 15/05/2017].

Wang, B. (2004). A Taxonomy of Sustainability in Highway Construction. University of Toronto, Canadá.

Ward, J. H. (1963). Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, 58(301), 236–244. https://doi.org/10.1080/01621459.1963.10500845

Watson, M. K., Lozano, R., Noyes, C., Rodgers, M. (2013). Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology. Journal of Cleaner Production, 61, 106–116. https://doi.org/10.1016/j.jclepro.2013.09.010

Wemmenhove, R., de Groot, W. T. (2001). Principles for university curriculum greening - An empirical case study from Tanzania. International Journal of Sustainability in Higher Education, 2(3), 267–283. https://doi.org/10.1108/14676370110388354

Wey, W. M., Wu, K. Y. (2007). Using ANP priorities with goal programming in resource allocation in transportation. Mathematical and Computer Modelling, 46(7–8), 985–1000. https://doi.org/10.1016/j.mcm.2007.03.017

Wey, W. M., Wu, K. Y. (2008). Interdependent urban renewal project selection under the consideration of resource constraints. Environment and Planning B: Planning and Design, 35(1), 122–147. https://doi.org/10.1068/b33045

Whitmer, A., Ogden, L., Lawton, J., Sturner, P., Groffman, P.M., Schneider, L., Hart, D., Halpern, B., Schlesinger, W., Raciti, S., Bettez, N., Ortega, S., Rustad, L., Pickett, S.T.A., Killilea, M., (2010). The engaged university: providing a platform for research that transforms society. Frontiers in Ecology and the Environment, 8(6), 314–321. https://doi.org/10.1890/090241

Wikimedia Commons. (2007). Retrieved from https://commons.wikimedia.org/wiki/File:Departments_of_El_Salvador_named.svg.

Wolters, W. T. M., Mareschal, B. (1995). Novel types of sensitivity analysis for additive MCDM methods. European Journal of Operational Research, 81(2), 281–290. https://doi.org/10.1016/0377-2217(93)E0343-V

World Commission on Environment and Development (WCED). (1987). Our Common Future. United Kingdom: Oxford University Press.

Wright, T. S. A., Wilton, H. (2012). Facilities management directors' conceptualizations of sustainability in higher education. Journal of Cleaner Production, 31, 118–125. https://doi.org/10.1016/j.jclepro.2012.02.030

Xing, K., Ness, D., Lin, F. R. (2013). A service innovation model for synergistic community transformation: Integrated application of systems theory and product-service systems. Journal of Cleaner Production, 43, 93–102. https://doi.org/10.1016/j.jclepro.2012.11.052

Xu, H., Gao, X., Wang, T., Xue, K. (2010). Harmony Search Optimization Algorithm: Application to a Reconfigurable Mobile Robot Prototype. In Z. W. Geem (Ed.), Recent Advances In Harmony Search Algorithm (Vol. 270, pp. 11–22). Berlin: Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-04317-8

Yadollahi, M., Ansari, R., Abd Majid, M. Z., Yih, C. H. (2015). A multi-criteria analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia. Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, 11(5), 638–654. https://doi.org/10.1080/15732479.2014.893002

Yepes, V., García-Segura, T., Moreno-Jiménez, J. M. (2015). A cognitive approach for the multi-objective optimization of RC structural problems. Archives of Civil and Mechanical Engineering, 15(4), 1024–1036. https://doi.org/10.1016/j.acme.2015.05.001

Yepes, V., Martí, J. V., García-Segura, T. (2015). Cost and CO2 emission optimization of precast–prestressed concrete U-beam road bridges by a hybrid glowworm swarm algorithm. Automation in Construction, 49(PA), 123–134. https://doi.org/10.1016/j.autcon.2014.10.013

Yepes, V., Pellicer, E., Ortega, A. J. (2012). Designing a Benchmark Indicator for Managerial Competences in Construction at the Graduate Level. Journal of Professional Issues in Engineering Education and Practice, 138(1), 48–54. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000075

Zamarrón-Mieza, I., Yepes, V., Moreno-Jiménez, J. M. (2017). A systematic review of applocation of multi-criteria decision analysis for aging-dam management. Journal of Cleaner Production, 147(1), 217–230. https://doi.org/10.1016/j.jclepro.2017.01.092

Zastrow, P., Molina-Moreno, F., García-Segura, T., Martí, J. V., Yepes, V. (2017). Life cycle assessment of cost-optimized buttress earth-retaining walls: A parametric study. Journal of Cleaner Production, 140, 1037–1048. https://doi.org/10.1016/j.jclepro.2016.10.085

Zavadskas, E. K., Baušys, R., Lazauskas, M. (2015). Sustainable Assessment of Alternative Sites for the Construction of a Waste Incineration Plant by Applying WASPAS Method with Single-Valued Neutrosophic Set. Sustainability, 7(12), 15923–15936. https://doi.org/10.3390/su71215792

Zhang, X., Wu, Y., Shen, L., Skitmore, M. (2014). A prototype system dynamic model for assessing the sustainability of construction projects. International Journal of Project Management, 32(1), 66–76. https://doi.org/10.1016/j.ijproman.2013.01.009

ANEXOS

Anexo A: PORTADA DE ARTÍCULOS PÚBLICADOS

Anexo A.1: Portada del articulo *Social Sustainabilty in the life cycle of Chilean public infraestrure*, publicado en Journal of Construction Engineering and Management-ASCE (Capítulo 3)

Case Study

Social Sustainability in the Lifecycle of Chilean Public Infrastructure

Leonardo A. Sierra[1]; Eugenio Pellicer, M.ASCE[2]; and Víctor Yepes[3]

Abstract: To enhance concern for the social aspects of sustainability and to delineate the criteria to be considered at each stage of the lifecycle of an infrastructure, this paper aims to determine the relevance of a set of criteria that evaluate social sustainability throughout the lifecycle of a public civil infrastructure. This research presents the results of a case study applying the Delphi method to 24 Chilean experts consulted in a series of three rounds. In addition, binomial statistical tests and Kendall's coefficient were used to show the convergence of the experts. Thus, it was identified that of 36 initial criteria assessed at each stage of the lifecycle, the consideration of 20 is required at the design stage, 29 at the construction stage, 33 during operation, and 27 at demolition. The most relevant criteria, per lifecycle stage, were Stakeholder Participation (design and demolition stages), External Local Population (design stage), Internal Human Resources (construction and demolition stages), Macro-Social Action of Socioenvironmental Activities (construction stage), and Macro-Social Action of Socioeconomic Activities (operation stage). **DOI: 10.1061/(ASCE)CO.1943-7862.0001099.**

Author keywords: Case study; Chile; Delphi; Infrastructure; Lifecycle; Social sustainability; Project planning and design.

Introduction

At the beginning of the 1970s, the concept of sustainable development had already been established as "economic development that can be of benefit to current and future generations without damaging the planet's resources or biological organisms" (EPA 1969). Years later, the Brundtland Report (WCED 1987) broadened this definition, and the development term was transformed into a more qualitative, complex, multidimensional, and intangible concept. This focus made economic, social, and environmental concerns compatible, without jeopardizing the development opportunities of new generations or the future life of the planet (WCED 1987; UNCED 1992). In the last 30 years of the twentieth century, the discussion on sustainable development emphasized the need to bequeath a better natural world for future generations, but it was not until the end of the century that the international community began to understand that the goal must be to increase human abilities (Anand and Sen 2000).

In 1992 the construction industry initiated action plans proposed by the United Nations and its organizations through the "Agenda 21 for Sustainable Construction in Developing Countries." This plan was signed at its inception by more than 178 countries in the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil (UNCED 1992). Since then, awareness of pursuing an agenda oriented toward sustainability has been heightened, including the social considerations throughout the lifecycle of the project, such as design, construction, operation, and demolition (Boyle et al. 2010; Pellicer et al. 2014; Venegas 2003). However, this has not been enough, and the fundamental limitation of sustainability today is clear: it tends to concentrate on the biophysical and economic considerations of the constructed environment, without adequate consideration of the social aspects involved (CIB 2002; Torres-Machí et al. 2014, 2015). Indeed, some public sector projects have not sufficiently considered certain elements of social performance, which should be their main objective (Shen et al. 2010).

Not including the social dimension in an infrastructure's development will have detrimental effects in the short and long term that determine the results of the project. In the mid-short term, the dynamics of infrastructure development with the growing participation of various actors (Bakht and El-Diraby 2015) and their interactions involves emerging risks that challenge the achievement of the project results (Yepes et al. 2015) when prompt social treatment is not preconceived (Naderpajouh et al. 2014). These dynamics generally dominate other potential risks, such as the technical and economic complexities of the project (Alarcón et al. 2011). In contrast, in the long term, not adequately considering the social aspects may have detrimental effects that can jeopardize the quality of intragenerational life (Lehmann et al. 2013; Axelsson et al. 2013).

Today the definition of the criteria that comprise social sustainability in construction projects has yet to be clearly delineated, depending on the application contexts, the participants' perspectives, and the lifecycle stages (Bakht and El-Diraby 2015; Brent and Labuschagne 2006; Pellicer et al. 2014; Valdes-Vasquez and Klotz 2013). In Chile, in particular, despite recent initiatives adding concern for the social aspects (Government of Chile 2013), the focus remains on conceptual guidelines with a tangential orientation toward sustainability through social responsibility and not the social impact of the infrastructure.

A literature review was conducted to examine the social impacts addressed by various authors since 1970. Among the studies, a structure of social sustainability was identified; it focused on the social impact that business initiatives exert on society (Labuschagne et al. 2005). It broadly covered the impacts surveyed,

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Anexo A.2: Portada del articulo *Appraisal of infrastructure sustainability by graduate students using an active-learning method*, publicado en Journal of Cleaner Production (Capítulo 4)

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Appraisal of infrastructure sustainability by graduate students using an active-learning method

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ABSTRACT

Currently many university programs in the construction field do not take sustainability into account from a holistic viewpoint. This may cause a lack of sensitivity from future professionals concerning sustainability. Academics in construction must endeavor to instill a culture of sustainability in the curricula of their students. Therefore, this study proposes an active-learning method that allows graduate students in the construction field to take into consideration infrastructure sustainability from a variety of perspectives in a participatory process. The students applied an analytical hierarchical process to determine the appraisal degree of each criterion. A cluster statistical analysis was carried out, aiming to identify the profiles that influence decision-making. This method was applied to two classes of graduate students enrolled in the Master of Planning and Management in Civil Engineering at the Universitat Politècnica de València. This method identified a correlation between the profiles toward sustainability and the characteristics of the chosen infrastructure. It was also found that the method fulfills educational purposes: most of the students obtained more than 65% of the target learning outcomes. This approach promotes awareness and sensitivity to different points of view of the sustainability in a participatory context. It can be replicated in other contexts so as to obtain appraisals regarding various criteria that help enhance decision-making.

1. Introduction

The approach to sustainability has shifted the perspective of modern societies. Sustainability is associated with all practices that lead society to persist, survive and succeed in terms of environmental resources, economic development and quality of life to promote human development (Pappas et al., 2011). Phenomena such as global warming and social pressures, among others, are significant challenges that this generation must confront. Human activities are primarily responsible for these issues. Current development does not respond to existing needs without jeopardizing future generations' welfare. This is the core of the "sustainable development" paradigm (WCED, 1987).

Universities have a key role to play in creating a sustainable future. They educate professionals who are going to shape and manage the future society in the short term (Wright and Wilton, 2012). In the last decade, there has been growing interest in integrating sustainability into university curricula (Boks and Diehl, 2006; Wemmenhove and de Groot, 2001). Its introduction has been undertaken by adding content to existing courses, one-off workshops, or new courses that supplement current programs (Lozano and Young, 2013). Nonetheless, sustainability is a recent idea in modern society, which has not adequately permeated all university strata yet (Lozano, 2010; Lozano and Young, 2013).

Sustainability is composed of three equally important elements: social, economic and environmental (Labuschagne et al., 2005). However, according to Summers et al. (2004), only one-third of the public understands sustainability that way; the other two-thirds take into account only two out of the three aspects, always recognizing the centrality of the environmental component (García-Segura et al., 2014; Torres-Machí et al., 2014). In this line of thought, there are studies (Wright and Wilton, 2012; Watson et al., 2013) that affirm that sustainability is considered in higher education only when focused on the environment. While European experts in sustainability emphasize the sociological role of

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Anexo A.3: Portada articulo *Method for estimating the social sustainability of infrastructure projects* publicado en Journal of Environmental Impact Assessment Review (Capítulo 5)

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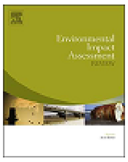

Method for estimating the social sustainability of infrastructure projects

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Social contribution
Social improvement
Infrastructure
Method
Social sustainability

ABSTRACT

Nowadays, sustainability assessments tend to focus on the biophysical and economic considerations of the built environment. Social facets are generally underestimated when investment in infrastructure projects is appraised. This paper proposes a method to estimate the contribution of infrastructure projects to social sustainability. This method takes into account the interactions of an infrastructure with its environment in terms of the potential for short and long-term social improvement. The method is structured in five stages: (1) social improvement criteria and goals to be taken into account are identified and weighed; (2) an exploratory study is conducted to determine transfer functions; (3) each criterion is homogenized through value functions; (4) the short and long-term social improvement indices are established; and finally, (5) social improvement indices are contrasted to identify the socially selected alternatives and to assign an order of priority. The method was implemented in six alternatives for road infrastructure improvement. The results of the analysis show that the method can distinguish the contribution to social sustainability of different infrastructure projects and location contexts, according to early benefits and potential long-term equitable improvement. This method can be applied prior to the implementation of a project and can complement environmental and economic sustainability assessments.

1. Introduction

The sustainable contribution of an infrastructure has to be measured within its own context. Social facets are more influenced by context than environmental or economic ones. These social facets have to be considered in the short and long term and must be properly defined for each project investment (Valdés-Vásquez and Klotz, 2013).

Infrastructure projects promote economic well-being, complement many social interventions and facilitate participation in sociopolitical processes (Asomani-Boateng et al., 2015). An infrastructure by itself, however, may have a reduced impact on society (Gannon and Liu, 1997; Van de Walle, 2009). The assessment of the social impact that an infrastructure has on a region has been under-researched to date. Since the mid-20th century, monetization-based methods have been widely used to evaluate infrastructure projects (Mostafa and El-Gohary, 2014). Nevertheless, some authors have introduced environmental aspects into this evaluation (Torres-Machí et al., 2014; Torres-Machi et al., 2015; Yepes et al., 2015a), with sustainability reaching beyond the analysis of monetary efficiency (Colantonio, 2011). Mostafa and El-Gohary (2014) emphasize the limitations of these methods compared to equitable distribution and the assessment of non-economic aspects; they also add the assumption that investment is inadequate if the benefits do not exceed the costs.

In the last decade, methods have been proposed to assess the sustainability of infrastructure projects, aiming to make sustainable development measurable. In Spain, the "Integrated Value Model for Sustainability Assessment" (MIVES in Spanish) can consider the social facet, even though it has been extensively used for the assessment of environmental and economic criteria (De la Cruz et al., 2015). The social facet can be assessed with a value function proportional to the average satisfaction of the experts. There is no evidence of a simultaneous treatment of different contexts considering the social facet. Nor is there a clear approach that maximizes the improvement of social need in the context of an infrastructure project.

The "Sustainability Appraisal in Infrastructure Projects" (SUSAIP) has been applied in the Chinese construction industry for bridges and viaducts (Ugwu et al., 2006a, 2006b). This method assesses different types of designs considering their geographic context. Thirty percent of its indicators consider the social facet. However, the method assumes the same conditions for different contexts. Furthermore, there is only one decision-maker in the method.

The "Technical Sustainability Index" (TSI) has been applied in Canada for electrification infrastructures (Dasgupta and Tam, 2005). This method takes into consideration a set of indicators applied to

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Anexo A.4: Portada articulo *Assessing the social sustainability contribution of an infrastructure project under conditions of uncertainty* publicado en Journal of Environmental Impact Assessment Review (Capítulo 6)

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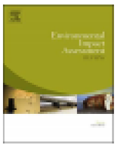

Assessing the social sustainability contribution of an infrastructure project under conditions of uncertainty

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Multicriteria decision-making
Uncertainty
Social sustainability

A B S T R A C T

Assessing the viability of a public infrastructure includes economic, technical and environmental aspects; however, on many occasions, the social aspects are not always adequately considered. This article proposes a procedure to estimate the social sustainability of infrastructure projects under conditions of uncertainty, based on a multicriteria deterministic method. The variability of the method inputs is contributed by the decision-makers. Uncertain inputs are treated through uniform and beta PERT distributions. The Monte Carlo method is used to propagate uncertainty in the method. A case study of a road infrastructure improvement in El Salvador is used to illustrate this treatment. The main results determine the variability of the short and long-term social improvement indices by infrastructure and the probability of the position in the prioritization of the alternatives. The proposed mechanism improves the reliability of the decision making early in infrastructure projects, taking their social contribution into account. The results can complement environmental and economic sustainability assessments.

1. Introduction

The social dimension is a pillar of sustainable development together with the economic and environmental aspects. Yet the treatment of the social dimension is less evolved (Valdés-Vásquez and Klotz, 2013, Dominguez-Gómez, 2016). Several methods have focused on identifying the environmental and economic impacts of infrastructure projects, without explicitly considering their social approach (Ahmadvand and Karami, 2009, Penadés-Pla et al., 2016, Karami et al., 2017). Social assessment is an overarching framework that embodies the evaluation of all impacts on humans and on the ways in which people interact with their socio-cultural, economic and biophysical surroundings (Vanclay, 2002, 2003). Specifically, Vanclay (2002) identifies seven categories of social impacts that could be considered in an assessment: health and social well-being; liveability; economic and material well-being; cultural; family and community; institutional, political and equity; and gender relations.

In the last decade some initiatives have been proposed that take into account the assessment of the social contribution. In the MIVES ("Integrated Value Method for Sustainability Assessments"), a function proportional to the satisfaction of the beneficiaries deals with the social aspects (Gómez-López et al., 2013). In the SUSAIP ("Sustainability Appraisal in Infrastructure Projects"), the social aspects are treated homogenously in different regional contexts and the stakeholders are considered less in the decision-making (Ugwu et al., 2006). In the TSI ("Technical Sustainability Index"), the immediate impacts are not considered and aspects like health, wealth and politics are treated within a set of environmental indicators (Dasgupta and Tam, 2005). In addition, some sustainability rating systems such as ENVISION, CEEQUAL or IS have included social aspects in their evaluations. However, these are more appropriate for developed countries, and they give less importance to the social aspects (Diaz-Sarachaga et al., 2016).

In most of these proposals, the social aspects have been interwoven with environmental assessment methods to measure sustainability. Moreover, the little familiarity and the difficulty in dealing with the social aspects mean they are taken less into consideration (Pope et al., 2004; Pellicer et al., 2016). The heterogeneity of regional development or the impossibility of standardizing an impact in different contexts are relativized aspects in the usual methods (Esteves and Vanclay, 2009). Indeed, the interaction between infrastructure type and location context affects its social contribution. Normally, the contribution to social improvement in the short and long term justifies the decision-making of a public project. Yet the two approaches are not necessarily given simultaneously (Gannon and Liu, 1997). In a short-term approach the

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Anexo B: MATERIAL SUPLEMENTARIO DEL CAPITULO 2

ANTECEDENTES DE LOS ESTUDIOS SELECCIONADOS PARA LA REVISION DEL ESTADO DEL ARTE

N°	Type of document	Studies	Year	Human capital			Community capital				Cultural capital	Productive capital						Soc. & institutional		Socioeconomic system			Business-community relations				N°	
				Basic human needs	Education	Health	Public opinion	Aesthetics	Security of the environmental	Identity and social cohesion	Culture and inheritance	Private property	Mobility and access	State of urbanization services	R+D+i	Land use	Distribution of the productive benefit	Stakeholder participation	Public management capacity	Economy and regional development	Economy and local development	Employment	User-oriented design	Staff training	Occupational health and safety	Ethical labor practices	Criteria count	Country
1	EVALUATION OF SUSTAINABILITY OF INFRASTRUCTURES AND INVOLVING THE SOCIAL DIMENSION	Amiril et al 2014	2014			c,o	pd	o	c		c,o		pd,o			pd		pd,c	pd,c		o				c		11	8
2		Axelsson et al 2013	2013		o	o		o	o	o	o		o				o	o				o				o	11	16
3		Bonsall and Kelly 2005	2005						o	o	o		o			o											5	5
4		Boz and El-adaway 2015	2015					c			c	c								c	c						5	1
5		Boz and El-adaway 2014	2014					c			c	c								c	c						5	1
6		Brocker et al. 2010	2010														o			o	o						3	6
7		Bueno and Vassallo 2015	2015							o							o				c,o	c,o					4	2
8		Chow et al. 2014	2014			o			o	o			o														4	1
9		Curiel-Esparza et al. 2016	2016			o			o				o														3	2
10		Dasgupta and Edwin 2005	2005			o	o		o			o								o					o		6	3
11		De la Cruz et al. Part 1 2015	2015			c, o	o		o	o			o			o				o	o	o			o		10	2
12		De la Cruz et al. Part 2 2015	2015			c,o	o		o	o			o			o				o	o	o			o		10	2
13		Delgado and Romero 2016	2016		o	o			o					o						o	o	o					7	12
14		Dobrovolskiiene et al. 2016	2016																pd			c,o		c	c	c	5	27
15		Fernandez-Sanchez and Rodriguez - Lopez 2010	2010		c		pd,c	c,o	c,o	o	c,o		o		pd			pd,c				c,o	c,o	c	c		13	2
16		Fernandez-Sanchez and Rodriguez-Lopez 2011	2011			c,o,d	pd	c,o	c,o,d	o	pd,c,o,d		o		pd,c,o,d			pd,c,o,d	o	o	c		c,o		c,o		14	2
17		Ferre et al. 2014	2014		o					o		o									o	o					5	1
18		Gervasio and Da Silva 2012	2012			c							c							o	c						4	4
19		Gervasio and Da Silva 2013	2013			c							c								c						3	4
20		Gilchrist and Allouche 2005	2005			c	c		c			c		c						c	c						7	3
21		Gilmour et al 2011	2011		o		pd,c,o			o		o	o	o				pd			o	o					9	5
22		Hong et al. 2011	2011			c,o		o	o		c,o		o			o						c,o					7	7
23		Jeon 2010	2010			o			o	o			o				o										5	1
24		Jeon et al. 2010	2010			o			o	o			o				o										5	1
25		Jeon et al. 2013	2013			o			o	o			o				o										5	1
26		Karami et al. 2017	2017	o	o	o	o			o	o	o						o	o		o	o					11	14
27		Koo et. al 2009	2009			c	c		c,o,d	pd	pd, c,o	pd	c,o			o		pd, c			c,o				c		11	1
28		Koo et. al2008	2008			c	c		c,o,d	pd	pd, c,o	pd	c,o			o		pd, c			o				c		11	1
29		Kucukvar et al. 2014	2014																	c	c	c			c		4	1
30		Labuschagne and Brent 2006	2006		c,o	c,o	c,o	o	c,o	o	c,o	pd,o	o	o	pd,c			pd,c,o	pd,o	o	c,o	c,o		c,o	c,o	c,o	19	9
31		Labuschagne and Brent 2008 I	2008				c,d	c,d	c	c	c	c	c,d	c,d				c,d	d	c	c,d	c,d		d		d	15	9
		Labuschagne and Brent 2008 II			c	c	c	c	c	c	c	c	c	c				c	c	c	c	c		c	c	c	18	
		Labuschagne and Brent 2008 III				c	c	c					c						c	c	c	c		c	c		10	
32		Lee et al. 2008	2008			o																o					2	13
33		Li et al. 2012	2012			o							o							o	o						4	7
34		MacAskill and Guthrie 2013	2013			c	c	c	c	c	c		c					pd,c		pd	c	c			c	c	13	5
35		Matthews et al. 2015	2015																	c	c				c		3	1
36		Mostafa and El-Gohary 2014	2014							o							o				o						3	1
37		Nishijima et al. 2007	2007														o										1	11
38		Ramani et al 2011	2011			o			o				pd, o			pd				o	o						6	1
39		Resendez et al. 2014	2014			o			o	o	o		o	o							o	o					8	1
40		Reza et al. 2014	2014			c,o														o	o	pd,c					4	3
41		Sabatino et al. 2015	2015			o							o														2	1
42		Sahely et al 2005	2005			c,o	c,o		c,o				o					pd,c									5	3
43		Shen et al. 2002	2002			c,o							c,o			c,o						c,o					4	7
44		Shen et al. 2005	2005						pd,d			pd	d			d		c			pd	c,o	o		c,o,d		9	7
45		Shen et al. 2007	2007				c		c		pd,c		pd, c , o	c,o		pd,d		d			o	c,o,d	pd	c	c,d		12	7
46		Shen et al. 2011	2011			o			o		o		o	o		o					o	o					8	7
47		Shiau et al 2015	2015		o	o				o					o	pd					o						6	13
48		Sierra et al. 2016	2016		pd,c,o	pd,o	pd,o	pd,o	c,d	pd,o	pd,c	pd,c	pd,d	pd,o	pd,c			pd,d	c,d	c,o	c,o	c,o		c,o	c,d	c,o,d	19	10
49		Thomopoulos et al. 2009	2009							o			o			o	o										4	5
50		Thomopoulos et al. 2013	2013							o			o			o	o										4	5
51		Ugwu and Haupt 2007	2007			c,o,d	c	c,o	c,o,d	pd, c, o	c,o		pd,c		pd,c	pd		d			o	c			c		13	9
52		Ugwu et. al 2006 P1	2006		c	c,o,d	c	c,o	c,o,d	pd, c, o	c,o		pd,c		pd,c	pd		d			o	c			c		14	7
53		Ugwu et. al 2006 P2	2006		c	c,o,d	c	c,o	c,o,d	pd, c, o	c,o		pd,c		pd,c	pd		d			o	c			c		14	7
54		Umer et al. 2016	2016			c		o	o	o	o		o							o	c						8	3
55		Van de Walle 2002	2002		o	o							o				o	o			o						6	1
56		Wu 2007	2007			c,o							c,o			c,o						c,o					4	7
57		Xinzheng et al. 2009	2009															pd									1	7
58		Yadollahi et al.2015	2015			c			c						pd					o	c	c		c	pd, c		8	8
59		Zavadskas et al. 2015	2015			o	pd					o															3	27
60		Zhang et al 2014	2014				o								o												2	7
61	RATING SYSTEMS OF SOCIAL SUSTAINABILITY IN INFRASTRUCTURES	Andreas et al. 2010	2010			c,o		o	c,o	pd,o	pd,o		c,o	o	pd			pd		o	o						11	1
62		CEEQUAL for projects ver 4.1 2010	2003				c	c,o			pd,o		pd			pd		pd,c				o					7	5
63		Diaz-Sarachaga et al. 2017a - SIRSDEC - Methods	2017							pd	pd,o	pd,c,o,d					o	pd			c	c,o					7	2
64		Diaz-Sarachaga et al. 2017b- SIRSDEC - Application	2017							pd	pd,o	pd,c,o,d					o	pd			c	c,o					7	2
65		ISCA 2012; IS (Infrastructure sustainability)	2012			o		o	c,o		pd,o				pd			pd									6	24
66		ISI 2015; ENVISION Guidance manual	2012			c,o		o	c,o	pd,o	pd,o		c,o	o	pd			pd		o	o						11	1
67		Muench et al 2011; Greenroads	2011			o	o	o	o	o	o		o		pd		o										9	1
68	METHODS OF INFRASTRUCTURE EVALUATION AND INCLUDING SOCIAL ASPECTS	Abu Dabous and Alkass 2008	2008			o			o											o	o						4	3
69		Aghdaie et al. 2012	2012			o			o				o								o						4	14
70		Ahern and Anandarajah 2007	2007			o			o				pd,o			pd				pd,o	pd						6	5
71		Balali et al 2014	2014					o		o			c														3	1
72		Berechmann and Paaswell 2005	2005																	o	o	o					3	1
73		Bitarafan et al. 2013	2013			o			o											o							3	14
74		Caliskan 2006	2006								pd,o									o	o						3	19
75		Chen et al. 2014 I	2014										o										o				2	7
		Chen et al. 2014 II											o										o					
76		Chou et al. 2013	2013								c																1	13
77		El-Diraby and O'Connor 200	2001						c				c								c				c		4	3
78		Ferrari 2003	2003			o							pd,o			pd											3	20
79		Ivanovic et al. 2013	2013										o							o	o						3	17
80		Jato-Espino et al. 2014	2014				o	o	c,o																c		4	2
81		Jeong et al 2014	2014								o	o	o														3	2
82		Leng et al. 2012	2012						o				o										o				3	7
83		Macura et al. 2011	2011										o														1	17
84		Mousavi et al 2014	2014			c		c	c														c		c		5	14
85		Pan 2008	2008			c		c	c														c		c		5	13
86		Pan 2009	2009			c			c														c		c		4	13
87		Shang et al. 2004	2004						o	pd			o							o	o	o					6	1
88		Su et al 2006	2006					o	o		pd	pd	pd,o			pd					o						7	13
89		Tsamboulas 2007	2007			o			o		o									o	o	o					6	23
90		Tsamboulas et al. 2007	2007								pd		o							o	o						4	23
91		Tudela et al 2006 I	2006			o			o				o								o						4	10
		Tudela et al 2006 II				o			o				o								o							
92		Wey and Wu 2007	2007										pd,o			pd				o							3	13
93		Wey and Wu 2008	2008								o							pd									2	13
94		Zhang et al 2016	2016			c,o,d																					1	7

				Contribution of method			Objective of study		Consideration of context					Evaluators		Labor of who participates			Participants in the evaluation process								Weight determination method								Method of grouping the judgments of the multiple evaluators							
N°	Type of document	Studies	Year	Social indicators	Method to obtain indicators	Method of assessing	Impact measure	Decision making	T1	T2	T3	T4	T5	An evaluator	Multiple evaluators	Structure decision making	Determine the weights	Evaluate alternatives	Experts	Institutions Governments	Municipalities	Community (inhabitants)	Infrastructure User	Academy and NGOs	Consultants and / or contractors	Others	No reporting method	AHP	ANP	Analysis by relation of order	Direct assignment	Credit scores	Entropy	Others	No reporting method	Geometric mean	SAW	Probability distribution	Regression	Fuzzy Operators	Delphi	Others
1	EVALUATION OF SUSTAINABILITY OF INFRASTRUCTURES AND INVOLVING THE SOCIAL DIMENSION	Amiril et al 2014	2014	1			1							1																												
2		Axelsson et al 2013	2013	1					1			1			1	1			1	1				1																		
3		Bonsall and Kelly 2005	2005			1		1				1		1																												
4		Boz and El-adaway 2015	2015	1	1		1			1					1	1			1																							
5		Boz and El-adaway 2014	2014	1	1		1			1					1	1			1																							
6		Brocker et al. 2010	2010			1	1					1		1																												
7		Bueno and Vassallo 2015	2015			1		1				1			1		1		1	1				1	1			1			1										1	
8		Chow et al. 2014	2014			1	1					1		1																1	1											
9		Curiel-Esparza et al. 2016	2016			1		1		1					1	1	1	1	1									1								1					1	
10		Dasgupta and Edwin 2005	2005			1		1					1	1																												
11		De la Cruz et al. Part 1 2015	2015			1		1	1	1					1	1				1	1		1	1	1			1										1				
12		De la Cruz et al. Part 2 2015	2015			1		1	1	1					1	1				1	1		1	1	1			1												1		
13		Delgado and Romero 2016	2016			1	1						1		1			1	1			1											1									1
14		Dobrovolskiiene et al. 2016	2016		1	1		1							1		1		1											1					1							
15		Fernandez-Sanchez and Rodriguez - Lopez 2010	2010	1	1		1		1						1	1			1	1			1	1	1			1														
16		Fernandez-Sanchez and Rodriguez-Lopez 2011	2011	1	1	1		1	1	1					1	1	1		1	1				1	1			1							1							
17		Ferre et al. 2014	2014	1		1		1	1			1			1	1				1											1											
18		Gervasio and Da Silva 2012	2012			1		1				1		1														1														
19		Gervasio and Da Silva 2013	2013	1			1					1		1																												
20		Gilchrist and Allouche 2005	2005	1			1					1		1																												
21		Gilmour et al 2011	2011	1			1		1						1	1				1	1			1	1																	
22		Hong et al. 2011	2011		1	1	1		1				1		1	1			1	1			1	1	1						1				1							
23		Jeon 2010	2010			1		1					1		1		1									1				1					1							
24		Jeon et al. 2010	2010			1		1					1		1		1									1				1					1							
25		Jeon et al. 2013	2013			1		1					1		1		1									1				1					1							
26		Karami et al. 2017	2017			1	1				1			1																												
27		Koo et. al 2009	2009			1		1				1		1																	1											
28		Koo et. al2008	2008			1		1				1		1																	1											
29		Kucukvar et al. 2014	2014			1		1							1		1	1	1														1							1		
30		Labuschagne and Brent 2006	2006	1		1	1					1		1																												
31		Labuschagne and Brent 2008 I	2008	1			1		1			1			1	1	1		1	1					1			1													1	
		Labuschagne and Brent 2008 II		1			1		1						1													1													1	
		Labuschagne and Brent 2008 III		1			1		1						1													1													1	
32		Lee et al. 2008	2008			1	1				1	1			1	1		1	1																						1	
33		Li et al. 2012	2012			1	1							1																												
34		MacAskill and Guthrie 2013	2013	1		1	1				1			1																												
35		Matthews et al. 2015	2015	1			1					1		1																												
36		Mostafa and El-Gohary 2014	2014			1		1					1		1		1		1			1						1														1
37		Nishijima et al. 2007	2007			1		1						1																			1									
38		Ramani et al 2011	2011	1		1	1						1		1		1			1										1											1	
39		Resendez et al. 2014	2014	1		1	1				1			1																	1											
40		Reza et al. 2014	2014			1	1					1		1																												
41		Sabatino et al. 2015	2015			1		1				1		1																	1											
42		Sahely et al 2005	2005	1		1	1					1		1																												
43		Shen et al. 2002	2002			1	1			1					1		1								1			1							1							
44		Shen et al. 2005	2005			1	1							1																	1				1							
45		Shen et al. 2007	2007	1			1		1						1	1				1			1		1																	
46		Shen et al. 2011	2011		1	1		1	1				1		1	1	1	1		1			1		1									1							1	
47		Shiau et al 2015	2015	1	1	1	1		1			1			1	1				1				1										1								
48		Sierra et al. 2016	2016	1			1		1	1					1	1	1		1	1	1			1	1						1										1	
49		Thomopoulos et al. 2009	2009			1	1						1		1		1			1				1	1			1									1					
50		Thomopoulos et al. 2013	2013			1	1		1				1		1	1	1			1				1	1			1									1					
51		Ugwu and Haupt 2007	2007	1		1		1					1		1	1	1		1						1			1							1							
52		Ugwu et. al 2006 P1	2006	1		1		1					1		1	1			1									1														
53		Ugwu et. al 2006 P2	2006	1		1		1					1		1	1			1									1														
54		Umer et al. 2016	2016			1	1			1					1	1	1		1												1				1							
55		Van de Walle 2002	2002			1	1	1	1				1		1	1	1	1	1		1	1	1				1															1
56		Wu 2007	2007			1	1			1					1		1		1												1				1							
57		Xinzheng et al. 2009	2009			1		1			1				1		1	1	1												1										1	
58		Yadollahi et al.2015	2015			1	1			1					1		1	1	1					1	1			1							1							
59		Zavadskas et al. 2015	2015			1		1					1		1		1	1								1	1								1							
60		Zhang et al 2014	2014			1	1						1		1			1					1		1									1	1							
61	RATING SYSTEMS OF SOCIAL SUSTAINABILITY IN INFRASTRUCTURES	Andreas et al. 2010	2010	1		1	1							1																		1										
62		CEEQUAL for projects ver 4.1 2010	2003	1		1	1		1					1																		1										
63		Diaz-Sarachaga et al. 2017a - SIRSDEC - Methods	2017	1		1	1							1																		1										
64		Diaz-Sarachaga et al. 2017b- SIRSDEC - Application	2017	1		1	1							1																		1										
65		ISCA 2012; IS (Infrastructure sustainability)	2012	1		1	1							1																		1										
66		ISI 2015; ENVISION Guidance manual	2012	1		1	1							1																		1										
67		Muench et al 2011; Greenroads	2011	1		1	1							1																		1										
68	METHODS OF INFRASTRUCTURE EVALUATION AND INCLUDING SOCIAL ASPECTS	Abu Dabous and Alkass 2008	2008			1		1						1														1														
69		Aghdaie et al. 2012	2012			1		1	1		1				1	1	1		1					1	1			1													1	
70		Ahern and Anandarajah 2007	2007			1		1					1		1		1		1					1	1						1				1							
71		Balali et al 2014	2014			1		1		1					1	1	1								1								1		1							
72		Berechmann and Paaswell 2005	2005			1		1					1		1		1		1												1										1	
73		Bitarafan et al. 2013	2013			1		1		1					1		1	1	1					1	1			1							1							
74		Caliskan 2006	2006			1		1	1	1					1	1	1	1		1		1		1	1			1							1							
75		Chen et al. 2014 I	2014			1		1		1					1		1		1	1				1	1					1			1		1							
		Chen et al. 2014 II				1		1							1															1			1		1							
76		Chou et al. 2013	2013			1		1			1				1		1		1						1			1												1		
77		El-Diraby and O'Connor 200	2001			1		1			1				1	1	1			1					1						1				1							
78		Ferrari 2003	2003			1		1		1					1		1			1								1							1							
79		Ivanovic et al. 2013	2013			1		1	1		1				1	1	1	1	1	1		1		1					1						1							
80		Jato-Espino et al. 2014	2014			1		1		1					1		1		1									1								1						
81		Jeong et al 2014	2014			1		1			1				1		1	1			1	1	1	1	1			1							1							
82		Leng et al. 2012	2012			1		1							1		1		1	1				1	1					1			1		1							
83		Macura et al. 2011	2011			1		1			1				1	1	1	1	1										1						1							
84		Mousavi et al 2014	2014			1		1		1					1		1	1	1	1					1			1												1		
85		Pan 2008	2008			1		1		1					1	1	1	1	1	1					1			1												1		
86		Pan 2009	2009			1		1		1					1	1	1	1	1									1												1		
87		Shang et al. 2004	2004			1		1	1				1		1	1	1			1	1								1							1						
88		Su et al 2006	2006			1		1	1	1					1	1	1	1	1	1								1										1				
89		Tsamboulas 2007	2007			1		1					1	1																												
90		Tsamboulas et al. 2007	2007			1		1							1	1	1		1	1	1			1				1						1							1	
91		Tudela et al 2006 I	2006			1		1		1					1		1	1				1						1							1							
		Tudela et al 2006 II				1		1							1			1				1																	1			
92		Wey and Wu 2007	2007			1		1			1				1	1			1										1						1					1	1	
93		Wey and Wu 2008	2008			1		1			1				1	1			1										1						1					1	1	
94		Zhang et al 2016	2016			1	1					1		1																												

		Methods of evaluation of alternatives (A: Grouping methods; B: Treatment of indicators)																					Treatment of uncertainty				Application							Focus			Impact on the life cycle				Consideration of equity						Promotion of social learning		
N°	Studies	A.- AHP	A.- ANP	A.- MIVES	A.- TOPSIS	A.- LCA	A.- COPRAS _Grey	A.- GRA	A.- VIKOR	A.- PROMETHEE	A.- SAW	A.- Arithmetic mean	A.- System Dinamic (SD)	A.- Emergy	A.- GP	A.- Other methods	B.- Social cost	B.- Artificial Scale	B.- MAUT	B.- Score	B.-Linguistic variables	B.- Grey clusteriong	Treatment of uncertainty	Fuzzy sets	Grey Systems	Probabilistic	Trasnport infrastructure	Bridges	Tunnels	Sewer, water and energy network	Sanitary treatment plants	Mining	Civil infrastructure in	Private	Publics	focus	Desing and planning	Construction	Use and maintenance	End of life	Report equity treatment	Transverse treatment	indicators	by econometric models/indicator	by functions of differences between groups	by vulnerability measurement specifics groups	Report learning treatment	by progressive assessment	by cognitive tools
1	Amiril et al 2014																						1				1										1	1	1										
2	Axelsson et al 2013																						1										1		1				1		1	1				1			
3	Bonsall and Kelly 2005															1							2			1	1								1				1		1	1				1			
4	Boz and El-adaway 2015											1								1			1				1			1	1					1		1											
5	Boz and El-adaway 2014											1								1			1				1			1	1					1		1											
6	Brocker et al. 2010															1							1				1								1				1		1	1		1					
7	Bueno and Vassallo 2015																						1				1									1		1	1		1		1	1					
8	Chow et al. 2014										1							1					1				1								1				1										
9	Curiel-Esparza et al. 2016	1							1														1				1								1				1										
10	Dasgupta and Edwin 2005											1						1					1							1						1			1										
11	De la Cruz et al. Part 1 2015			1															1				2			1				1						1		1	1										
12	De la Cruz et al. Part 2 2015			1															1				2	1						1						1		1	1										
13	Delgado and Romero 2016															1						1	2		1							1			1				1										
14	Dobrovolskiiene et al. 2016										1							1					1										1	1			1	1											
15	Fernandez-Sanchez and Rodriguez - Lopez 2010																						1										1		1		1	1	1										
16	Fernandez-Sanchez and Rodriguez-Lopez 2011															1		1					1				1									1	1	1	1										
17	Ferre et al. 2014															1							2			1				1					1				1		1		1			1			
18	Gervasio and Da Silva 2012									1							1						2			1		1								1		1	1										
19	Gervasio and Da Silva 2013					1											1						2			1		1								1		1											
20	Gilchrist and Allouche 2005															1	1						1				1		1	1						1		1											
21	Gilmour et al 2011																						1				1	1							1		1	1	1								1		1
22	Hong et al. 2011										1		1					1					1				1									1		1	1										
23	Jeon 2010										1							1					1				1	1							1				1		1		1		1		1		1
24	Jeon et al. 2010										1							1					1				1	1							1				1		1		1		1		1		1
25	Jeon et al. 2013										1							1					1				1	1							1				1								1		1
26	Karami et al. 2017												1					1					1							1					1				1										
27	Koo et. al 2009	1									1						1						1							1						1	1	1	1										
28	Koo et. al2008	1									1						1						1						1	1						1	1	1	1										
29	Kucukvar et al. 2014				1	1															1		2	1			1							1				1											
30	Labuschagne and Brent 2006					1										1							1								1	1		1			1	1	1										
31	Labuschagne and Brent 2008 I																						1									1		1				1		1	1		1			1			
	Labuschagne and Brent 2008 II																													1				1				1											
	Labuschagne and Brent 2008 III																														1			1				1											
32	Lee et al. 2008										1									1			1				1	1	1						1				1										
33	Li et al. 2012													1			1						1				1								1				1										
34	MacAskill and Guthrie 2013															1							1							1						1	1	1											
35	Matthews et al. 2015																1						1							1								1											
36	Mostafa and El-Gohary 2014															1							1				1	1							1				1		1	1		1					
37	Nishijima et al. 2007															1							2			1							1		1						1	1		1					
38	Ramani et al 2011										1							1					1				1	1							1		1		1										
39	Resendez et al. 2014										1									1			1				1	1							1				1		1		1			1			
40	Reza et al. 2014					1								1									1				1									1	1	1	1										
41	Sabatino et al. 2015										1								1				2			1		1								1			1										
42	Sahely et al 2005					1																	1							1					1			1	1										
43	Shen et al. 2002										1									1			1								1		1			1		1	1										
44	Shen et al. 2005										1		1							1			1								1		1			1	1	1	1	1									
45	Shen et al. 2007																						1										1			1	1	1	1	1									
46	Shen et al. 2011										1							1		1			1	1			1									1			1										
47	Shiau et al 2015										1							1					1				1	1							1		1		1		1		1			1			
48	Sierra et al. 2016																						1										1		1		1	1	1	1									
49	Thomopoulos et al. 2009										1							1					1				1	1							1				1		1	1			1				
50	Thomopoulos et al. 2013										1							1					1				1	1							1				1		1	1			1				
51	Ugwu and Haupt 2007										1							1		1			1										1			1	1	1	1	1									
52	Ugwu et. al 2006 P1										1							1		1	1		1					1								1	1	1	1	1							1		1
53	Ugwu et. al 2006 P2										1							1		1	1		1					1								1	1	1	1	1							1		1
54	Umer et al. 2016										1										1		2	1			1									1		1	1								1	1	
55	Van de Walle 2002										1							1					1				1								1				1		1	1				1			
56	Wu 2007										1									1			1								1					1		1	1										
57	Xinzheng et al. 2009							1			1												1										1			1	1	1											
58	Yadollahi et al.2015										1									1			1					1								1	1	1	1										
59	Zavadskas et al. 2015										1					1		1			1		2	1							1				1		1		1										
60	Zhang et al 2014										1		1							1			1								1					1													
61	Andreas et al. 2010										1									1			1										1	1			1	1	1										
62	CEEQUAL for projects ver 4.1 2010										1									1			1										1	1			1	1	1								1	1	
63	Diaz-Sarachaga et al. 2017a - SIRSDEC - Methods			1															1				1										1	1			1	1	1	1							1	1	
64	Diaz-Sarachaga et al. 2017b- SIRSDEC - Application			1															1				1									1	1	1			1	1	1	1							1	1	
65	ISCA 2012; IS (Infrastructure sustainability)										1									1			1										1	1			1	1	1								1	1	
66	ISI 2015; ENVISION Guidance manual										1									1			1										1	1			1	1	1								1	1	
67	Muench et al 2011; Greenroads										1									1			1				1	1	1					1			1	1	1								1	1	
68	Abu Dabous and Alkass 2008	1																			1		2			1		1							1				1										
69	Aghdaie et al. 2012						1														1		2		1			1							1				1										
70	Ahern and Anandarajah 2007														1					1			1				1								1		1		1										
71	Balali et al 2014									1													1					1								1		1	1										
72	Berechmann and Paaswell 2005										1							1					1				1		1						1			1	1										
73	Bitarafan et al. 2013	1																					1					1							1		1		1										
74	Caliskan 2006	1																					1					1	1						1		1		1								1		1
75	Chen et al. 2014 I				1																		1				1								1				1										
	Chen et al. 2014 II							1																			1								1				1										
76	Chou et al. 2013										1									1			2	1				1						1				1											
77	El-Diraby and O'Connor 200										1							1					1					1								1		1											
78	Ferrari 2003										1								1				1				1								1		1		1										
79	Ivanovic et al. 2013		1																	1			1				1	1							1				1										
80	Jato-Espino et al. 2014			1															1				2	1		1	1									1	1	1	1										
81	Jeong et al 2014										1									1			1										1		1		1		1								1		1
82	Leng et al. 2012							1															1				1								1				1										
83	Macura et al. 2011		1																				1				1								1				1										
84	Mousavi et al 2014	1																					2	1				1								1		1											
85	Pan 2008	1																					2	1				1								1		1											
86	Pan 2009	1																					2	1									1			1		1											
87	Shang et al. 2004		1															1					1				1								1		1		1										
88	Su et al 2006										1									1			2			1	1								1		1		1										
89	Tsamboulas 2007															1		1		1			1				1								1				1										
90	Tsamboulas et al. 2007										1									1			1				1								1		1		1										
91	Tudela et al 2006 I	1																					1				1								1				1										
	Tudela et al 2006 II															1			1				1				1								1				1										
92	Wey and Wu 2007		1												1								1				1								1		1		1										
93	Wey and Wu 2008		1												1								1				1						1		1		1		1										
94	Zhang et al 2016					1																	2			1		1								1		1	1	1									

Legend:

Country (first table):
1: USA; 2:Spain; 3: Canada; 4:Portugal; 5:United Kingdom; 6: Germany; 7:China; 8:Malaysia; 9: Southafrica; 10: Chile; 11: Switzerland; 12:Perú;13: Taiwán;14: Irán; 15: Denmark; 16:Sweden; 17:Serbia; 18:European United; 19:Turkey; 20: Italy; 21: World Bank; 22: New Zeland; 23: Greece; 24: Australia; 25: France; 26: Ghana; 27: Lithuania

Social criteria (first table):
pd=Desing and planning; c=Construction; o=Use and maintenance; d= End of life

Consideration of the context (second table):
T1 Stakeholders who define the assessment structure with context representation;
T2 The personal opinion of the stakeholders who evaluate criteria or alternatives;
T3 A synthesis of the contextual information so that the actor evaluates and makes the decision;
T4 The contextual information processing through an assessment mechanism;
T5 A mixed system (the stakeholders' opinions and quantitative information processing)

Treatment of uncertainty (second table) :
1: Deterministic; 2: Uncertain varibles

References:

ID References in alphabetical order:

68 Abu Dabous, S., Alkass, S. (2008). Decision support method for multi-criteria selection of bridge rehabilitation strategy. Constr. Manag. Econ. 26(8): 883–894, doi:10.1080/01446190802071190

69 Aghdaie, M.H., Zolfani, S.H., Zavadskas, E.K. (2012). Prioritizing constructing projects of municipalities based on AHP and COPRAS-G: A case study about footbridges in Iran. Balt. J. Road Bridg. Eng. 7(2):145–153, doi:10.3846/bjrbe.2012.20

70 Ahern, A., Anandarajah, G. (2007). Railway projects prioritization for investment: Application of goal programming. Transp. Policy 14(1): 70–80, doi:10.1016/j.tranpol.2006.10.003

1 Amiril, A., Nawawi, A.H., Takim, R., Nur, S., Ab, F., 2014. Transportation Infrastructure Project Sustainability Factors and Performance. Procedia Soc. Behav. Sci. 153, 90–98. doi:10.1016/j.sbspro.2014.10.04

61 Andreas, G., Allen, J., Farley, L., Kher Kao, J., Mladenova, I. (2010). Towards the Development of a Rating System for Sustainable Infrastructure: A Checklist or a Decision-Making Tool? in: Proceedings of the Water Environment Federation. USA, pp. 379–371. doi:10.2175/194864710798284643

2 Axelsson, R., Angelstam P., Degerman E., Teitelbaum S., Andersson K., Elbakidze M., Drotz M.K. (2013). Social and Cultural Sustainability: Criteria, Indicators, Verifier variables for measurement and maps for visualization to support planning, AMBIO. A Journal of the Human Environmental, 42(2): 215–228, doi: 10.1007/s13280-012-0376-0

71 Balali, V., Mottaghi, A., Shoghli, O., Golabchi, M. (2014). Selection of Appropriate Material, Construction Technique, and Structural System of Bridges by Use of Multicriteria Decision-Making Method. Transp. Res. Rec. J. Transp. Res. Board 2431(1): 79–87, doi:10.3141/2431-11

72 Berechman, J., Paaswell, R.E. (2005). Evaluation, prioritization and selection of transportation investment projects in New York City. Transportation. 32(3), 223–249, doi:10.1007/s11116-004-7271-x

73 Bitarafan, M., Arefi, S.L., Zolfani, S.H., Mahmoudzadeh, A. (2013). Selecting the best design scenario of the smart structure of bridges for probably future earthquakes. Procedia Eng. 57(1): 194–199, doi:10.1016/j.proeng.2013.04.027

3 Bonsall, P., Kelly, C. (2005). Road user charging and social exclusion: The impact of congestion charges on at-risk groups. Transp. Policy 12(5): 406–418, doi:10.1016/j.tranpol.2005.06.007

4 Boz, M., El-adaway, I. (2014). Managing Sustainability Assessment of Civil Infrastructure Projects Using Work, Nature, and Flow. J. Infrastruct. Syst. 30(5): 4014019–1, doi:10.1061/(ASCE)ME.1943-5479.0000203

5 Boz, M.A., El-adaway, I.H. (2015). Creating a Holistic Systems Framework for Sustainability Assessment of Civil Infrastructure Projects. J. Constr. Eng. Manag. 141(2): 4014067–1, doi:10.1061/(ASCE)CO .1943-7862.0000911

6 Bröcker, J., Korzhenevych, A., Schürmann, C. (2010). Assessing spatial equity and efficiency impacts of transport infrastructure projects. Transp. Res. Part B Method. 44(7): 795–811, doi:10.1016/j.trb.2009.12.008

ID References in alphabetical order:

7 Bueno, P.C., Vassallo, J.M. (2015). Setting the weights of sustainability criteria for the appraisal of transport projects. Transport 30(3): 298–306, doi:10.3846/16484142.2015.1086890

74 Caliskan, N. (2006). A decision support approach for the evaluation of transport investment alternatives. Eur. J. Oper. Res. 175(3): 1696–1704, doi:10.1016/j.ejor.2005.02.035

62 CEEQUAL ltd (2010). The Assessment and Awards Scheme for improving sustainability in civil engineering and the public realm. Assessment Manual for Projects in the UK and Ireland (No. ver. 4.1). United Kingdom.

75 Chen, S., Leng, Y., Mao, B., Liu, S. (2014). Integrated weight-based multi-criteria evaluation on transfer in large transport terminals: A case study of the Beijing South Railway Station. Transp. Res. Part A Policy Pract. 66(1): 13–26. doi:10.1016/j.tra.2014.04.015

76 Chou, J.S., Pham, A.D., Wang, H. (2013). Bidding strategy to support decision-making by integrating fuzzy AHP and regression-based simulation. Autom. Constr. 35(1):517–527. doi:10.1016/j.autcon.2013.06.007

8 Chow, J.Y.J., Hernandez, S. V., Bhagat, A., McNally, M.G. (2014). Multi-Criteria Sustainability Assessment in Transport Planning for Recreational Travel. Int. J. Sustain. Transp. 8(2): 151–175, doi:10.1080/15568318.2011.654177

9 Curiel-Esparza, J., Mazario-Diez, J.L., Canto-Perello, J., Martin-Utrillas, M. (2016). Prioritization by consensus of enhancements for sustainable mobility in urban areas. Environ. Sci. Policy 55(1): 248–257, doi:10.1016/j.envsci.2015.10.015

10 Dasgupta, S., Tam, E.K. (2005). Indicators and framework for assessing sustainable infrastructure. Can. J. Civ. Eng. 32(1): 30–44, doi:10.1139/l04-101

11 De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J. (2015a). Chapter 4 Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 1 : The MIVES - Monte Carlo Method, in: Corona, C., Arredondo, A., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 69–106, doi:10.4018/978-1-4666-6631-3.ch004

12 De la Cruz, M.P., Castro, A., del Caño, A., Gómez, D., Lara, M., Cartelle, J.J. (2015b). Chapter 5: Comprehensive Methods for Dealing with Uncertainty in Assessing Sustainability Part 2: The Fuzzy-MIVES Method, in: Corona, C., Lozano, J., Cascales, M. (Eds.), Soft Computing Applications for Renewable Energy and Energy Efficiency. IGI Global, 107–140, doi:10.1017/CBO9781107415324.004

13 Delgado, A., Romero, I. (2016). Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. Environ. Model. Softw. 77(1): 108-121, doi: 10.1016 / j.envsoft.2015.12.011.

63 Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D. (2017a). Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC). Environ. Sci. Policy. 69(1): 65–72, doi: 10.1016/j.envsci.2016.12.010

64 Diaz-Sarachaga, J.M., Jato-Espino, D., Castro-Fresno, D. (2017b). Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study. Environ. Sci. Policy. 69(1): 73–80, doi:10.1016/j.envsci.2016.12.011

14 Dobrovolskiiene, N., Tamošiuniene, R. (2016). An index to measure sustainability of a business project in the construction industry: Lithuanian case. Sustain. 8(1): 14. doi:10.3390/su8010014

77 El-Diraby, T.E., O'Connor, J.T. (2001). Model for Evaluating Bridge Construction Plans. J. Constr. Eng. Manag. 127(5): 399–405, doi:10.1061/(ASCE)0733-9464(2001)127:5(399)

15 Fernández-Sánchez, G., Rodríguez-López, F. (2010). A methodology to identify sustainability indicators in construction project management - Application to infrastructure projects in Spain. Ecol. Indic. 10(6): 1194–1201, doi:10.1016/j.ecolind.2010.04.009

16 Fernández-Sánchez, G., Rodríguez-López, F. (2011). Propuesta para la integración de criterios sostenibles en los proyectos de ingeniería civil: un caso práctico. Inf. la Construcción. 63(1): 65–74, doi:10.3989/ic.10.043

78 Ferrari, P. (2003). A method for choosing from among alternative transportation projects. Eur. J. Oper. Res. 150(1), 194–203. doi:10.1016/S0377-2217(02)00463-0

17 Ferre, L.E., Mccormick, B., Thomas, D.S.K. (2014). Potential for use of social vulnerability assessments to aid decision making for the Colorado Dam safety branch, Conference of Association of State Dam Safety Officials. 1-21, San Diego.

18 Gervásio, H., Da Silva. L.S. (2012). A probabilistic decision-making approach for the sustainable assessment of infrastructures. Expert Syst. Appl. 39(8): 7121–7131, doi: 10.1016/j.eswa.2012.01.032.

19 Gervásio, H., Da Silva, L.S. (2013). Life-cycle social analysis of motorway bridges. Struct. Infrastruct. Eng. 9(10): 1019–1039, doi:10.1080/15732479.2011.654124

20 Gilchrist, A., Allouche, E.N. (2005). Quantification of social costs associated with construction projects: State-of-the-art review. Tunn. Undergr. Sp. Technol. 20(1): 89–104, doi:10.1016/j.tust.2004.04.003

21 Gilmour, D., Blackwood, D., Banks, L., Wilson, F. (2011). Sustainable development indicators for major infrastructure projects. Proc. Inst. Civ. Eng. Eng. 164(1): 15–24, doi:10.1680/muen.800020

22 Hong, Y., Liyin, S., Tan, Y., Jianli, H. (2011). Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. Autom. Constr. J. 20(8): 1060–1069, doi:10.1016/j.autcon.2011.04.007

65 ISCA Infrastructure Sustainable Council of Australia (2012). Infrastructure Sustainable (IS) Overview [WWW Document]. http://isca.org.au/is-rating-scheme/about-is (accessed 4.8.17).

66 ISI - Institute for Sustainable Infrastructure (2015). ENVISION Rating System For Sustainable Infrastructure. Washington, DC 20005

ID References in alphabetical order:

79 Ivanović, I., Grujičić, D., Macura, D., Jović, J., Bojović, N., (2013). One approach for road transport project selection. Transp. Policy 25, 22–29, doi:10.1016/j.tranpol.2012.10.001

80 Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V.C., Ballester-Muñoz, F. (2014). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. Expert Syst. Appl. 41(15):6807–6817, doi:10.1016/j.eswa.2014.05.008

23 Jeon, C. (2010). Incorporating Uncertainty into Transportation Decision Making: Sustainability-Oriented Approach. Transp. Res. Rec. J. Transp. Res. Board. 2174(1): 58–67, doi:10.3141/2174-09

24 Jeon, C.M., Amekudzi, A. a., Guensler, R.L. (2010). Evaluating Plan Alternatives for Transportation System Sustainability: Atlanta Metropolitan Region. Int. J. Sustain. Transp. 4(4): 227–247. doi:10.1080/15568310902940209

25 Jeon, C.M., Amekudzi, A.A., Guensler, R.L. (2013). Sustainability assessment at the transportation planning level: Performance measures and indexes. Transp. Policy 25(1): 10–2, doi:10.1016/j.tranpol.2012.10.004

81 Jeong, J.S., García-Moruno, L., Hernández-Blanco, J. (2014). Un modelo web para la asistencia en la toma de decisiones en la integración de las construcciones rurales mediante planificación espacial multi-criterio. Inf. la Construcción 66(533): 1–10, doi:dx.doi.org/10.3989/ic.13.001

26 Karami, S., Karami, E., Buys, L., Drogemuller, R. (2017). System dynamic simulation: A new method in social impact assessment (SIA). Environ. Impact Assess. Rev. 62(1): 25–34, doi:10.1016/j.eiar.2016.07.009

27 Koo, D.-H., Ariaratnam, S.T., Kavazanjian, E. (2009). Development of a sustainability assessment model for underground infrastructure projects. Can. J. Civ. Eng. 36: 765–776, doi:10.1139/L09-024

28 Koo, D.-H., Ariaratnam, S.T. (2008). Application of a Sustainability Model for Assessing Water Main Replacement Options. J. Constr. Eng. Manag. 134: 563–574, doi:10.1061/(ASCE)0733-9364(2008)134:8(563)

29 Kucukvar, M., Gumus, S., Egilmez, G., Tatari, O. (2014). Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision making method. Autom. Constr. 40(1):33-43, doi:10.1016/j.autcon.2013.12.009

30 Labuschagne, C., Brent, A.C. (2006). Social Sustainability Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry. Int. J. Life Cycle Assess. 11(1): 3–15, doi: 10.1065/lca2006.01.233

31 Labuschagne, C., Brent, A.C. (2008). An industry perspective of the completeness and relevance of a social assessment framework for project and technology management in the manufacturing sector. J. Clean. Prod. 16(3):253–262, doi:10.1016/j.jclepro.2006.07.028

32 Lee, W., Lin, C., Kuo, F. (2008). Developing a Sustainability Evaluation System in Taiwan to Support Infrastructure Investment Decisions. Int. J. Sustain. Transp. 2(3): 194–212, doi:10.1080/15568310701517406

82 Leng, Y., Kou, C., Zhou, N., Li, Q., Liang, Y., Xu, Z., Chen, S. (2012). Evaluation on Transfer Efficiency at Integrated Transport Terminals through Multilevel Grey Evaluation, in: 8th International Conference on Traffic and Transportation Studies. Elsevier B.V., Changsha, 587–594, doi:10.1016/j.sbspro.2012.04.132

33 Li, D., Hui, E.C.M., Xu, X., Li, Q. (2012). Methodology forassessing the sustainability of metro Systems based on emergy analysis. J. Manag. Eng. 28(1): 59–69, doi:10.1061/(ASCE)ME.1943-5479.0000092.

34 MacAskill, K., Guthrie, P. (2013). Risk-based approaches to sustainability in civil engineering. Eng. Sustain. 166(ES4): 181–190, doi:10.1680/ensu.12.00001

83 Macura, D., Bošković, B., Bojović, N., Milenković, M. (2011). A model for prioritization of rail infrastructure projects using ANP. Int. J. Transp. Econ. 38(3): 285–309.

35 Matthews, J.C., Allouche, E.N., Sterling, R.L. (2015). Social cost impact assessment of pipeline infrastructure projects. Environ. Impact Assess. Rev. 50(1): 196–202, doi:10.1016/j.eiar.2014.10.001

36 Mostafa, M., El-Gohary, N. (2014). Stakeholder-sensitive social welfare–oriented benefit analysis for sustainable infrastructure project development, J. Constr. Eng. Manage.140(9): 04014038, doi: 10.1061/(ASCE)CO.1943-7862.0000788.

84 Mousavi, S.M., Gitinavard, H., Siadat, A. (2014). A new hesitant fuzzy analytical hierarchy process method for decision-making problems under uncertainty, in: IEEE International Conference on Industrial Engineering and Engineering Management. Industrial Engineering and Engineering Management (IEEM), Malaysia, 622–626, doi:10.1109/IEEM.2014.7058713

67 Muench, S., Anderson, J., Hatfield, J., Koester, J.R., Soderlund, M. (2011). Greenroads Manual v1. 5. Seattle, WA: University of Washington.

37 Nishijima, K., Straub, D., Havbro Faber, M. (2007). Inter-generational distribution of the life-cycle cost of an engineering facility. J. Reliab. Struct. Mater. 1(3): 33–46.

85 Pan, N.F. (2009). Selecting an appropriate excavation construction method based on qualitative assessments. Expert Syst. Appl. 36(3): 5481–5490, doi:10.1016/j.eswa.2008.06.097

86 Pan, N.F. (2008). Fuzzy AHP approach for selecting the suitable bridge construction method. Autom. Constr. 17(8): 958–965, doi:10.1016/j.autcon.2008.03.005

38 Ramani, T.L., Zietsman, J., Knowles, W.E., Quadrifoglio, L. (2011). Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement. J. Transp. Eng. 137(6): 404–415, doi:10.1061/(ASCE)TE.1943-5436.0000255.

ID References in alphabetical order:

39 Resendez. L; Dueñas-Osorio. L, P.J. (2014). Social Sustainability in Economic, Social and Cultural Context. The international journal of social sustainability in Economic, social and cultural context. 11(1): 25–38.

40 Reza, B., Sadiq, R., Hewage, K. (2014). Emergy-based life cycle assessment (Em-LCA) for sustainability appraisal of infrastructure systems: A case study on paved roads. Clean Technol. Environ. Policy. 16(2): 251–266, doi:10.1007/s10098-013-0615-5

41 Sabatino, S., Frangopol, D.M., Dong, Y., (2015). Sustainability-informed maintenance optimization of highway bridges considering multi-attribute utility and risk attitude. Eng. Struct. 102(1): 310–321, doi:10.1016/j.engstruct.2015.07.030

42 Sahely, H.R., Kennedy, C. a, Adams, B.J. (2005). Developing sustainability criteria for urban infrastructure systems. Can. J. Civ. Eng. 32(1): 72–85, doi:10.1139/l04-072

87 Shang, J.S., Tjader, Y., Ding, Y. (2004). A unified framework for multicriteria evaluation of transportation projects. IEEE Trans. Eng. Manag. 51(3): 300–313, doi:10.1109/TEM.2004.830848

43 Shen, L., Wu, M., Wang, J., (2002). A model for assessing the feasibility of construction project in contributing to the attainment of sustainable development. J. Constr. Res. 3(1): 255–269, doi: 10.1142/S1609945102000151

44 Shen, L.Y., Wu, Y.Z., Chan, E.H.W., Hao, J.L. (2005). Application of system dynamics for assessment of sustainable performance of construction projects. J. Zhejiang Univ. Sci. 6 A(4): 339–349, doi:10.1631/jzus.2005.A0339

45 Shen, L., Hao, J.L., Tam, V.W., Yao, H. (2007). A checklist for assessing sustainability performance of construction projects. J. Civ. Eng. Manag. Publ. 13(4): 273–281, doi:10.1080/13923730.2007.9636447

46 Shen, L.Y., Wu, Y., Zhang, X. (2011). Key Assessment Indicators for the Sustainability of Infrastructure Projects. J. Constr. Eng. Manag. 137(6): 441–541, doi:10.1061/(ASCE)CO.1943-7862 .0000315

47 Shiau, T.A., Huang, M.W., Lin, W.Y. (2015). Developing an Indicator System for Measuring Taiwan's Transport Sustainability. Int. J. Sustain. Transp. 9(2): 81–92, doi:10.1080/15568318.2012.738775

48 Sierra, L., Pellicer, E., Yepes, V. (2016). Social sustainability in the life cycle of Chilean public infrastructure. J. Constr. Eng. Manage. 142(5), doi: 10.1061/(ASCE)CO.1943-7862.0001099.

88 Su, C.W., Cheng, M.Y., Lin, F.B. (2006). Simulation-enhanced approach for ranking major transport projects. J. Civ. Eng. Manag. 12(4): 285–291, doi:10.1080/13923730.2006.9636405

49 Thomopoulos, N., Grant-Muller, S., Tight, M.R. (2009). Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology. Eval. Program Plann. 32(1): 351–359, doi:10.1016/j.evalprogplan.2009.06.013

50 Thomopoulos, N., Grant-Muller, S. (2013). Incorporating equity as part of the wider impacts in transport infrastructure assessment: An application of the SUMINI approach. Transportation. 40(2): 315–345, doi:10.1007/s11116-012-9418-5

89 Tsamboulas, D.A., (2007). A tool for prioritizing multinational transport infrastructure investments. Transp. Policy 14(1): 11–26, doi:10.1016/j.tranpol.2006.06.001

90 Tsamboulas, D., Yiotis, G., Mikroudis, G. (2007). A Method for Multi-criteria analysis in Transportation infrastructure Investments. Int. J. Transp. Econ. 34(1): 113–131. doi:10.1016/j.tranpol.2006.06.001

91 Tudela, A., Akiki, N., Cisternas, R. (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investment. Transp. Res. Part A Policy Pract. 40(5): 414–423, doi:10.1016/j.tra.2005.08.002

51 Ugwu, O., Haupt, T. (2007). Key performance indicators and assessment methods for infrastructure sustainability: south-african construction industry perspective. Build. Environ. 42(2): 665–680, doi:10.1016/j.buildenv.2005.10.018

52 Ugwu, O.O., Kumaraswamy, M.M., Wong, A., Ng, S.T. (2006a). Sustainability appraisal in infrastructure projects (SUSAIP): Part 1. Development of indicators and computational methods. Autom. Constr. 15(2): 239–25, doi:10.1016/j.autcon.2005.05.006

53 Ugwu, O.O., Kumaraswamy, M.M., Wong, a., Ng, S.T. (2006b). Sustainability appraisal in infrastructure projects (SUSAIP): Part 2. A case study in bridge design. Autom. Constr. 15(2):229-238, doi:10.1016/j.autcon.2005.05.005

54 Umer, A., Hewage, K., Haider, H., Sadiq, R. (2016). Sustainability assessment of roadway projects under uncertainty using Green Proforma: An index-based approach. Int. J. Sustain. Built Environ. In Press, doi:10.1016/j.ijsbe.2016.06.002

55 Van de Walle, D. (2002). Choosing Rural Road Investments to Help Reduce Poverty. World Dev. 30, 575–589, doi:10.1016/S0305-750X(01)00127-9

92 Wey, W.M., Wu, K.Y. (2007). Using ANP priorities with goal programming in resource allocation in transportation. Math. Comput. Model. 46 (7-8): 985–1000, doi:10.1016/j.mcm.2007.03.017

93 Wey, W.M., Wu, K.Y. (2008). Interdependent urban renewal project selection under the consideration of resource constraints. Environ. Plan. B Plan. Des. 35(1): 122–147, doi:10.1068/b33045

56 Wu, M. (2007). An alternative model for assessing the sustainable development of a construction project, in: International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2007. IEEE, Shanghai, pp. 5499–5507.

57 Xinzheng, A., Ruixue, D., Cheng, Y. (2009). Evaluation Analysis on Sustainable Development of Civil Engineering Construction, in: International Conference on Information Management, Innovation Management and Industrial Engineering. IEEE Computer society, pp. 219–222, doi:10.1109/ICIII.2009.60

ID References in alphabetical order:

58 Yadollahi, M., Ansari, R., Majid, M. Z. A., Yin C.H. (2015). A multi-criteria analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia. Struct. Infrastruct. Eng. 11(5): 638-654, doi:10.1080/15732479.2014.894002.

59 Zavadskas, E.K., Baušys, R., Lazauskas, M. (2015). Sustainable Assessment of Alternative Sites for the Construction of a Waste Incineration Plant by Applying WASPAS Method with Single-Valued Neutrosophic Set. Sustainability. 7(12): 15923–15946, doi:10.3390/su71215792

60 Zhang, X., Wu, Y., Shen, L., Skitmore, M. (2014). A prototype system dynamic model for assessing the sustainability of construction projects. Int. J. Proj. Manag. 32(1): 66–76, doi:10.1016/j.ijproman.2013.01.009

94 Zhang, Y.R., Wu, W.J., Wang, Y.F. (2016). Bridge life cycle assessment with data uncertainty. Int. J. Life Cycle Assess. 21(4): 569–576, doi:10.1007/s11367-016-1035-7