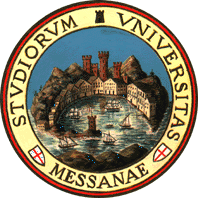
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**University of Messina**

Ph.D. Thesis

**AN INTEGRATED LIFE CYCLE THINKING-BASED FRAMEWORK FOR THE SUSTAINABILITY ASSESSMENT OF URBAN INFRASTRUCTURE PROJECTS**

Submitted By

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In partial fulfillment of the requirements

for the degree of Doctor of philosophy in

**Economics, Management and Statistics**

By Supervision of

**Professors; Roberta Salomone, Giuseppe Ioppolo and Jun Nakatani**

December, 2017

**This thesis is lovely dedicated to my Parents;**

For their endless love, support and encouragement.

**ABSTRACT**

According to the UN report 2014, more and more people are migrating from rural area to urban area which is expected to increase with the passage of time. But this unmanageable expansion causes negative environmental, economic and social impacts on cities which are the biggest challenge to sustainability. There are different aspects that influence city metabolism and its sustainability like infrastructures, transportation, aging of building, energy consumption, etc. Employing effective management of urban infrastructure is one of the main ways to ensure sustainability and provide good living condition to the citizens. The central goal of this thesis is to propose a life cycle thinking based sustainability assessment framework for the evaluation of urban infrastructures which will guide the policy and decision makers in their decisions for the evaluation of sustainable development through a set of sustainability criteria and indicators. In order to identify the main requirements of the proposed sustainability assessment framework for urban infrastructure, first, a qualitative literature review of current sustainability approaches developed or applied in the built infrastructure context has been carried out. Then the main findings of the literature review have been used as inputs to design the proposed integrated framework. The framework is composed of three sections: (i) project structuring (ii) project analysis (iii) resolution/implementation. Finally, the most critical part of the proposed framework (Identification of key criteria and indicators) has been implemented in the context of Middle East countries, specifically UAE and Saudi Arabia, infrastructure projects, in order to test the applicability of the proposed sustainability assessment framework.

**ACKNOWLEDGMENT**

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Messina, December 2017

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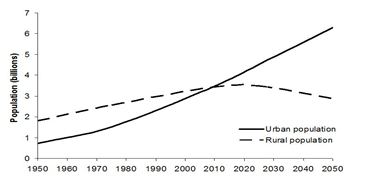
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**INTRODUCTION**

**1. Background** **of** **the** **Research**

The practices and lifestyles of today’s society cannot be sustained as it seems from the growing scientific evidence that show we are beyond the capacity of the earth in terms of environmental pollution and of the use of resources (IPCC, 2013; UNEP, 2012). Cities and urban places are growing dramatically in unmanageable way across the globe (Kaye et al., 2006); the population of the world reached seven billion people and half of them are living in urban areas (UN, 2014) (Fig. 1) because it offers tremendous potential: jobs, health services, economies of scale that improve the inhabitants’ quality of life (Kotter and Friesecke, 2011; Ioppolo et al., 2014). In general, urbanization is keeping an important role for the sustainable global development. Cities are no longer merely reflecting a space for living and for production, but now they deeply influence and form political affairs and society at each level and give new content to culture, norms and regulation. These also became vital factors in environmental changes and sustainability development process.

**Figure1.** World urban and rural population forecast (adapted from United Nation 2014).s



All these urban transformations and expansions cause negative environmental, economic and social impacts for cities that include increased energy demand, climate change, fail to generate jobs, and human health problems: this is one of the biggest challenges to sustainability issues (Girardet, 2004).

A sustainable development can optimize the potential of global urbanization dynamics directed towards sustainable solution for persuasive urban issues (SNSD, 2013). Hence, researchers and urban systems practitioners have introduced the “Urban Metabolism” concept to examine the sustainability of urban systems which apply the same model of animal’s metabolism. Indeed, UM is a multi-disciplinary and important concept that may be defined as; “*the sum of all technical and socioeconomic activities that take place in cities, resource extraction, production of energy, waste emissions*” (Kennedy et al., 2011), as well as the exchange of input and output of different resources that occur in the development of urban planning, resulting in growth of the city. In practice, it takes into account the quantification of resources and flows of energy, as an input and output resources and a system for assemblage of input energy for a particular urban region (Zorpas et al., 2017). All these resources and facilities if mismanaged will influence the metabolism system and structure of cities, like infrastructures of transportation, building infrastructure, energy infrastructure, water and wastewater management and urban vegetation (Girardet, 1992; Kennedy et al., 2011), which are considered to be the skeleton of the cities. Urban infrastructure are the basic sociotechnical systems which provide fundamental facilities such as power supplies, building, water, roads, etc. that are necessary for the everyday function of the society and its development has huge socio-economic and environmental consequences. Employing effective management of urban infrastructure is one of the ways to ensure “sustainable development” and provide good living condition to the citizens.

The concept of sustainable development was first used using the term “Sustainability” in the National Energy Policy Act, 1969 of the United States. However, the sustainable development concept got accelerated in the late 1980’s, subsequently the Brundtland Report publication via the World Commission on Environment and Development in 1987, and in this way the concept of sustainability in urban infrastructure got the attention of policy makers. Sage (1998) refers to sustainable development as something that “*meets the needs of human beings through simultaneous technological and socioeconomic progress and preservation of the nature and natural resource system*”.

Understanding the dynamics of sustainability is very important for urban infrastructure (as a system, not independently), because policy makers do not just consider the question “how” to develop, but also about the ways how they interrelate with the scale of sustainability challenges. To carry out an infrastructure project, different multi resources during its life cycle stages are needed, which could be vulnerable to different hazardous like negative impact on the environment, economy and society. Indeed, with the assessment of sustainability it can also minimize the resource uses and reduce negative impacts, but sustainability is something that is different for different people; in general it can be measured in term of three aspects: economic sustainability, environmental sustainability and social sustainability.

* Economic Sustainability - The role of any infrastructure, but specifically highways, bridges, roads and building is vital for the economic development as well as for the social and environmental development because it links workers to the industry, goods and services to the market and people from rural areas to urban areas (Work Bank, 2004). An economic system in term of “economic sustainability” is one, which fulfill the need of urban general public specially the poor and enhance the urban environmental naturalness. It contains resource use to guarantee the sustainability of natural assets and does not pursue to get economic stability at the responsibility of environmental sustainability (Basiago, 1998). For economic dimension, there are different approaches for cost and performance calculation. In case of urban infrastructure, it is usually done by considering the life cycle costs which accounts all the initial investment cost, land use, design a construction as well as maintenance and operating of an infrastructure and its value as security. If the assessment is limited to actual cost then one can refer it as Life Cycle Costing (LCC). The main challenges for LCC are the various aspects when deliberating life cycle cost (Finkbeiner et al., 2010). The way to employ the “economic sustainability” concept in practice is to approach urban designs that fulfill the needs of urban service specifically infrastructure systems, while improving the unaffectedness of the urban environment.
* Environmental Sustainability - From the environmental perspective, an infrastructure performs an effective role for environmental sustainability as it locks in ingesting forms for eras to come (UN-ESCAP, 2006) and it is basically and well meshed with people’s lives, economic development and environmental sustainability (UN-ESCAP, 2007). These projects may cause negative environmental impact in the form of global warming potential and other environmental impacts; therefore, the assessment of environmental sustainability is a crucial part of the project. Life Cycle Assessment (LCA) represents the application concern with the environmental dimension of sustainability. The ISO 14040 and 14044 as international standards systems is the main stream for performing LCA. LCA is an analytical tool for environmental assessment taking in account all phases of a system as well as all environmental impacts from the input side (input resources) and from the output side, such as emission to air and wastes, etc. In practice, the environmental sustainability approach suggests a development process that allows the society to live it the limitation of biophysical environment (Goodland, 1995).
* Social Sustainability - Social sustainability involves different concepts, including: empowerment, participation, equity, accessibility, sharing and institution, etc. (Krykun, 2016) and it is the most complex aspect among all three aspects of sustainability because it is intangible and hard to calculate. In the context of urbanization, it can be defined as the ongoing ability of the city to function in long run viable setting in human communication, interaction and cultural development. In a more crucial logic, social sustainability creates the tie between environmental decay and social condition (such as equity and poverty) (Rutton, 1991). Different authors have worked for identifying approaches, for the interpretation of social sustainability (Sachs, 1999; Godschalk, 2004; Chiu, 2002, 2003) and tried to put some order on the concept, but these works created as much questions as they answered. Moreover, no consensus exists on what perspective and criteria would be adopted in describing social sustainability. The widely held social indicators measure the degree to which social issues in a specific area of life could be obtained. However, the values on which performance measurement proceeds are difficult to quantify. Social Life Cycle Assessment (SLCA) is used for the analysis of social aspects of sustainability but it is still in infancy of research. However, the guidelines published by UNEP (2009) address the overall methods and concept of SLCA of a product.

Integrating and assessing economic, social and environmental aspects is one of the ways for the sustainability development of infrastructure. An assessment tool that can be used to achieve these goals is Life Cycle Sustainability Assessment (LCSA) which combines environmental Life Cycle Assessment (LCA), social and socio-economic Life Cycle Assessment (S-LCA) and Life Cycle Costing (LCC) to evaluate the overall cost of the impacts of environmental, social and economic aspects and benefits in decision-making processes towards more sustainable products (Guinee et al., 2011). LCA and S-LCA are methods for the assessment, respectively, of the potential environmental impacts and the positive and negative social impacts that provide accounting of direct, indirect, and supply chain effects of resource transformation and use. LCC, applies in urban environments, includes costs associated to the life cycle of an infrastructure (buildings, roads, pathways, rights-of-ways, parking lots, wires, pipes, ditches, bridges, etc.). Other researchers have adopted different approaches such as sustainability indicators, multi-criteria decision analysis (MCDA), and Systems dynamics (SD) approaches, as well as agent based modeling for the dynamic behavior of the stakeholders (Shen et al., 2011; Ugwu and Haupt, 2007; Wang et al., 2008; Batouli and Mostafavi, 2016); these tools are used to evaluate the impacts that considered economic, social and environmental aspect but with reductionist and non-reductionist approach instead of integration. It has given a space for sustainable development which caused a failure to define common priorities where all stakeholders will agree upon.

In terms of research done, the agenda 21 concluded that there is an absence of comprehensive study where various stakeholders of the construction industry raise each issue autonomously with other issue to which it is associated (UNEP-IETC and CIB, 2002). To ensure the sustainability of a system in long term, it is important that the system can survive the susceptibilities in calamity condition, which are the prerequisite for the attainment of sustainability. Therefore, a framework should be beyond the conventional pillars of sustainability, in order to address the susceptibilities and complexity of the system (Upadhyaya, 2013). These objectives can be obtained for infrastructure by ensuring a framework based on life cycle thinking tools. This research attempts to meet this gap by introducing a life cycle based sustainability assessment framework that will be capable of guiding stakeholders in their decision-making process for urban infrastructure.

**2. Objective** **and** **Goals**

Many researchers consider that various tools and methods might bring different outcomes and that the multiple implementations of different techniques should be useful for an integrated comprehensive solution (Haimes, 1992). Therefore, sustainable development decision making for the built environment needs new approaches with the ability to synthesize and incorporate all dimensions and numerous points of views in a full way (Deakin et al., 2001). The goal of the present thesis is to propose a life cycle based sustainability assessment framework for the evaluation of urban infrastructures which will help policy makers in their decision for the evaluation of best alternative through a set of sustainability criteria and indicators.

The following are the identified objectives to meet the goals:

* to consider and identify the various issues involved in the development of urban infrastructures;
* to examine the existing approaches, tools and frameworks of sustainability that might be useful for the assessment of the sustainability of urban infrastructures;
* to develop an LCT-based framework that is composed of various techniques for long term future and current issues;
* to identify different sustainability criteria and indicators useful for the assessment of urban infrastructure projects;
* to test a part of the proposed LCT framework, specifically for the identification of indicators that represents the most critical aspect of the implementation of the framework.

**3. Research Questions**

* How to manage Economic, Social and Environmental aspects in the context of urban metabolism for the evaluation of urban infrastructure projects?
* How to introduce life cycle thinking tools in an integrated framework for the evaluation of the sustainability of urban infrastructures?
* How to design this integrated sustainability framework in order to ease its use by public policy makers for urban planning and the evaluation of best alternative among different urban infrastructure projects?

**4. Significance of the Research**

Sustainable development in infrastructure is a multi-dimensional phenomenon, because:

* it includes the interaction and interdependencies among different resources, the perceived interrelated objectives and dynamic behavior of different parties involved in the project, and
* it includes the three pillars of sustainability.

Therefore, a new cohort of modeling tools to assess semi-quantitatively the three dimensions of sustainable development in term of multiple domains, scales and generation is needed (Heijungs et al., 2010; Guinee et al., 2010).

This research aims to contribute in the development of a life cycle based framework that combined numerous life cycle thinking concepts and that will help and guide decision makers and other stakeholders in a step by step process for the evaluation of the sustainability of an infrastructure. In support of developing LCT based framework for sustainable infrastructure following urban metabolism (UM) theory, this study proposes an assessment framework that incorporates different dimension of sustainability and the stakeholders changing behavior and numerous other approaches followed by industrial ecologist and other experts. For the optimization of the system, as an optional stage, the framework could use sustainability network theory and agent based simulation model in order to capture the dynamic behaviors of stakeholders and the evolving performance of different resources under various socio-environmental condition.

**5. Thesis Structure**

This dissertation is organized as in the following:

* INTRODUCTION - This explains the arguments for the pathway of this research. It also explains the background of the topic, the research objectives and research questions that are to be addressed in the following papers.
* Paper I SUSTAINABILITY ASSESSMENT OF URBAN INFRASTRUCTURES: A LITERATURE REVIEW – which examines the state of the knowledge by addressing relevant literature background, that includes different approaches towards urban infrastructure sustainability, frameworks mainly used for sustainability assessment, and a critical discussion that would identify the research gaps and the need of future research.
* Paper II A LIFE CYCLE THINKING BASED FRAMEWORK FOR THE SUSTAINABILITY ASSESSMENT OF URBAN INFRASTRUCTURE - starting from the research gaps, this paper explains in detail the proposed framework developed for the assessment of the sustainability of infrastructures.
* Paper III LCT BASED FRAMEWORK FOR INFRASTRUCTURE DEVELOPMENT: APPLICATION – which illustrates the implementation of a part of the proposed assessment framework in order to demonstrate, step by step, how sustainability assessment would be carried out; the paper also includes how the sustainability indicators, questionnaire for collection of data, analysis of data and validation of results has been developed. Finally, operative guidelines are formulated.
* CONCLUSIONS – This synthesizes the main research findings and recommendation for further studies.

**PAPER I**

**SUSTAINABILITY ASSESSMENT OF URBAN INFRASTRUCTURES: A LITERATURE REVIEW**

**Abstract**

Urban infrastructure is composed of crucial utility systems such as transport, water and water waste, housing and green infrastructure, energy, waste and communication. A sustainable management of these infrastructures entails an efficient way to measure their performance in terms of environment, economic and social aspects. The purpose of this paper is to evaluate the current approaches used for the assessment of sustainability in the urban infrastructures context, specifically building, roads, pavements and bridges in order to highlight if and how sustainability assessment tools play a fundamental role in the design of urban infrastructures within the urban metabolism theory. Based on the objectives of the research, the paper carried out a qualitative literature from 1991 to May 2017 in this specified field. The framework for the analysis of materials includes the database Web of Science, Scopus and Google Scholar from which all relevant materials were identified. The literature review highlighted that various sustainable development approaches have been developed and applied in different ways with different indicators, depending on the assumptions connected to the system boundaries, but less intention has been given to the integrated assessment of life cycle thinking tools for infrastructure project. Most of the authors focused on the development of sustainability indicators without the consideration of life cycle impact of the indicators. On the contrary, a well-defined framework that can categorize the indicators based on life cycle assessment into their different attributes is highly recommended and can be used for sustainability assessment of infrastructure projects at different stages of their life cycle.

**1. Introduction**

Sustainable Assessment (SA) of urban infrastructure is becoming more and more important and many countries have made it as one of the managerial focal points. Multiple urban infrastructure projects are carried on for serving the growing population of the cities and these projects need a balanced equilibrium among environmental, social and economic aspects. Besides these, other issues are vulnerability aspect, ranging from impacts of climate changes on our urban communities to cultural-based elements. Therefore, a standard change is needed to address the infrastructure concern issues and its possible interconnection with public debt, public health and limited environmental resources. Management policies for infrastructure systems have to maximize the benefits and minimize the stated risks and other stressors that would arise in the future. However, SA in urban infrastructures is one of the utmost complex sorts of assessment approaches. The Brundtland Report (1987) defined Sustainable Development (SD) as “the development that fulfills the needs of the current generation without compromising the ability of future generations to meet their needs.” It can be defined as, an approach that helps the policy and decision-makers in deciding what actions to be taken and what not to be taken in attempting to make a more sustainable society (Devuyst, 2001). Since SA became important practice in institutional, policy and projects appraisals, its objectives have to follow the “plans and activities that create an optimum contribution to sustainability development (SD)” (Verheem, 2002). It has also been acknowledged that sustainable urban infrastructure emphases on mitigation of dangerous emissions and avoidance of excessive consumption of natural resources (non-renewable). Since sustainability in infrastructures is a contribution to global sustainability, accordingly its impacts on and necessary involvement in global sustainability development efforts could not be ignored.

The SA of urban infrastructure is an effective and efficient way not only for the implementation of plans but also to gauge the success and measure performance in terms of economic, social and environment aspects. At the same time, it is essential because of its high consumption of resources, severe greenhouse gases emission and land resource wasting. For the effective management of complexity in urban infrastructure and the trade-off among these systems, there is a need of sustainability assessment procedure to be performed. In order to fulfill the stated issues in connection with urban infrastructure, it is important to identify the best present practices with concern issues and knowledge gaps.

The purpose of this study is to analyze current sustainability assessments tools and frameworks in the context of urbane infrastructure, in order to identify the key characteristics that a methodological framework for urban infrastructure project assessment should satisfy. In particular, this paper intends to discuss the following objectives:

* identification and analysis of various issues affecting the construction of urban infrastructure;
* Critical analysis of the existing approaches, tools and frameworks of sustainability that might be useful for the assessment of urban infrastructure sustainability.

**2. Research Methodology**

Based on the objectives of the research, this paper carried out a qualitative literature review to identify, evaluate and interpret the current state of knowledge about the topic.

The reasons to carry out as a first research method step the literature review are to encapsulate the existing knowledge around the topic, identify knowledge gaps for further research (Kitchenham, 2004), and draw the conceptual content of the topic which could contribute in the development of the framework.

Considering that the materials for the research topic were extremely fragmented in a vast majority of areas, the study here presented has the following boundaries:

* The analysis of the literature on sustainability in the field of urban infrastructure has been carried out focusing on buildings, bridges and pavements. This choice has been made because such infrastructure projects are long live investment and have huge impacts on the sustainability of a country economy, environment and society if mismanaged;
* Relevant materials and relevant articles, reports and books were select from Web of Science (WoS), Scopus and Google scholar databases. These databases are the leading source for publications in a variety of areas of research and multidisciplinary studies covering engineering, social science, arts, and humanities and so on.

To select the most relevant materials on the topic a step by step process was used in order not to miss important research papers. A time span from 1991 to May 2017 was selected in order to gather all the relevant studies published in 27 years. The year 1991 is taken as starting point because during that time the term sustainability, introduced by the Brundtland report, began to be used also in the context of urban infrastructures.

An initial unrestricted search with the keywords “sustainability and urban infrastructure” displayed thousands of results that were difficult to consider for this study. Multiple refiners to reasonably limit down search results were applied because the preliminary analysis of the studies was identified from very diverse fields of research in which many of the studies and journals were not related to the area of interest of the present study.

The keywords used for the selection of relevant material are: sustainability assessment tools, urban infrastructure, sustainability assessment framework, sustainability indicators, triple bottom line approaches, life cycle costing, life cycle assessment, social life cycle assessment, and system dynamics.

Domain areas used are: construction building technology, energy fuel, urban studies, environmental science ecology, social science other topics, engineering, architecture, and science technology other topics.

Furthermore, in the selection of literature, emphasis on methodologies rather than applications has been applied.

Titles, abstracts and key words have been read to see if the article was applicable to answer the guiding objectives. If it seemed applicable, then the full article has been read in order to determine if it should be included or not. This process helped to further narrow down the quantity of irrelevant articles available. The comprehensive selection procedure took a long time to select the most relevant articles about the topic. Articles fulfilling the assessment criteria were further evaluated for the various frameworks and tools used inside them. After carefully reading and analyzing a great number of papers 125 articles were selected for the analysis. The following table shows the articles with the highest number of citations.

The critical analyses of the selected studies are discussed in the following, in two separate sections for Life cycle thinking approaches (tools, methods and models) and for assessment frameworks (reporting an integrated perspective).

**Table 1. Main Characteristics Of The Most Cited Papers Selected For The Review**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Ugwu O.O. |  | 2006 |  | 165 |  | automation in construction |  | Sustainability appraisal in infrastructure projects (SUSAIP) Part 1. Development of indicators and computational methods |  | Methodological |  | MCDA  /AHP |  | Key performance indicators for Infrastructure Projects |  | Hong Kong |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Ugwu O.O. |  | 2007 |  | 274 |  | Building and Environment |  | Key performance indicators and assessment methods for infrastructure sustainability- A South African construction industry perspective |  | Application |  | MCDA  /AHP |  | Key performance indicators for Infrastructure Projects |  | South Africa |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Sahely Halla R. |  | 2005 |  | 247 |  | NRC Research Press |  | Developing sustainability criteria for urban infrastructure systems |  | Methodological/Application |  | LCA |  | Sustainability assessment of infrastructure systems |  | Toronto, Canada |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Thabrew Lanka |  | 2009 |  | 158 |  | Journal of Cleaner Production |  | Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation |  | methodology |  | LCA |  | Environmental decision making |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Jifeng Wang |  | 2008 |  | 132 |  | Journal of transportation systems engineering and information technology |  | System dynamics model of urban transportation system and its application |  | methodology/application |  | System Dynamics |  | urban transportation |  | China |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Xing Yangang |  | 2009 |  | 111 |  | Accounting Forum |  | A framework model for assessing sustainability impact of Urban development |  | methodology |  | Full Cost Analysis (FCA) |  | Buildings |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Lundin M |  | 2002 |  | 221 |  | Urban Water |  | A life cycle assessment based procedure for development of environmental sustainability indicators for Urban water systems |  | methodology/application |  | LCA |  | Urban water management |  | Sweden/South Africa |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Makropoulos C.K |  | 2008 |  | 237 |  | Environmental Modeling and Software |  | Decision support for sustainable option selection in integrated urban water management |  | methodology/application |  | Urban water pioneering tool (UWOT) |  | Urban water management |  | UK |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Ravetz Joe |  | 2000 |  | 273 |  | Environmental Impact Assessment Review |  | Integrated Assessment for sustainability appraisal in cities and regions |  | methodology/application |  | Integrated Assessment |  | cities and regions |  | UK |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Nuissl Henning |  | 2009 |  | 123 |  | Land use Policy |  | Environmental Impact Assessment of Urban Land use transitions- A context sensitive approach |  | methodology/application |  | Impact Assessment (IA) |  | Land Use consumption |  | not specified |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Begic F |  | 2007 |  | 124 |  | Energy |  | Sustainability assessment tool for the decision making in selection of energy system |  | Application |  | MCA |  | Energy |  | Bosnia |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| [Bentivegna](http://www.tandfonline.com/author/Bentivegna%2C+Vincenzo) V |  | 2002 |  | 135 |  | building research and information |  | A vision and methodology for integrated sustainable urban development |  | methodology |  | BEQUEST |  | Urban fabric |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bribian IZ |  | 2009 |  | 456 |  | Building and Environment |  | Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification |  | methodology/application |  | LCA |  | Building design/energy |  | Spain |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Button K |  | 2003 |  | 153 |  | Ecological Economics |  | City management and urban environmental indicators |  | Descriptive Study |  | Sustainability Indicators |  | cities and regions |  | not specified |

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| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Edum-Fotwe |  | 2009 |  | 127 |  | International Journal of Project Management |  | A social ontology for appraising sustainability of construction projects and developments |  | methodology |  | S.LCA |  | urban built environment |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Hopwood B |  | 2005 |  | 1557 |  | sustainable development |  | Sustainable development: Mapping different approach |  | Descriptive Study |  | integrated approaches |  | Sustainable development |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Kennedy C |  | 2011 |  | 402 |  | Environmental Pollution |  | The study of urban metabolism and its applications to urban planning and design |  | Review |  | Urban metabolism |  | urban planning practice in Curitiba (Brazil), Kerala (India) and Nayarit (Mexico) |  | India, Brazil and Mexico |

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| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Meadows, D. H |  | 1998 |  | 879 |  | A report to the balaton group; the sustainability institute: Hartland, VT. |  | Indicators and information systems for sustainable development |  | Descriptive Study |  | sustainability indicator |  | Test of Indicators for sustainable development |  | Netherlands |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Muga H.E |  | 2008 |  | 301 |  | Journal of Environmental Management |  | Sustainability of Wastewater Treatment Technologies |  | application |  | sustainability indicator methods |  | water treatment technologies |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Newman PWG |  | 1999 |  | 525 |  | Landscape and Urban Planning |  | Sustainability and cities: Extending the Metabolism Model |  | methodology/application |  | Extended Metabolism |  | cities and regions |  | Australia |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Padgett J. E |  | 2010 |  | 114 |  | Structural Safety |  | Risk-based seismic life-cycle cost–benefit (LCC-B) analysis for bridge retrofits assessment. |  | methodology/application |  | LCC/CBA |  | Bridges |  | USA |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Rees W |  | 1996 |  | 1000 |  | Environmental Impact Assessment Review, |  | Urban Ecological Footprints: Why Cities cannot be Sustainable - and Why they are a Key to Sustainability |  | Descriptive Study |  | Ecological Footprint |  | ecological role of cities on ecosphere |  | USA |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Rijsberman, M. A |  | 2000 |  | 142 |  | Environmental Impact Assessment Review |  | Different approaches to assessment of design and management of sustainable urban water systems |  | Descriptive Study |  | integrated approaches |  | urban water system |  | not specified |

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| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Runhaar Hens |  | 2007 |  | 150 |  | Impact Assessment and Project Appraisal |  | What Makes Strategic Environmental Assessment Successful Environmental Assessment? The role of context in the contribution of SEA to decision-making |  | methodology/application |  | SEA |  | Environmental decision making |  | Netherlands |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Sachs I |  | 1999 |  | 225 |  | Sustainability and the social sciences: |  | Social sustainability and whole development: exploring the dimensions of sustainable development |  | Descriptive Study |  | SLCA |  | Social dimension of sustainability |  | not specified |
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| Sala S |  | 2015 |  | 41 |  | Ecological Economics |  | A systemic framework for sustainability assessment |  | methodology |  | SA/Scenario Analysis |  | Relevancy and Policies Challenges for Sustainable Assessment |  | not specified |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Shen LI-Yin |  | 2011 |  | 300 |  | Habitat International |  | The application of urban sustainability indicators–A comparison between various practices. |  | Descriptive Study |  | sustainability indicator methods |  | Selection of indicators |  | not specified |
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| Stoglehner G |  | 2003 |  | 204 |  | Journal of cleaner production |  | Ecological footprint—a tool for assessing sustainable energy supplies |  | methodology/application |  | Ecological Footprint |  | Energy |  | not specified |

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| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
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| Van Kamp I |  | 2003 |  | 586 |  | Landscape and urban planning |  | Urban environmental quality and human well-being: towards a conceptual framework and demarcation of concepts; a literature study |  | Review |  | not specified |  | urban environmental quality and human well being |  | not specified |
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| Tzoulas K |  | 2007 |  | 1193 |  | Landscape and Urban Planning |  | Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review |  | Review |  | Indicator approach |  | Green infrastructure/Human health/Ecosystem health |  | not specified |
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| Yigitcanlar T |  | 2010 |  | 99 |  | Sustainability |  | Developing a sustainability assessment model: The sustainable infrastructure, land-use, environment and transport model |  | methodology |  | geographical information system tools (GIS) |  | To assist urban planners in urban sustainability assessment |  | not specified |
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| Basbagill J |  | 2013 |  | 180 |  | Building and Environment |  | Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts |  | methodology/application |  | LCA |  | Building's early design stage |  | not specified |

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| Huang Yue |  | 2009 |  | 193 |  | Journal of Cleaner Production |  | Development of a life cycle assessment tool for construction and maintenance of asphalt pavements |  | methodology/application |  | LCA |  | Asphalt pavements |  | UK |
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| Jorgensen A |  | 2008 |  | 392 |  | International Journal of LCA |  | Methodologies for Social life cycle assessment |  | Descriptive Study |  | SLCA |  | formulation of Indicators |  | not specified |
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| Kopri E |  | 2008 |  | 141 |  | Managerial Auditing Journal |  | Life cycle costing: A review of published case studies |  | Review |  | LCC |  | Case Studies |  | not specified |
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| Becker H. A |  | 2001 |  | 265 |  | Journal of Operational Research |  | Social Impact Assessment |  | Descriptive Study |  | SIA |  | methodologies and applications description in various project |  | not specified |
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| Ali HAEM |  | 2013 |  | 48 |  | Journal of King Saud University- Engineering Science |  | Indicators for measuring performance of building constructions companies in Kingdom of Saudi Arabia |  | Application |  | Sustainability Indicators |  | Economic, Environmental & Social |  | Saudi Arabia |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Mori K |  | 2015 |  | 29 |  | Habitat International |  | Methodological framework of sustainability assessment in city sustainability index (CSI): A concept of constraint and maximization indicators |  | methodology |  | Sustainability Indicators |  | Economic, Environmental & Social |  | Not Specified |

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| **Author** |  | **Year** |  | **Citation** |  | **Journal Name** |  | **Topic** |  | **Study Type** |  | **Tool Type** |  | **Study Focus** |  | **Country** |
| Nijkamp P |  | 2000 |  | 136 |  | Ecological Economics |  | Sustainability assessment of development scenario: methodology and application to Thailand |  | methodology/application |  | Scenario Analysis |  | Economic, Environmental & Social |  | Thailand |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Huang Shu-Li |  | 1998 |  | 148 |  | Landscape and Urban Planning |  | A framework of indicator system for measuring Taipei's Urban Sustainability |  | methodology/application |  | Sustainability Indicators |  | Economic |  | Taiwan |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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**3. Critical review**

**3.1. Life cycle thinking approaches toward urban sustainability assessment**

The elements of sustainability assessment described in the literature are explained in a huge number of principles, concepts and guide models. Different tools and approaches are analyzed to know the methodological differences between the approaches, the conceptual and philosophical nature of the approach and persuading the choice for, and the adequacy of, the approach. Urban sustainability assessment comprises different challenges and debates as described above. Meanwhile urban sustainability assessment frameworks generate a fast-growing arena worldwide. There are various techniques and tools used for the assessment of urban sustainability depending on the project specific and country specific aspects.

**Urban Metabolism**

*Definition:*

Urban metabolism is a vital framework that provides an effective and sustainable ways for the assessment of input and output materials of a city. It behaves the cities as an assemblage of systematic processes that recognizes environmental and resource utilization issues by using indicators (Zhang et al., 2015). The consumption of water, food and energy are taken as inflow while water wastes, solid waste air emissions and heat are taken as outflows (Wolman, 1969).

*Method description:*

A life cycle approach is considered in the urban metabolism assessment by taking usually tangible entities. This approach is well appropriate for engineering systems such as transportation, energy, water and waste which have supplementary tangible inputs and outputs, but it might not capture the qualitative and intangible parameters of a systems. In urban metabolism framework, quantification is also essential due to which it presents a balance sheet of resources using in the form of inputs and outputs. There is no consideration for adjudging the effectiveness of determinations intricate in the process of making the system more sustainable and even there is also no particular consideration for economic and social aspects and nor for climate change effects (Jyoti, 2013). The studies those used UM metrics and principles have concluded the increasing demand for natural resources by the urban and these outcomes have made the rationale for different resource efficiency and sustainability initiatives globally.

**Extended Metabolism**

*Definition:*

The extended metabolism approach deliberates livability as an element of metabolism. Materials, water, land, food all are considered as input resources while the changing aspects of human settlement are deliberated as functional stage and wastes and livability conditions are as output resources. Hence in this regard, the extended metabolism approach advances on metabolism approach by adding social aspects (Newman, 1999).

*Method description:*

The applications of this approach might apply to individual business/project, neighborhoods and industrial areas and cities or projects can also be compared for their sustainability. Moreover, for advancing the livability conditions, the application of the approach necessitates reducing inputs and waste outputs. It is broadly defined that comprises multiple parameters such as urban design quality, community, accessibility, housing, education, employment, income and health. However, it might be influenced by the actions that are considered to decrease input and wastes output in the urban infrastructure system. The important element of all social well-being and livability is health, which is mostly affected by the environment issues, so in this regards public and employees’ health should be a part for the assessment of infrastructure sustainability. The extended metabolism approach does not add climate change management for the sustainability of a system (Jyoti, 2013).

**Life Cycle Assessment LCA**

*Definition:*

Life cycle assessment (LCA) is an environmental assessment tool for the consumption of resource and energy, and emissions to environment which are calculated from raw material extraction till the end of life cycle stage of product/services. The source of life cycle assessment (LCA) tools could be traced after the agenda 21’s which aims for the incorporation of environmental aspects with other aspects such as economic, social and institutional of urban development (UNCED, 1992). This caused in a shift for methodology development from environmental to life cycle assessment.

*Method description:*

Generally, there are four stages of life cycle assessment: definition of goal and scope, inventory analysis, impact assessment and interpretation of the final results. The functional unit (FU) is the basis for the calculation of all input and output that’s why it reflects the basic function of the considered system. The efficacy of LCA highly depends on the system boundary (SB) and availability of data without which the quantification of input and output cannot be fulfilled. LCA addresses widely sustainability matters such as environmental limitations, social equity and the requirement for stakeholders’ participation. LCA are being used to different urban infrastructure projects including water, building and asphalt pavement in order to evaluate the energy and material usage and resource emission to environment in the form of Green House Gases (GHG) and pollutions (Godskesen et al., 2011; Buckley et al., 2011, Lundin, 2002; Racoviceanu and Karney, 2010; Bribian, 2009; Basbagill, 2013; Huang et al., 2009).

In spite of this, this method still indicate limitations to a range of sustainability concerns like it only takes into account quantitative indicators but cannot assess qualitative indicators which is a main issue for urban infrastructure projects. Moreover, LCA methodologies are failed to incorporate all sustainability aspects such as social and economics of the tasks of sustainability assessment in urban context. Nevertheless, LCA tools have assisted considerably to the assessment of sustainability with the coverage of spatial scales and urban activities.

**Life Cycle Costing LCC**

*Definition:*

LCC is the commonly used assessment practices for economic aspects. It can be defined as “ a costing tool for procurement and production that considered the cost of all life cycle stages of a particular system to be analyzed; it determines the total cost of owning and operating an item over a period of time.

*Method description:*

LCC applied to construction of urban infrastructure as a tool used for the evaluation of different projects from the perspective of economic sustainability. The most common use of LCC is the selection of alternatives and design-offs comparisons and optimization (Padgett et al., 2010; Rahman and Vanier, 2004; Seong, 2010; Sing, 2005; Korpi and Ala-Risku, 2008) which is one of the aims of policy makers when assessing different project options on the basis of sustainability. The process of LCC is directed by the ISO 15686 standards (ISO 15686-5. 2008). The European commission allotted David Langdon Management consulting in 2006, to develop a corporate methodology for the construction projects whose published the final report in 2007, and the proposed framework is anticipated to be companionable with ISO 15686-5 (Davis Langdon, 2007).

From the urban sustainability assessment perspective as it states: the sum of total of socio-economic and environmental process that occur in a system, resulting growth, energy, production and elimination of waste, the use of LCC in this context will determine and maintain level of sustainability by managing cost at each of its level. Similar to LCA, it also takes into account the qualitative indicators, thus qualitative aspects such as comfort and other environmental related indicators are neglected.

**Social life cycle assessment SLCA**

*Definition:*

Social life cycle assessment (SLCA) is a practice used to explore social and socioeconomic influences and the benefits and damage of products or systems throughout the whole life cycle with specific or specific data. It gives information and facts for decision making, prompting discourse on the socio-economic aspects in the scene to improve well-being of stakeholders (Jorgensen, 2008). As comparing to other social tools, SLCA has an impression of social influences that a project life cycle can deliver during the cradle to grave boundaries.

*Method description:*

SLCA processes are more in common with the process of LCA. Both methods have similar structure according to ISO 14040 framework that are goal and scope definition, LCI analysis, life cycle impact assessment and interpretation that evaluate the impacts of all phases of the life cycle of a project (Sachs, 1999; UNEP/SETAC, 2009). This approach can also be used with environmental and economic aspects for the provision of more sustainable point of view (Ristimaki and Junnila, 2015; Halog, 2011; Azapagic, 2016). It presents numerous indicators and related ‘specific and generic data’ that could be qualitative, quantitative, and semi-quantitative. Regarding infrastructure, it takes into account different qualitative indicators such as health and safety measure, effect on stakeholders and community and other site-specific indicators (Edum-Fotwe and Price, 2009). The majority of studies choose social indicators based on the availability of data because the main difficulty in SLCA is the deficiency of data availability.

**Urban Footprint**

*Definition:*

This approach is based on the assessment of the land area needed to sustain urban metabolism and population in the city. It takes into account the land use for infrastructure, forests, agriculture, material, energy and land for waste acclimatization in an urban area (Rees and Wackernagel, 1996; Eaton et al., 2007).

*Method description:*

The fundamental indicator for the quantification of urban footprint is the ratio of built up and reduction of other types of land use. This analysis achieves importance in the perspective of rapid urbanization and consequent pressure on infrastructure, land and energy. It considers the biophysical and ecological aspects of urban periphery, and interprets the resource consumption in terms of land area utilized. Peripheral settlements are more often responsible for the provision of materials and food for the city to maintain its inhabitants. Hence the system boundary of the urban is extended to those peripheral areas: sustainability of the particular region is normally assessed rather than the urban itself. The footprint of large city (area-wise) and sparse population may be larger than a densely occupied small city; however, the urban systems may not be more sustainable because may be other constraints (e.g. economic, health) might affect sustainability (Stoglehner, 2003; Scotti et al., 2009).

The urban footprint approach does not consider the dynamics involved in an urban system; though the system model is abstractly straightforward (input and output). In UF analysis, quantification is important and may be suitable for small and big size cities.

**Sustainable Indicators method**

*Definition:*

Generally, indicators are used as a tool to assess different criteria and options in reflection of sustainability. Sustainability indicators are one of the tools to gather data about the key sustainability indicators that would be assess through life cycle management approach to find out the sustainability of economic, environment and social indicators of a project.

*Method description:*

Sustainability indicators approach has been used in many studies for the assessment of sustainability of urban infrastructure projects. There is need of a well define framework in order to assess the sustainability of an urban activity following sustainability indicator approach because using this approach without a framework will not be useful and even it is difficult to use the approach because of the dynamics in the indicators qualitative and quantitative attribute of a system. Multiple biophysical, human interaction and ecosystem might not allow indicators to consider all sustainability aspects unless within a certain well-designed framework. Various studies have been performed in the urban context include buildings, bridges, roads, transportation, water and waterwastes infrastructure projects using sustainability indicators approach (Thorsten, 2007; Sahely, 2006; Palme, 2007; Ugwu and Haupt, 2007; Hellstrom et al., 2000; Ugwu et al., 2006; Lundin et al., 1999; Bell and Morse, 1999; Alyami et al., 2013; Foxon et al., 2002; Fernández and Rodríguez, 2010). This approach has also been used for waste water treatment (Vleuten-Balkema and Juliana van der, 2003; Lee et al., 2006; Muga and Mihelcic, 2008). According to Bell and Morse 1999, it is significant to define the system’ long-term performance while most of the sustainability indicators do not reveal the ability of a system to sustain or improve over time (Milman and Short, 2008). Bagheri 2006 contends that sustainability is neither “static goal” nor “system state” to be obtained and advocate for “backcasting” by the support of indicators. But system approach should be used to examine the sustainability of a system (Bell and Morse, 1999; Hellstrom et al., 2000)

One of the issues with this technique is relating what is the contribution of indicators to the actual sustainability. A well-defined framework can categorize the indicators on life cycle based assessment into their different attributes and can be used for sustainability assessment of a system at different stages of their life cycle. From methodological side, sustainability indicators approach is suitable for the assimilation of tools for the evaluation of a project from several dimensions for sustainability assessment. Choosing indicators based on their functions is more significant than selecting based on outcomes (Tam, 2002) because indicators selection based on function could be more sensitive to the dynamics conditions.

**Ranking**

*Definition:*

This approach is broadly used by organizations to rank different criteria for attaining more objective oriented projects (Hesampour et al., 2016). Generally, multicriteria analysis method is utilized for scoring different criteria by employing weighting scheme and then final score is calculated to find out the final rank of different options.

*Method description:*

Particular criteria are wrecked down in three sections: first the goals of the criteria have to be set. Then it enlightens the applicability of the criteria that which criteria is applicable in terms of types of projects work and Lastly, it shapes what has to be attained in order to get points for the specific criteria. For instance, if 6 is assigned to a most suitable and 0 is assigned to not suitable in every category then the city with highest scored assigned will be ranked first in all options. The issues and priorities for criteria are different from place to place; the weight assign to a criterion in one place cannot be exactly relevant in the place. These variances are not revealed in the ranking approach. Ranking approach as MCDA validates the inclusion of quantitative and qualitative factors into decision analysis and is useful when analytical resources or information are limited.

In some case the ranking process is done based on mathematical models (Kahn, 1995) in which the impact of city’s features and interrelationship among them are not revealed in the results. In this regard, this approach couldn’t provide full sustainability picture of a system. Different indicators such as climate changes etc. can be included as a ranking criterion but generally it is generic in nature and do not take into consideration specifically the implementation of the policy relates to sustainability of infrastructure. Some examples of particular and broad criteria are listed below in table

**Table. 2. Example of Ranking Criteria used in Cities**

|  |  |  |
| --- | --- | --- |
| **Specific Criteria** |  | **Broad Criteria** |
| Congestion, metro transportation, commuting to work, green building (leadership in energy and environmental design-LEED), tap water quality, air quality, housing affordability, land use, local food and agriculture, green economy, natural disaster risk, climate change policies, energy, water supply and knowledge base/communication |  | Economic security, ecological integrity, empowerment and governance, social well-being and infrastructure and built environment. |

**Source:** SustainLane, 2008;Jyoti, 2013; Upadhyaya, 2014

**Environmental Impact Assessment (EIA)**

*Definition:*

It is the positive or negative environmental consequences of a project prior to the assessment to move ahead with the planed actions. It is also defined by International Association for Impact Assessment (IAIA) 1999 as “the process of identification, evaluation and mitigation the social, biophysical and other pertinent effects of development proposals earlier to key decision took place and commitment made.

*Method description:*

The aims of the EIA are to ensure that the policy maker take into account the environmental impact while deciding to proceed or not to proceed with the project. The approach is recognized to the potential of assessing the sustainability of a system. Usually, local laws and legislation are accessed to define whether an EIA is needed to assess the project impacts. However, most of the stakeholders consider this method performs not satisfactory in practice (Sheate, 2003; Benson, 2003). The ability to integrate strategy and scenario development by adding assessment is not instinctive and difficult. The applications of the approach are based single-project, involve only direct stakeholders (Nuissl et al., 2009; World B, 1991; UNDP, 2002), while interconnections of activities and indirect stakeholders are difficult to represent.

The main censures of EIA are its limited consideration of substitutions, scientifically inappropriate impact estimations, and stakeholders’ involvement in appropriate manner as the study products do not clue to comprehensible interpretations (Shepard and Bowler, 1997; Wood, 2003; Cashmore et al., 2004). Furthermore, EIA studies entail hard questions about system boundaries i.e. incorporating up and downstream activities when the project is limited to the local context. However, EIA is reflected as a good way for the assessment of chosen project.

**Social impact assessment (SIA)**

*Definition:*

It is can define as the process of identifying the future consequences of a proposed current plan related to organizations, individuals and social macro-system. Typically, social impact assessment is carried out in order to assess the social insinuation of a project and it is done under EIA traditional legislation and law (Becker, 2001). One of the key goals of this approach is to determine how the people positively affect by the project and how these social changes would be managed (UNEP, 2003).

*Method description:*

This approach usually involves structured interview and questionnaire based survey. The survey is directed by the population who are directly affected by the project and the main stakeholders in the project. However, some other researchers have explained SIA as taking in initial stage that embraces problem assessment, designing project, and a main stage that contains strategy and scenario development, raking of different strategies, impact assessment and evaluation. In some examples, SIA performed as a stand-alone tool combined ecological and economic in the social aspects (Akpofure and Ojile, 2003; Becker, 2001).

Like EIA, it is also single project based and do not decrease transaction costs and uncertainty, nor it assist in getting the commitment of various stakeholders for integrated project development.

**Risk Assessment (RA)**

*Definition:*

Risk assessment is the determinations of qualitative or quantitative inference of risk concern to a well define condition.

*Method description:*

In a risk management process, RA is a principle step that typically includes two quantities of measuring risk: the probability of the occurrence and the magnitude of the potential loss. The two major steps for the estimation of risk are (i) the identification of hazardous, (noise, radiation, chemical etc.) and (ii) quantification of exposure, that show the impurity amount that a person inheritance have it. Then the outcomes of the above steps are brought together to get an estimated risk. Due to the various exposures and susceptibilities, this resultant risk might vary among the population. In the development projects the approach is applied in a participating manner including the stakeholders. RA is broadly used in a community in healthcare and policy representatives in identification of potential risks in cartel process between community and stakeholder judgments which has the benefit of fostering stakeholders’ commitment in multi-stakeholder perspectives (Fisher, 1991; Andrews, 2013). In the end of the analysis, public involvement takes place for comments and feedbacks but since the process of assessment is not more translucent, so this step of the process could not merge various interpretations easily by the stakeholders in various disciplines.

RA does not assist integrating upstream and downstream inter-linkages of stakeholders. Moreover, it does not usually facilitate cultural, social and economic aspects, i.e. community aspirations and needs, in the assessment. Therefore, it is not a stand-alone assessment method that might provide a whole perception of development problems, and integrate required aspect of sustainability for consent building in strategy development and in cross-sectorial decision making.

**Systems Dynamics (SD)**

*Definition:*

In many studies, computer bases simulation models are developed to understand and analyze the system sensitivity and variability. In this context Forrester 1958, introduced SD model which is used for simulating urban system, it involves computer based simulation modeling for understanding, framing and conferring complex problems and concerns of urban systems. System Dynamics is one of the well-organized complexity science methods whose basic concept is to understand how all the factors interact with each other in a system through feedbacks loops. These feedbacks loops are distinct as close chain of cause and effect which is also useful for modeling the interconnections among systems to see how their connection produce particular behavior for the system.

*Method description:*

Due to the complex nature of urban system, it is not appropriate to use the traditional method to analyze and simulate. Therefore, SD approach has been used in urban complex infrastructure systems. The process of system dynamics could be classified in three stages: i) Preliminary analysis, it is important to define the system boundary and identify internal and external factors/variables, particularly for casual loops. (ii) Specified analysis, based on the outcomes of the first stage, equations and coefficients are identified for conducting quantitatively the simulation process. (iii) Comprehensive Analysis (Wang, 1998), the simulation outcomes from various scenarios are evaluated and compared, and policy recommendations and relevant assumptions are summarized. It used for evaluating the relationship between land use and transportation (Haghani et al., 2003), estimating the performance of regional development, (Ding et al., 1998) and evaluating the environmental effects of industrial gardens (Yang and Xue, 2007). System dynamic models have been developed for the sustainability assessment of urban infrastructure projects in different regions (Zhou and Liu 2015; Jifeng et al., 2008; Ilyas et al., 2016).

The issue with the approach, it is capable to run one situation at a time, though it can capture a great deal of assortment in the varying value of its variables. Various groups and stakeholders with dynamics culture may carry different assumptions which may show quite different model. A SD diagram may become extremely complex when real situation with many variables is modeled. Ultimately, this demonstrating process can keep up the selection and execution of sustainable systems.

**Multi Criteria Assessment (MCA)**

*Definition:*

Multi criteria assessment (MCA), that is suitable for sustainability assessment when a single-criteria approach is not viable and particularly when both quantitative and qualitative criteria are important (Upadhyaya et al., 2014). It is an assessment tool use for the assessment of different alternative options in consideration of the goals and objectives of the project sustainability. The purpose is to guide the decision makers in decision making process to achieve the best sustainable option for their project.

*Method description:*

Different methods and tools such as weighted product model (WPM), weighted sum model (WSM), Techniques for Order of Preference by Similarity for Ideal Solution (TOPSIS), PROMETHEE, MAUT and CP, and multi-objective optimization are used commonly while other tools are Simple Additive Weightings (SAW), Critic Method (CM) and Entropy Method (EM) discussed by Yilmaz and Harmancioglu (2010). In this regards, simpler tools and methods of weight assigning are quite popular and more effective. A literature review study done by “Pohekar” in which highest papers have used multi-objective methods straightforward and WSM was the frequently used method (Pohekar and Ramachandran, 2004). A review study by Huang et al. (2011), proposes that the commendations were alike however, various tools of MCA were applied for same problem. Generally urban infrastructure assessment decisions are carried out by multiple stakeholders with multi objectives which are challenging to trade off. Thus, the foremost criticism in the applications of MCA in decision making is assigning weight to the criteria and indicators, and then its impact on the final consequences of the assessment (Alvarez et al., 2009; Steele et al., 2008). An integration of two approaches is usually suggested by the literature while assigning weights (Upadhyaya et al., 2013): that are (i) assigning weight through stakeholder participation and (ii) assigning weights through experts opinions. These approaches apply experience and understanding of the issues that the system is dealing with. The weight that is assigned by the decision maker to an indicator is vital in the assessment of sustainability and it might be affected by spatial or temporal variation and the stakeholder’s conferred belief, preference and interest, e.g. a stakeholder is more interest in financial benefit from a project will weight economics attributes more than other attributes. giving similar weight to all attributes by the decision makers show the neutral behavior of decision maker for eliminating the bias from the assessment process (Janssen et al., 2005), and sensitivity analysis could show preferences and changes (Alvarez et al., 2009). Nonetheless, giving equal weighting will not account for the specific characteristic of the system but it should show some priorities in weighting for assessment process. In other way, assigning equal weight will fail to dig out any specific problem in the system. Lastly, a decision-making system should involve some kind of check and balance for the prevention of bias in the system.

The involvement of different stakeholders in the process of decision is considered to be one of the crucial elements of sustainability assessment. There are few stakeholder-involvement-based frameworks in decision making but are not tested particularly for infrastructure project in urban planning context. Generally, the parties or institution responsible for making decision gives information and data to the stakeholders and they provide feedback based on their knowledge and preferences. The following table summarizes the stated approach on the basis of their applicability, advantages and disadvantages.

**Table. 3. Summary of various tools, methods and approaches for the sustainability assessment of urban infrastructure**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** |  | **References** |  | **Main detail** |  | **Application** |  | **Advantage** |  | **Disadvantage** |
| **Ranking** |  | Kahn, M. E. 1994 |  | Based on weighting Score for different categories |  | Infrastructure projects, institution and cities products |  | It is considered to be simple method, can be utilized as a pre-screening tool, taking into account both quantitative and qualitative indicators |  | This method doesn’t take into consideration the spatial and temporal variability |
|  |  |  |  |  |  |  |  |  |  |  |
| **Footprint** |  | Eaton et al. 2007, Rees & Wackernagel. 1996 |  | It interprets the consumption of resources in terms of land used |  | Institution, product, cities, infrastructure |  | Easy to visualize, affects are specified in single unit (ha). |  | It is a complex method; it needs to take into consideration resources such as, food material. Difficult to specified improvement area. |
|  |  |  |  |  |  |  |  |  |  |  |
| **Sustainable indicators method** |  | Thorsten R. 2007, Sahely H. 2006, Ugwu & Haupt. 2007, Hellstrom D et al. 2000, Uhlmann V. 2003, Osborne AT. 2003, Ugwu et al. 2006 |  | It is based on different criteria and indicators for each criteria and may be sub indicators |  | Specifically infrastructure project. Biofuel energy sector, product, institution and cities. |  | It is a good tool for the use of tangible and intangible parameters |  | It is difficult to use with a well-designed framework because of the complexity in indicators and their sub indicators and criteria. |
|  |  |  |  |  |  |  |  |  |  |  |
| **Urban metabolism** |  | Wolman. 1969, Zhang et al. 2015 |  | It considers the urban input and output resource like human body metabolism. Material flow analysis technique is used for the calculation of resources |  | In urban infrastructure project. MFA is an applicative tool for its calculation |  | Simple and Scientific |  | Quantification of the input and output is required so data quality and availability might affect the results. |

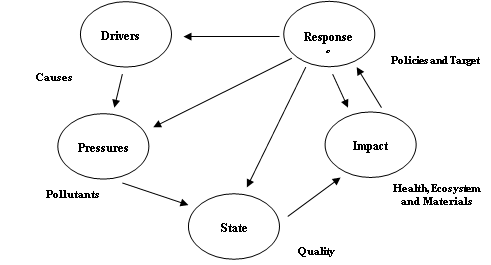
|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** |  | **References** |  | **Main detail** |  | **Application** |  | **Advantage** |  | **Disadvantage** |
| **Extended metabolism** |  | Newman A. 1999 |  | Similar to urban metabolism technique this method considers livability as output |  | Cities metabolisms |  | Simple and Scientific |  | Like urban metabolism this tool also can be affected by data quality and availability for the quantification of input and output |
|  |  |  |  |  |  |  |  |  |  |  |
| **Life cycle assessment** |  | Godskesen et al. 2011, Buckley et al. 2011, Racoviceanu & Karney. 2010 |  | Basically use from environmental prospective for the assessment of environmental indicator like GHG, etc. |  | Various products and services and for infrastructure projects as well. |  | Easy step by step process, simple and scientific |  | Need quality data, otherwise result can be affected. |
|  |  |  |  |  |  |  |  |  |  |  |
| **Life cycle costing** |  | Davis Langdon, 2007  Korpi E and Ala-Risku T. 2008 |  | Basically use for the economic assessment of project sustainability. Considering factors like life cycle cost, initial cost, etc. |  | Different projects for urban infrastructure (references are mentioned above). |  | Simple and scientific, step by step process. (Davis Langdon, 2007) |  | Difficult to consider environmental cost, need quality data and availability of data. |
|  |  |  |  |  |  |  |  |  |  |  |
| **Environmental Impact Assessment** |  | Sheate WR. 2003, Benson JF. 2003, Wood C. 2003, Cashmore M et al. 2004 |  | Accepted by researcher that contributes to an amusing intangible understanding of sustainable development. |  | Products/ services  Construction projects, joint infrastructure projects. |  | Is considered to be a good way for the assessment of a particular project. Local laws are used for its determination. |  | The procedure is not transparent. Entail difficult questions about system boundary. Not well suited to reduce uncertainty |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** |  | **References** |  | **Main detail** |  | **Application** |  | **Advantage** |  | **Disadvantage** |
| **Social impact assessment** |  | Becker HA. 2001, Akpofure EA & Ojile M. 2003 |  | Main objective is analyzing how a project can affect people and how to manage this social change. |  | Cities, products/services, urban infrastructures |  | Integrating ecological and economical aspects in the view of social aspects, step by step processing consist on structure interview. |  | Like environmental impact assessment, it also doesn’t reduce transaction cost and uncertainty. |
|  |  |  |  |  |  |  |  |  |  |  |
| **Risk Assessment** |  | Fisher F. 1991, Andrews RNL. 2013 |  | It is typically involves for measuring two quantities of risk, i) the probability of occurrence ii) the magnitude of the potential lost |  | Widely used tool among healthcare and policy agents. Construction of infrastructure, city planning, other urban projects. |  | Stepwise easy process. Technical and quantitative estimation process involving stakeholders. |  | Limited usefulness for multi-stakeholders contexts. Long process. Not more transparent process. |
|  |  |  |  |  |  |  |  |  |  |  |
| **System Dynamics** |  | Haghani et al. 2003  Ding F et al. 1998  Yang YF & Xue HF. 2007  Jun Z & Yinglia L. 2015 |  | The approach bases on feedback control theory, with computer simulation tools, uses in quantitative research of socioeconomic field. |  | Industrial ecology, government decisions, corporate organization, urban systems |  | Stepwise system following computer software, useful in modeling interconnection among indicator through positive and negative feedbacks loops. |  | Not easily understandable to common stakeholders. Based on some mathematical model and a mathematical model could not be able to deal with different kinds variables |
|  |  |  |  |  |  |  |  |  |  |  |
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Approach** |  | **References** |  | **Main detail** |  | **Application** |  | **Advantage** |  | **Disadvantage** |
| **Multi Criteria Analysis (MCA)** |  | Alvarez GM et al. 2009,  Steele K et al. 2008  Janssen R et al. 2005 |  | It is suitable for sustainability assessment when a single-criteria approach is not viable and particularly when both quantitative and qualitative criteria are important. |  | Infrastructure projects, Technologies, Products. |  | MCA could structure the assessment of a complex issue along both normative and cognitive dimensions.  It can enable multi-stakeholder procedures, transparency and argument about the particular elements in policy analysis |  | What are the applicable means to integrate MCDA in various assessment and policy making conditions?  Long Process  Different stakeholders are involved which may create bias in the process. |

**3.2 Various Framework for the Assessment of Urban Sustainability**

Since the conception of sustainability development introduced as a major issue, a large number of frameworks, methodologies and tools developed in relation to urban sustainability assessment. The methods mainly used are different in their content and scope in the way they assess the sustainability. Some of them are indicator-based assessment whose applications have been carried out in many socio-economic and environmental scientific fields. Aggregated lists of sustainability indicators and criteria for urbanization have been introduced by different regional and international institutions, such as European Commission on Science, Research & Development (ECSRD) (2000), the United Nations (2007) and the European Foundation 1998. In addition to these, there are composite sustainability indices developed currently such as the “Environmental performance index (EPI)”, “Environmental Sustainability Index (ESI)” and “Environmental Vulnerability Index (EVI)” and the Wellbeing of Nations and National Footprint Accounts (SEDAC, 2007).

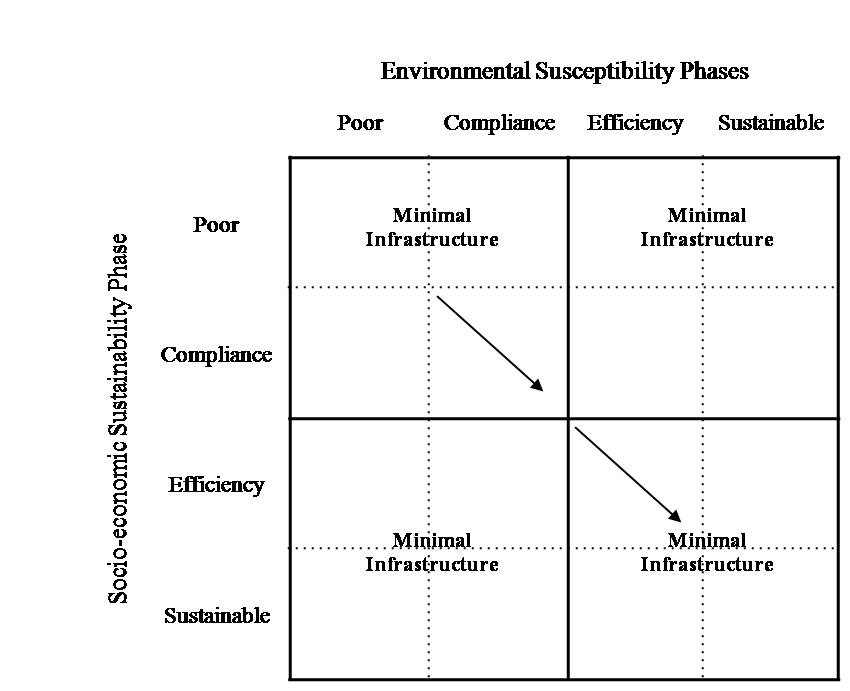
The selection and development of sustainability indicators for urban systems is a complex phenomenon. The Causal Network (CN) is a common framework for the development of indicators, which is the combination of causal and feedback loops series such as pressure state response (PSR) framework (Pakzad and Osmond, 2016). OECD (1993) introduced PSR framework that is based on state and response indicators which explain the issues triggered by human activities. The state indicators observe physical, biological and chemical quality of environment while the response indicators show the response of the societies for the changes and issues caused by the environmental changes (Segnestam, 2002). The framework is advanced by “EEA” to worldwide recognized framework “Driving force-Pressure-State-Impact-Response” (DPSIR). According to the framework there is a causal links among the indicators that initiates with “Driving force” (human activities and economic sectors) through “Pressure” (wastes and emissions) to “States” (chemical, physical and biological) and “Impact” which show the environmental harm to ecosystem, human health and functionality, eventually the indicators sitting, prioritization and targets of these environmental issues are lead to political responses (Kristensen, 2004). These causal links define the stable interactions among natural resources and human activities which determine the level of sustainability for urban development. The assessment of urban sustainability gives a central approach for the effective use of natural resources though adapting human demands and activities through a crucial tool to understand the natural and physical features of urban settlements actions in rapports of their potential, risks and weaknesses in the process of urban planning (Pakzad and Osmond, 2016).

**Figure 1. DPSIR Framework**

**Source: (**Kristensen P, 2004)

There are other numerous sustainability assessment frameworks developed mainly for various urban infrastructure projects. Ugwu (2007) presented an approach for identifying key performance indicator through an analytical decision framework for achieving the sustainability of an urban infrastructure project in the context of developing countries (South Africa). The author used “additive utility model” in “Analytical hierarchy process (AHP)” for multicriteria decision making process and ‘weighted sum model” tool in multicriteria decision analysis for the development of framework used for computation of sustainability index (Ugwu and Haupt, 2007). The issues with these frameworks are they don’t deliberate life cycle analysis of the project and were not developed in the context of urban sustainability.

Dunphy proposed a conceptual framework “sustainability change matrix” and “Sustainability phase model” for evaluating organizational changes for corporate sustainability (Dunphy 2000, 2002). Then this conceptual framework has been utilized for designing “infrastructure sustainability phase model and sustainability change matrix” for infrastructure socioeconomic and environmental sustainability (Ashraf and Hossain, 2012). There are four defined sustainability phases for any infrastructure project: “poor, compliance, efficiency and sustainable”. Various indicators and tools are used to classify the sustainability phase and different distinct steps would be defined for the transformation of an infrastructure to sustainability. This framework through different sustainability phases helps the decision makers and other stakeholders to enhance their vision in the scope of a structures framework for assessing infrastructure towards a sustainable system.

**Figure2. Infrastructure Sustainability Change Matrix**

**Source: (**Ashraf, M & Hossain, Md. R. 2012)

A systematic framework for SA that composes on knowledge systematization on scientific and technical sustainability evaluation addressing crucial decision-making elements is proposed by (Sala et al., 2015). The framework follows a systemic approach for sustainability assessment based on literature multi-scale, which is fundamentally concern in three levels, “ontological, methodological and epistemological”. The role of decision making elements in the framework is to aware the analyst of possible indicators or variables which would influence the analysis of the final outcomes. The framework might be used for assessing existing and new policies and measure and for the impact of consumption and productions of goods/services, and the efficient sustainability management services put by private and public companies. On the basis of these multi interconnected objectives in the infrastructure system sustainability a simulation framework in evolving socio-technical infrastructure system has been introduced (Batouli and Mostafavi, 2016). The framework integrates various dimensions for infrastructure network sustainability and dynamic changes in the stakeholders’ behavior, environmental, social and asset performance conditions. This framework used “agent based simulation model” in order to capture the integration of all these elements and is compose of three components. The socio-environmental condition that are changes in demand service and the range of available funds for network preservation might lead to adaptive behavior in the process of decision making by agency, which eventually affect the state of the physical network. The collaborations between agency and physical network lead to a constant performance condition for a network while constant performance condition is connected with some level of performance and with environmental and cost impacts and this constant condition is stated as the performance regime for the network.

Several social science research frameworks and models stated the environmental changes effects on human physical and mental health. The implementation of “green infrastructure notion” for the sustainability of urban planning has a vital influence. Green infrastructure concept could increase the contribution to biodiversity conservation, resilience of ecosystems, urban habitats enhancement and discharge pressure on the environment such as escalation and land use changes, climate changes and disintegration by human activities. The clear consent is that biodiversity and green open space are subsidized positively to improve the physical and mental health of the urban residents (Pakzad and Osmond, 2016). Picket et al. (1997, 2001) developed an incorporated human ecosystem framework to analyze urban systems in the context of biological, social and physical aspects. The interrelated parts of stated framework are the “resource system” and “human social system”. Resource system is composed of socioeconomic resources and cultural, and ecosystems design and process while human social system compose of social organizations and cycles. Then Grimm et al. (2000) revised the same framework on the bases of the findings from land cover and land use changes on the interface between ecological and social systems. In general, these models assist in the description of green infrastructure concept but they do not address the relation between human health and ecosystems (Tzoulas et al., 2007). A more complex and complete framework have been established by Van Kamp (2003) that combined different factors which influence the quality of life of community, built environment, cultural, social and economic as well as personal factors. However, there are ambiguous relationships among these factors. Thus, on this ground the framework proposed by Tzoulas (2003) of green infrastructure for urban areas give an idea for combining the ecology concept, such as community health, ecosystem and mental health.

The “arch of health” an integrated framework illustrates the cultural, environmental and socio-economic, inherited and lifestyle aspects of public health, community, living and working condition of community (WHO, 1998). To enhance the application of “arch of health” framework within organizations, it has been combining with developmental principles (organizational, environmental, social and personal factors) and with system theory by Paton et al. (2005). The Millennium Ecosystem Assessment body (MESAB) introduced another integrated framework for the assessment of global ecosystem dynamics and their effects on ecosystem and human health. The framework associates human wellbeing and ecosystem services through socioeconomic aspects. Human wellbeing were divided into five classes: (i)social relationship, (ii)freedom of liking, (iii) health, (iv) security and (v) access to resources; and ecosystem services are divided into four classes: (i)cultural, (ii) facilitating, (iii) regulating and (iv) provisioning (MEA, 2003). The framework is wide enough that included many factors and parameters but has been criticized in his study, that it does not obviously differentiate among psychological biological and epidemiological characteristics of health (Tzoulas et al., 2007).

**Figure3. Framework for Assessing Infrastructure System**

**Products**

**Services**

**Energy**

**Material**

**Environmental**

**Susceptibility**

**Engineering**

**Susceptibility**

**Socio-Economic**

**Susceptibility**

**Residuals**

Source: (Sahely et al., 2005)

To achieve a sustainable infrastructure, first it is necessary to understand how an infrastructure project links to the sustainability principles. Sahely et al. (2005) introduced a framework which emphases mainly on important interactions between infrastructure and economic, social and environmental systems as shown in the figure 5. The process involves definition of overall goals, indicators, system boundaries and sustainability criteria. SA is a decisive step based on the performance measure of an infrastructure in terms of sustainability indicators. A planning tool for various infrastructures sustainability has been reported in the study of Yigitcanlar and Dur (2010); they stressed that indicators should signify all sustainability spheres on the theoretical front but in practice the indicators should have assessment possible parameters. A study based on Swedish research presented a set of criteria for water management infrastructure and advised that the criteria should be concise to easily measure for practical use (Hellstroma et al., 2000). Some of the studies define a general list of relevant indicators for sustainable infrastructure (Huang et al., 1998; Magalhaes, 1994; Symth and Dumanski, 1995; Palme, 2007; Tweed and Sutherland, 2007; Shen et al., 2011). Multi-criteria decision analysis (MCDA) and Fuzzy Cognitive Map (FCM) (Kosko, 1986) are important assessment methodologies, MCDA for decision having complexity featuring inconsistent objectives, various kind of data and high uncertainty has been widely used in infrastructure projects for indicators and criteria selection (Linkov et al., 2004; Ugwu et al., 2006). FCM was used for sustainable urban infrastructure in Australian context (Alsulami and Mohamed, 2011) and for green-blue infrastructure projects (Antucheviciene et al., 2010).

The goals of the sustainability must be defined well in an infrastructure system; Donnelly and Boyle (2009) argue that the sustainability of any system cannot be guaranteed only at project level because the system must be considered in the context of bigger system and the services it relates such as wastewater and water reticulation, transportation and energy, etc. long and short terms sustainability threats must be considered across region through coordinated, extensive, and in specific context approaches that define the risks and threats to the systems sustainability, and the course of actions that are essential to reduce or eliminate risk to an acceptable level, only then site-specific actions can address sustainability (Lim, 2009). These sustainability assessment tools show that numerous distinct assessments that are project based would be needed for an incorporated assessment.

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| **Table 4. Summary of the various integrated frameworks** | | | | | | | | |
| **Reference** |  | **Topic** |  | **Application** |  | **Advantages** |  | **Disadvantages** |
| Ugwu et al., 2006 |  | Sustainability appraisal in infrastructure projects (SUSAIP) Part 1. Development of indicators and computational methods |  | Infrastructure |  | The development of key performance indicators of economic, social and environment sustainability which can be used for urban infrastructure projects. |  | It did not consider life cycle analysis of the project. |
|  |  |  |  |  |  |  |  |  |
| Ugwu et al., 2006 |  | Sustainability appraisal in infrastructure projects (SUSAIP) Part 2. A case study in bridge design |  | Bridge Infrastructure |  | The development of key performance indicators of economic, social and environment sustainability which can be used for urban infrastructure projects. |  | It did not consider life cycle analysis of the project. |
|  |  |  |  |  |  |  |  |  |
| Pakzad and Osmond, 2015 |  | A conceptual framework for assessing green infrastructure sustainability performance in Australia |  | Green infrastructure projects |  | The concept may increase the contribution to biodiversity conservation, resilience to ecosystem. It also improves the physical and mental health of Urban Residents |  | It does not consider economic, social and environmental aspects of sustainability. |
|  |  |  |  |  |  |  |  |  |
| Ugwu and Haupt, 2007 |  | Key performance indicators and assessment methods for infrastructure sustainability- A South African construction industry perspective |  | Infrastructure, south African context |  | The development of key performance indicators of economic, social and environment sustainability which can be used for urban infrastructure projects. |  | It did not consider life cycle analysis of the project. |

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| **Reference** |  | **Topic** |  | **Application** |  | **Advantages** |  | **Disadvantages** |
| Sahely and Kennedy, 2005 |  | Developing sustainability criteria for urban infrastructure systems |  | water management infrastructure, Canada |  | Focus on feedback and key integration mechanism between infrastructure and social, economic and environmental system. Integration among aspects sustainability |  | The consideration of risk among the aspects are neglected, focus of the study is from engineering prospective rather than urination. The framework is very generic. |
|  |  |  |  |  |  |  |  |  |
| Thabrew et al, 2009 |  | Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation |  | Project based, cross sectoral sector, setting management goals. |  | Life cycle thinking approach along with stakeholders, simple easily understandable process. |  | Lack of economic and social aspects. |
|  |  |  |  |  |  |  |  |  |
| Pakzad and Osmond, 2015 |  | Developing a sustainability indicator set for measuring green infrastructure performance |  | Green infrastructure projects, social indicators |  | scientific approach, useful indicators for green infrastructure performance |  | Lack of economic and social consideration. |
|  |  |  |  |  |  |  |  |  |
| Alsulami and Mohamed, 2011 |  | Key Sustainability Indicators for Infrastructure Systems: An Australian Perspective |  | various infrastructure project, building, roads |  | Developed key sustainability indicators based on their relevancy and frequency of used. Consideration of technical aspects along with environmental, social and economic aspects. |  | Limited to Australian context. |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** |  | **Topic** |  | **Application** |  | **Advantages** |  | **Disadvantages** |
| Fernandez-Sanchez and Rodríguez-Lopez, 2010 |  | A methodology to identify sustainability indicators in construction project management-Application to infrastructure projects in Spain |  | linear infrastructure projects, |  | Step by step process for the selection of indicators. Consideration of AHP |  | Limited to linear infrastructure projects rather than urban infrastructure, lack of integrated assessment. |
|  |  |  |  |  |  |  |  |  |
| Halog and Manik, 2011 |  | Advancing integrated systems modeling framework for life cycle sustainability assessment |  | Biofuel sector |  | the use of LCA, LCC, S-LCA along with stakeholder analysis |  | Difficult to implement. Need quality data |
|  |  |  |  |  |  |  |  |  |
| Hellstrom et al., 2000 |  | A framework for systems Analysis of Sustainable urban water management |  | water system infrastructure projects |  | Scientific approach, covering broad aspects of sustainability include economic, social and environmental. |  | limited to the described project (sustainable urban water management) |
|  |  |  |  |  |  |  |  |  |
| Xing et al., 2009 |  | A framework model for assessing sustainability impact of Urban development |  | oil industry, construction industry, buildings |  | More holistic approach for sustainability assessment. simple and quantitative approach |  | Limited consideration of social and environmental consideration. More focus on economic benefit |
|  |  |  |  |  |  |  |  |  |
| Makropoolos et al., 2008 |  | Decision support for sustainable option selection in integrated urban water management |  | water management infrastructure, UK |  | provide guidelines and decision support tools for the implementation sustainability |  | Lack of economic aspects, limited to the described project. |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** |  | **Topic** |  | **Application** |  | **Advantages** |  | **Disadvantages** |
| Ravetz, 2000 |  | Integrated Assessment for sustainability appraisal in cities and regions |  | policies and program, environmental metabolism of the city, cumulative effects |  | integrated approach, consideration of spatial issue at city level |  | complex process at project level |
|  |  |  |  |  |  |  |  |  |
| Dasgupta and Tam, 2005 |  | Indicators and framework for assessing sustainable infrastructure |  | Civil infrastructure system, water infrastructure |  | development of infrastructure indicators for sustainability assessment |  | Specified project, lack of project assessment on the basis of LCT tools. |
|  |  |  |  |  |  |  |  |  |
| Sala et al., 2015 |  | A systemic framework for sustainability assessment |  | various policy supports, |  | systematic approach, step by step process |  | Difficult to implement in infrastructure sector. |
|  |  |  |  |  |  |  |  |  |
| Yigitcanlar and Dur, 2010 |  | Developing a sustainability assessment model: The sustainable infrastructure, land-use, environment and transport model |  | urban localities, urban areas, transport infrastructure, water, stormwater, sewerage and power infrastructure |  | Integrated assessment framework considering land use, urban form, and urban demography. Tools for the assessment decision making. |  | Absence of sustainability assessment tools use for infrastructure project. |

**4. Synthesis of main results**

Infrastructure projects consume plenty of energy and resources, occupying land and other resources which result negative impact on environment as well as on social dislocation. Thus, it is important to keep balance among economic, social and environmental aspects of infrastructure sustainability. However, the main issues regarding urban infrastructure sustainability are:

* The lack of common perceptions of sustainability among different stakeholders. Different stakeholders have different perception and preferences for sustainability. Therefore, identifying common understanding regarding sustainability among the stakeholders will promote integrated approach for the project sustainability.
* Another issue is the identification of key criteria and indicators for the project sustainability. To achieve sustainability, first it is important to understand what the objectives of the project are, and how to relate it with the principles of sustainability. Therefore, the identification of sustainability indicators will give the basis upon which the sustainability of the project can be measured.
* Lack of life cycle analysis of the key sustainability indicators and the interrelationship among these indicators. To achieve economically, environmentally and socially sustainable project, it is necessary to know the life cycle impact of the indicators on the project life cycle. Indeed, these impact can be determined by carrying out life cycle thinking based tools.

The existing urban sustainability assessments frameworks establish a rapid developing arena globally while face different debates and challenges by the urban sustainability practitioners and researchers. Researchers have proposed various tools and frameworks for sustainability assessment of urban infrastructures but each of them is different in the scope and in the interpretation and presentation of their results. Numerous studies have focused on the effective role of tools used for the assessment of project sustainability in which some covered all dimensions of sustainability e.g. economic, environment and social (Halog and Manik, 2011; Azapagic, 2016; Hellstrom et al., 2000; Karol et al., 2009; Haapio and Viitaniemi, 2008; Xing et al., 2009) while others focused on environmental scope (Thabrew et al., 2009; Lundin and Morrison, 2002). In this way, these studies have used different assessment tools according to their aim and purpose of the study. Several examples of LCA performed in urban building infrastructure are available in the studies (Khasreen et al., 2009; Bribia, 2009). However, LCA have some limitations to sustainability concern because it considers only quantitative indicators and cannot assess qualitative indicators which are an important aspect of infrastructure sustainability. Moreover, LCA methodologies do not integrate social and economic aspects of sustainability. The LCC techniques for the economic aspect of sustainability have the similar limitation as LCA because they also do not consider qualitative indicators in their analysis. Regarding infrastructure sustainability, S-LCA takes into account different qualitative indicators such as health and safety measure, effect on stakeholders and community and other site-specific indicators (Edum-Fotwe and Price, 2009). But the main difficulty in S-LCA is the lack of proper assessment methodology and deficiency of data availability of social indicators (Sachs, 1999).

To overcome these issues, many researchers performed sustainability indicators (SI) approaches by choosing key performance indicators for assessing the sustainability of their projects (Ugwu and Haupts, 2007; Dasgupta and Tam, 2005; Sahely et al., 2005; Ugwu et al., 2006; Heijungs et al., 2010). However, one of the issues with sustainability indicators approach is relating what is the contribution of indicators to the actual sustainability? There is not a single set of indicators or a single criterion that fits for each policy and project (Meadows, 1998). Another issue with sustainability indicator methods is the lack of life cycle analysis of the chosen indicators and none of the study has raised this issue in their proposed frameworks. From the methodological side, sustainability indicators approaches are suitable for the integration in assessment tools for the evaluation of the sustainability of projects but major deficiencies are their failure for considering the affects among different sustainability indicators and the lack of uncertainty analysis. SD approach is used in urban complex infrastructure in order to understand the interaction and sensitivity among different indicators through feedback loops. Choosing indicators based on their functions is more significant than selecting based on outcomes (Tam, 2002) because indicators selection based on function could be more sensitive to the dynamics conditions. However, SD diagram might become more complex when real situation with different variable is modeled.

In this paper the different approaches, methodologies, and frameworks developed in the literature for urban infrastructure have been critically reviewed and the findings of those methodologies have been also discussed. Our study reveals that some researches has been carried out for the development of sustainability assessment tools in the infrastructure sectors but they do not focus entirely on urbanization and do not cover sustainability concerns of the infrastructure projects which could ease decision-making in directing and facilitating sustainable urban infrastructure development. The approaches used in the literature have varied degree of relevancy and reliability for an integrated assessment of sustainability in term of goal and scope and phase of life cycle of projects. Another deficiency in these studies is their lack of application for other regions as well as for other projects because all these researches were designed for a particular project such as urban water and wastewater management with country specific indicators (Balkema et al., 2002; Rijsberman et al., 2000; Sahely et al., 2005; Dasgupta and Tam, 2005). Moreover, by using analytical models that focus on single dimension of sustainability might not be effective because of the multiple aspects of sustainability such as economic, environmental and social whose have interdependent variables. Analytical tool could not be able to deal with all these variables. Besides these issues, we have not found integrated modeling approaches that assess semi-quantitatively the three dimensions of sustainable development in term of multiple domains, scales and generation. So, the currently used approaches for the sustainability development are limited in their ability to properly analyze the needs of various stakeholders in infrastructure projects. So far, such a structure approach for organizing the data that are required for decision making process does not exist. This means that, sustainable development necessitates new method that incorporates environmental and socioeconomic aspects of sustainability and is capable of guiding the decision makers in decision making process. The analyzed tools and frameworks highlighted in the literature review give a good foundation for the establishment of such an assessment framework. The development of this structure framework that the decision-makers could follow while carrying out infrastructure project will help to assess the sustainability of projects to be evaluated.

**5. Conclusion**

Sustainable development in infrastructure is a multi-dimensional phenomenon that involves interdependencies among resources, interrelated objectives which depend on the dynamics behavior of different stakeholders, and evolving provisions in the environmental and social systems. Sustainable development also emphases on mitigation of dangerous emissions and avoidance of excessive consumption of natural resources (non-renewable) therefore, for the effective management of urban infrastructure, there is a need of sustainability assessment procedure to be performed while carrying out an infrastructure project. In order to fulfill the stated issues in connection with urban infrastructure, it was important to identify the best present practices with concern issues and knowledge gaps. This paper was based on the review of the previous studies published on sustainability in urban infrastructure. The main objective of the paper is to evaluate different sustainability assessment approaches regarding environmental and socioeconomic burdens in determining infrastructure sustainability based on life cycle thinking perspective. The performed literature review highlights that, researchers have proposed various tools and methods for the sustainable development of different urban infrastructures but less attention has been given to the integrated assessment of life cycle thinking tools for infrastructure projects. Although there are frameworks and methodologies that assess all pillars of sustainability in different sectors but these are not often implemented. Most of the studies have adopted sustainability indicator approach which is one of the useful approaches for the project sustainability but they have not considered the life cycle impact of the indicators at various stages of the project. The indicator approach is usually project specific or region specific which cannot be implemented as a whole system. Nevertheless, different tools collectively can provide a sound basis upon which relevant criteria and indicators for sustainable development can be established. Therefore, a well-defined integrated assessment framework should categorize the indicators on life cycle based assessment into their different attributes and should be used for sustainability assessment of a system at different stages of their life cycle.

**PAPER II**

**A LIFE CYCLE THINKING BASED FRAMEWORK FOR THE SUSTAINABILITY ASSESSMENT OF URBAN INFRASTRUCTURE**

**Abstract**

Sustainable Assessment (SA) of urban infrastructure is becoming more and more important and many countries have made it as one of the managerial focal points. Multiple urban infrastructure projects are carried on for serving the growing population of the cities and these projects need a balanced equilibrium among environmental, social and economic aspects. In this context, infrastructure assessment using Life Cycle Thinking (LCT) based approaches should be an endure part for a sustainable urban renovation. The purpose of this study is to develop an integrated assessment framework for urban infrastructure, embracing the economic, social and environmental sustainability criteria. The proposed integrated assessment mix not only is based on a LCT approach, but also concerns assimilate temporal and spatial scales as well as different stakeholders’ inputs and look forward and backward. Considering that sustainability in the urban infrastructure is measured by the major three pillars including economy, environment and society, the proposed model uses Life Cycle Assessment(LCA), Social Life Cycle Assessment (SLCA) and Life Cycle Costing(LCC) along with stakeholder analysis supported by multi-criteria decision analysis (MCDA) for identifying the key sustainability criteria, metrics and indicators. The framework can be optimized further by using agent based modeling system dynamics and sustainability network theory. The main focus of the LCT based infrastructure assessment framework is to recognize the pathway that an urban infrastructures process should pursue to accomplish key sustainability concerns covering the interrelated socio-economic and environmental aspects.

**1. Introduction**

To date, most of the sustainability assessment tools that have been developed mainly focus on general infrastructure projects and do not particularly address infrastructure in the context of urbanization (Ugwu and Haupts, 2007; Ugwu et al., 2006). In the meantime, due to the complexities of urban infrastructure sustainability issues, and the broad aspects and planning consideration that are needed to be addressed, stakeholders cannot confront sustainable development autonomously. They must recognize that sustainable development requires multilevel and multi-disciplinary planning approaches for the identification of critical risks and threads during the development of urban infrastructure. Consequently, such projects require close participation of all stakeholders and the knowledge and expertise of all disciplines beyond their hold.

For the development of sustainability assessment framework for urban infrastructure, a literature review of current sustainability approaches that have been developed or applied in the built infrastructure was carried out. Drawing on the review of different sustainability assessment approaches, it has been found that less attention has been given to the approaches for the analysis of infrastructure projects that might be hardly understood from the aspects of sustainability by multiple stakeholders (Dasgupta and Tam, 2005). It also reveals the research that carried out for the development of sustainability assessment tools and infrastructure (Ugwu and Haupts, 2007; Dasgupta and Tam, 2005; Sahely et al., 2005; Ugwu et al., 2006; Heijungs et al., 2010; Halog and Manik, 2011; Azapagic, 1999) but these researches performed traditional, not sustainable infrastructure solution. The tools and methods used have varied degree of relevancy and reliability for an integrated assessment of sustainability in term of goal and scope and phase of life cycle of projects (Karol et al., 2009; Haapio and Viitaniemi, 2008; Xing et al., 2009; Yigitcanlar and Dur, 2010; Linkov et al., 2004; Ugwu et al., 2006). The lack of research for the analysis of infrastructure systems is much unexpected because infrastructures such as roads, highways, bridges and building contribute to a broad range of built environment of the world. Therefore, more attention must be given to the sustainable development of urban infrastructure to which this research is motivated. As mentioned in the literature, there is a huge demand for a structure approach that is capable of guiding the decision makers in the process of decision making regarding infrastructure project sustainability. So far, there is no standard framework for this purpose however, the tools used in these studies can assist in the development of this framework. Some of the scholars consider that different methods can bring different findings therefore, multi techniques and methods should be applied to a system for an integrated comprehensive solution (Haimes, 1992). The main idea that motivate this research and to solve different sustainability issues explored in the current literature is anchored in these questions:

* “How to introduce life cycle thinking tools in an integrated framework for the evaluation of the sustainability of urban infrastructure?”
* “How to design this integrated sustainability framework in order to ease its use by public policy makers for urban planning and the evaluation of best alternative among different urban infrastructure projects?”

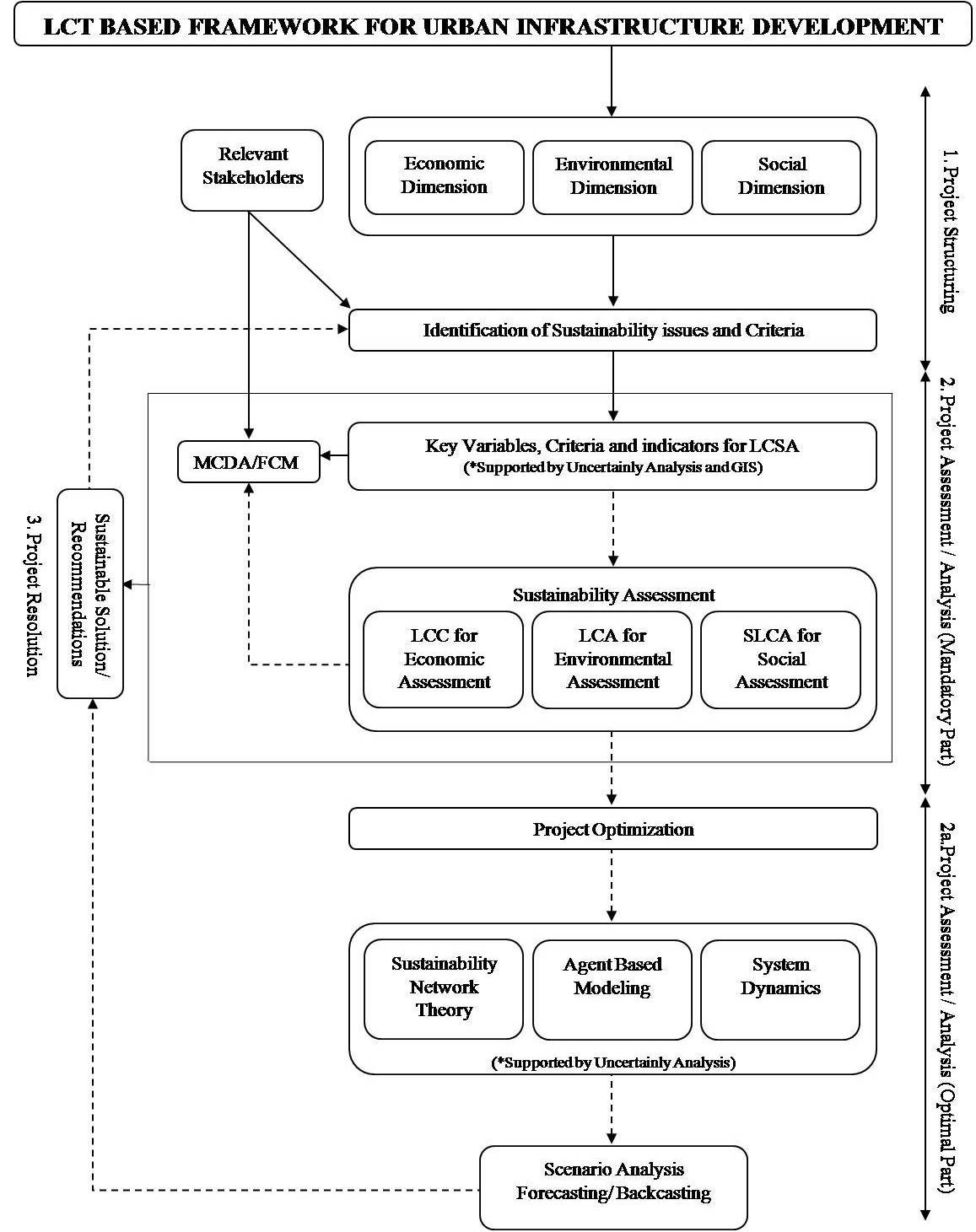
To follow these questions the aims of this paper is to develop LCT based integrated framework for the assessment of economic, environmental and social aspects of sustainability for urban infrastructure projects. The primary purpose of this assessment framework is to assist the decision makers through decision making guidelines in a step by step process towards sustainable development of urban infrastructure.

**2. LCT BASED FRAMEWORK**

The proposed LCT based sustainability framework ensues the normal approach in decision analysis (e.g. Belton and Stewart, 2002) and is composed of:

1. Project Structuring, which is a conceptual stage and where conciliation takes place among stakeholders,
2. Project analysis which is further divided into mandatory and optional sections,
3. Project resolution/implementation, where decision takes place for the implementation of the project.

The role of different components of the framework is to make the decision-makers conscious of various possible factors that will affect the end result of the assessment.

**Fig: 1 Life Cycle Thinking Based Sustainability Assessment Framework**

**2.1 Project Structuring**

The first and important step in carrying out a project is the definition of its scope. Project Structuring is a conceptual stage, where conciliation takes place among stakeholders. The project experts may grasp that what must be carried out in order to sit key sustainability criteria and indicators. The purpose is to sit sustainability goals based on economic, social and environmental criteria, therefore it would involve conciliation on various sustainability indicators and expectations of different stakeholders in order to achieve the required objectives of environmental, economic and social dimension of sustainability.

**Environmental dimension** - infrastructure is the producer of very huge environmental impact that contribute to high level of waste emission, GHG emission, pollution (water, soil, air and noise etc.), energy use, ecological footprints and a composite process forces it to find the sustainable solution for the future growth. Environmental policymakers are commonly unfamiliar with the extent of environmental sustainability and are focus on very short-term objectives and extremely persuaded by vested interests that oppose the evolution to sustainability (SDSN, 2012). However, if environmental impacts of any urban infrastructure are not considered then it becomes dangerous for environment and causes land degradation, air pollution, ecological footprints etc. Therefore, during planning an infrastructure project the policymakers and stakeholders need to focus specifically on environmental efficiency by considering factors for reducing greenhouse emission, lowering pollutant level, renewable strategies etc.

**Economic dimension** - complementary to the environment, economic dimension is also an important aspect of sustainable infrastructure, the stakeholders focus on efficiency and profitability of different kinds of infrastructure capital. The economic evaluation is more often done by considering different kinds of life cycle cost e.g., initial cost, production cost, maintenance and end of life cost. A key challenge to economic dimension of urban infrastructure system is its different perspectives e.g. public policy and public economy perspective. Urban infrastructure needs to be managed a possible efficient way, so as not to waste the financial and natural resources regardless of the prospective to be used (DWSD, 2009, 2012).

**Social dimension** - the social dimension of sustainable urban infrastructure refer to the impact infrastructure certainly have on the society and on its inhabitants. The main concern here is that various users have equivalent access to urban infrastructure services and also to the quality of the services provided to diverse part of urban area. So for the social dimension the urban policymakers need to pay attention to affordability, equity, health & safety and ensuring appropriate living condition to the society and other community specific factors. They need to make it sure that the citizens can afford the infrastructure services, they are treated equally and moreover, cultural heritage are protected. These social benefits are predicted by evaluating the effects of the project on stakeholders at local, national and global levels (GRI, 2002).

**Relevant Stakeholders** - citizens, users, investor, owners and policy makers all are the key stakeholders associated with urban infrastructure systems and each of them have their own expectations, demands and objectives that need to be fulfilled. Indeed, it is generally difficult to consider the diversity of stakeholders with their different views, but a sustainable urban infrastructure system also means optimally balancing these different s and demands of the stakeholders. For this purpose, engaging stakeholders to understand their point of views is probably an essential step in decision making process.

**Identification of sustainability issues and criteria** - since sustainability of the infrastructure project is assessed on economic, social and environmental aspects, the aim of this stage is to define the decision makers and stakeholders’ expectations and sustainability issues through mutual consultation, and then these will be translated into measurable sustainability indicators for decision making criteria. The stakeholders can identify their particular roles in connection with the related roles of other stakeholders and in addition to express their own preferences, they have to recognize the preferences of each other too. One of the important tasks during this stage is to set goal and scope. For example, the goal might be to achieve the most sustainable option with minimum cost or to find the best policy options to tackle climate changes. Depending on the goal, the scope will be from “cradle to grave” about all related activities from production to end of life.

**2.2 Project Analysis**

Evaluating sustainability is a decisive step to measure the performance of infrastructure in terms of sustainability indicators. It involves the assessment of key indicators identified during the consultation process. As the assessment is carried out on life cycle thinking base, there are various evaluation techniques that assess the environmental, economic and social impacts all over the life cycle of a project. Indeed, LCA, LCC and SLCA are commonly used tools for the estimation of environment, economic and social indicators respectively.

**Life cycle costing** - LCC analysis is a technique uses to examine the economic indicators for the assessment of sustainability. It reflects all the costs involved all over the lifetime of an infrastructure initiated from construction phase to the end of its life span (Padgett, 2010). The life cycle cost of a product or any manufacturing plant can be assessed as (Swarr et al., 2011):



Where  represent the life cycle activity and represent their unit cost, e.g. the total LCC of a system will include the costs of construction, maintenance & operation and decomposition of the plant.

**Life cycle assessment** - LCA is a widely accepted decision supporting tool for assessing environmental indicators of a product or a project for the entire lifetime. LCA has international agreed methodology, standardized by the ISO 14044 and 14040 standards (ISO, 2006) Environmental impacts can be anticipated in LCA as proposed by (Azapagic, 1999).

In the above equation, the variable  is the relative contribution of burden  to environmental impact Environmental burden  represents the consumption of materials and energy and their emission to the water, soil and air. In this regard, if global warming potential is environmental impact  then the emission of carbon dioxide CO2 would be environmental burden  with the contribution  to the GWP 1kg CO2 eq./kg CO2. The environmental burden in this context can be calculated as:

In this equation, the variable represent environmental burden for a unit life cycle activity  whereas represent the level of the activity. In the stated example if CO2 is released from burning of a fuel, then the variable is the emission for a unit fuel, e.g. kg CO2 per MJ or kg of fuel, and the quantity of fuel showing the level of activity.

**Social life cycle assessment** - The social life cycle assessment (SLCA) is a tool that takes into account the social indicators for assessing social dimension of sustainability of a project. Most of the social indicators measure the degree of how social goals and values of a specific region can be attained. The quantitative social impacts can be calculated by the following equation.

The variable  represents the impact for a life cycle activity  to social impact, e.g. if is the quantity of jobs created by the production of a product, then represent the quantity of jobs created per unit output of every activity  in the life time.

Examples of qualitative impacts are social capital, stakeholders’ participation and cultural heritage etc. These kind of impacts can either be left descriptive, original or can be transformed to quantitative indicators by using a scale from 1 – 5 to show how “relevant” or “irrelevant” the impact from one option to another options.

**Key Variable, Criteria and Indicators** - After having identified the sustainability issues and expectations of different stakeholders, the expected criteria and indicators should be reconciled in order to exclude more or less similar indicators, and to choose the most vital indicators which are relevant for developing a sustainable project. The indicators identified at this stage would be used as decision criteria in the decision making process. Variability and sensitivity analysis can also be performing in order to assure that we have chosen the most relevant indicators. Given the need for the LCT approaches, LCA, SLCA and LCC could be utilized to guide the choice of environmental, social and economic indicators respectively on the basis of identified issues of sustainability. Each stakeholder has their own particular economic, social and environmental criteria and interest for the development of a sustainable infrastructure system. However, the main challenge here is to select manageable numbers of indicators for decision making process and at the same time the indicators should address all the sustainability issues.

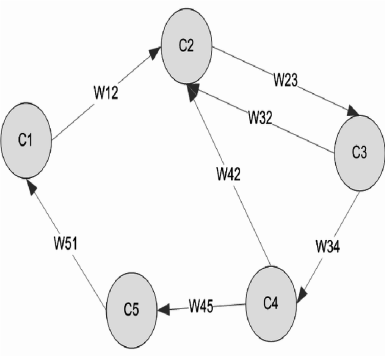
**Multi Criteria Decision Analysis** - Depending on the interest of decision makers and stakeholders and the type of infrastructure project, there could be large numbers of decision indicators/criteria involved in which some would be better for each other but some would be worse based on their comparison. The quantified indicators in the sustainability assessment process are then used in the decision making process. Therefore, the core challenges is to assist stakeholders to learn about their own and other participants preferences in order to reach a comprise solution (Azapagic and Perdan, 2005). To deal with this complexity and ranking of each indicator and criteria, MCDA can be used, whereby stakeholders need to articulate their choices for diverse sustainability criteria (Halog and Manik, 2011). MCDA is a decision making and operational evaluation tools which is useful for assessing complex sustainability issues comprise conflicting objectives, various kind data, high uncertainty and multiple interests and aspects. It has been generally used in environmental and socioeconomic systems. In general MCDA includes  alternatives which are evaluated on  multiple criteria (sustainability criteria), in which  criteria C of  substitute A has the performance of. All criteria/indicators are represented by their performance and weighted accordingly, in which represent the weight of  criteria. The group decision matrix can be express with. There are three categories of weighting the criteria: (i) subjective weighting such as analytical hierarchy process (AHP), pair-wise comparison etc.), (ii) objective weighting (entropy method etc.) and (iii) combination method (Halog and Manik, 2011). MCDA has greatly support sustainability assessment of current and emergent multi-attribute methods. For example, AHP permits decision makers to rank different indicators and criteria by calculating Eigen values. The idea follows Pareto principle which state that 80% of impacts come from 20% of causes which mean the decision makers should focus on critical variables that edict the sustainability of any system.

**Figure: 2 Grouped decision metrics or stakeholders decision metric of MCDA**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Criteria** |  | C1 | C2 | … | Cn |
|  | **Weights** |  | W1 | W2 | … | Wn |
|  |  |  |  |  |  |  |
|  | A1 |  | X11 | X12 | … | X1n |
| **Alternatives** | A2 | X= | X21 | X22 | … | X2n |
| … | … | … | … | … |
|  | An |  | Xm1 | Xm2 | … | Xmn |

**Fuzzy cognitive Map (FCM) -** Assessing the sustainability of infrastructure system is a complex processes therefore, many authors also acclaimed the effectiveness and capability of FCM for the complex nature of infrastructure system. FCM is a modeling method derived from the integration of two methodologies, namely neural networks and fuzzy set theory. It is based on graph theory, consists of factors/nodes and weighted interconnections which represent the casual relationships among them. The main characteristic of this technique is its capability of modeling interaction among diverse variables, it shows the behavior of the system in term of nodes and each node represents a variable of the system (Dickerson and Kosko, 1997) as shown in its graphical representation (Kosko, 1986).

**Figure: 3 A typical FCM**



Source: (Kosko, 1986)

In infrastructure system, where investment cost, energy efficiency, land use, GHG emissions and social impacts are the vital criteria, these tools are certainly applicable. Modeling causal relationship among different sustainability indicators helps in identifying key indicators that can lead to better decision making and proficient indicator-based reporting. MCDA and FCM give great applicability to facilitate sustainability assessment of different infrastructure systems to evaluate the sustainable metabolism throughout the system considering different criteria. Through these approaches, we can capitalize the potential of LCT methods as well as account stakeholders’ influence.

**Project Optimization** - The existing MCDA and LCT approaches are deliberated steady-state methods whereby they provide historically based data. They do not forecast the future trend and projections and do not consider the interaction of different criteria, metrics and outputs over time. To make more useful results for policy and decision makers, it is necessary to model the dynamics interrelationships among these variables over time (Halog and Manik, 2011). Taking into account the complexity of developing such resilient and sustainable system, a new system based included metrics and modeling methods with the consideration of three pillar of sustainability, stakeholders’ perspective and their interrelation should be developed. Computational tools for the assessment of sustainability can support to model the critical variables that can affect system behavior to achieve environmental, social and economic efficient outcomes. The economic indicators as well as environmental and social quantified in the second stage sustainability assessment using life cycle thinking tools are critical variables to start with for system modeling. The established tools and methods described above for sustainability assessment together with computational tools, agent based modeling, system dynamics and sustainability network theory can be helpful for the dynamics interrelationship to create a dynamic sustainability assessment for any investigated system. However, in our framework these steps are taken as optional for the sustainability assessment depends on the interest of decision makers and type of the project that are carried out.

**Agent Based Modeling (ABM)** - It is a computational tool for any system that is composed of multiple actors (individual or collective entity such as groups or organizations) for simulating their interaction to assess the effect on the considered system (Holland and Miller, 1991). ABM can be applied to model the interrelations of agents or sub-agents utilizing the indicators, metrics and variables as performance measures. It could appropriately model the complex behavior of system members; which is relevant in infrastructure projects because of the project complexity and the dynamics behavior of the project’s stakeholders. Contemporary urban infrastructures show themselves as complex and consistent socio-technical system. The interactions between agency and infrastructure network lead to a stable performance position which is associated with cost and environmental impact (Batouli and Mostafavi, 2016). The Fig Shows graphical representation of an agent based system in which every circle stand for a sub system of agents (e.g. companies or groups etc.) represent by little dots and the whole arrows show the interactions of agents and sub-system of agents. Though these interactions driven by a small set of rules which administer their actions, account for complex system actions whose evolving dynamic features cannot be clarified by evaluating its component parts (Holland and Miller, 1991). Therefore, ABM means to seek at global consequences of local or individual interactions in a particular geographical region. One of the important objectives of ABM is to study the tradeoff/correlation among various sustainability objectives for the infrastructure performance regime. We could model the existing dynamic interaction among the sustainability indicators as well as for the future projections.

**Figure: 4 Graphical presentation of agent based system**

**System Dynamics (SD)** - Modeling causal relationship helps in identifying key interrelationship among sustainability indicators which can lead to better decision making and proficient indicator-based reporting. Urban infrastructure is a complex system with nonlinear feedback loops among subsystems and multiple variables that are influenced by economic, social and environmental factors. Therefore, system dynamics (SD) modeling could be influential in this complex system of sustainable urban infrastructure. The methods of SD are grasped by linking feedback loops among metrics and variables which would help to see how their interaction will create particular system behavior. The feedback loop is represented by casual loop diagram in which different variable are connected positive or negative loops. Mathematically in SD, a model is made in a nonlinear, first order integral equation such as:

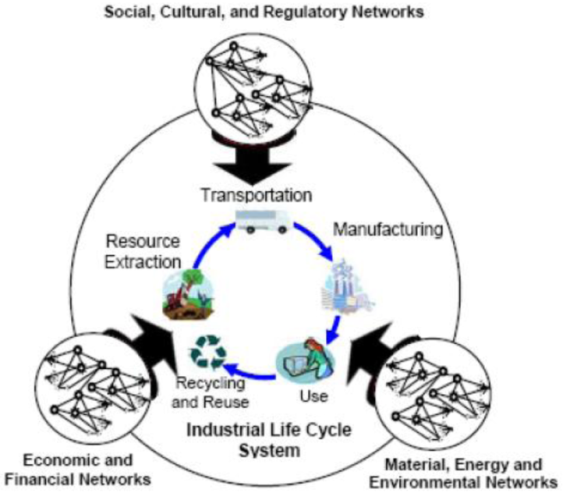


Where  represent vector of variables,  shows set of parameters and  is nonlinear function. Analyzing such systems is carried out by dividing simulated time into distinct intervals of length  and step the system by time one  at a time.

SD has been applied in the Canadian oil sands industry and in bioethanol production for their sustainability assessment (Chan et al., 2004; Halog, 2008). It has been used in modeling urban transportation system in china (Jifeng et al., 2008). The value of SD modeling tie together macro, meso and micro level impacts (that have been identified in LCC, LCA, SLCA and MCDA tools) in practicing a complex system over time. Eventually, SD modeling process can hold the implementation and selection of sustainable systems. Therefore, applying SD and ABM as a platform with other methods and tools, such as life cycle thinking approach and MCDA can be integrated to provide a productive dynamic sustainability assessment.

**Sustainable Network Theory (SNT)** - The two dynamics system methods SD and ABM can perform synergistically with SNT for supporting optimal, sustainable decisions and policies and for the aim of enriching the outcomes of any system considered. Although SNT could overlay with SD but together these tools can be used to assess the scaling up of any emergent technology such as infrastructure systems. Kim (2008) illustrated an SNT framework for the industrial structure which is considered in an integrated sense to include industrial and social dimensions, production and services components and use and end of life activities. Network theory helps in prioritization of conflicting factors (e.g. as in MCDA), can facilitate identification of causal loops (system dynamics cases) and support policy implementation and intervention at the right levels (Halog and Manik, 2011). Taking into account economic, social and environmental dynamics within particular geographical region, SNT, SD and ABM can make appropriate model needed for a more resilient dynamic sustainability evaluation.

**Figure5. Conceptual model of Sustainability Network Theory (Kim, 2008)**

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**Scenarios Analysis** - Once goal and scope (sustainability criteria, indicators and metrics) have been defined by using the above mentioned methods, the decision makers and stakeholders can advance to classify different scenarios/options to be considered. It would help decision makers to explore a range of potential strategies according to the scenarios made from the modeling of the upper mentioned computational tools. Backcasting, forecasting and foresighting are scenario development approaches for policy making and planning. Backcasting entails planning backwards from a specified set of goals or preferred future end point (i.e. social sustainability) to the current state, in order to establish the substantial feasibility of that prospect and the policy actions that would be necessary to attain the state (Holmberg and Robert, 2000). Backcasting assist in evaluating different futures responsive to current state and deals with problems in an alternative way rather than extrapolate present options/scenarios from into the future (Robinson, 2003). Contrary, utilize forecasting (i.e. data analysis methodology) to create future scenarios from present information. Forecasting facilitate policymakers to recognize reasonable estimations of different present activities. Forecasting helps in avoiding losses by considering all significant information in building appropriate decisions (Dreborg, 1996). Furthermore, foresighting and forecasting are two different things. The purpose of foresighting is to create or change the future by connecting it to the present, while forecasting is the inactive effort to predict or diagnose future events. So the main difference between the two is that in forecasting the current state conclusion is missing. On the other side Foresighting provide numerous benefits that include early identification of problems, engaging experts and policymakers in actively forecasting for the future, carrying people together to strengthen the existing network, create an appropriate future and educating them on critical future related problems. It could have a positive impact on sustainable infrastructure policy by giving a way for investigating its broader economic, environmental and social implications.

By taking into account various scenarios initiating from business-as-usual aspect to diverse scenarios both through backcasting or foresighting, we can make various results for our sustainability assessment measures and define critical substitute scenarios or systems to be strongly considered for developing sustainable technology, infrastructure system, policy, decision, intervention etc. All these are with the assumption of gathering good quality data. There are different statistical tools, quantitative and qualitative analysis and uncertainty and sensitivity analysis that we can do to improve the strength of our results. The addition of stakeholders’ perspectives and dynamic interactions of diverse variables through computational tools in the proposed framework improves relevancy for sound life cycle thinking approach for urban sustainable metabolism.

**2.3 Project Resolution**

In the third stage of the decision-making process of the proposed framework, the decision and policymakers use the results of the project analysis stage that have been identified for the selection of most sustainability criteria, indicator or metric for the sustainable infrastructure project. If all the stakeholders agree to the defined criteria/scenario then a recommendation of decision can be made otherwise the process will be repeated in a reiterative way to encourage further learning about the decided criteria and guarantee that consequent decisions are acquired with a full knowledge of possible consequences. Thus, the proposed framework utilized in a reiterative manner to suit the kind of stakeholders and problem. The proposed framework is generic and can be applied to different kind of infrastructure project for the assessment of sustainability criteria to analyze the project metabolism.

**3. Conclusions**

Sustainability in infrastructure development is a vital part for a sustainable urban planning, because sustainable urban development have greater role on the economy, environment and society of a city or a whole state. Pursuing sustainable urban development and its metabolism requires a systems and life cycle thinking approach in order to get the sustainability goals of environmental, economic and social criteria. In an attempt to support this process, we have proposed life cycle thinking based infrastructure framework that is capitalized by stakeholders’ analysis using MCDA tools and system dynamic modeling. The developed framework is composed of life cycle thinking as well as computational tools such as agent based modeling, system dynamics and sustainable network theory. The focus of the framework is to recognize the pathway that an infrastructure project should entail to achieve specific sustainability goals associated with socio-economic and environmental aspects. However, the application of the proposed framework requires huge quality data which is difficult to obtain if not directly involved in the management of a public infrastructure project. Therefore, the actual practitioners of the infrastructure industry who have access to the projects data can perform the assessment of economic, environmental and social indicators using the life cycle tools. The proposed framework with the support of technical staff and practitioners of life cycle thinking tools would help in decision making regarding the sustainability assessment of urban infrastructure projects. Therefore, construction industries and urban planners should apply the framework in their infrastructure projects. It can be applied for project assessment at multiple scales as well as at individual and system level that would help in different scenarios by considering economic, environmental and social goals of a considered project. The sustainability assessment tools stated in the framework can assist the urban decision makers in understanding the decision issues and its consequences for the sustainable urban infrastructure. Furthermore, by following the framework, the decision makers can trade-offs among different preferences which allow them for more relevant decisions.

**PAPER III**

**Development of Key Sustainability Criteria and Indicators: Testing Limiting part of the Proposed Framework**

**Abstract**

For the achievement of sustainable urban development goals, infrastructure have an important role which requires life cycle based systems taking into consideration the concerns of various stakeholders about economic prosperity, social quality of life, and environmental integrity. Indeed, identifying appropriate indicators for infrastructure is necessary in order to evaluate it for the desire goals of sustainability. For this purpose, a life cycle thinking (LCT) based assessment framework has been proposed in the paper II of this work. In this paper, the most critical step of the proposed framework (the identification of key indicators) has been applied in the context of Middle East countries specifically UAE and Saudi Arabia infrastructure projects, in order to test the applicability of the sustainability assessment framework. Considering that the application of this integrated methodological framework highly depends on the availability of quality databases as well as the proper identification of the key sustainability indicators, this paper mainly focused on the process of identification of these indicators. The most significant and relevant indicators of sustainability in infrastructure projects were rated through a survey questionnaire by the infrastructure experts’ judgments using four elements: Relevance, Practicality, Reliability, and Importance. In particular, this paper focuses on the unique characteristics of Middle East countries to identify, and prioritize different sustainability indicators affecting the construction of infrastructure projects. The aim of this study is the appraisal of various indicators which would be used in evaluating the sustainability of infrastructure systems. The ANOVA test and Analytic hierarchy process (AHP) method are used to determine the significance and weighting score of various indicators.

**1. Introduction**

Any infrastructure in the context of urbanization is called sustainable when it considers all triple pillars of sustainability into its development, i.e. social economy, social integration, and environment aspects (Fernandez and Rodriguez, 2010). Sustainability in infrastructure for urban planning is one of the facts that cannot be ignored because of its influence on the environmental and socioeconomic prosperity of a region. However, the transformation of this concept into decision-making process in order to give a practical shape is not clear. This has been proved that construction specialists are facing a very challenging task of transforming and understanding sustainability objectives into real actions in their projects. This process worsened by the triple bottom line perspective of sustainability with the deficiency of tight methodological framework for different hierarchical levels. Therefore, it was crucial to develop tools and techniques that will allow socioeconomic and environmental commitments to be met (Rodriguez and Fernandez, 2008; Ugwu and Haupt, 2007).

Middle East has been undergoing infrastructure boom for the past few decades because of the fast growth of oil industry and aggregate revenues. Nowadays these countries are investing more in their state infrastructure with billions of urban development projects in both private and public sectors (Bannan et al., 2012). The Urban Infrastructure in Middle East specifically Saudi Arabia and UAE is obsessed by certain factors of sustainability. Necessary requirements for the general approach for identification and definition of factors and then incorporate them into an integrated methodology, enables to measure all aspects of sustainability. The difficulty is how these sustainability challenges are to be addressed in an integrated holistic method for decision-making regarding infrastructure projects. Currently the industry is lacking methodological framework that bring nation tactical sustainability measures such as economy, environment and society, etc. into their infrastructure projects. The framework can define, for instance, the different range of actions would need to be improved or new plans led in order to achieve the desired sustainability goals from a project. There is a huge demand of integrated tools that analyze the projects sustainability by identifying indicators and criteria through different stakeholders that fill the gap of triple bottom lines of sustainability.

Most often, there are difficulties for weighting the sustainability objectives of a project and become challenging for the stakeholders to evaluate a particular project by incorporating its strength with different sustainability indicators. This kind of evaluation of different sustainability indicators for each infrastructure project will contribute in decision regarding the project and its sustainability value. The two key concerns that could affect the decision-making process are “extracting valuable data from experts and combining the group of expert, subject sentiments by resolving disagreements” (Elbarkouky and Fayek, 2010; Ugwu et al., 2006). To contribute this effort, a framework has been developed whose one of the aims it to identify key sustainable indicators and evaluate them through project experts to reach a consensus considering life cycle thinking approach of sustainability. The aim of this paper is the testing of a part of the framework in order to check its applicability by identifying and selecting sustainability criteria and indicators considering socioeconomic and environmental benefits that would be used for the appraisal of infrastructure sustainability. The scope of our paper is the indicators’ identification which are based on four elements “practicality, relevancy, importance and reliability” towards sustainability in the context of Middle East countries. After this step the indicators would be prioritized by the stakeholders using analytical hierarchy process (AHP) as a tool of multi-criteria decision analysis (MCDA).

With this paper, we will fulfill the last two objectives of our research goal that are:

* identification of different sustainability criteria and indicators for the assessment of urban infrastructure projects;
* test the LCT framework for the part that is specifically focused on the identification of indicators.

**2. Research Methodology**

*Development of indicators and questionnaire design*

Attitudinal research (qualitative approach) has been used to detect the level of significance of sustainability aspects (Economic, Environment and Social) and their indicators. This approach has been adopted to subjectively evaluate different opinions of the people for a particular question, variable or attribute (Naoum, 1998). The ISO standard offers the framework to track when selecting and categorizing indicators and sets the importance to be national, international and regionally comparable. A set of potential indicators common in assessing the sustainability of infrastructure project were found from rigorous literature review of earlier studies on sustainability criteria and indicators, government guidelines on sustainability assessments, case studies project data including reviewing international, national and regional norms related to sustainability aspects of the project under study and then questionnaire-based survey were piloted for indicators validation. Sources for indicators selection are: Saleh et al., 2013; Button, 2002; Tweed and Sutherland, 2007; Balkema et al., 2002; Rijsberman et al., 2000; Hellstroma et al., 2000; Antucheviciene et al., 2010; Carrera and Mack, 2010; Ugwa and Haupt, 2007; ISO 21929-1, 2011; Ugwu et al., 2006; Alsulami and Mohamed, 2011; Ugwu and Mohan, 2003.

A total of 50 questionnaires were returned from various construction companies that gave a response rate of approximately 100%. In order to attain our desired objectives, we prepared a detailed questionnaire and mentioned the particular contexts of the study to the respondents. The questionnaire is divided into two portions. Part 1 contains the respondents’ background information such as demographic data, etc., while part 2 concentrates on obtaining information on the appropriateness of proposed sustainability indicators use in assessing the sustainability of infrastructure projects.

In Part I, with personal demographic information, the questionnaire include questions on Global Reporting Initiative (GRI) and United Nations Commission on Sustainability Development (UNCSD) awareness of the respondents as sustainability appraisal instruments and the use of these agendas in practice. The data analysis shown that sustainability assessment tools are common practice and sustainability are being used as an important aspect in the kingdom of Saudi Arabia and UAE over many years as part of their economic and infrastructure development. Personal background data also consist of respondent’s participation and experience in sustainable infrastructure project(s). Table 1 encapsulates the key demographic data of the stakeholders. It shows that 56% (28 out of 50 respondents) were involved in sustainability based projects, while 44% (22 out of 50 respondents) have experience of using sustainability appraisal tools.

In Part 2, the sustainability indicators that were identified were broadly categorized in social (8), economic (7) and environmental (10) criteria. Respondents were asked to rate these entire indicators on four elements including practicality, importance, relevance, and reliability towards sustainability for urban infrastructure projects. Given the number of queries in the questionnaire the elements of analysis were determined on the scale as “Not, Less, normal and High relevant” with one more additional option of “No Opinion” if the respondents have no idea about the chosen indicators. Respondents were also given an option to add additional indicators if significant and rate them accordingly to their experience and knowledge. The ensuing section described the result and discussion as mentioned in the proposed framework.

**3. Results and Discussion**

*Stakeholders and decision makers*

The purpose of the decision problem reflected here is to evaluate key sustainability aspects and different indicators options based on life cycle thinking approach that would get the highest environmental, economic and social benefits. The goal is to define areas of conformity and uncertainty among infrastructure projects experts on how to organize and what criteria to include for assessing sustainability of the infrastructure project. To enable consideration of such aspects associated with the life cycle sustainability assessment of the project, the groups of stakeholders that included planning engineers and managers, senior project manager and project directors of different international and national construction companies in the Middle East specifically UAE and Saudi Arabia have been consulted. The consultation method involved a combination of questionnaire based survey with construction industry professionals to identify how they perceive various sustainability aspects and indicators for their projects. This helps the decision makers to choose the set of indicators needed for the sustainability of proposed infrastructure project. The results of the analysis are proposed to be used to construct recommendation to the construction industry in their infrastructure projects specifically urban infrastructures.

**Table1. Stakeholders’ demographic data**

|  |  |  |  |
| --- | --- | --- | --- |
| **Position of the Stakeholders** |  | **Involvement in sustainability-driven projects** |  |
| Project Director | 13 | Yes: Involved in the Projects | 28 (56%) |
| Senior Project Managers | 14 | No: Not Involved in the Project | 22 (44%) |
| Project Managers | 12 |  |  |
| Planning Engineers | 11 |  |  |
|  |  |  |  |
| **Awareness of sustainability initiative** |  | **Exp. in using sustainability appraisal tools** |  |
| GRI (Global Reporting Initiative) | 36 (72%) | Yes: Used | 23 (46%) |
| UNCSD (United Nations Commission for Sustainability Development) | 33 (66%) | No: Not Used | 27 (54%) |

**Identification of sustainability issues and Criteria**

The key sustainability issues and decision indicators have been recognized through an extensive questionnaire survey with expert stakeholders. The indicators for the assessment of infrastructure sustainability mentioned in the questionnaire circulated among different professionals, experts and officials dealing with infrastructure projects in order to score each of the indicators based on the level of their significance. In total, 50 experts took part in this process representing construction industry. As a result of this process different economic, environmental and societal sustainability issues were defined to be used as decision criteria. Each indicator deals with a particular sustainability issue on different stages of the life cycle. For example, life cycle cost considers provision of total cost along the whole project for each stage of the life cycle e.g. designs, construction, operation and demolish. Similarly, initial cost, land use and cultural heritage provision for the design phase of the whole life cycle of a project. The following section describes the analysis of the economic, environmental and social indicators chosen for the sustainability assessment of infrastructure project in Middle East infrastructure sector.

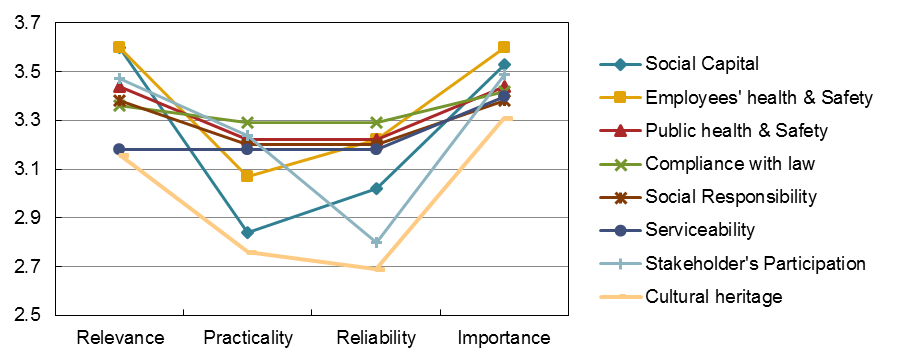
**Key Variables, Criteria and indicators for LCSA**

This section discusses and reveals the perceptions of stakeholders for the level of significance of different key indicators towards sustainability. The questionnaire data has been checked for each of the indicators on the basis of four aforesaid elements by using descriptive statistics techniques. Then AHP has been performed in order to see the preferences and weight of these indicators. The following figures show the mean score of the criteria as rated by 50 experts’ stakeholders which we has further tested by “Anova” and “Tukey Post hoc” techniques for the significant differences among the four attributes.

**Figure: 1 Economic Indicator**

**Figure: 2 Environmental Indicators**

**Figure: 3 Social Indicators**



Based on the average rating, economic indicators show more significance as they rated high, followed by social, then environmental indicators. Economic and Social indicators found highly important as scored high in the attribute of “Importance” by the stakeholders. Moreover, social indicators also ranked high as more relevant indicators than that of economic and environmental indicators, which shows the stakeholders motivation and preferences towards social values. This result is totally controversial with the previous studies whose results found the social aspects as the least relevant and important indicators. It shows that Middle East infrastructure sector is more concern with social values or it may be suggestions from the experts for the public infrastructure. Another reason might be that the indicators we chosen such as employee’s and public health and safety, compliance with law and serviceability are highly practically used in all kind of organizations. From the practicality perspective, economic indicators are highly practical than environmental and social indicators as it is common phenomenon of having economic benefit from a project. Reliability attribute are not highly ranked, but are scored more for economic indicators which shows that economic indicators like *life cycle cost* and *improvement in regional economy*, *rehabilitating cost of ecosystem* also have the perception of environmental and social aspects, that might be the reason the stakeholders rely more on economic indicators for project sustainability. One of the arguments for this order of rating might be experts give high score to those indicators they know the best.

In summary, it is shown that all the chosen indicators play an important role in the life cycle of infrastructure project and show their significance to sustainability in one of the attributes as well as they will influence the project sustainability value if do not take into consideration very well. Furthermore, the overall chosen indicators are relevant and important for assessing the sustainability as all indicators are highly rated. The indicators that are ranked low reliable and practical while more relevant and important indicated that there are challenges and high uncertainty with the measurement of these indicators. The following table shows the indicators with highly significant differences with those of without significant differences which are found through multiple comparison test (Tukey Post hoc Test).

**Table. 2 Indicators with Significant differences**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Economic Indicators** | **Environmental Indicators** | **Social Indicators** |
| **Indicators with**  **Significant Differences** | Initial Cost  Importance ˃ Reliability | Ozone Layer Depletion  Relevant ˃ Reliability | Social Capital  Relevant/importance ˃ Practicality  Relevant/Importance ˃ Reliability |
| Cost of Employment  Importance ˃ Reliability | Renewable Resource Consumption  Importance/Relevant ˃ Reliability | Employees Health & Safety  Relevant ˃ Practicality  Relevant/Importance ˃ Reliability |
| Financial Return  Importance ˃ Reliability | Waste Generation  Importance ˃ Reliability  Importance ˃ Practicality | Stakeholders Participation  Relevant/Practical/Importance ˃ Reliability |
|  | Water Use  Relevant ˃ Practicality  Relevant ˃ Reliability | Cultural Heritage  Importance ˃ Reliability  Importance ˃ Practicality |
| **Indicators without**  **Significant Differences** | Life Cycle Cost | Global Warming Potential | Public Health & Safety |
| Rehabilitating Cost of Ecosystem | Acidification | Compliance with Law |
| Improvement in Regional Economy | Eutrophication | Social Responsibility |
| Resettling Cost of Residence | Land Use | Serviceability |
|  | Indoor Air Quality |  |
|  | Noise Level |  |

**Economic Indicators Analysis**

As one of our purposes is to see the level of significance of the indicators on the basis of selected four elements, the above table shows the result of each indicator at particular attribute. From the analysis of multiple comparison tests, it is observed that the *initial cost* is highly important, relevant and practical rather than reliable for sustainability. It is general understanding that *initial cost* is deliberated more for the economic assessment of a project. The *financial return* and *improvement in regional economy* indicators are also rated more by the respondents which means they are highly significant for economic sustainability. One of the purposes of assessing the project is to have financial benefit from the initial investment, therefore, it is also considered more significant by the stakeholders. During the assessment of project for its cost benefit analysis, *initial cost* and *financial return* are also the main indicators to take into account for calculation. Most of the infrastructure projects are publically owned and with its installation it *increases regional economy* by providing job and business opportunities to the locals. These are the reasons that these indicators are perceived more significant. The respondents rated *cost of employment* indicator more relevant and important which shows its future consideration in the assessment of project sustainability. From the *table 03*, it shows there are significant difference between importance and reliability among the scoring of element of analysis of *initial cost, financial return* and *cost of employment*. The scoring of *life cycle cost* is unanticipated as it is an important indicator in the economic assessment but it is ranked low by the experts, because it might possible that uncertainty is connected with this indicator through different stages of project life cycle which cannot be estimated in the initial stage of the project. The indicators that show no differences among the four elements of analysis are more or less significant for economic sustainability of infrastructure. Based on average score of indicators *resettling cost of residents* scored less but still are significant as equal to *life cycle cost*. The significance of *rehabilitating cost of ecosystem* cannot be ignored because among other purposes of infrastructure projects, one is to restore the degraded ecosystems as a part of life cycle thinking approach towards sustainable urbanization.

**Environmental Indicators Analysis**

Ten indicators were analyzed under this aspect, which were considered highly utilized and important for infrastructure sector sustainability. As it is showed in the results *Global warming potential* and *renewable resource energy* are scored high among environmental indicators and show more relevancy and importance from the environmental perspective of sustainability. The possible reason is that, these indicators are on the top of current debate among environmental policy makers and concerns about *GWP* are strongly supported by United Nations Framework Convention on Climate Changes (Rogelj et al., 2016). In the context of Middle East, another reason is that *renewable resource energy* also give economic benefit that is why it is more practically utilized in the infrastructure sectors as compared to other indicators such as *Acidification, eutrophication* etc. The respondents rated *Noise level*, *Eutrophication* and *water use* low for sustainability. Indeed, from the score in the relevance attribute show that these indicators are relevant to sustainability but might not be more important and practically used indicators for infrastructure projects. Another reason is that may be the respondents are more economic benefit oriented rather than environmental that is why they scored high those environmental indicators whose have also economic benefits. In this regard if we see *land use* and *indoor air quality* indicators there are scored high because one has economically positive impacts *(land use)* and another is highly demanded by the clients *(indoor air quality).* The result of *acidification* is considered more practical and important while there is no significant difference which shows it is fair significant in all attributes. Furthermore, *Ozone layer depletion, water use, waste generation* and *renewable resource* *consumption* show significant differences which indicate the variation of scoring among their elements of analysis.

**Social Indicators Analysis**

As we mentioned above that social aspect requires deep research especially in the field of infrastructure as it is being neglected by the researchers and now gradually gets some attention for its significance in the perspective of infrastructure development for achieving sustainability objectives (Edum-Fotwe and Price. 2009). Like environmental issued, social issues are also on current debates among the practitioners and policy decision makers, since social indicators are usually qualitative therefore these are considered to be difficult to deal with for sustainability assessment in relations of its quantification. In this study, we put eight social indicators from different literature for the experts’ perception. Moreover, some indicators were suggested by stakeholders from public point of view towards the project such as public perception, public access and respecting minorities etc. As from our analysis in the above tables *health & safety* indicators as well as *compliance with law* are high scored. *Public health & safety* and *compliance with law* indicators have no significant difference but *employee’s health & safety* are found significant differences where it is rated high relevant and high important compare to reliability and practicality which also justifies and strengthens the result of (Ugwu et al., 2006) where *safety and health* was ranked top on stakeholders’ perception among all indicators for sustainability assessment. In term of differences among the element of analysis for the indicators *serviceability,* and *social responsibility* there are also no significant difference and all are rated high, which demonstrate their consideration for sustainability. *Social capital, stakeholders’ perception* and *culture heritage* found variant in scoring among all attributes. *Social capital* and *stakeholders’ perception* are perceived more relevance and important. *Social capital* perception could be because of the socially oriented culture of Middle East countries but technically, *social capital* is not more reliable for the sustainability of a project specifically for infrastructure projects. *Stakeholders’ participation* is considered to be one of the challenging indicators to reliably quantify because among the scientific community there is no international agreement on *stakeholder participation* and its inclusion explanation (Hurley et al., 2008). However, there is a rising apprehension from the industry professional about the significant role of public awareness and *stakeholders’ participation* in achieving and understanding sustainability development (Alsulami and Mohamed, 2011). The result for *culture heritage* is very unexpected because it is a relevant indicator to sustainability in social aspects and Middle East is full of heritage and famous for it, which cannot be ignored when assessing sustainability of a project in that region. Moreover, it should be noted that every region and country will have their country and side specific sustainability priorities and usually some of social indicator components have far-reaching and unforeseen impacts even after the construction of project has been finished.

As showed in the tables most of the indicators under study are valid for serious concern due to the high score in relevance and importance attributes by the entire respondent. *Initial cost, financial return, improvement in regional economy, Renewable resource energy, GWP* and *Employees and Public* *health and safety,* and *compliance with law* are the highly scored indicators with least mean value *3.33/4*, in stakeholders’ perspective that cover the triple bottom line of sustainability. Moreover, in term of difference in score, there are very minor differences among the mean score of indicators in the categories of relevance and importance, which indicate that the respondents scored the indicators more in relevance and important attributes, which shows we have chosen highly significant indicators which are justified by the rating of infrastructure experts. At the meantime, all indicators deserve further attention in order to make them more reliable and practical.

**Analytical Hierarchy Process (AHP) Analysis**

The multi-criteria decision analysis approaches is recognized for the assessment of sustainability of a system and are used when decision has to be taken for the identification of a most preferred solution of stated system. According to the procedure of MCDA, it is not bounded just for selecting the desired solution but could be used for the assessment of a single project/system on the foundation of different sustainability indicators. AHP as one of MCDA techniques has been used for ranking the indicators in their respective aspects based on the responses from various experts of infrastructure sector. For complex situation, AHP allows the group of stakeholders for decision making by simplifying the natural process of decision making into pairwise comparisons among the indicators/parameters (Chandratilake and Dias, 2013).

Following Saaty and Vargas ( 2012), we used pair comparisons methods in order to calculate the weight and ranking of the chosen indicators. The experts were divided into four groups according to their designations which are Project Directors, Senior Project Managers, Project Managers and Planning Engineering. The Stakeholders who answered “no opinion” to any of the questions in the questionnaire were not taken into consideration in pairwise comparison analysis. Saaty (1980) recognized the linear scale of 1-9 integers as the best scale for the demonstration of weight ratio and has been used in most of the applications. Salo and Hamalainen (1997) exhibit the advantage of the balanced scale while matching two elements. Some of the researchers stated that the choice scale depends on decision problem and on individuals who carry it (Harker and Vargas, 1987; Poyhonen et al., 1997). Our questionnaire data was not on the basis of likert scale Therefore; I have developed the following two equations for our data analysis, with the contribution of Prof. Jun Nakatani during my Research & Mobility program at University of Tokyo, Japan. We have calculated the values for each cell of the metrics by taking “difference between the mean values of two indicators”. Weighting score of the indicators were calculated according to the eigenvector/eigenvalue method. Furthermore, consistency ratio (CR) was also determined to justify whether the experts’ responses of the questionnaire are adequately consistent. All these analyses have been mentioned in the appendixes and a table has been shown as an example in the end of this section.

If Mean Value (A) ≥ Mean Value (B) then,

1. ***X = (Mean Value (A) - Mean Value (B)) × 4 + 1***

If Mean Value (A) < Mean Value (B) then,

1. ***X = 1 / (Mean Value (A) - Mean Value (B)) × 4 + 1***

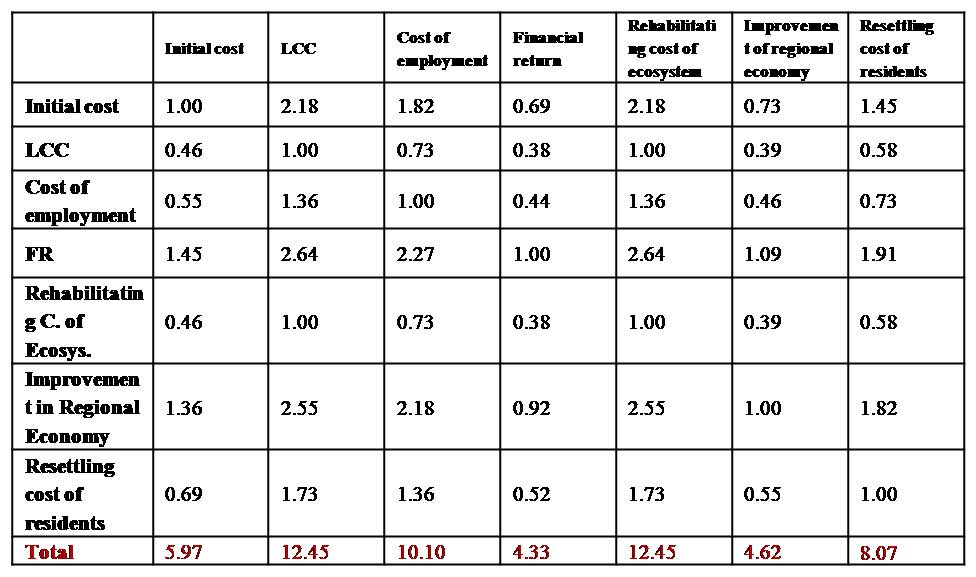
The aims were to find weights for each indicator in the model as these can be utilized to obtain the collective assessment of project sustainability. As we explained in the above section that *initial cost*, *financial return* and *improvement in regional economy* were more significant economic indicators in different attribute, they also weighted high in the pair comparison analysis. The project director weighted *initial cost* and *improvement in regional economy* *20%* each as their top priority, then *financial return* and *rehabilitating cost of ecosystem* *14%* each and third highly weighted score are *12%* for *life cycle cost* and *cost of employment*. The same group of stakeholders ascribed high significance to *renewable resource consumption* *(14%)* and *noise level* *(13%)* in the environmental aspect. The group gave more priority to social indicators than environmental indicators. *Social capital* and *employees’ health & safety* are prioritized high with *(16%)* each weighted scored, followed by *compliance with law* *(15%).* Another reason of environmental indicator that weighted less than other aspect might be because there are more indicators in environmental aspects as compare to indicators in social aspects. Obviously 1 is divided among all environmental indicators whose decrease the weighted score for each indicator.

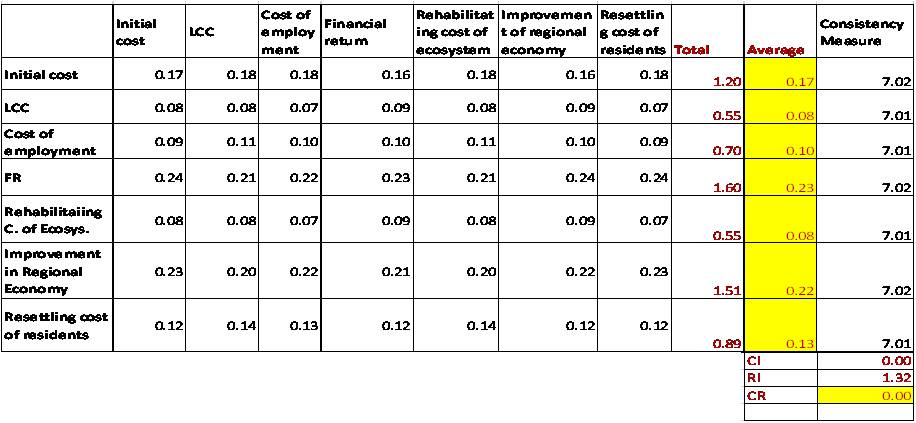
The second group of senior project managers also weighted the initial cost high among other indicators. For the environmental aspects, *global warming potential* and *land use* are weighted high with *20%* and *17%* respectively. *Acidification* is scored *14%* and *renewable resource consumption* as one of the most important environmentally high considered indicator is weighted *13%*. For social indicators, the group of stakeholders focused more on the *stakeholders’ participation* in the decision making, which is also practically more recognized indicator to be considered when decisions take place for sustainability assessment of a project. *Stakeholders’ participation* and *serviceability* indicators are ranked in the top with *17%* weighted score each, then the groups give more significant importance to *Employee’s and Public health and safety* indicators with *14%* weighting score.

The project managers group gave more priority in economic aspect to *rehabilitating cost of ecosystem, cost of employment, financial return* and *improvement in regional economy* with *20%, 18%, 17%* and *15%* respectively. For environmental aspect, *indoor air quality* is at the high weighted score 18% in this group of experts, then *global warming potential* and *renewable resource consumption* in second high ranking, weighted scores *17%* each. In case of social aspect, the project managers ranked *social responsibility* indicator as most weighted score in the process *(21%)* then *employees and public health and safety* as also considered high by senior project managers group. The project managers ranked them second more weighted indicators with *19%* score both of them.

In the last group of stakeholders who were planning engineers, have focused on *financial return, improvement in regional economy* and *initial cost* and put them in their top ranking for the economic sustainability of infrastructure project. As explained above these indicators cover different aspects so therefore these are more focused by the stakeholders. The planning engineers weighted them *23%, 22%* and *17%* for each of these indicators in the AHP analysis. This is the only group who gives more priority to *ozone layer depletion* and put it in top rank with *14%* score. *Global warming potential* and *renewable resource consumption* are ranked second in this group which scored *13%*. In case of social aspect, *compliance with law* is scored *22%* with top ranking followed by *social capital* 14% and *employees’ health & safety* also *14%*. *Public health & safety* are closely weighted with 13% score.

**Table3. AHP analyses for indicators weighting**





Based on the allocation of weights, these results show that there are some common indicators among all respondent groups, which are deliberated significant and scored high by all group of experts. In economic category, these indicator are *initial cost, financial return, cost of employment* and *improvement in regional economy,* in environmental category these are *global warming potential, renewable resource consumptions, land use* and *indoor air quality* while in category of social aspects these are *Employees’ health and safety, Public health and safety, social capital, stakeholder participation, compliance with law* and *social responsibility*. Most probably the score of environmental indicator in AHP analysis would be different if we chose equal numbers of indicators in each category. However, this analysis gives us important consideration that which indicators are preferred more by the experts for their significance to the assessment of project sustainability. The explanation of these sustainability indicators form the foundation for the determination to which limit the individual indicator is fulfilled.

**Analysis of the Economic, Environmental and Social Aspects**

In the following figures the illustration of different weighting sets (Economic, Environmental and Social) is represented. The life cycle sustainability triangle (LCST) is the representation adopted by Hofstetter et al. (1997), for weighting various environmental impacts by chemical mixtures problems. This can be applied for the weighting of any three aspects (Finkbeiner et al., 2010). In our study, the ranking of economic, social and environment aspects are to be weighted by the different groups of experts. In the triangle area, each point matches to a particular weighting set *(Wec, We, Ws)*. Wec, We and Ws represent the weighting of economic, environment and social aspects respectively. As we can see from the following figures, the *economic aspect* of infrastructure sustainability is weighted highest as most important aspect among all groups of stakeholders. This was expected from the analysis because in infrastructure projects it is a common phenomenon to have economic benefits from it either for individual purpose or for the state purposes. All of the researches that have been done in this field have ranked the economic aspect at the top of sustainability achievements.

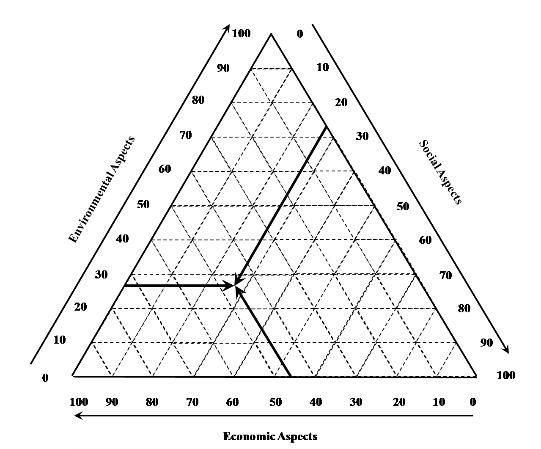
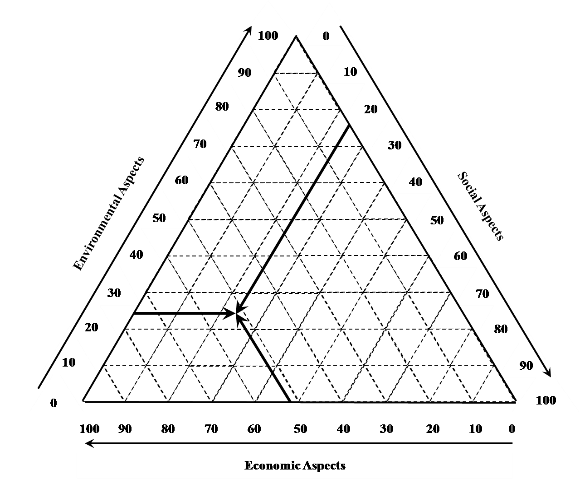
**Figure4. Life cycle sustainability triangle of AHP analysis result**

**Wec Weighting of Eco. Aspect**

**We Weighting of Env. Aspect**

**Ws Weighting of Soc. Aspect**

**Wec + We + Ws = 100%**



**Fig 4a. Project Directors Analysis Fig 4b. Senior Project Managers Analysis**

Wec = 46%

We = 27%

Ws = 27%

Wec = 52%

We = 24%

Ws = 24%

Wec = 37%

We = 26%

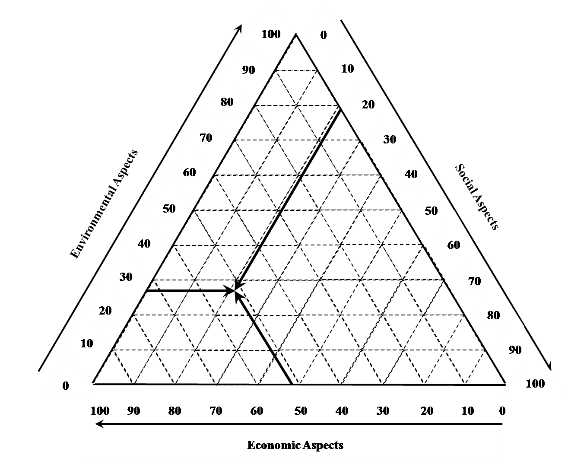
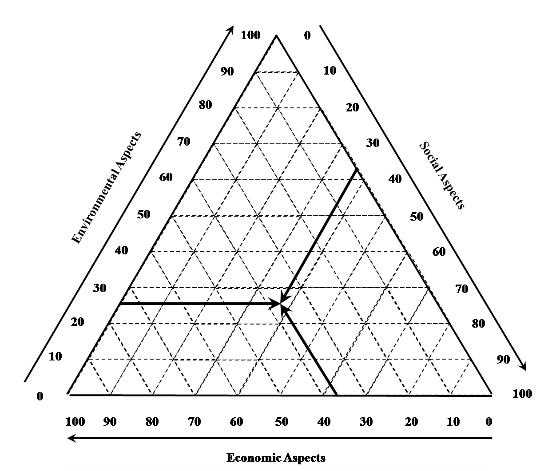
Ws = 37%

Wec = 52%

We = 27%

Ws = 21%

**Fig 4c. Project Managers Analysis Fig 4d. Planning Engineering Analysis Analysis**

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The case of *environmental and social aspects* in our study is quite different, they go close parallel to each other while in other studies they ranked and considered *environmental aspect* higher than *social aspect.* The project directors and senior project managers as one of the senior hierarchy have put social and environmental aspects in equal importance by given equal score to both of the aspects. It can be noticed that planning engineering have ranked social aspect more than environmental aspect and ranked it equal to that of *economic aspect,* while the project managers group have ranked it close next to *environmental* *aspect* by scoring *environmental aspect 27%* and *social aspect 21%*. The result shows that emphasis of environmental and social responsibility and its fulfillment efforts in the context of Middle East countries. The analysis highlighted that the respondents were quiet familiar and used with sustainability assessment tools and have been experienced in different projects that have followed the life cycle thinking approaches for the project sustainability. Through proper monitoring and controlling of the infrastructure against these sustainability aspects and their indicators, we can enhance sustainability in overall urban infrastructure development.

**4. Conclusion**

Various Infrastructure systems have great influence for the attainment of sustainability in the context of urbanization. And then this sustainable urban development have greater role on the economy, environment and society of a city or a whole state. Therefore, the right quantification of sustainability of infrastructure systems would be attained through the use of accurate indicators following the life cycle thinking approach covering all pillars of sustainability. This paper presented a limited application of life cycle thinking based sustainability assessment framework for urban infrastructure project developed in the 1st part of this research. The study identified the most useful indicators through life cycle approach, considering economic, social and environmental concerns of various experts require for sustainable urban infrastructure systems. Sustainability indicators related to urban development have been chosen from the literature and then evaluated through questionnaire survey on the basis of four elements (relevant, practical, reliable and important) towards sustainability from the infrastructure projects experts located in the Middle East countries. The experts were highly qualified and experienced in the sustainability assessment tools and sustainability based infrastructure projects. Then we analyzed the results of the questionnaire survey in order to find out the perception of these experts about the importance of Economic, Social and environmental aspects and significance of their indicators based on four elements that could be evaluated using life cycle sustainability assessment techniques in order to see the sustainability of urban infrastructure systems. For the priority weighting score of these indicators, Analytical Hierarchy Process (AHP) has been used for the judgments in pairwise comparisons. Then the priority of economic, environment and social aspects also analyzed through pair comparison method.

The study highlighted that most of these sustainability indicators were highly important and relevant for measuring sustainability performance. Therefore, these indicators should be seriously considered for determining the infrastructure systems sustainability that will lead to sustainable urbanization. We also suggest that those indicators which found more significant and prioritize high in AHP analysis should be included in all kind of infrastructure projects for their sustainability that would help in achieving urban development goals from infrastructure perspective. Indeed, we have also seen some different opinions in the priority of indicators and aspects for which there should be dialogue among the experts in order to achieve their mutual consensus about the most significant indicators. In contrast to other studies, our analysis found social indicators highly significant same like environment and some of the experts gave them more importance than environmental indicators. This is most probably because of most relevant and practical indicators we have chosen for the analysis in the category of social aspects. Through the comprehensive sustainability assessment tools stated in the framework can assist the urban decision makers in understanding the decision issues and its consequences for the sustainable urban infrastructure.

**5. CONCLUSIONS**

The construction of urban infrastructure specifically roads, highways, building and bridges are considered to be the backbone for the economic development of a nation. At the mean time these infrastructure projects consume a lot of energy and other resources and have negative effects on the environment and society. More and more people are migrating from rural areas to urban areas because it provides jobs opportunities, health services and quality of life to the inhabitants. But these chain effects of urban infrastructure as well as the unsustainable activities by the people cause serious threads to sustainable development. Therefore, for the last few years these unsustainable activities have taken the attention of researchers, environmental policy makers and even urban planners for the construction of sustainable urban infrastructure development. This phenomenon called for new approaches to establish for the integration of all dimensions and various points of views by the stakeholders for the sustainable development of urban infrastructure. Considering the issues, the goal of this research is to develop a life cycle thinking based sustainability assessment framework for urban infrastructures which would assist the decision makers in their decisions for the evaluation of best alternative through a set of sustainability criteria and indicators. The status goal was achieved through the following objectives.

*Consideration and identification of various issues in the development of urban infrastructures and attempts to discourse them.*

From the literature review the issues for which a lack of common perception and consensus regarding infrastructure sustainability among different stakeholders has been identified, as well as the issue of common indicators for different dimension of sustainability. The stakeholders interpret the sustainability according to their own preferences without considering the preferences of other stakeholders. This makes it worse by the complexity of the infrastructure development and diversity of culture and indicators from region to region. The criteria and indicator of one region may be sustainable for another region. Therefore, for the implementation of sustainability in urban infrastructure projects, various stakeholders’ perception, interest and priorities should be identified and in addition to their own preferences they have to recognize the preferences of other stakeholders. In the absence of consensus and common perception regarding sustainability, the goals of sustainable development cannot be achieved.

*To examine the existing approaches, tools and frameworks of sustainability that might be useful for the assessment of the sustainability of urban infrastructures;*

From the literature review, different tools and framework have been examined and the pros and cons of these approaches have also been discussed. These approaches for urban sustainability assessments establish a rapid developing arena globally but confronting different debates and challenges by the urban planners and researchers. Each of these tools is different in the scope and in the interpretation of their results. Numerous studies have focused on the effective role of tools used for the project sustainability in which some covered all dimensions of sustainability e.g. economic, environment and social while others focused on environmental scope. Most of the framework followed sustainability indicator approach which in mainly project based or region based and cannot be implement to other regions. The sustainability indicators based framework are lacking of life cycle impact of the indicators for the sustainability assessment of the projects. In this way, these studies have used different assessment tools according to their aim and purpose of the study. Considering the lack of life cycle assessment in these approaches, we have suggested for having well-defined framework that can categorize the indicators on life cycle based assessment into their different attributes and can be used for sustainability assessment of a system at different stages of their life cycle.

*To develop of LCT-based framework that is composed of various techniques for long term future and current issues;*

After the critical analysis of the literature review, we stated that the currently used approaches for the sustainability development are limited in their ability to properly analyze the needs of various stakeholders in infrastructure projects. However, we need an integrated assessment framework that incorporates different dimension of sustainability incorporating stakeholders’ perspectives through LCT tools and techniques. For this purpose, the analyzed tools and frameworks highlighted in the literature review give a good foundation for the establishment of such an assessment framework. The LCT based sustainability framework is composed of three stages: (i) Project Structuring, which is a conceptual stage and where conciliation takes place among stakeholders on sustainability issues (ii) Project analysis which is further divided into mandatory and optional sections. The key sustainability criteria and indicators could be developed by using MCDA tools and then these indicators can be analyzed by the LCT tools for the assessment of sustainability and (iii) Project resolution/implementation, where decision takes place for the implementation of the project. This approach is based on the identification of key sustainability indicators, to measure and balance the aspects of sustainability in different stages of an infrastructure project.

* identification of different sustainability criteria and indicators for the assessment of urban infrastructure projects;
* test of the LCT framework for the part that is specifically for the identification of indicators.

The above two objectives has been perform during my stay as a visiting scholar at University of Tokyo, Japan. One of the main characteristic and critical issues of the proposed framework is the identification and evaluation of the most relevant indicators because the sustainability assessment of a project can be determined on the basis of the selected indicators. These indicators can be country specific or project specific and the indicators of one region might not be relevant for the assessment of the project of another region. Therefore, the framework has been tested for a limited part, specifically that related to the identification of key indicators; the testing has been performed in the context of Middle East countries specifically UAE and Saudi Arabia infrastructure projects. The sustainability indicators related to urban development have been chosen from the literature and then evaluated through questionnaire survey on the basis of four elements (relevant, practical, reliable and important) towards sustainability from the infrastructure projects experts located in the Middle East countries. Then we analyzed the questionnaire data by using descriptive statistics techniques for the more significant indicators. We also found the most significant differences among the attributes of analysis. AHP as a tool of MCDA has been performed in order to see the preferences and weight of these indicators and criteria. The study highlighted that most of these sustainability indicators were highly important and relevant for measuring sustainability performance. We also suggest that those indicators which found more significant and prioritize high in AHP analysis should be included in all kind of infrastructure projects for their sustainability that would help in achieving urban development goals from infrastructure perspective. In contrast to other studies, this analysis found social indicators highly significant and some of the experts gave them more importance than environmental indicators. Generating both qualitative and quantitative information along with stakeholders input contribute extensively to increase transparency and develop understanding, which may lead to build consensus among the stakeholders and reduced uncertainty. The developed LCT based framework can be both as a consensus building and assessment approach for sustainable development.

**Future Direction**

The proposed framework requires huge quality data for a single project difficult to be obtained by a researcher. Only the practitioners that have access to the project data can perform the assessment of economic, environmental and social indicators using the life cycle tools. Therefore, the construction industry experts should implement the framework in their infrastructure projects with the support of technical staff and practitioners of life cycle thinking tools that would help in decision making regarding the sustainability assessment of urban infrastructure systems.

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**APPENDIX**

**Questionnaire**

This questionnaire has been designed to find out the “**Integration of Economic, Environmental and Social issues for the design of sustainable urban systems*”.*** Please evaluate economic, environmental, and social indicators from the following viewpoints:

1. Do you think each indicator is **relevant** to the project which you are engaged in?
2. Do you think each indicator is **practical** for evaluation of the project?
3. Do you think each indicator is **reliable**?
4. Do you think each indicator is **important** in execution of the project?

Your responses in this regard will be a healthy addition towards the analysis of the study. It is ensured that the information you provide will be strictly used for academic purpose and will be kept confidential.

By: KAMRAN KHAN

(Ph.D.Student (Urban Planning): \_\_\_\_\_\_\_ University of Messina, Italy)

**Respondents Information**:

**Gender: (i)** Male **(ii)**  Female

**Age: (i)** 26-30 **(ii)** 31-35 **(iii)** 36-40 **(iv)** 40-45 (v) above 45

**Designation/Position: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Years of Experience in current Organization:**

**(i)** Less than 1 **(ii)** 1 – 3 **(iii)** 4 – 7 **(iv)** Above 7

**Total (overall) Professional Experience in years:**

**(i)** Less than 1 year **(ii)** 1 – 3  **(iii)** 4 – 7 **(iv)** 8 – 10 **(v)** Above 10

**Qualification:**

1. High School
2. Diploma
3. First Degree
4. Master’s Degree
5. Ph.D.
6. Others (s): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Knowledge of Sustainability tools and initiatives:**

Do you know about Global Reporting Initiative (GRI)? (i) Yes (ii) No

Do you know about United Nations Commission for Sustainability Development (UNCSD)?

1. Yes (ii) No

Have you ever used Sustainability Assessment techniques (life cycle costing, life cycle assessment, social impact assessment etc.)? (i) Yes (ii) No

If “Yes” please specify the name of the techniques(s). \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

Have you ever been involved in sustainability driven- project? (i) Yes (ii) No

If “Yes” please specify the name(s). \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**Economic Indicators**

**Initial Cost**

Costs incurred during the design and construction process.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | Highly relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | Highly practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Life cycle cost**

Cost of an asset or its parts throughout its life cycle, while fulfilling its performance requirements.

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| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Cost of Employment**

The actual amount paid for all employee wages and benefits. This includes wages, salaries, commissions, employer match of taxes such social security and Medicare etc.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Financial Return**

The amount of revenue, an investment generates over a given period of time as a percentage of the amount of capital invested.

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| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Rehabilitating cost of ecosystem**

It means to repair and replace the essential or primary ecosystem structures and functions which have been altered or eliminated by disturbance.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

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| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Improvement in regional economy**

The benefit of the infrastructure project in the improvement of regional economy.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

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| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| Not important | Less important | Important | Highly Important | No Opinion |

**Resettling cost of residents**

The consideration of the total cost of resettling of the residents.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

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| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

Please suggest the economic indicator(s) that is/are not specified in the questionnaire and is/are valuable according to your experience.

1). \_\_\_\_\_\_\_\_\_\_

2). \_\_\_\_\_\_\_\_\_\_

3). \_\_\_\_\_\_\_\_\_\_

So on….

**Environmental Indicators**

**Global warming potential**

(This indicator measures the greenhouse gas emissions that have a potential impact on the climate. Increasing emissions have led to an increase in atmosphere concentrations of the long-lived GHG gases)

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Acidification**

(Acidification occurs when the capacity of the soil or water bodies to resist or neutralize acidifying atmospheric deposition begins to decline.)

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

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| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| Not important | Less important | Important | Highly Important | No Opinion |

**Ozone layer depletion**

(This indicator measures the release of gases that have a potential impact on the stratospheric ozone layer, which protects earth’s flora and fauna against the sun’s ultraviolet UV)

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

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| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Eutrophication**

(Eutrophication happens when water systems receive excess nutrients that cause excessive plant growth such as algae. It can lead to a local increase in biodiversity)

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| Not important | Less important | Important | Highly Important | No Opinion |

**Renewable resources consumption**

Resources that are grown, naturally replenished or cleansed on a human time scale. This indicator measures the use of renewable material and energy resources.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

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| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

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| Not important | Less important | Important | Highly Important | No Opinion |

**Waste generation**

Quantity of materials or products those enter a waste stream before composting, incinerating, land filling, or recycling. This indicator measures the production of the total volume of non-hazardous and hazardous wastes that has a potential impact on the generation of waste for disposal.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

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| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Water use/water reuse**

The amount of water used or allocated by a project for its production. There are numerous measure of water use depend on the nature of the project.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Not relevant | Less relevant | | Relevant | | High relevant | | No Opinion | |
| Not practical | | Less practical | | Practical | | High practical | | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Land use/extent of land acquisition**

This indicator measures the avoidance of consuming of Greenfield lands through the reuse of Brownfield and derelict areas, refurbishment, using infill sites and re-development of existing built environment.

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| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Indoor Air quality**

This indicator measures the quality of indoor air that has a potential impact on the human health, olfactory comfort and perceived comfort of users of the building.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Noise level**

This indicator measures different level of noise level in different circumstances.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

Please suggest the environmental indicator(s) that is/are not specified in the questionnaire and is/are valuable according to your experience.

1). \_\_\_\_\_\_\_\_\_\_

2). \_\_\_\_\_\_\_\_\_\_

3). \_\_\_\_\_\_\_\_\_\_

So on….

**Social Indicator**

**Social capital**

(The networks of relationships among people who live and work in a particular society, enabling that society to function effectively)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Employees’ health & Safety**

This indicator measure the measurement of employees’ health & safety measures taken by the decision makers.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Public Health & Safety**

This indicator measure the measurement of general public’ health & safety measures taken by the decision makers.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Compliance with laws**

This indicator mean either the construction company or project considers compliance with the law or they acting in accordance with a request or a command, rule or instruction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

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| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Social responsibility**

This indicator measure the cooperate social responsibility of the project either is it according to the GRI or UNCSD followed

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| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Serviceability**

It expresses the fitness for purpose of the building that has a potential impact on the ability of a building to fulfill the user requirement, from the functionality point of view.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Stakeholders’ participation**

This indicator refers to the involvement of the users of the building and the surroundings and other stakeholders in the infrastructure project.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

**Culture heritage**

This indicator shows the considering of culture heritage while planning for the construction of the project.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not relevant | Less relevant | Relevant | High relevant | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not practical | Less practical | Practical | High practical | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not reliable | Less reliable | Reliable | Highly reliable | No Opinion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Not important | Less important | Important | Highly Important | No Opinion |

Please suggest the social indicator(s) that is/are not specified in the questionnaire and is/are valuable according to your experience.

1). \_\_\_\_\_\_\_\_\_\_

2). \_\_\_\_\_\_\_\_\_\_

3). \_\_\_\_\_\_\_\_\_\_

So on….

**Economic Indicators**

**SENIOR PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** |
| **Initial cost** | 1 | 2.2 | 3.3 | 3 | 2.9 | 2.6 | 3 |
| **LCC** | 0.4545455 | 1 | 2.1 | 1.8 | 1.7 | 1.4 | 1.8 |
| **Cost of employment** | 0.3030303 | 0.4762 | 1 | 0.76923 | 0.714285714 | 0.588235294 | 0.769230769 |
| **F.R** | 0.3333333 | 0.5556 | 1.3 | 1 | 0.909090909 | 0.714285714 | 1 |
| **Rehabilitating C. of Ecosystem** | 0.3448276 | 0.5882 | 1.4 | 1.1 | 1 | 0.769230769 | 1.1 |
| **Improvement of regional economy** | 0.3846154 | 0.7143 | 1.7 | 1.4 | 1.3 | 1 | 1.4 |
| **RCR** | 0.3333333 | 0.5556 | 1.3 | 1 | 0.909090909 | 0.714285714 | 1 |
| **Total** | 3.1536854 | 6.0898 | 12.1 | 10.0692 | 9.432467532 | 7.786037492 | 10.06923077 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** | **Total** | **Average** | **Consistency Measure** |
| **Initial cost** | 0.32 | 0.36 | 0.27 | 0.30 | 0.31 | 0.33 | 0.30 | 2.19 | 0.31 | 7.03 |
| **LCC** | 0.14 | 0.16 | 0.17 | 0.18 | 0.18 | 0.18 | 0.18 | 1.20 | 0.17 | 7.02 |
| **Cost of employment** | 0.10 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.56 | 0.08 | 7.01 |
| **F.R** | 0.11 | 0.09 | 0.11 | 0.10 | 0.10 | 0.09 | 0.10 | 0.69 | 0.10 | 7.01 |
| **Rehabilitating C. of Ecosystem** | 0.11 | 0.10 | 0.12 | 0.11 | 0.11 | 0.10 | 0.11 | 0.74 | 0.11 | 7.01 |
| **Improvement of regional economy** | 0.12 | 0.12 | 0.14 | 0.14 | 0.14 | 0.13 | 0.14 | 0.92 | 0.13 | 7.01 |
| **RCR** | 0.11 | 0.09 | 0.11 | 0.10 | 0.10 | 0.09 | 0.10 | 0.69 | 0.10 | 7.01 |
|  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  | RI | 1.32 |
|  |  |  |  |  |  |  |  |  | CR | 0.00 |

**PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** |
| **Initial cost** | 1 | 1.3636 | 0.611111111 | 0.64706 | 0.578947368 | 0.733333333 | 1.363636364 |
| **LCC** | 0.7333333 | 1 | 0.5 | 0.52381 | 0.47826087 | 0.578947368 | 1 |
| **Cost of employment** | 1.6363636 | 2 | 1 | 1.09091 | 0.916666667 | 1.272727273 | 2 |
| **FR** | 1.5454545 | 1.9091 | 0.916666667 | 1 | 0.846153846 | 1.181818182 | 1.909090909 |
| **rehabilitating cost of ecosystem** | 1.7272727 | 2.0909 | 1.090909091 | 1.18182 | 1 | 1.363636364 | 2.090909091 |
| **Improvement of regional economy** | 1.3636364 | 1.7273 | 0.785714286 | 0.84615 | 0.733333333 | 1 | 1.727272727 |
| **RCR** | 0.7333333 | 1 | 0.5 | 0.52381 | 0.47826087 | 0.578947368 | 1 |
| **Total** | 8.7393939 | 11.091 | 5.404401154 | 5.81356 | 5.031622954 | 6.709409888 | 11.09090909 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** | **Total** | **Average** | **Consistency Measure** |
| **Initial cost** | 0.11 | 0.12 | 0.11 | 0.11 | 0.12 | 0.11 | 0.12 | 0.81 | 0.12 | 7.00 |
| **LCC** | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.09 | 0.09 | 0.63 | 0.09 | 7.00 |
| **Cost of employment** | 0.19 | 0.18 | 0.19 | 0.19 | 0.18 | 0.19 | 0.18 | 1.29 | 0.18 | 7.00 |
| **FR** | 0.18 | 0.17 | 0.17 | 0.17 | 0.17 | 0.18 | 0.17 | 1.21 | 0.17 | 7.00 |
| **rehabilitating cost of ecosystem** | 0.20 | 0.19 | 0.20 | 0.20 | 0.20 | 0.20 | 0.19 | 1.38 | 0.20 | 7.00 |
| **Improvement of regional economy** | 0.16 | 0.16 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 | 1.05 | 0.15 | 7.00 |
| **RCR** | 0.08 | 0.09 | 0.09 | 0.09 | 0.10 | 0.09 | 0.09 | 0.63 | 0.09 | 7.00 |
|  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  | RI | 1.32 |
|  |  |  |  |  |  |  |  |  | CR | 0.00 |

**PLANNING ENGINEERS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** |
| **Initial cost** | 1 | 2.1818 | 1.818181818 | 0.6875 | 2.181818182 | 0.733333333 | 1.454545455 |
| **LCC** | 0.4583333 | 1 | 0.733333333 | 0.37931 | 1 | 0.392857143 | 0.578947368 |
| **Cost of employment** | 0.55 | 1.3636 | 1 | 0.44 | 1.363636364 | 0.458333333 | 0.733333333 |
| **FR** | 1.4545455 | 2.6364 | 2.272727273 | 1 | 2.636363636 | 1.090909091 | 1.909090909 |
| **Rehabilitaiing C. of Ecosys.** | 0.4583333 | 1 | 0.733333333 | 0.37931 | 1 | 0.392857143 | 0.578947368 |
| **Improvement in Regional Economy** | 1.3636364 | 2.5455 | 2.181818182 | 0.91667 | 2.545454545 | 1 | 1.818181818 |
| **Resettling cost of residents** | 0.6875 | 1.7273 | 1.363636364 | 0.52381 | 1.727272727 | 0.55 | 1 |
| **Total** | 5.9723485 | 12.455 | 10.1030303 | 4.3266 | 12.45454545 | 4.618290043 | 8.073046252 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** | **Total** | **Average** | **Consistency Measure** |
| **Initial cost** | 0.17 | 0.18 | 0.18 | 0.16 | 0.18 | 0.16 | 0.18 | 1.20 | 0.17 | 7.02 |
| **LCC** | 0.08 | 0.08 | 0.07 | 0.09 | 0.08 | 0.09 | 0.07 | 0.55 | 0.08 | 7.01 |
| **Cost of employment** | 0.09 | 0.11 | 0.10 | 0.10 | 0.11 | 0.10 | 0.09 | 0.70 | 0.10 | 7.01 |
| **FR** | 0.24 | 0.21 | 0.22 | 0.23 | 0.21 | 0.24 | 0.24 | 1.60 | 0.23 | 7.02 |
| **Rehabilitating Cost of Ecosystem** | 0.08 | 0.08 | 0.07 | 0.09 | 0.08 | 0.09 | 0.07 | 0.55 | 0.08 | 7.01 |
| **Improvement in Regional Economy** | 0.23 | 0.20 | 0.22 | 0.21 | 0.20 | 0.22 | 0.23 | 1.51 | 0.22 | 7.02 |
| **Resettling cost of residents** | 0.12 | 0.14 | 0.13 | 0.12 | 0.14 | 0.12 | 0.12 | 0.89 | 0.13 | 7.01 |
|  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  | RI | 1.32 |
|  |  |  |  |  |  |  |  |  | CR | 0.00 |
|  |  |  |  |  |  |  |  |  |  |  |

**PROJECT DIRECTORS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** |
| **Initial cost** | 1 | 1.6923 | 1.692307692 | 1.46154 | 1.46153846 | 1 | 2.076923076 |
| **LCC** | 0.5909091 | 1 | 1 | 0.8125 | 0.812499999 | 0.590909091 | 1.384615384 |
| **C. of Employment** | 0.5909091 | 1 | 1 | 0.8125 | 0.812499999 | 0.590909091 | 1.384615384 |
| **Financial return** | 0.6842105 | 1.2308 | 1.230769232 | 1 | 1 | 0.684210527 | 1.615384616 |
| **Rehabilitating Cost of Ecosystem** | 0.6842105 | 1.2308 | 1.230769232 | 1 | 1 | 0.684210527 | 1.615384616 |
| **Improvement in Regional Economy** | 1 | 1.6923 | 1.692307692 | 1.46154 | 1.46153846 | 1 | 2.076923076 |
| **Resettling cost of residents** | 0.4814815 | 0.7222 | 0.722222223 | 0.61905 | 0.619047619 | 0.481481482 | 1 |
| **Total** | 5.0317207 | 8.5684 | 8.568376071 | 7.16712 | 7.167124537 | 5.031720718 | 11.15384615 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Initial cost** | **LCC** | **Cost of employment** | **Financial return** | **Rehabilitating cost of ecosystem** | **Improvement of regional economy** | **Resettling cost of residents** | **Total** | **Average** | **Consistency Measure** |
| **Initial cost** | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.19 | 1.39 | 0.20 | 7.00 |
| **LCC** | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.82 | 0.12 | 7.00 |
| **C. of Employment** | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.82 | 0.12 | 7.00 |
| **Financial return** | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.98 | 0.14 | 7.00 |
| **Rehabilitating Cost of Ecosystem** | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.98 | 0.14 | 7.00 |
| **Improvement in Regional Economy** | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.19 | 1.39 | 0.20 | 7.00 |
| **Resettling cost of residents** | 0.10 | 0.08 | 0.08 | 0.09 | 0.09 | 0.10 | 0.09 | 0.62 | 0.09 | 7.00 |
|  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  | RI | 1.32 |
|  |  |  |  |  |  |  |  |  | CR | 0.00 |

**Environmental Indicators**

**SENIOR PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** |
| **GWP** | 1.00 | 1.70 | 3.50 | 5.50 | 1.80 | 2.90 | 3.40 | 1.30 | 1.90 | 4.30 |
| **Acidification** | 0.59 | 1.00 | 2.80 | 4.80 | 1.10 | 2.20 | 2.70 | 0.71 | 1.20 | 3.60 |
| **Ozone layer depletion** | 0.29 | 0.36 | 1.00 | 3.00 | 0.37 | 0.62 | 0.91 | 0.31 | 0.38 | 1.80 |
| **Eutrophication** | 0.18 | 0.21 | 0.33 | 1.00 | 0.21 | 0.28 | 0.32 | 0.19 | 0.22 | 0.45 |
| **Renewable Resource consumption** | 0.56 | 0.91 | 2.70 | 4.70 | 1.00 | 2.10 | 2.60 | 0.67 | 1.10 | 3.50 |
| **Waste generation** | 0.34 | 0.45 | 1.60 | 3.60 | 0.48 | 1.00 | 1.50 | 0.38 | 0.50 | 2.40 |
| **Water use** | 0.29 | 0.37 | 1.10 | 3.10 | 0.38 | 0.67 | 1.00 | 0.32 | 0.40 | 1.90 |
| **Land use** | 0.77 | 1.40 | 3.20 | 5.20 | 1.50 | 2.60 | 3.10 | 1.00 | 1.60 | 4.00 |
| **Indoor air quality** | 0.53 | 0.83 | 2.60 | 4.60 | 0.91 | 2.00 | 2.50 | 0.63 | 1.00 | 3.40 |
| **Noise level** | 0.23 | 0.28 | 0.56 | 2.20 | 0.29 | 0.42 | 0.53 | 0.25 | 0.29 | 1.00 |
| **Total** | 4.78 | 7.51 | 19.39 | 37.70 | 8.04 | 14.79 | 18.56 | 5.77 | 8.60 | 26.35 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** | **Total** | **Average** |
| **GWP** | 0.21 | 0.23 | 0.18 | 0.15 | 0.22 | 0.20 | 0.18 | 0.23 | 0.22 | 0.16 | 1.97 | 0.20 |
| **Acidification** | 0.12 | 0.13 | 0.14 | 0.13 | 0.14 | 0.15 | 0.15 | 0.12 | 0.14 | 0.14 | 1.36 | 0.14 |
| **Ozone layer depletion** | 0.06 | 0.05 | 0.05 | 0.08 | 0.05 | 0.04 | 0.05 | 0.05 | 0.04 | 0.07 | 0.54 | 0.05 |
| **Eutrophication** | 0.04 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.25 | 0.02 |
| **Renewable Resource consumption** | 0.12 | 0.12 | 0.14 | 0.12 | 0.12 | 0.14 | 0.14 | 0.12 | 0.13 | 0.13 | 1.28 | 0.13 |
| **Waste generation** | 0.07 | 0.06 | 0.08 | 0.10 | 0.06 | 0.07 | 0.08 | 0.07 | 0.06 | 0.09 | 0.73 | 0.07 |
| **Water use** | 0.06 | 0.05 | 0.06 | 0.08 | 0.05 | 0.05 | 0.05 | 0.06 | 0.05 | 0.07 | 0.57 | 0.06 |
| **Land use** | 0.16 | 0.19 | 0.17 | 0.14 | 0.19 | 0.18 | 0.17 | 0.17 | 0.19 | 0.15 | 1.69 | 0.17 |
| **Indoor air quality** | 0.11 | 0.11 | 0.13 | 0.12 | 0.11 | 0.14 | 0.13 | 0.11 | 0.12 | 0.13 | 1.21 | 0.12 |
| **Noise level** | 0.05 | 0.04 | 0.03 | 0.06 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.38 | 0.04 |
|  |  |  |  |  |  |  |  |  |  |  |  | CI |
|  |  |  |  |  |  |  |  |  |  |  |  | RI |
|  |  |  |  |  |  |  |  |  |  |  |  | RC |

**PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** |
| **GWP** | 1.00 | 1.84 | 2.36 | 5.28 | 1.00 | 2.56 | 4.84 | 2.00 | 0.93 | 4.08 |
| **Acidification** | 0.54 | 1.00 | 1.52 | 4.44 | 0.54 | 1.72 | 4.00 | 1.16 | 0.52 | 3.24 |
| **Ozone layer depletion** | 0.42 | 0.66 | 1.00 | 3.92 | 0.42 | 1.20 | 3.48 | 0.74 | 0.41 | 2.72 |
| **Eutrophication** | 0.19 | 0.23 | 0.26 | 1.00 | 0.19 | 0.27 | 0.69 | 0.23 | 0.19 | 0.45 |
| **Renewable Resource consumption** | 1.00 | 1.84 | 2.36 | 5.28 | 1.00 | 2.56 | 4.84 | 2.00 | 0.93 | 4.08 |
| **Waste generation** | 0.39 | 0.58 | 0.83 | 3.72 | 0.39 | 1.00 | 3.28 | 0.64 | 0.38 | 2.52 |
| **Water use** | 0.21 | 0.25 | 0.29 | 1.44 | 0.21 | 0.30 | 1.00 | 0.26 | 0.20 | 0.57 |
| **Land use** | 0.50 | 0.86 | 1.36 | 4.28 | 0.50 | 1.56 | 3.84 | 1.00 | 0.48 | 3.08 |
| **Indoor air quality** | 1.08 | 1.92 | 2.44 | 5.36 | 1.08 | 2.64 | 4.92 | 2.08 | 1.00 | 4.16 |
| **Noise level** | 0.25 | 0.31 | 0.37 | 2.20 | 0.25 | 0.40 | 1.76 | 0.32 | 0.24 | 1.00 |
| **Total** | 5.58 | 9.49 | 12.78 | 36.92 | 5.58 | 14.21 | 32.65 | 10.44 | 5.27 | 25.90 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** | **Total** | **Average** | **Consistency Measure** |
| **GWP** | 0.18 | 0.19 | 0.18 | 0.14 | 0.18 | 0.18 | 0.15 | 0.19 | 0.18 | 0.16 | 1.73 | 0.17 | 10.20 |
| **Acidification** | 0.10 | 0.11 | 0.12 | 0.12 | 0.10 | 0.12 | 0.12 | 0.11 | 0.10 | 0.13 | 1.12 | 0.11 | 10.19 |
| **Ozone layer depletion** | 0.08 | 0.07 | 0.08 | 0.11 | 0.08 | 0.08 | 0.11 | 0.07 | 0.08 | 0.11 | 0.85 | 0.08 | 10.14 |
| **Eutrophication** | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.04 | 0.02 | 0.25 | 0.03 | 10.06 |
| **Renewable Resource consumption** | 0.18 | 0.19 | 0.18 | 0.14 | 0.18 | 0.18 | 0.15 | 0.19 | 0.18 | 0.16 | 1.73 | 0.17 | 10.20 |
| **Waste generation** | 0.07 | 0.06 | 0.07 | 0.10 | 0.07 | 0.07 | 0.10 | 0.06 | 0.07 | 0.10 | 0.77 | 0.08 | 10.12 |
| **Water use** | 0.04 | 0.03 | 0.02 | 0.04 | 0.04 | 0.02 | 0.03 | 0.02 | 0.04 | 0.02 | 0.30 | 0.03 | 10.04 |
| **Land use** | 0.09 | 0.09 | 0.11 | 0.12 | 0.09 | 0.11 | 0.12 | 0.10 | 0.09 | 0.12 | 1.03 | 0.10 | 10.17 |
| **Indoor air quality** | 0.19 | 0.20 | 0.19 | 0.15 | 0.19 | 0.19 | 0.15 | 0.20 | 0.19 | 0.16 | 1.81 | 0.18 | 10.19 |
| **Noise level** | 0.04 | 0.03 | 0.03 | 0.06 | 0.04 | 0.03 | 0.05 | 0.03 | 0.05 | 0.04 | 0.41 | 0.04 | 10.03 |
|  |  |  |  |  |  |  |  |  |  |  |  | CI | 0.01 |
|  |  |  |  |  |  |  |  |  |  |  |  | RI | 1.49 |
|  |  |  |  |  |  |  |  |  |  |  |  | CR | 0.01 |

**PLANNING ENGINEERS**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** |
| **GWP** | 1.00 | 2.00 | 0.86 | 2.28 | 0.93 | 1.36 | 1.20 | 1.36 | 1.84 | 1.20 |
| **Acidification** | 0.50 | 1.00 | 0.46 | 1.28 | 0.48 | 0.61 | 0.56 | 0.61 | 0.86 | 0.56 |
| **Ozone layer depletion** | 1.16 | 2.16 | 1.00 | 2.44 | 1.08 | 1.52 | 1.36 | 1.52 | 2.00 | 1.36 |
| **Eutrophication** | 0.44 | 0.78 | 0.41 | 1.00 | 0.42 | 0.52 | 0.48 | 0.52 | 0.69 | 0.48 |
| **Renewable Resource consumption** | 1.08 | 2.08 | 0.93 | 2.36 | 1.00 | 1.44 | 1.28 | 1.44 | 1.92 | 1.28 |
| **Waste generation** | 0.74 | 1.64 | 0.66 | 1.92 | 0.69 | 1.00 | 0.86 | 1.00 | 1.48 | 0.86 |
| **Water use** | 0.83 | 1.80 | 0.74 | 2.08 | 0.78 | 1.16 | 1.00 | 1.16 | 1.64 | 1.00 |
| **Land use** | 0.74 | 1.64 | 0.66 | 1.92 | 0.69 | 1.00 | 0.86 | 1.00 | 1.48 | 0.86 |
| **Indoor air quality** | 0.54 | 1.16 | 0.50 | 1.44 | 0.52 | 0.68 | 0.61 | 0.68 | 1.00 | 0.61 |
| **Noise level** | 0.83 | 1.80 | 0.74 | 2.08 | 0.78 | 1.16 | 1.00 | 1.16 | 1.64 | 1.00 |
| **Total** | 7.86 | 16.06 | 6.95 | 18.80 | 7.38 | 10.45 | 9.21 | 10.45 | 14.56 | 9.21 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** | **Total** | **Average** | **Consistency Measure** |
| **GWP** | 0.13 | 0.12 | 0.12 | 0.12 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 1.27 | 0.13 | 10.01 |
| **Acidification** | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.62 | 0.06 | 10.00 |
| **Ozone layer depletion** | 0.15 | 0.13 | 0.14 | 0.13 | 0.15 | 0.15 | 0.15 | 0.15 | 0.14 | 0.15 | 1.43 | 0.14 | 10.01 |
| **Eutrophication** | 0.06 | 0.05 | 0.06 | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.53 | 0.05 | 10.01 |
| **Renewable Resource consumption** | 0.14 | 0.13 | 0.13 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 0.13 | 0.14 | 1.35 | 0.13 | 10.01 |
| **Waste generation** | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 0.09 | 0.97 | 0.10 | 10.01 |
| **Water use** | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 1.09 | 0.11 | 10.01 |
| **Land use** | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 0.09 | 0.97 | 0.10 | 10.01 |
| **Indoor air quality** | 0.07 | 0.07 | 0.07 | 0.08 | 0.07 | 0.06 | 0.07 | 0.06 | 0.07 | 0.07 | 0.69 | 0.07 | 10.01 |
| **Noise level** | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 1.09 | 0.11 | 10.01 |
|  |  |  |  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  |  |  |  | RI | 1.49 |
|  |  |  |  |  |  |  |  |  |  |  |  | CR | 0.00 |

**Project Director**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** |
| **GWP** | 1.00 | 0.54 | 0.60 | 0.54 | 0.46 | 0.71 | 0.86 | 0.57 | 0.60 | 0.50 |
| **Acidification** | 1.84 | 1.00 | 1.16 | 1.00 | 0.76 | 1.44 | 1.68 | 1.08 | 1.16 | 0.86 |
| **Ozone layer depletion** | 1.68 | 0.86 | 1.00 | 0.86 | 0.68 | 1.28 | 1.52 | 0.93 | 1.00 | 0.76 |
| **Eutrophication** | 1.84 | 1.00 | 1.16 | 1.00 | 0.76 | 1.44 | 1.68 | 1.08 | 1.16 | 0.86 |
| **Renewable Resource consumption** | 2.16 | 1.32 | 1.48 | 1.32 | 1.00 | 1.76 | 2.00 | 1.40 | 1.48 | 1.16 |
| **Waste generation** | 1.40 | 0.69 | 0.78 | 0.69 | 0.57 | 1.00 | 1.24 | 0.74 | 0.78 | 0.63 |
| **Water use** | 1.16 | 0.60 | 0.66 | 0.60 | 0.50 | 0.81 | 1.00 | 0.63 | 0.66 | 0.54 |
| **Land use** | 1.76 | 0.93 | 1.08 | 0.93 | 0.71 | 1.36 | 1.60 | 1.00 | 1.08 | 0.81 |
| **Indoor air quality** | 1.68 | 0.86 | 1.00 | 0.86 | 0.68 | 1.28 | 1.52 | 0.93 | 1.00 | 0.76 |
| **Noise level** | 2.00 | 1.16 | 1.32 | 1.16 | 0.86 | 1.60 | 1.84 | 1.24 | 1.32 | 1.00 |
| **Total** | 16.52 | 8.96 | 10.23 | 8.96 | 6.97 | 12.68 | 14.94 | 9.58 | 10.23 | 7.87 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **GWP** | **Acidification** | **Ozone layer depletion** | **Eutrophication** | **Renewable resource consumption** | **Waste generation** | **Water use** | **Land use** | **Indoor air quality** | **Noise level** | **Total** | **Average** | **Consistency Measure** |
| **GWP** | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.60 | 0.06 | 10.00 |
| **Acidification** | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 1.12 | 0.11 | 10.00 |
| **Ozone layer depletion** | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.98 | 0.10 | 10.00 |
| **Eutrophication** | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 1.12 | 0.11 | 10.00 |
| **Renewable Resource consumption** | 0.13 | 0.15 | 0.14 | 0.15 | 0.14 | 0.14 | 0.13 | 0.15 | 0.14 | 0.15 | 1.42 | 0.14 | 10.01 |
| **Waste generation** | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.79 | 0.08 | 10.00 |
| **Water use** | 0.07 | 0.07 | 0.06 | 0.07 | 0.07 | 0.06 | 0.07 | 0.07 | 0.06 | 0.07 | 0.67 | 0.07 | 10.00 |
| **Land use** | 0.11 | 0.10 | 0.11 | 0.10 | 0.10 | 0.11 | 0.11 | 0.10 | 0.11 | 0.10 | 1.05 | 0.10 | 10.00 |
| **Indoor air quality** | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.98 | 0.10 | 10.00 |
| **Noise level** | 0.12 | 0.13 | 0.13 | 0.13 | 0.12 | 0.13 | 0.12 | 0.13 | 0.13 | 0.13 | 1.27 | 0.13 | 10.01 |
|  |  |  |  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  |  |  |  | RI | 1.49 |
|  |  |  |  |  |  |  |  |  |  |  |  | CR | 0.00 |

**Social Indicator Analysis**

**SENIOR PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** |
| **Social Capital** | 1.00 | 0.78 | 0.83 | 1.32 | 1.00 | 0.68 | 0.68 | 2.12 |
| **Employees Health & Safety** | 1.28 | 1.00 | 1.08 | 1.60 | 1.28 | 0.83 | 0.83 | 2.40 |
| **Public Health & Safety** | 1.20 | 0.93 | 1.00 | 1.52 | 1.20 | 0.78 | 0.78 | 2.32 |
| **Compliance with Law** | 0.76 | 0.63 | 0.66 | 1.00 | 0.76 | 0.56 | 0.56 | 1.80 |
| **Social Responsibility** | 1.00 | 0.78 | 0.83 | 1.32 | 1.00 | 0.68 | 0.68 | 2.12 |
| **Serviceability** | 1.48 | 1.20 | 1.28 | 1.80 | 1.48 | 1.00 | 1.00 | 2.60 |
| **Stakeholders’ Participation** | 1.48 | 1.20 | 1.28 | 1.80 | 1.48 | 1.00 | 1.00 | 2.60 |
| **Cultural Heritage** | 0.47 | 0.42 | 0.43 | 0.56 | 0.47 | 0.38 | 0.38 | 1.00 |
| **Total** | 8.67 | 6.93 | 7.40 | 10.92 | 8.67 | 5.91 | 5.91 | 16.96 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | **Social Capital** | **Employee Health & Safety** | | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | | **Serviceability** | | **Stakeholders’ Participation** | | | **Cultural heritage** | **Total** | **Average** | **Consistency Measure** |
| **Social Capital** | | | 0.12 | 0.11 | | 0.11 | 0.12 | 0.12 | | 0.11 | | 0.11 | | | 0.13 | 0.93 | 0.12 | 8.01 |
| **Employees Health & Safety** | | | 0.15 | 0.14 | | 0.15 | 0.15 | 0.15 | | 0.14 | | 0.14 | | | 0.14 | 1.16 | 0.14 | 8.01 |
| **Public Health & Safety** | | | 0.14 | 0.13 | | 0.14 | 0.14 | 0.14 | | 0.13 | | 0.13 | | | 0.14 | 1.09 | 0.14 | 8.01 |
| **Compliance with Law** | | | 0.09 | 0.09 | | 0.09 | 0.09 | 0.09 | | 0.09 | | 0.09 | | | 0.11 | 0.74 | 0.09 | 8.01 |
| **Social Responsibility** | | | 0.12 | 0.11 | | 0.11 | 0.12 | 0.12 | | 0.11 | | 0.11 | | | 0.13 | 0.93 | 0.12 | 8.01 |
| **Serviceability** | | | 0.17 | 0.17 | | 0.17 | 0.16 | 0.17 | | 0.17 | | 0.17 | | | 0.15 | 1.34 | 0.17 | 8.01 |
| **Stakeholders’ Participation** | | | 0.17 | 0.17 | | 0.17 | 0.16 | 0.17 | | 0.17 | | 0.17 | | | 0.15 | 1.34 | 0.17 | 8.01 |
| **Cultural Heritage** | | | 0.05 | 0.06 | | 0.06 | 0.05 | 0.05 | | 0.07 | | 0.07 | | | 0.06 | 0.47 | 0.06 | 8.00 |
|  |  |  | |  |  | |  | |  | |  | |  |  | CI | 0.00 | |
|  |  |  | |  |  | |  | |  | |  | |  |  | RI | 1.41 | |
|  |  |  | |  |  | |  | |  | |  | |  |  | CR | 0.00 | |

**PROJECT MANAGERS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** |
| **Social Capital** | 1.00 | 0.37 | 0.37 | 0.47 | 0.34 | 0.74 | 0.61 | 2.08 |
| **Employees Health & Safety** | 2.72 | 1.00 | 1.00 | 1.60 | 0.83 | 2.36 | 2.08 | 3.80 |
| **Public Health & Safety** | 2.72 | 1.00 | 1.00 | 1.60 | 0.83 | 2.36 | 2.08 | 3.80 |
| **Compliance with Law** | 2.12 | 0.62 | 0.62 | 1.00 | 0.56 | 1.76 | 1.48 | 3.20 |
| **Social Responsibility** | 2.92 | 1.20 | 1.20 | 1.80 | 1.00 | 2.56 | 2.28 | 4.00 |
| **Serviceability** | 1.36 | 0.42 | 0.42 | 0.57 | 0.39 | 1.00 | 0.78 | 2.44 |
| **Stakeholders’ Participation** | 1.64 | 0.48 | 0.48 | 0.68 | 0.44 | 1.28 | 1.00 | 2.72 |
| **Cultural Heritage** | 0.48 | 0.26 | 0.26 | 0.31 | 0.25 | 0.41 | 0.37 | 1.00 |
| **Total** | 14.96 | 5.36 | 5.36 | 8.03 | 4.64 | 12.47 | 10.68 | 23.04 |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** | **Total** | **Average** | **Consistency measure** |
| **Social Capital** | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.06 | 0.06 | 0.09 | 0.54 | 0.07 | 8.02 |
| **Employees Health & Safety** | 0.18 | 0.19 | 0.19 | 0.20 | 0.18 | 0.19 | 0.19 | 0.16 | 1.48 | 0.19 | 8.07 |
| **Public Health & Safety** | 0.18 | 0.19 | 0.19 | 0.20 | 0.18 | 0.19 | 0.19 | 0.16 | 1.48 | 0.19 | 8.07 |
| **Compliance with Law** | 0.14 | 0.12 | 0.12 | 0.12 | 0.12 | 0.14 | 0.14 | 0.14 | 1.04 | 0.13 | 8.06 |
| **Social Responsibility** | 0.20 | 0.22 | 0.22 | 0.22 | 0.22 | 0.21 | 0.21 | 0.17 | 1.67 | 0.21 | 8.06 |
| **Serviceability** | 0.09 | 0.08 | 0.08 | 0.07 | 0.08 | 0.08 | 0.07 | 0.11 | 0.66 | 0.08 | 8.03 |
| **Stakeholders’ Participation** | 0.11 | 0.09 | 0.09 | 0.08 | 0.09 | 0.10 | 0.09 | 0.12 | 0.78 | 0.10 | 8.04 |
| **Cultural Heritage** | 0.03 | 0.05 | 0.05 | 0.04 | 0.05 | 0.03 | 0.03 | 0.04 | 0.33 | 0.04 | 8.02 |
|  |  |  |  |  |  |  |  |  |  | CI | 0.01 |
|  |  |  |  |  |  |  |  |  |  | RI | 1.41 |
|  |  |  |  |  |  |  |  |  |  | CR | 0.00 |

**PLANNING ENGINEERS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** |
| **Social Capital** | 1.00 | 1.00 | 1.08 | 0.57 | 1.72 | 1.16 | 1.24 | 2.64 |
| **Employees Health & Safety** | 1.00 | 1.00 | 1.08 | 0.57 | 1.72 | 1.16 | 1.24 | 2.64 |
| **Public Health & Safety** | 0.93 | 0.93 | 1.00 | 0.54 | 1.64 | 1.08 | 1.16 | 2.56 |
| **Compliance with Law** | 1.76 | 1.76 | 1.84 | 1.00 | 2.48 | 1.92 | 2.00 | 3.40 |
| **Social Responsibility** | 0.58 | 0.58 | 0.61 | 0.40 | 1.00 | 0.64 | 0.68 | 1.92 |
| **Serviceability** | 0.86 | 0.86 | 0.93 | 0.52 | 1.56 | 1.00 | 1.08 | 2.48 |
| **Stakeholders’ Participation** | 0.81 | 0.81 | 0.86 | 0.50 | 1.48 | 0.93 | 1.00 | 2.40 |
| **Cultural heritage** | 0.38 | 0.38 | 0.39 | 0.29 | 0.52 | 0.40 | 0.42 | 1.00 |
| **Total** | 7.31 | 7.31 | 7.79 | 4.40 | 12.12 | 8.29 | 8.81 | 19.04 |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** | **Total** | **Average** | **Consistency Measure** |
| **Social Capital** | 0.14 | 0.14 | 0.14 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 1.10 | 0.14 | 8.02 |
| **Employees Health & Safety** | 0.14 | 0.14 | 0.14 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 1.10 | 0.14 | 8.02 |
| **Public Health & Safety** | 0.13 | 0.13 | 0.13 | 0.12 | 0.14 | 0.13 | 0.13 | 0.13 | 1.04 | 0.13 | 8.02 |
| **Compliance with Law** | 0.24 | 0.24 | 0.24 | 0.23 | 0.20 | 0.23 | 0.23 | 0.18 | 1.79 | 0.22 | 8.02 |
| **Social Responsibility** | 0.08 | 0.08 | 0.08 | 0.09 | 0.08 | 0.08 | 0.08 | 0.10 | 0.67 | 0.08 | 8.01 |
| **Serviceability** | 0.12 | 0.12 | 0.12 | 0.12 | 0.13 | 0.12 | 0.12 | 0.13 | 0.98 | 0.12 | 8.02 |
| **Stakeholders’ Participation** | 0.11 | 0.11 | 0.11 | 0.11 | 0.12 | 0.11 | 0.11 | 0.13 | 0.92 | 0.11 | 8.02 |
| **Cultural heritage** | 0.05 | 0.05 | 0.05 | 0.07 | 0.04 | 0.05 | 0.05 | 0.05 | 0.41 | 0.05 | 8.01 |
|  |  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  |  | RI | 1.41 |
|  |  |  |  |  |  |  |  |  |  | CR | 0.00 |

**PROJECT DIRECTORS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** |
| **Social Capital** | 1.00 | 1.00 | 1.40 | 1.08 | 1.44 | 1.76 | 1.68 | 1.60 |
| **Employees Health & Safety** | 1.00 | 1.00 | 1.40 | 1.08 | 1.44 | 1.76 | 1.68 | 1.60 |
| **Public Health & Safety** | 0.71 | 0.71 | 1.00 | 0.76 | 1.04 | 1.36 | 1.28 | 1.20 |
| **Compliance with Law** | 0.93 | 0.93 | 1.32 | 1.00 | 1.36 | 1.68 | 1.60 | 1.52 |
| **Social Responsibility** | 0.69 | 0.69 | 0.96 | 0.74 | 1.00 | 1.32 | 1.24 | 1.16 |
| **Serviceability** | 0.57 | 0.57 | 0.74 | 0.60 | 0.76 | 1.00 | 0.93 | 0.86 |
| **Stakeholders’ Participation** | 0.60 | 0.60 | 0.78 | 0.63 | 0.81 | 1.08 | 1.00 | 0.93 |
| **Cultural Heritage** | 0.63 | 0.63 | 0.83 | 0.66 | 0.86 | 1.16 | 1.08 | 1.00 |
| **Total** | 6.12 | 6.12 | 8.43 | 6.53 | 8.71 | 11.12 | 10.49 | 9.87 |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Social Capital** | **Employee Health & Safety** | **Public Health & Safety** | **Compliance with Law** | **Social Responsibility** | **Serviceability** | **Stakeholders’ Participation** | **Cultural heritage** | **Total** | **Average** | **Consistency Measure** |
| **Social Capital** | 0.16 | 0.16 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 | 0.16 | 1.30 | 0.16 | 8.00 |
| **Employees Health & Safety** | 0.16 | 0.16 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 | 0.16 | 1.30 | 0.16 | 8.00 |
| **Public Health & Safety** | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.95 | 0.12 | 8.00 |
| **Compliance with Law** | 0.15 | 0.15 | 0.16 | 0.15 | 0.16 | 0.15 | 0.15 | 0.15 | 1.23 | 0.15 | 8.00 |
| **Social Responsibility** | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.12 | 0.92 | 0.12 | 8.00 |
| **Serviceability** | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.72 | 0.09 | 8.00 |
| **Stakeholders’ Participation** | 0.10 | 0.10 | 0.09 | 0.10 | 0.09 | 0.10 | 0.10 | 0.09 | 0.76 | 0.10 | 8.00 |
| **Cultural Heritage** | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.81 | 0.10 | 8.00 |
|  |  |  |  |  |  |  |  |  |  | CI | 0.00 |
|  |  |  |  |  |  |  |  |  |  | RI | 1.41 |
|  |  |  |  |  |  |  |  |  |  | CR | 0.00 |

**Economic, Environmental and Social Aspect Assessment**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Senior Project Managers** | | | | | | | | | | |
|  | **Economic** | **Environmental** | **Social** |  |  | **Economic** | **Environmental** | **Social** | **Total** | **Average** |
| **Economic** | 1 | 2.2 | 2.2 |  | **Economic** | 0.52 | 0.52 | 0.52 | 1.57 | 0.52 |
| **Environmental** | 0.45 | 1 | 1 |  | **Environmental** | 0.24 | 0.24 | 0.24 | 0.71 | 0.24 |
| **Social** | 0.45 | 1.00 | 1 |  | **Social** | 0.24 | 0.24 | 0.24 | 0.71 | 0.24 |
| **Sum** | **1.91** | **4.20** | **4.20** |  |  |  |  |  |  |  |
| **Project Managers** | | | | | | | | | | |
|  | **Economic** | **Environmental** | **Social** |  |  | **Economic** | **Environmental** | **Social** | **Total** | **Average** |
| **Economic** | 1 | 2 | 2.32 |  | **Economic** | 0.52 | 0.53 | 0.50 | 1.55 | 0.52 |
| **Environmental** | 0.50 | 1 | 1.32 |  | **Environmental** | 0.26 | 0.27 | 0.28 | 0.81 | 0.27 |
| **Social** | 0.43 | 0.76 | 1 |  | **Social** | 0.22 | 0.20 | 0.22 | 0.64 | 0.21 |
| **Sum** | **1.93** | **3.76** | **4.64** |  |  |  |  |  |  |  |
| **Planning Engineers** | | | | | | | | | | |
|  | **Economic** | **Environmental** | **Social** |  |  | **Economic** | **Environmental** | **Social** | **Total** | **Average** |
| **Economic** | 1 | 1.4 | 1 |  | **Economic** | 0.37 | 0.37 | 0.37 | 1.11 | 0.37 |
| **Environmental** | 0.71 | 1 | 0.7142857 |  | **Environmental** | 0.26 | 0.26 | 0.26 | 0.79 | 0.26 |
| **Social** | 1.00 | 1.40 | 1 |  | **Social** | 0.37 | 0.37 | 0.37 | 1.11 | 0.37 |
| **Sum** | **2.71** | **3.80** | **2.71** |  |  |  |  |  |  |  |
| **Project Directors** | | | | | | | | | | |
|  | **Economic** | **Environmental** | **Social** |  |  | **Economic** | **Environmental** | **Social** | **Total** | **Average** |
| **Economic** | 1 | 1.64 | 1.64 |  | **Economic** | 0.45 | 0.45 | 0.45 | 1.35 | 0.45 |
| **Environmental** | 0.61 | 1 | 1 |  | **Environmental** | 0.27 | 0.27 | 0.27 | 0.82 | 0.27 |
| **Social** | 0.61 | 1.00 | 1 |  | **Social** | 0.27 | 0.27 | 0.27 | 0.82 | 0.27 |
| **Sum** | **2.22** | **3.64** | **3.64** |  |  |  |  |  |  |  |