INTEGRATING SUSTAINABILITY AND LCA

PILOT APPLICATION ON TRANSPORTATION INFRASTRUCTURE PROJECTS

NATIONAL RESEARCH COUNCIL OF CANADA (NRCC)
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EXECUTIVE SUMMARY

The present research proposes a **Sustainability Lifecycle Tool** for integrating sustainability assessment with Lifecycle assessment for transportation projects. Project sustainability is defined as a balance of social, economic, and environmental trade-offs, considering the project's lifecycle performance.

The analysis for the development of the **Sustainability Lifecycle Tool** was based on:

A. A review of Lifecycle Assessment (LCA) of infrastructure in terms of the triple bottom line (TBL).
B. A review of three widely used Sustainability Assessment systems for the lifecycle of a project, Envision. CEEQUAL and ISCA.
C. An analysis of a transportation infrastructure project.

The research findings were summarized and formulated the proposed tool to enhance the lifecycle sustainability of transportation infrastructure projects. A sustainability assessment system was chosen to be the basis of the proposed tool instead of the LCA methodology, since:

- A sustainability assessment framework, by definition, considers the environmental, social, and economic aspects of a project. In contrast, LCA, as explained in the analysis, accounts only for either environmental or economic impacts.

- A sustainability assessment considers the entire Lifecycle of a project.
- LCA follows a highly technical and labor- and data-intensive process. Capacity building is necessary for agencies to perform LCAs in-house, which has been a constraint for LCA's use.

Among the three analyzed systems, the Envision® framework was selected to be used as the basis of the proposed model to address lifecycle sustainability and the needs of transportation. The proposed tool prioritizes strategies on the triple bottom line impacts and potential trade-offs.

The proposed tool, the **Sustainability Lifecycle Tool**, can be used for the self-assessment of transportation projects (roadways, bridges, and transit) within the Envision® framework. It incorporates input from:

- The literature review on infrastructure LCA and transportation infrastructure LCA.
- Analysis of the three Sustainability Assessment frameworks.
- Input from Ontario's Ministry of Transportation West Region for the replacement of a typical bridge.

The proposed tool highlights the indicators, which are specific to lifecycle stages and to the Triple Bottom Line, already included in Envision and proposes to be used together with the Envision Guidance manual. It contains greater detail than the Pre-assessment Checklist, where Envision criteria are presented as YES/NO answers, but contains less detail than the Envision Online Scoresheet, which constitutes the detailed full Envision assessment.

The Sustainability Lifecycle Tool is presented with its manual, and the replacement of the bridge by MTO West Region's Structural Standards and Specifications Office (previous Bridge Office) and Regional Office's Structural Section is used as a case study of how to use the tool.

The application of the model to transportation projects was requested by the sponsor of this research project and should be considered as a first step to eventually lead to a general tool for all types of infrastructure projects, consistent with Envision and its philosophy.

INTRODUCTION

RESEARCH OBJECTIVES

Sustainability relies on human, cultural, and social capital, as well as on monetary and natural resources. The interactions among those drive economic growth, social equity, and environmental protection. Balancing them is a challenge of sustainable urban development. Concentrating on one area might result in neglecting others.

The objective of this research is to develop a tool for guiding the approach and practice for sustainable design and management of transportation projects. The tool intents to be used by owners, consultants, and contractors in identifying and selecting design and management alternatives towards sustainable roadways, bridges, and transit projects. The tool aims to balance social responsibility, environmental protection, and economic development, with emphasis on lowering the carbon footprint of Core Public Infrastructure (CPI) projects in a changing climate. To ensure a comprehensive assessment, the consideration of the full lifecycle of projects is necessary, based on a systems approach on the principles of Lifecycle Assessment (LCA).

Scope Definition

(a) an analysis of environmental, social, and economic impacts,
(b) of transportation infrastructure projects,
(c) for early planning use, offering a comparative analysis of different alternatives.

RESEARCH METHODOLOGY

The present research proposes a tool for integrating sustainability assessment and lifecycle assessment, with application to transportation projects. Towards this objective, the analysis has three dimensions:

A. Review of Lifecycle Assessment (LCA) of infrastructure in terms of the triple bottom line (TBL). The literature review on infrastructure LCA methodology and transportation infrastructure LCA methodology provides an overview of the state-of-practice. It identifies constraints and gaps in addressing the full range of sustainability (environmental, social, and economic). An overview of LCA state-of-practice in Canada is also provided as a reference.

B. Review of sustainability assessment in terms of the lifecycle of a project. An analysis and cross-examination of the most widely used sustainability certification systems (Envision®, CEEQUAL®, and ISCA®) determines the extent of considering lifecycle within the sustainability rating process and identifies gaps.

C. Presentation of a transportation infrastructure project. A small-scale typical bridge replacement project by the Ministry of Transportation of Ontario (MTO) provides input for the research. The bridge project serves as a vehicle to:

- provide insight into the context of sustainability practice in transportation projects in Canada;

- identify the environmental, social, and economic impacts of transportation projects and present priorities, needs and strategies, and potential areas for improvement in managing inevitable trade-offs in the lifecycle performance of assets;
- calibrate a sustainability rating system's methodology in terms of how the lifecycle stages and TBL impacts of a transportation project are taken into consideration, and
- calibrate the proposed model through its application on a project that provided both input and an example of use.

PART I

BACKGROUND RESEARCH

CHAPTER 1.

LITERATURE REVIEW ON THE LCA METHODOLOGY

Lifecycle assessment (LCA) is a valuable tool to document and analyze environmental considerations of products and services for decision making toward sustainability.[1]

LCA applications can be divided into internal use, such as knowledge generation, strategic planning, and forecasting, or external use, such as environmental labeling, an environmental audit of companies, and environmental information.[2] LCA can be used, for example, to develop criteria for green public procurement and in environmental product declarations (EPDs) (EC, 2015; Uttam, 2014). "LCA may be applied within the whole process of decision-making: identification of issues and impacts, analysis context and baseline, contributing to the development of alternatives, assessment of impacts, comparing the options" (UNECE, 2007).

Sustainable development of infrastructure must increasingly be guided by planning approaches that "push back" the analytical boundaries to include economic, environmental, and even social dimensions. There is a mandate for the development and use of holistic planning approaches to trace the interactions between these factors. Today multiple forces drive the need for systems planning and integrated approaches such as Lifecycle costing and Lifecycle assessment as decision-making tools to assess the impacts of infrastructure projects through their whole Lifecycle. Government regulations press for Lifecycle accountability, business is adopting LCA initiatives, and environmental degradation leads to environmental criteria in both consumer markets and government procurement guidelines.

After reviewing a series of documents (articles, papers, reports, and on-line methodological tools) on LCA theory and practice, the present literature review presents general findings to reflect the state of practice, and reviews in greater detail specific cases related to the defined scope of the present research.

The review reaffirms an ongoing effort to build a robust LCA methodology characterized by an increased exchange of LCA information, a flow of data between LCA scientists and practitioners; it is, therefore, an evolving field of research. LCA research has shown, for example, the importance of including "mining operations (e.g., materials for infrastructure) and primary energy (i.e., fossil fuel) in the system boundary because of their dominating contribution to the environmental inventory."[3]

Some research projects had set their framework: building their theoretical foundation on existing methodologies and tools, then contributing additional methodological choices, and testing them on specific case studies to provide and evaluate results. Studies identify impacts per lifecycle stage – in most cases, based on actual examples – to highlight areas of the most critical need for focus. There are also examples of impact-specific studies, primarily GHG emissions LCAs and energy LCAs.

[1] UNEP (2003).
[2] Stripple and Erlandson (2004).
[3] Chester et al. (n.d.)

1.1 LIFECYCLE ASSESSMENT (LCA) METHODOLOGY

The International Organization for Standardization (ISO) has an international standard for LCA, which consists of a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system[4] throughout its Lifecycle." Its technical framework has been standardized in the ISO 14040 series.[5] Since their release in 2006, a rapidly growing number of (environmental) LCA studies have been published.

According to ISO 14040, LCA consists of four phases:

- **Goal and scope definition:** the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen, and the required level of detail is defined. The goal is related to the context of the study, why it is done, and who will use the result. The scope of the study is similar to methodological choices made in modeling, such as options to model, selection of a functional unit[6] impact categories, system boundaries, and data quality requirements.
- **Analysis of the Lifecycle inventory** is the accounting stage of the study, where Lifecycle data for all inputs to and outputs from the system are assessed and assembled (water, energy, raw material, waste, emissions, etc.) Having established the system boundary, the practitioner can develop a Lifecycle inventory of the indicators of interest by evaluating the processes, activities, services, products, and supply chain, ultimately allocating the effects of each to the functional unit.[7]
- **Impact assessment**: the effects of using resources and the generated emissions are grouped and quantified into a limited number of impact categories, which may then be weighed for importance.
- **Interpretation**: the results are reported in a most informative way, and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

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[4] ISO defines a product as "any goods or service." It can be categorized as services (e.g., transport), software, hardware (e.g., pipes), or processed materials (e.g., asphalt).

[5] The international standards for LCA methodology, prepared by the ISO, are divided into the following parts:
- Principles and framework (ISO 14040),
- Goal and scope definition and inventory analysis (ISO 14041),
- Lifecycle impact assessment (ISO 14042),
- Lifecycle impact interpretation (ISO 14043).

[6] The functional unit is a key element of LCA. It is a measure of the function of the studied system, and it provides a reference to which the inputs and outputs can be related. Examples of functional units in the transportation sector: (for a comparison of transport modal options) provision of 10,000 passengers per day between Point A and Point B 20 km apart with a journey time of 1 hour, over 60 years; or (for comparing different rail track designs) 1 km of rail track with 60 equivalent million gross tons per annum and a service life of 60 years.

[7] Chester et al. (n.d.).

1.1.1 DEFINITION OF THE SYSTEM'S BOUNDARY

A critical step in any LCA is the selection of the system boundary, which determines which Lifecycle components will and will not be included in the assessment. Boundary definition in infrastructure is not straightforward due to a large number of actors and activities that are implied, and the long duration of projects and their service life.

LCA theory dictates that the system boundary should be from cradle to grave – for example, from raw materials extraction from the earth (cradle) to the deposition of waste back in the earth (grave) – to capture exchanges between the natural environment and the human-made systems. Nevertheless, the practice of LCA includes various approaches, such as cradle-to-gate[8] or cradle-to-site.[9]

The following can be considered system boundaries:

- Boundaries between the technical system and nature,
- The geographical area,
- The time horizon (either the impact of present conditions or future scenarios),
- Boundaries between the current Lifecycle and related Lifecycles of other technical systems, since most activities are interrelated. For example, the Lifecycle of the products used to construct an infrastructure project can also be under analysis in different systems, which leads to an endless and complex list of inflows and outflows.

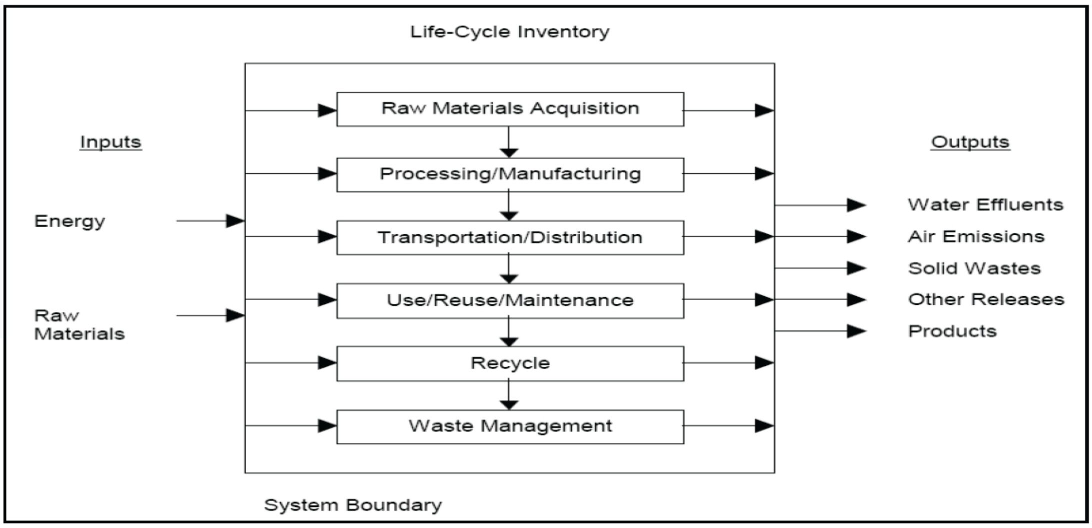

Fig.1: Graph[10] showing a general overview of a product LCA

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[8] A study with these boundaries considers all activities starting with the extraction of materials, their transportation, refining, processing, and fabrication activities until the material or product is ready to leave the factory gate.

[9] A study with these boundaries includes the cradle-to-gate results and also the transportation of the material or product to its site of use.

[10] European Commission Life Program.

1.1.2 IMPACT CATEGORIES

In general, the definition of impact categories as related to indicators of their effects on humans and the environment is based on international best practices; in some cases, adaptations and additions are made based on local context or national impact assessment models.

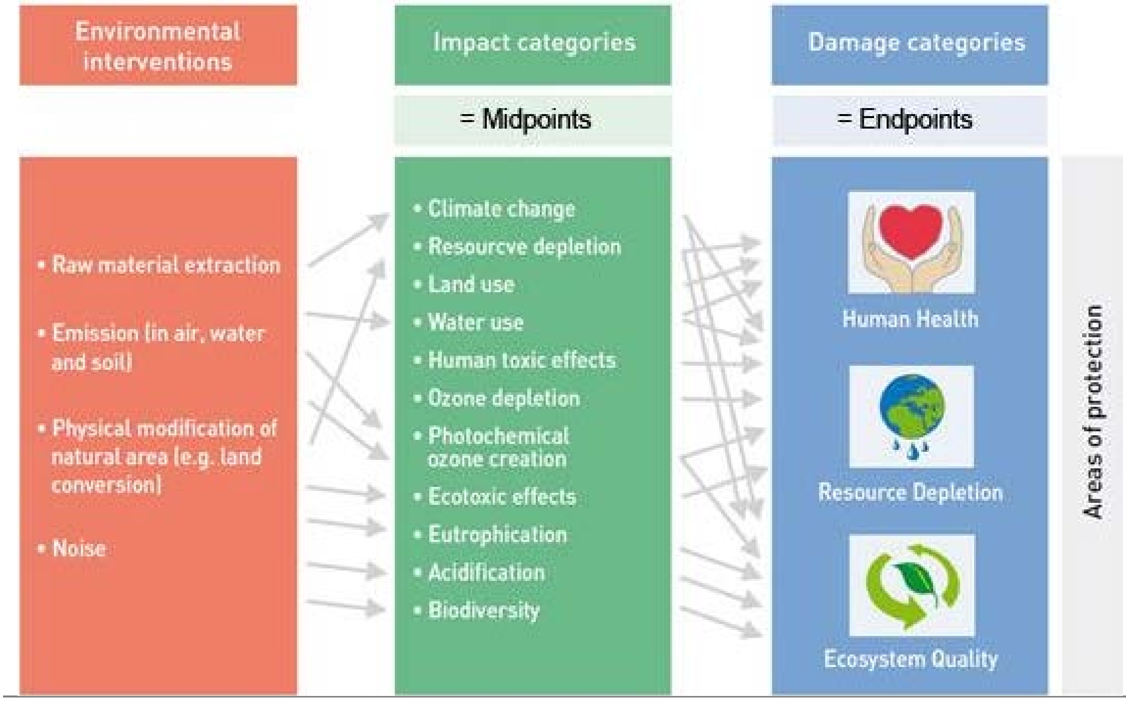

Fig.2: Overall UNEP/SETAC scheme of the environmental Lifecycle impact assessment (LCIA) framework, linking LCIA results via the midpoint categories to damage categories. (source: UNEP/SETAC, 2011)

Impacts are presented in different categories that can be broadly grouped into energy use, resource use, emissions, toxicity, and waste generation. Impacts often include eight or more separate impact indicators. Each of these types of impacts can be modeled, in terms of the damaging effect on aspects of the environment, as impacts to people (humans), impacts on nature (ecosystems), and depletion of resources. The measurement of the impacts is based on specific impact studies and analyses. For example, a carbon footprint analysis is a monocriterion analysis focused on only one environmental impact: climate change by GHG emission. "Carbon footprint analysis is a subset of a complete LCA. Three core standards around carbon footprint analysis are the GHG Protocol, ISO/TS 14067, and PAS 2050."[11]

Because of the complexity of the Lifecycle impact assessment (LCIA) stage, methodologies have been developed to facilitate comparisons and tradeoffs among different planning/product alternatives, simplify the LCA process for decision-makers, and enable

[11] https://www.thebalancesmb.com/carbon-footprint-vs-Lifecycle-2878059

benchmarking. These methodologies are tools that relate LCIA results to environmental impacts. LCIA results are classified within impact categories, each with a category indicator. Two approaches to characterization can take place along the impact pathway of an impact indicator: midpoint approach and endpoint approach. Research shows that the selection of the impact assessment methodology varies by type and scale of infrastructure and is based on each LCA objective.

The selection of midpoint or endpoint can influence the results due to the critical differences in how the environmental relevance of indicators is taken into account. Midpoint models provide a higher level of certainty and are known as problem-oriented approaches (i.e., regarding GHG emissions). They are based on the early stages in the cause-effect chain. Endpoint models are generally known as damage-oriented approaches. They are considered to be more understandable to decision-makers because the information is consolidated into a single score (i.e., human health impacts – skin cancer). They are based on later changes in the environmental mechanism. By including a wide range of effects, endpoint approaches have the potential to help an analyst discover issues that had not been considered at the start of an LCA study. According to literature, although endpoint categories begin to quantify human health impacts, LCA still does not have fully established ways to address such impacts.

LCIA tools follow mostly midpoint or endpoint methods. An overview of the widely used LCIA methodologies is highlighted here. The midpoint approach methodologies mostly used are CML, TRACI, and EDIP 2003 for Industrial Products. The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is the most well-developed method for the US context and widely used for LCAs conducted in the US.[12] It is a comprehensive impact assessment methodology developed by the US Environmental Protection Agency (EPA) that includes the midpoint categories of:

- Global warming,
- Smog formation,
- Energy use,
- Ozone depletion,
- Acidification,
- Eutrophication,
- Human health impacts, and
- Ecotoxicity.

Research is ongoing to quantify the use of land and water in a future version of TRACI. The endpoint methodologies mostly used today are EPS 2000, Eco-scarcity, and Eco-Indicator. Eco-Indicator includes the environmental damage categories of

- Climate change,
- Ozone layer depletion,

[12] Harvey et al. (2018).

- Acidification,
- Eutrophication,
- Carcinogenics,
- Respiratory effects,
- Ionizing radiation,
- Ecotoxicity,
- Land use,
- Mineral resources, and
- Fossil resources.

These categories are further aggregated into three areas of protection: (a) quality of ecosystems, (b) human health, and (c) natural resources.

In the last 15 years, international initiatives have tried to develop comprehensive LCIA tools that combine both methods. Examples of such tools that are available today include ReCiPe, Impact 2002+, and the Japanese methodology LIME, with its characterization factors based on Japanese environmental profiles. The ReCiPe methodology is considered a follow-up of CML and Eco-Indicator tools. It addresses 18 midpoint categories and the three endpoint categories mentioned above. Its regional validity is for Europe. LUCAS is an LCIA method of Canadian-specific context. LUCAS considers both midpoint and endpoint categories. It was developed to address an increasing need for LCA studies in Canadian industries. Before LUCAS, LCA studies were using methodologies based on average values for regions other than Canada.[13]

1.1.3 THE IMPORTANCE OF ASSUMPTIONS

The results of an LCA depend highly on the assumptions. Such assumptions often relate to technology changes, such as the future fuel efficiency of vehicles. Analyses can take into consideration that "fuel efficiency is expected to increase over time and vehicles of all types are expected to use less fuel during the project lifetime," or that the share of biofuel and electric-powered vehicles will increase over the next 40 years, the expected lifetime of an LCA study. However, it may instead be assumed that there will be no change in the lifetime of the LCA study.

1.1.4 LCA AS AN ADAPTABLE FRAMEWORK

LCA is an adaptable framework allowing any quantifiable flow to be evaluated. It is up to the LCA practitioners to select the suite of environmental indicators to understand the resource and environmental tradeoffs of their systems. Tradeoffs could include energy, environmental effects (e.g., greenhouse gas emissions, criteria pollutant emissions), costs, labor requirements, and so on. However, a broad suite of indicators can avoid unintended

[13] Later modifications of Impact 2000+ developed public nonspatial, spatial European, and world versions of some categories.

tradeoffs; e.g., an LCA of electric cars should track both greenhouse gases and human health effects, since new technology could reduce GHG emissions by switching to lower-carbon energy in propulsion but may increase health impacts to those living near battery manufacturing facilities. "As an LCA practitioner, you can perform your LCA in many different ways, as long as you carefully document what you do."[14]

Existing LCAs have revealed that while hundreds of Lifecycle components can be evaluated, only a handful tend to dominate results. Developing a rigorous LCA requires a continuous commitment to gathering data and interpreting results in several iterations. Many agencies and decision-makers may not have the capacity to invest in extensive LCAs but may desire to understand what the hotspots are in their transportation systems.[15]

Moreover, by analyzing current data gaps, an agency can develop procedures to collect precise data that will facilitate future analyses. In future requests for proposals, the agency can incorporate manufacturing process disclosure requirements or consider requiring that suppliers perform a supply chain LCA to assess embodied energy and emissions in their vehicle creation and delivery process.

The scope of an LCA, including its boundary and its level of detail, depends on the subject and the intended use of the study. Finally, as various LCA studies point out, the indicator development and selection focus mostly on the desired outcomes of each study.

1.1.5 THE LEVEL OF DETAIL OF AN LCA STUDY

The choice of the level of complexity of an LCA study is something to be determined in each study based on:

- The project/study objective,
- The perceived value placed on the specific impact categories,
- The availability of inventory data and accompanying parameters,
- The depth of knowledge and comprehension in each impact category,
- The quality and availability of modeling data: data precision often comes at the expense of lengthy and potentially costly analysis, and an agency/owner will likely face tradeoffs with data quality; use of data requires critical thinking about how possible errors may impact the assessment,
- The uncertainty and sensitivity of analyses,
- The level of validations,
- The available supporting software, and
- The level of funding resources.[16]

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[14] PRé (2016).
[15] Manzo and Salling (2016).
[16] UNEP (2003).

An LCA can draw data from a variety of databases, with proper reference to those data sources. Within a specific LCA model, the parameters can be defined by the user, based on adequate information. When such information is not available, a set of default parameter values can be used. However, default values have inherent assumptions and may not be applicable to a specific project.[17]

1.2 AVAILABLE LCA TOOLS

LCAs can be costly and time-consuming, thus limiting their use as analysis techniques in both the public and the private sectors. However, the growing trend for Lifecycle accounting and the required high level of expertise have led to the creation of LCA software tools to streamline the process and encourage a broader audience to a new lifecycle way of thinking.

These tools are supported by large databases containing information on a range of materials, construction machines, energy sources, environmental systems, waste types, transport vehicles, etc. Among the available tools are SimaPro, the most widely used software in the consulted studies; GaBits; Umberto LCA+; OpenLCA; and One Click LCA.

There are also examples of tools that build upon previous models, such as the Lifecycle Considerations in EIA of Road Infrastructure (LICCER). It is a case of a research project[18] for the development of an easy-to-use model, consisting of a modular framework and guidelines, based on existing tools and methodologies for LCA of road infrastructure for assessment of GHG emissions and energy use in the early planning of road infrastructure.[19]

1.3 TRANSPORTATION INFRASTRUCTURE-SPECIFIC LCA METHODOLOGIES

The review of various transportation-related studies provides insight on the main components and considerations for the LCA of a transportation system; the processes with impact on each phase of a project; the specific impact indicators; and the considered costs per owner and user of the infrastructure per phase of the project lifecycle.

Transportation projects are large-scale and long-lifespan projects that consume high amounts of energy and materials over this long lifetime. There are representative types of projects serving several goals with an inevitable tradeoff between them. Often, a single source cannot provide funding, and multiple sources imply the need to bring together

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17 Potting et al. (2013).

18 research project of the cross-border funded joint research program "ENR2011 ENERGY – Sustainability and Energy-Efficient Management of Roads."

19 Early planning is defined as the choice of road corridor (choice of route selection) and choice of construction type, e.g., plain road, tunnel, or bridge.

different interests with different objectives and, thus, different weights in any appraisal process (Vickerman, 2007).

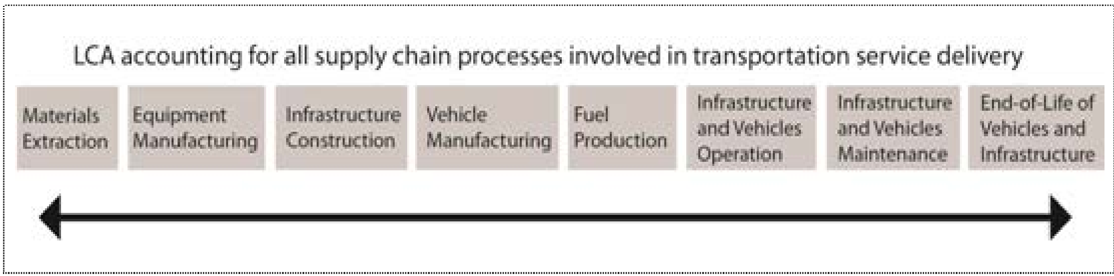
They consist of system expansion, rehabilitation, maintenance, and reconstruction projects to address safety risks, unmet transit needs, urban congestion, urban capacity deficiencies, and future growing demand due to demographic shifts. There are several system-analytic-based applications for the transport sector, such as the environmental impact assessment (EIA), the strategic environmental assessment (SEA), environmental product declarations (EPD),[20] and other strategic decision supports relating to investments in different infrastructure systems. LCAs provided the additional capacity for system evaluation of transportation projects.

LCA has been used to evaluate the environmental impacts of road infrastructure since the 1990s. However, it has not been common to include LCA in the early planning stages. It is instead performed when the siting of a road, for example, has already been chosen (Kluts and Miliutenko, 2012).[21]

Though LCA studies consider different elements of transportation infrastructure and different system boundaries, they can be generally grouped into those concentrating on:

- The transport sector,
- The road and bridge infrastructure (from site clearance to the installation of road equipment), or
- The supply chain of construction materials and the use of by-products, recycled, and secondary materials.

A full transport LCA has two parts: the LCA of the infrastructure and that of the actual transport vehicle.



Many LCAs are performed for the pavement alone for comparison of different types of construction materials, for example, bitumen and concrete pavements or virgin materials

[20] An environmental product declaration (EPD) is an independently verified and registered document that communicates transparent and comparable information about the Lifecycle environmental impact of products. As it is a voluntary declaration of the Lifecycle environmental impact, having an EPD for a product does not imply that the declared product is environmentally superior to alternatives. ISO 14025: Environmental labels and declarations – Type III Environmental Declarations – Principles and procedures (2006).

[21] Potting et al. (2013).

with recycled or secondary materials, or for various asphalt mixing techniques. Studies have also been performed to analyze greenhouse gas and air pollutant emissions of different fuel types, different transportation modes, or different construction and earthworks techniques.[22]

As such studies have different system boundaries, functional units, analysis periods, and include different materials and construction activities, their quantitative results cannot be directly compared with each other. However, there are efforts to conclude the relative contribution of different lifecycle phases, materials, and processes.

Many of the studies explore the limitations of available methods, trying to expand the impacts considered by road-testing new methodologies to approximate the complexity of transportation infrastructure.

Transportation infrastructure LCAs are studies in which each studied object is unique; the variations are significant primarily due to geotechnical conditions, geographic location, meteorological conditions, traffic intensity, etc. These variations will define the size of efforts in the road or bridge construction process, e.g., the extent of earthworks required and the technical composition of a road, which varies substantially depending on the land characteristics along the route (Stripple, 2001) and also fuel consumption, as there is an expectation that consumption will be greater for a sloping road, in comparison to a flat road.[23] Additional to the site-specific variations are those of the specific choices made for each studied object, such as the different types of paving, the sizing of the pavement layers, the particular road type (highway; heavy-duty corridor or local; urban or rural, etc.), the construction equipment used and its fuel type, the construction and maintenance processes realized, etc.

The consideration of vehicles' operation during the Lifecycle of a transportation project contributes additional complexity to the assessment of transportation service. Different transportation modes, different types of vehicles, e.g., electric and biofuel vehicles, as well as the national energy mix, constitute some of the various parameters to consider.

1.3.1. GOAL AND SCOPE DEFINITION

The system boundaries used in transportation LCAs vary in terms of which main Lifecycle stages are considered. For example, in various transportation LCAs, the decommissioning phase was not considered, based on the low probability (as experienced) of actual cases of demolishing transportation projects. A road, due to maintenance procedures, has a high residual value compared to an ordinary "product." Therefore, it was considered more useful to analyze a particular time period, usually 40 or 60 years. With a more extended period, the initial construction phase will be less dominant, and the maintenance and operation processes will be more critical (Stripple and Erlandsson, 2004).

[22] Liljenström (2013).
[23] Potting et al. (2013).

Operation and maintenance stages may be either merged as one stage or considered as different stages. Other cases consider the extraction/production of materials as a separate stage or include it in each of the construction, operation, and maintenance stages. These are a matter of user choice and do not influence the final results, as long as the description of each stage is clear.

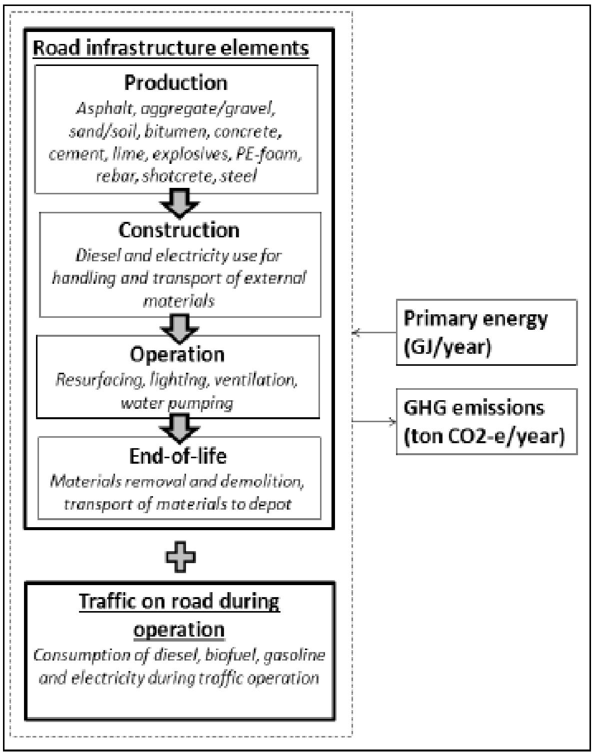


Fig.3: Simplified system boundaries in the LICCER model [24]

The functional unit to be used in the LCA modeling also varies. It is a measure of the function/performance of the studied system, and it provides a reference to which the inputs and outputs can be related. Examples of functional units in the transportation sector include:

- (For a comparison of modal transport options), provision of 10,000 passengers per day between Point A and Point B with a journey time of 1 hour, -over a defined number of years;
- (For comparing different rail track designs), 1 km of rail track with 60 equivalent million gross tons per annum (annual tonnage moved over it) and service life of a defined number of years;
- (For roadworks), the so-called road object, a section of the road itself with its road length (1 km), road width (13 m), surface thickness, etc. According to Stripple (2001), "In the choice of the final functional unit for the analysis of the roadwork, it

[24] Brattebe et al. (2013).

has emerged that a section of the road itself is the simplest and the most representative functional unit";

- (For different corridor options), "road enabling annual transport from A to B over an analysis time horizon of a defined number of years."

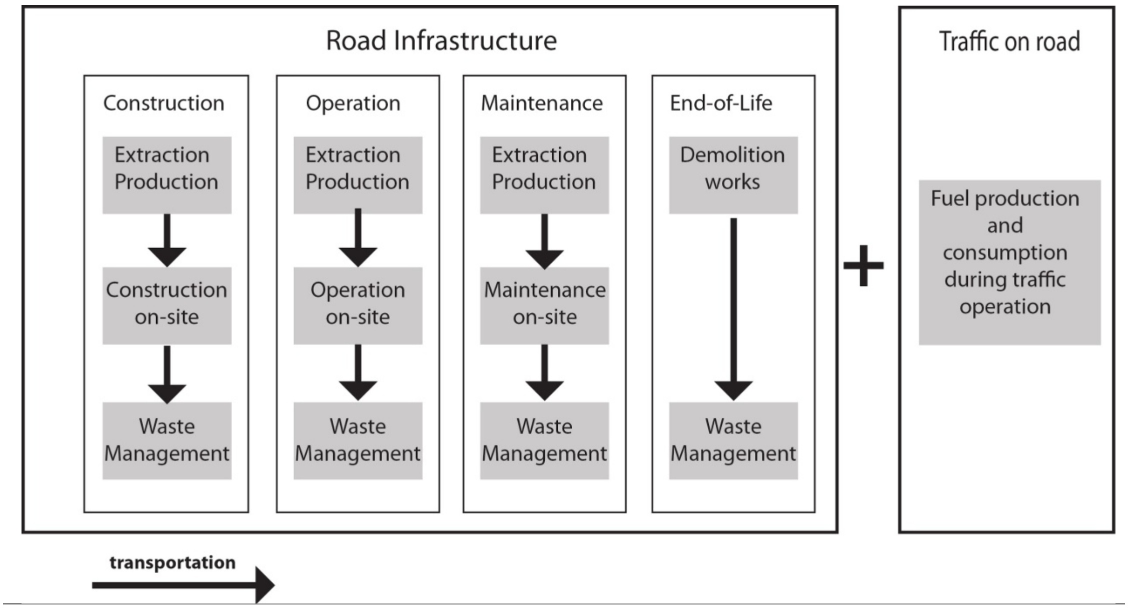


Fig.4: Material production not as a separate Lifecycle stage, but instead merged within others[25]

1.3.2. LIFECYCLE INVENTORY ANALYSIS

An LCA begins with an inventory of the materials and processes with impact (direct, indirect, and supply chain) that are relevant to the transportation system. Direct processes are energy use (fuel combustion) and emissions associated with the movement of the vehicle.[26] Indirect processes are those that support the direct processes, such as vehicle manufacture, infrastructure, and energy production services. Studies have calculated these processes per phase of a project to identify the hotspot areas of the Lifecycle. The construction, operation, and maintenance of the road network have, in many cases, from an environmental point of view, been regarded as less significant than the impact of vehicles using the road during its lifetime (Stripple, 2001).

The inventory data for the production phase includes excavation of raw material, transportation of materials, and processing of these materials to construction components.

Studies performed involve the impacts of processes per phase of the project.

[25] Adapted from graph in Miliutenko (2016).
[26] Chester et al. (n.d.).

The main processes with impact within the construction phase involve the equipment activities:

- Pavement leveling, spreading, and rolling,
- Transportation of raw materials from the place of origin to the mixing plant,
- Transportation from the mixing plant to the construction site.

However, there is a variety in the level of detail that each assessment will incorporate. E.g., as part of the project mobilization, the movement of the labor force to and from the construction site can also be included.

The operation and maintenance phase mainly calculates the environmental impact of various operations and maintenance activities during the long-term use of the infrastructure. These activities have different frequencies, from daily operational activities such as road lighting and ventilation in the case of tunnels to routine maintenance activities on an annual basis. Especially the maintenance activities have various categories:

- Routine maintenance is undertaken yearly, either cyclic (dependent on environmental factors rather than traffic levels) or reactive, as, e.g., patching carried out in response to the appearance of cracks or potholes,
- Periodic maintenance undertaken at intervals of several years to ensure the structural integrity of the road, usually programmed as regular long-term maintenance work,
- Emergency maintenance,
- Rehabilitation works,
- Reconstruction and upgrading.

Direct impacts include the environmental impacts of material production and maintenance construction required for maintenance activities, which are similar to the material production and construction phases. Indirect impact refers to traffic delays caused by maintenance activities, which create an additional environmental burden, in the case of partially or entirely blocking traffic for a while, causing vehicles to slow down or bypass, which will result in increased fuel consumption.

Finally, the end-of-life phase includes demolition of the road superstructure, bridges, and guardrails, earthworks necessary to restore the land area to natural conditions, and transportation of materials to landfills and deposits. As part of this phase also the environmental impact caused by different treatment methods, such as recycling and reuse of materials, is calculated.

There will be a large amount of labor input in the process of road construction, maintenance, and recycling. At the same time, some direct monetary contribution as an indirect fee is inevitable

1.3.3. LIFECYCLE IMPACT ASSESSMENT

The overall environmental impact is calculated via the amount of material and equipment used and the environmental impact per-unit amount. The environmental indicators mainly chosen are energy consumption and air emissions. These are parameters that can be easily quantified and therefore included in an LCA model.

Energy consumption occurs not only through direct use during the construction and operation of the infrastructure and vehicle circulation. A key concept used in assessment is the embodied energy of materials, fuels, and vehicles, defined as the total of all energy sequestered in materials/equipment during all processes of production, on-site construction, and final demolition and disposal. It is the energy used during extraction, processing, and manufacturing, as well as the energy used in the transportation of finished materials from manufacturing/prefabrication plant to worksite or the point of sale for vehicles.[27]

The embodied energy of construction materials forms a significant proportion of the overall energy consumed during the Lifecycle of a given mode of transport. Therefore, it becomes critical to understand the embodied energy values of key construction materials used in the transportation sector.[28]

"Other parameters such as biodiversity or biological barrier effects are much more difficult to handle and very difficult to quantify and, therefore, not possible to include in an LCA model. **A suggestion to handle this problem can be to include the difficult parameters in a checklist. The list can then be handled separately.** A simple yes/no form can be used in environmental impact assessment, or some kind of index or point system can be used in the final evaluation" (Stripple and Erlandsson, 2004).

Characterization factors allow for comparing the ability of different substances to cause the same environmental impact because they convert the results from impact assessment into a standard unit of a category indicator.

1.3.4. LIFECYCLE COST ANALYSIS

Transportation is one of the sectors where Lifecycle cost analysis has been a requirement for government projects exceeding certain investment thresholds. The calculation process of Lifecycle cost analysis divides the total cost into two categories according to the undertaker of cost: owner and user cost.

Owner costs are related to investment and maintenance, which can be calculated by the budget method. User costs are the vehicle operation cost (including fuel savings and savings on spare parts due to better ride quality of pavement), delay cost, and Accident

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27 Gorige and Uday (2017).
28 Ibid.

cost (accident cost savings). These can be incorporated as values and calculated within specific economic indicators.

There is less progress in LCA for bridges, compared to roadways. The relatively few studies did not include all life stages. More recent LCAs divide the Lifecycle of the bridge into four stages: manufacturing, construction, use, and end-of-life, and they typically compare bridge design variants (24,25,26,27). The manufacturing stage is usually found to be the Lifecycle stage with the highest environmental impact and is driven by concrete, asphalt, and steel material inputs.[29]

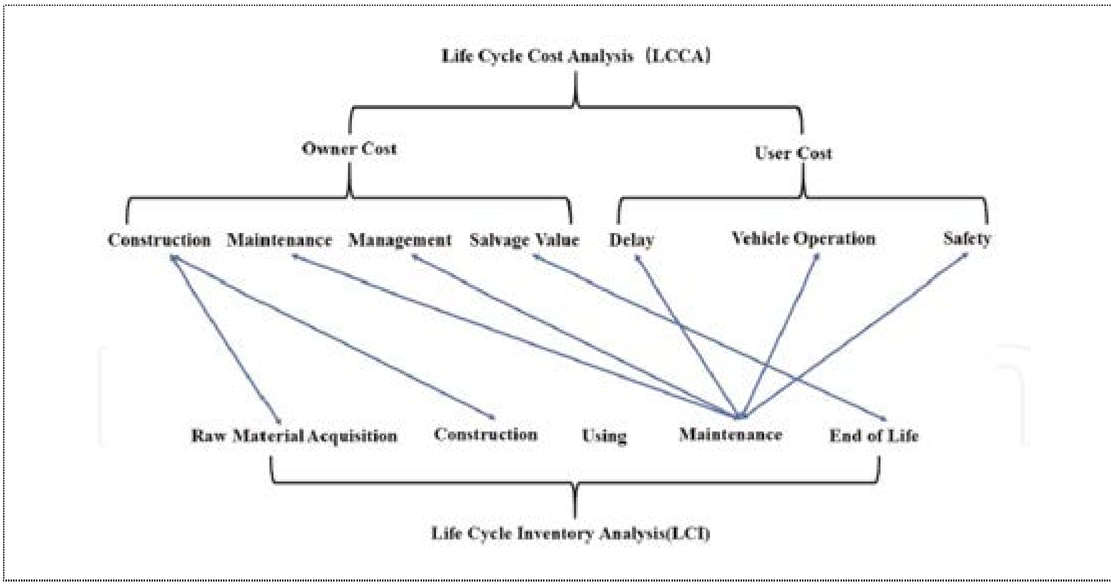

Fig.5: Example of LCCA boundary[30]

As in the case of environmental LCAs, literature review points to ongoing research on a different road and traffic conditions, choices among transportation modes, vehicle types, etc. One common feature of these studies is questioning the accuracy of cost estimations made.

The literature highlights that investment decisions for transportation projects are made under uncertainty (lack of accuracy of cost forecasts and uncertain demand during the long timescale for large projects to be planned, approved, and constructed) and have to be guided by analytical tools to determine their feasibility.

Apart from the more straightforward criteria used for economic evaluation, studies highlight the importance and challenge of accounting for environmental and social costs.

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29 Athena Sustainable Materials Institute, "LCA for Roadways and Bridges Roadmap for greater adoption of LCA as a decision-support tool," March 2018 assigned by the Construction Research Centre of the National Research Council Canada.

30 Graph source: Liu et al. (2019).

Environmental and social costs are related to noise, visual intrusion, and local air pollution or global climate effects. However, a degraded road pavement obligates vehicles to move slower, thus, to exhaust more pollutants, produce more dust, and create low-frequency noise. Noise and dust reduction with a new road are calculated within the potential benefits of a new road, along with accident prevention (Tudela, Akiki, and Cisternas, 2006).

Social performance measures include access to jobs and community destinations, crashes, vehicle miles traveled (VMT), health impacts, land consumption, and economic measures, including job creation and land value.

1.4 GAPS ON SUSTAINABILITY IN LCA METHODOLOGY

While the methodology for (environmental) LCA has developed and matured over the last decades, a shared conclusion is that there are still several fields that need attention, such as methods for assessing impacts on ecosystem services from land use and impacts from water use, weighting methods and quality assurance of LCA databases (Finnveden et al., 2009). Furthermore, appropriate indicators at both macroeconomic and sectoral levels must be identified for better understanding and quantification of infrastructure services throughout their LC, in different geographical areas, and from various human activities.

Another identified gap of the standardized LCA as a tool for infrastructure performance assessment is that it focuses on environmental impacts and does not account for the inevitable economic and social tradeoffs of projects.

Research also demonstrates that the use of LCA in infrastructure systems requires a broad perspective and wider system boundaries. The multitude of interactions between infrastructure services requires all infrastructure components and phases to be considered in determining the whole LC impact. Infrastructure planning also needs to consider users and resources better. Literature shows that building LCA models of urban scale is a complex and resource-intensive process. Nevertheless, LCA models give valuable insights to strategic planners, enhances information exchanges among various stakeholders and disciplines, and captures the impacts associated with the consumption of resources, which is not part of the classic strategic planning processes.

Another critical gap in infrastructure-related LCAs results from the seasonal and territorial nature of the infrastructure resources, both from demand and supply perspectives. Water's seasonal nature, for example, makes water systems an essential example of the interdependence between infrastructure planning and use/operation.[31] Water ecosystems face considerable risks in terms of water quantity and quality that have to be managed in a way that protects local and regional human and environmental health. Many water quantitative approaches are available, including hydrological modeling, water accounting,

[31] Many LCAs can be found for urban water consumption.

water footprint assessment (WFA),[32] and LCIA. Geographically, infrastructure decision-makers face conflicts between pressing local goals/impacts (public and environmental health) and global environmental focus (e.g., GHG emissions). Although LCA is useful for characterizing global environmental impacts of urban infrastructure, there is a pressing need to balance these impacts with local, often regulated, environmental, and public health objectives.

The UNEP report "Towards a green economy" states that "we cannot manage what we do not measure." Without adequate and consistent data and sources of information on the availability, use, and productivity of prime resources, for example, planning decisions cannot be made on a rational basis.

1.5 EMERGING APPROACHES IN LCA

More recent methodological developments have aimed at broadening the perspective and system boundaries, as well as expanding the scope of indicators of the standardized LCA to address its gaps.

Examples of broader system boundary LCAs are, e.g., the urban-scale LCAs and watershed-scale Lifecycle assessments introduced in water infrastructure assessment.

Watershed LCA (WLCA) is an integration of LCA and risk assessment, the method that quantifies exposure and risk to human health or ecosystem function in different pollutants' release scenarios. Risk assessment principally focuses on sinks/receptors of pollutants, while LCAs focus on emission sources. The blending of the two methods and their parallel results can contribute to more sustainable watershed management and development, given that a large geological unit such as a watershed is a sink for anthropogenic pollutants from production activity, living consumption, and transportation by a massive population within its limits.[33]

The broadening of LCA scope indicators has two principal directions:

1. add new quantitative considerations into environmental LCAs,
2. complement environmental LCAs with social and economic impact indicators.

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32 Water footprint (WF) was introduced in 2002 as an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer. The WF is the total volume of freshwater used to produce goods and services. It is a temporally and geographically explicit indicator that shows the amount of water used and when and where it was consumed. WFA uses a volumetric approach and, as a consumption-based indicator, is meant to provide information on single products, or at the corporate level in the context of sustainable, equitable, and efficient water management and allocation. It can be used at various levels: river basin, global, product, or corporate.

33 "Integrative Application of Lifecycle Assessment and Risk Assessment to Environmental Impacts of Anthropogenic Pollutants at a Watershed Scale" (2017), https://www.researchgate.net/publication/322024021_Integrative_Application_of_Life_Cycle_Assessment_and_Risk_Assessment_to_Environmental_Impacts_of_Anthropogenic_Pollutants_at_a_Watershed_Scale

An example of the first direction is the integration of water footprint assessment (WFA) into water infrastructure LCA analysis to address the recognized deficit of quantitative volume-oriented water resource assessments. WFA uses a volumetric approach and, as a consumption-based indicator, is meant to provide information on single products, or it can be used at the corporate level in the context of sustainable, equitable, and efficient water management and allocation. It can be used at various levels: river basin, global, product, or corporate. An ongoing ISO process tries to translate the WF into LCA calculations by adding a weighting factor (Hoekstra et al., 2011).

The second direction aims at an integrated and comprehensive Lifecycle sustainability assessment (LCSA) by combining environmental with social impact (social Lifecycle assessment, SLCA) and economic impact evaluation (Lifecycle costing, LCC). The UNEP/SETAC Lifecycle Initiative, departing from the ISO 14040 model, "moved on to adopt a broader approach toward sustainable development to convert the existing (environmental) LCA technique "into a triple-bottom-line sustainable development technique."

The development of each technique follows the priorities that companies tend to put, typically assessing first the economic viability and after that environmental and perhaps social aspects of a proposed infrastructure project.

Lifecycle costing, the economic component of the approach is the oldest of the three Lifecycle techniques and quite developed. Lifecycle costing is beneficial for monitoring costs under different scenarios, making it attractive to the product's clients and the financial sector and a mainstream business practice. It is based on simple engineering economics, considering all the costs that will be incurred during the lifetime of the product, work, or service:

- Purchase price and all associated costs (delivery, installation, insurance, etc.),
- Operating costs, including energy, fuel and water use, spares, and maintenance,
- End-of-life costs (such as decommissioning or disposal) or residual value (i.e., revenue from the sale of a product).[34]

Costs are normalized to represent the same FUs and be comparable.

LCC is especially useful when project alternatives that fulfill the same performance requirements but differ concerning initial costs and operating costs have to be compared to select the one that maximizes net savings. The economic indicators used to determine the feasibility of infrastructure projects are the net present value (NPV), internal rate of return (IRR), payback period (PP), and profitability index (PI). CBA is the most common evaluation method.

34 European Commission.

However, similarly to an environmental LCA, the parameter assumptions, and the range of issues to be taken into account are critical for consistent evaluation. LCC is a tool suitable for infrastructure owners who are also operators. "In traditional contracting methods where the operation is not included, the Lifecycle costing principles are not relevant" (Stapledon, 2012).

Efforts are made to respond to the question if tools that have emerged through the prism of economic analysis (rather than sustainability) are useful in assessing the broader sustainability costs and benefits of infrastructure projects. Notably, the question of whether LCC covers monetization of externalities, i.e., environmental burdens, is crucial for any findings following this approach.

In this direction, a more sophisticated tool is the multiple objective determination analysis (MODA), or multi-criteria analysis (MCA), that examines the objectives of the investment and how each one will be measured. MODAs use dashboards with algorithmic formulas that weigh and interrelate the goals to allow for a holistic understanding. It is the preferred approach for problems with conflicting objectives. It uses both qualitative and quantitative parameters and enables the assessment of non-monetized values (Tudela, Akiki, and Cisternas, 2006).

SLCA is the most recent addition to the LCA methods, which is concerned with the social hotspots or impacts of a product or process over its Lifecycle (Lenzo et al., 2017). One critical question of each social impact assessment is: What are different social goals (economic, health, safety, etc.) that should be considered?

This raises the question of adequate and consistent social indicators. The indicators used in the current practice of SLCA are defined based on available sets of indicators developed in social impact assessment domains by different actors and with different purposes:

- Government institutions, e.g., the list of social indicators adopted in the Human Development Index (HDI, UNDP, 2015), or the UNEP guidelines for social LCA (UNEP, 2009);
- Nongovernmental organizations, e.g., indicators for fair trade;
- Industries, e.g., indicators adopted for corporate social responsibility;
- The scientific community, e.g., a different set of indicators for assessing the social-related impacts of specific products/countries/supply chains.[35]

Existing efforts to list social impact indicators are not prescriptive, but instead, suggest organizing frameworks that can be adapted to the needs of the user. Social impact indicators are time-, region-, circumstance-specific, and often management-related and are, therefore, by definition, difficult to predict. Social impact studies combine quantitative but also qualitative indicators. A potential problem with the qualitative indicators, e.g., social well-being, is that their evaluation is inevitably subjective, the result of

[35] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC99101/lbna27624enn.pdf

interpretation. Their assessment must be based on a transparent, informed, and highly contextualized narrative. Therefore, participatory-based approaches for expert elicitation need to be included on a case-by-case basis.[36]

As in the case of the standardized LCA, different methodologies are tested in case studies. Despite the active development in the field of SLCA, there is broad agreement that it is not yet possible to carry out a comprehensive SLCA and that consistent indicator sets are needed. In an early attempt, the United Nations Environment Program and the Society of Environmental Toxicology and Chemistry (UNEP/SETAC) spearheaded the formulation of guidelines for SLCA methodology for social impact assessment and published these guidelines in the UNEP/SETAC Lifecycle Initiative website in 2009.

Stakeholders play a crucial role in SLCA methodology (UNEP, 2009). Therefore, indicators developed for evaluation in SLCA are phased according to the stakeholders (workers, local community, consumers, society, and value chain actors) who will be affected by a project's activities throughout its lifecycle. However, an extensive list of selected indicators does not exist because their use depends on the goal and scope of a particular study.

Lifecycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social, and economic negative impacts and benefits in decision-making processes toward more sustainable products throughout their Lifecycle (UNEP, 2011). What UNEP suggests is that existing lifecycle-based techniques that are currently used independently can be used in a combined way to conduct an LCSA.

Klöpffer formulates the conceptual “equation” of Lifecycle sustainability assessment: LCSA = LCA + LCC + SLCA (Klöpffer, 2008). This suggests that existing lifecycle-based techniques that are currently used independently can be used in a combined way to conduct an LCSA for integrated decision making on the triple bottom line of sustainable development. A prerequisite of this “equation” is that the system boundaries and functional units of LCA, LCC, and SLCA are similar.

LCSA is a trans-disciplinary integration framework of models rather than a model in itself. However, it has to be emphasized again that other approaches also exist. In many cases, these are open-ended methods in the constant process of updating and adapting to new input. Cross-comparisons of the available tools realized point to the shortcomings of individual tools and propose hybrid methodologies for the evaluation of projects rather than one specific method to respond to the identified weaknesses.

An example of such hybrid evaluation tools is the so-called triple bottom line valuation (TBL-CBA) or sustainable return on investment (SROI). It is a study of high complexity that accounts for a sustainable project's total value, and not only its financial feasibility at the point of procurement. TBL-CBA aims to determine how projects add value by assigning a

36 Van Haaster et al. (2017).

monetary value to environmental or social benefits. Autocase®, created in 2012 by Impact Infrastructure, is an example of such a tool with the added value of streamlining the complex analysis process of TBL-CBA. Through cloud-based automated technology, Autocase® "synthesizes hundreds of industry- and government-recognized research studies to provide smart default values"; after combining these values with project-specific data input, it computes and reports the project's full range of costs and benefits.

Another example of a total value assessment tool is the International Institute for Sustainable Development (IISD)'s Sustainable Asset Valuation (SAVi) tool, a simulation tool customized for four sectors/asset categories – energy, buildings, roads, and water infrastructure – to inform decision making for both governments and investors. Through a system dynamics methodology, SAVi integrates and processes data in a nonlinear fashion and generates a conventional cost-benefit analysis with the added value of the quantification of broader co-benefits, avoided costs, and project risks. According to IISD, SAVi is a tool capable of "demonstrating the business case for sustainable infrastructure and how improved sustainability performance can affect future cash flows and contribute to more attractive financial returns." The tool's outcome is sustainable project finance modeling presented through reports and illustration of results under various customized scenarios.

Among the recommendations encountered in the literature is that of incremental implementation of an LCA in the case of public agencies. Rather than performing a full LCA of current and future infrastructure and operations, many agencies will implement LCA incrementally through their planning processes and when considering contracts. This incremental approach can be useful as agencies consider LCA impacts as they are faced with decisions, for example, when considering a contract to purchase new vehicles or when considering the routing and vehicle technology of a new fixed guideway system.

Additionally, the contracting process is appropriate for addressing impacts, as hotspots tend to correlate with high non-labor and capital expenditures.[37]

1.6 OVERVIEW OF LCA STATE-OF-PRACTICE IN CANADA

It is worth referring to LCA practice in Canada to reaffirm or not the gaps and constraints in LCA practice presented as part of the literature review. For that purpose, t

The March 2018 report "LCA for Roadways and Bridges Roadmap for greater adoption of LCA as a decision-support tool," by the Athena Sustainable Materials Institute, addresses the LCA practice in Canada. The research project was commissioned by the Construction Research Centre of the National Research Council of Canada. The study's objective was to provide a roadmap for using LCA in the design and maintenance of roadways and bridges, reduce environmental impacts, and facilitate the use of LCA as an evidence-based tool for

[37] Chester et al. (n.d.)

decision-making. According to the report, LCA is well-established in several transportation agencies in Canada as a tool to understand and manage the lifecycle cost impacts of long-lived publicly owned assets. At the same time, it observes that LCA has not been widely adopted yet (2018).

The 2018 report was based on both literature review and multiple stakeholder interviews, such as researchers, transportation agencies and materials industries, that shared a consistent message on the current constraints of LCA use as a tool: "concerns about data quality and unintended consequences; no strong motivation to do LCA; and a need to integrate LCA with infrastructure design and costing processes." The report also provides an overview of the on-going research on LCA by Athena Sustainable Materials Institute and the Cement Association of Canada with the development and updates of LCA tools. On-going research efforts show that the construction industry recognizes the need to support the development of environmentally compatible and more sustainable construction products, and how comprehensive environmental information related to potential impacts enables the development process. The Environmental Product Declarations (EPDs) provide evidence. The EPDs are from cradle-to-gate, accounting for raw material supply, transport, and manufacturing. There are EPDs for structural precast concrete [38] and ready-mixed concrete products by the Canadian Ready-Mix Concrete Association. Similar organizations exist in the USA.

Moreover, there have been research efforts on how climate change can be incorporated into infrastructure lifecycle assessments.[39] Climate change may accelerate pavement deterioration and therefore increase lifecycle costs of maintaining roadways and bridges. An LCA that integrates the impact of a changing climate requires an understanding of how infrastructure degrades, its service life, and changes in maintenance schedules for chronic and extreme weather events

38 Established by the Canadian Precast/Prestressed Concrete Institute

39 Numerous pavement LCA studies have been undertaken, though none considered how climate change would affect the road structure's service life. However, several studies consider the service life and associated Lifecycle costs of road networks where impacts due to climate change were included. None of bridge LCA studies consider climate change impacts on bridge performance. Source: Guest, G., Zhang, J., Maadani, O. and Shirkhani, H., "Incorporating the impacts of climate change into infrastructure lifecycle assessments: A case study of pavement service life performance, Journal of Industrial Ecology 2019; 1-13."

CHAPTER 2.

ANALYSIS OF SUSTAINABILITY ASSESSMENT TOOLS

2.1. OVERVIEW OF SUSTAINABILITY ASSESSMENT TOOLS

Three widely used infrastructure-specific rating tools were studied on how they address lifecycle stages in terms of social, environmental, and economic sustainability.

- ISI Envision® rating tool (USA)
- UK's CEEQUAL®, and
- Australia's IS® Scheme.

	ENVISION	CEEQUAL	IS Rating System
1st version of tool released	2012	2003	2012
Country of origin	UNITED STATES	UNITED KINGDOM	AUSTRALIA
Organizations/ Owners	Institute for Sustainable Infrastructure (ISI)	BRE Global Limited (BREEAM family schemes)	Infrastructure Sustainability Council of Australia (ISCA)
Project stages application	Planning/Design Construction Operation	Planning/Design Construction Operation/Maintenance	Planning/Design Construction Operation
Sustainability topics covered	Quality of Life Leadership Resource Allocation Natural World Climate and Resilience	Management Landscape and Historic Environment Resilience Pollution Communities and Stakeholders Resources Land Use and Ecology Transport Innovation	Management and Governance Using Resources Emissions, Pollution and Waste Ecology People and Place Innovation
Award levels	Platinum (50%) Gold (40%) Silver (30%) Verified (20%)	Outstanding (? 90%) Excellent (? 75%) Very Good (? 60%) Good (? 45%) Pass (?30%)	Leading (75 to 100) Excellent (50 to <75) Commended (25 to <50)
Version used for the analysis	3.0	6.0	1.2
Rating Tools statistics as at June 2020 (sourced from tool websites)			
No of awarded projects	87 awarded projects	260 Final Awards 100 Interim Client & Design Awards 250 projects & contracts currently assessed	63 Certified Ratings
Projects Value		Accumulative civil engineering value of work exceeds £30 billion.	Over $60 billion in infrastructure and civil works projects/assets across Australia & New Zealand have either been certified or registered.

These tools were selected as they are mostly used by the industry to assess the sustainability of infrastructure projects, including transportation infrastructure, and they include third-party verification. The three tools are cross-examined against the LCA methodology to map overlaps and assess to what degree they can potentially contribute to the identified gaps of LCA, e.g., to consider socio-economic impacts. The objective of this cross-examination is to test the viability of the hypothesis that sustainable infrastructure rating systems can form a consistent assessment tool for addressing lifecycle. Therefore, the rating tools are being filtered through:

- The triple-bottom-line approach to sustainability,
- The lifecycle stages of a project,
- The sustainable performance indicators used for assessment.

2.1.1. ENVISION® RATING TOOL (VERSION 3)

Envision® was developed by the Zofnass Program for Sustainable Infrastructure at Harvard University and the Institute for Sustainable Infrastructure (ISI), which makes it available to the industry worldwide. ISI is a not-for-profit education and research organization founded by the American Public Works Association, the American Council of Engineering Companies, and the American Society of Civil Engineers. ISI is the hub of a unique community of organizations and individuals involved in the planning, design, construction, and maintenance of infrastructure. Before being officially launched in 2012, Envision was pilot-tested in specific projects. Envision has been applied to billions of dollars' worth of infrastructure projects.

On April 30, 2015, the Envision Review Board (ERB) was formed to oversee the ongoing development of ISI's Envision. The 15 members of the ERB were selected from the US and Canada for their knowledge and expertise in the application of the Envision rating system. They represent a broad cross-section of the industry, including private companies, public agencies, universities, and nonprofits. Feedback and captured lessons learned from the application of the tool on projects were incorporated into two updated versions of Envision so far, with Envision version 3 being the latest version.

Envision provides industry-wide sustainability metrics for all types and sizes of infrastructure projects to help users assess and measure the extent to which their project contributes to conditions of sustainability across social, economic, and environmental indicators. Furthermore, the Envision framework recognizes that these sustainability factors are variable across a project's lifecycle. As such, Envision helps users optimize project resilience for both short-term and long-term impacts.

Envision is a framework of tools that includes 64 sustainability and resilience indicators, called "credits," organized in five categories and 14 subcategories by subject matter:

1. Quality of Life (Wellbeing, Mobility, Community)
2. Leadership (Collaboration, Planning, Economy)
3. Resource Allocation (Materials, Energy, Water)
4. Natural World (Siting, Conservation, Ecology)
5. Climate and Resilience (Emissions, Resilience)

Fig.6: Envision categories of impact

Every infrastructure project impacts all five Envision categories, often with complex tradeoffs. By grouping the credits into broader categories of impact, Envision helps users to navigate the complex tradeoffs or synergies across the credits. "When addressing sustainability and resiliency in the face of changing variables, it is difficult to assess the full range of benefits and impacts across the broad scope of social, environmental, and economic factors. The Envision framework provides a structure in which users can measure progress and identify potential tradeoffs amid this complex mix of objective, subjective, quantifiable, and qualitative criteria."

Each category includes a credit on "Innovate or Exceed Credit Requirements," through which the Envision encourages innovation across all aspects of sustainability and resilience. Innovation points are given when a project advances sustainable infrastructure practices or shows exceptional performance beyond the expectations of the credit requirements.

The following levels of achievement define the level and quality of project performance in each Envision credit:

- **Improved (lowest)**: Performance that is above conventional. Slightly exceeds regulatory requirements.
- **Enhanced**: Sustainable performance that is on the right track. There are indications that superior performance is within reach.
- **Superior**: Sustainable performance at a very high level.
- **Conserving**: Performance that has achieved essentially zero negative impact.
- **Restorative (highest)**: Performance that restores natural or social systems. Such performance receives the highest award possible and is celebrated as such. The Restorative level is not applicable to all performance objectives.

Not all credits have five levels of achievement. The levels are determined by the nature of the credit and the ability to make meaningful distinctions between levels.

The Envision framework consists of:

1. The Envision Guidance Manual.
2. The Envision Pre-Assessment Checklist (internal assessment): an early-phase high-level pre-assessment.

3. The Envision Online Scoresheet (internal assessment): the detailed online assessment tool and calculator. An online tool that allows project teams to assess projects using Envision collaboratively, upload documentation, describe key features of the project, and register the project for third-party verification.
4. The Envision Verification (external assessment): an independent third-party project review process. Projects may choose to pursue one of two verification pathways: Path A: Design + Post-Construction, Path B: Post-Construction.
5. Envision Awards by ISI: projects can be recognized at four award levels: Verified: 20%, Silver: 30%, Gold: 40%, Platinum: 50%.

Fig.7: Envision verification pathways

Table 1. Envision Credits

QUALITY OF LIFE

- QL1.1 Improve Community Quality of Life
- QL1.2 Enhance Public Health & Safety
- QL1.3 Improve Construction Safety
- QL1.4 Minimize Noise & Vibration
- QL1.5 Minimize Light Pollution
- QL1.6 Minimize Construction Impacts
- QL2.1 Improve Community Mobility & Access
- QL2.2 Encourage Sustainable Transportation
- QL2.3 Improve Access & Wayfinding
- QL3.1 Advance Equity & Social Justice
- QL3.2 Preserve Historic & Cultural Resources
- QL3.3 Enhance Views & Local Character
- QL3.4 Enhance Public Space & Amenities
- QL0.0 Innovate or Exceed Credit Requirements

LEADERSHIP

- LD1.1 Provide Effective Leadership & Commitment
- LD1.2 Foster Collaboration & Teamwork
- LD1.3 Provide for Stakeholder Involvement
- LD1.4 Pursue Byproduct Synergies
- LD2.1 Establish a Sustainability Management Plan
- LD2.2 Plan for Sustainable Communities
- LD2.3 Plan for Long-Term Monitoring & Maintenance
- LD2.4 Plan for End of Life
- LD3.1 Stimulate Economic Prosperity & Development
- LD3.2 Develop Local Skills & Capabilities
- LD3.3 Conduct a Lifecycle Economic Evaluation
- LD0.0 Innovate or Exceed Credit Requirements

RESOURCE ALLOCATION

- RA1.1 Support Sustainable Procurement Practices
- RA1.2 Use Recycled Materials
- RA1.3 Reduce Operational Waste
- RA1.4 Reduce Construction Waste
- RA1.5 Balance Earthwork On-Site
- RA2.1 Reduce Operational Energy Consumption
- RA2.2 Reduce Construction Energy Consumption
- RA2.3 Use Renewable Energy
- RA2.4 Commission & Monitor Energy Systems
- RA3.1 Preserve Water Resources
- RA3.2 Reduce Operational Water Consumption
- RA3.3 Reduce Construction Water Consumption
- RA3.4 Monitor Water Systems
- RA0.0 Innovate or Exceed Credit Requirements

NATURAL WORLD

- NW1.1 Preserve Sites of High Ecological Value
- NW1.2 Provide Wetland & Surface Water Buffers
- NW1.3 Preserve Prime Farmland
- NW1.4 Preserve Undeveloped Land
- NW2.1 Reclaim Brownfields
- NW2.2 Manage Stormwater
- NW2.3 Reduce Pesticide & Fertilizer Impacts
- NW2.4 Protect Surface & Groundwater Quality
- NW3.1 Enhance Functional Habitats
- NW3.2 Enhance Wetland & Surface Water Functions
- NW3.3 Maintain Floodplain Functions
- NW3.4 Control Invasive Species
- NW3.5 Protect Soil Health
- NW0.0 Innovate or Exceed Credit Requirements

CLIMATE & RESILIENCE

- CR1.1 Reduce Net Embodied Carbon
- CR1.2 Reduce Greenhouse Gas Emissions
- CR1.3 Reduce Air Pollutant Emissions
- CR2.1 Avoid Unsuitable Development
- CR2.2 Assess Climate Change Vulnerability
- CR2.3 Evaluate Risk and Resilience
- CR2.4 Establish Resilience Goals and Strategies
- CR2.5 Maximize Resilience
- CR2.6 Improve Infrastructure Integration
- CR0.0 Innovate or Exceed Credit Requirements

2.1.2. CEEQUAL® (VERSION 6 - FOR INFRASTRUCTURE PROJECTS)

The Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) is based in the UK, operating since 2003, and has been available internationally since 2011. It is an evidence-based sustainability assessment, rating, and certification scheme for civil engineering, infrastructure, landscaping, and public realm works. It was formally developed by an industry-representative team led by the Institution of Civil Engineers (ICE) with government financial support from DETR (now DETRA), the DTI Partners in Innovation (PII) schemes, and the ICE's Research & Development Enabling Fund, UK. CEEQUAL's transition from environmental assessment and awards to a sustainability assessment and awards scheme was completed in its 2012 release of version 5. The Assessment Manuals were reviewed, revised, and updated by CEEQUAL's panel of experts to reflect current industry best practices. In November 2015, CEEQUAL Ltd was acquired by BRE Global Limited, and CEEQUAL is now part of the BREEAM family of schemes.

Fig.8: CEEQUAL development timeline (https://www.ceequal.com/news/introducing-ceequal-version-6/)

It was created to encourage environmental excellence in civil engineering projects and deliver improved environmental and sustainability performance in project specification, design, and construction. It is a tool that assesses the full sustainability credentials of infrastructure projects and contracts. It supports Governments (including the UK Government) by providing the infrastructure professions and industry worldwide with an incentive and protocol for assessing, benchmarking, and rating the sustainability performance.

The CEEQUAL methodology is available as two schemes: 1. CEEQUAL for Projects, and 2. CEEQUAL for Term Contracts. CEEQUAL for Projects[40] can be used on any infrastructure project that involves the construction of new assets or the refurbishment of existing ones. CEEQUAL for Term Contracts is used to assess the maintenance of assets or the construction of small repetitive works.

[40] CEEQUAL for Projects is divided into two editions: UK & Ireland and International.

Projects can be any type or size of civil engineering, infrastructure, landscaping, or public realm.[41] This includes the construction or refurbishment of assets such as roads, railways, ports, airports, coast and river works, water supply, wind farms, power stations, retail and business parks, flood alleviation schemes, wastewater treatment works and utilities, plus specialist projects such as demolition or remediation works. CEEQUAL includes the three Assessment Stages of (a) Strategy, (b) Design/Interim Design, and (c) Construction. A project team can assess and be awarded for the "Whole Project" or just parts of its process, meaning "Strategy & Design," "Design only," "Design & Construction," "Construction only." These are the Assessment Types of CEEQUAL.

The diagrams below present the relation between the Assessment Stages and the Project Phases and the relationship between the Assessment Types of CEEQUAL and the Assessment Stages.

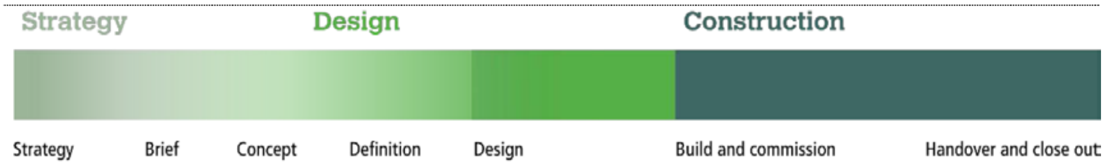

Fig.9: Assessment Stages against typical Project Phases

Table 2. Assessment Types against Assessment Stages

Assessment type	Assessment stages included in scope of assessment		
	Strategy	Design	Construction
Whole Project	✓	✓	✓
Strategy & Design	✓	✓	
Design only		✓	
Design & Construction		✓	✓
Construction only			✓

CEEQUAL is organized in "8 Categories – 30 Assessment Issues – 248 Assessment Criteria". The eight categories include a total number of 30 Assessment Issues (see below), which in their turn include different Assessment Criteria. The system's latest version also incorporates **optional innovation credits** which come in two forms:

- **Exemplary level performance criteria** – optional criteria within the technical manual for exemplary performance (currently only available within '7.2 Reducing whole life carbon project emissions').
- **Approved innovation credit applications** – reward for innovations not covered elsewhere within the manual. Approved innovation credit applications go through a

[41] For large or complex, multi-package projects, CEEQUAL provides separate assessments at the package or sub-project level in a way that enables them to be given individual package scores and for those scores to be aggregated into an overall score for the Whole Project Assessment Type.

formal peer-review process and must demonstrate their sustainability benefit and unique innovation.

CATEGORY	ASSESSMENT ISSUE
1. Management	1.1 Sustainability leadership
	1.2 Environmental management
	1.3 Responsible construction management
	1.4 Staff and supply chain governance
	1.5 Whole life costing
2. Resilience	2.1 Risk assessment & mitigation
	2.2 Flooding and surface water run-off
	2.3 Future needs
3. Communities & Stakeholders	3.1 Consultation & engagement
	3.2 Wider social benefits
	3.3 Wider economic benefits
4. Land use & Ecology	4.1 Land use and value
	4.2 Land contamination & remediation
	4.3 Protection of biodiversity
	4.4 Change& enhancement of biodiversity
	4.5 Long-term management of biodiversity
5. Landscape & Historic environment	5.1 Landscape & visual impact
	5.2 Heritage assets
6. Pollution	6.1 Water pollution
	6.2 Air, noise and light pollution
7. Resources	7.1 Strategy for resource efficiency
	7.2 Reducing whole life carbon emissions
	7.3 Environmental impact of construction products
	7.4 Circular use of construction products
	7.5 Responsible sourcing of construction products
	7.6 Construction waste management
	7.7 Energy use
	7.8 Water use
8. Transport	8.1 Transport networks
	8.2 Construction logistics

Each issue defines a level of performance (the 248 Assessment Criteria), against which the assessed project demonstrates compliance (providing evidence) to achieve CEEQUAL credits. The Assessment criteria, which are listed in the tables that follow, provide clear guidance, and entitle the necessary specifics for the Issues to be addressed. These issues are mostly covered in Envision documentation based on the level of achievement.

CEEQUAL assesses to which extent a project has exceeded the statutory and regulatory minima. Therefore, projects need to go beyond legal requirements to get an award. For example, the grade ‘Pass’ suggests that the project’s environmental performance is approximately 30% above minimum legal compliance to the best practice represented by the highest possible score. The minimum standards must be achieved for a project to be awarded. However, to continue to drive sustainability best practice in infrastructure, it is expected that minimum standards to be extended in the future to cover other rating levels. The minimum standards have been pitched at a stretching but achievable level, given current performance levels in the industry. It is anticipated these will also rise in the coming years to ensure ‘Outstanding’ rated projects are truly outstanding.

Table 3.
Rating Levels

Rating	Version 6
Outstanding	≥ 90%
Excellent	≥ 75%
Very good	≥ 60%
Good	≥ 45%
Pass	≥ 30%
Unclassified	< 30%

It should be noted that a 100% score in the CEEQUAL assessment is not possible. Some issues conflict with each other, and a high score on one aspect may mean that points will not be scored on other aspects. For example, refurbishment of a historic bridge may call for materials to be brought from a long distance so that they match the existing materials. In contrast, another question rewards the project for minimizing the distance of transporting materials.

Weightings[42] are a fundamental part of CEEQUAL’s assessment methodology. It is a way of defining and ranking the relative impact of the Categories by taking account of the scale of impact and influence that projects under assessment typically have on various sustainability issues. Where necessary, these weightings may be adjusted to suit specific national or regional contexts through the completion of a formal weightings exercise.[43] The scores of the International version need to be weighted by the project team undertaking an international assessment to ensure the weighting is specific to the locality of the project. The Assessor also needs to take into consideration local regulations and practices in each country.[44]

In addition to the category scores, the overall score, and the final CEEQUAL rating and verified performance against individual assessment issues, it also provides users with a credible set of key performance indicators for a range of impacts across the project lifecycle.

As an international tool and because of the variety of activities and impacts that the system addresses, CEEQUAL does not define a single, overall boundary for a project; infrastructure assets exist as part of complex systems. As a result, the limit of a CEEQUAL assessment – what is included and what is excluded – is not always immediately obvious (e.g., National or

[42] The weightings have been derived from an assessment of both CEEQUAL Version 5 and BREEAM Infrastructure (Pilot) weightings with adjustments based on how the scope of each section has changed in CEEQUAL Version 6.

[43] A weightings exercise for Hong Kong was completed in 2013 and led to an International Manual with Hong Kong weighted scores, which is now in full use there. In addition, CEEQUAL -led weights surveys are under way in Sweden and other Nordic Countries and will be started shortly for the Gulf States Region. (Source: “International projects: Using CEEQUAL outside the UK and Ireland”, https://www.CEEQUAL.com/downloads/)

[44] The Assessment Manual for International Projects explains how this weighting process should be done, and the verification of the assessment includes verification of the weighting process.

International Standards to follow). Instead, the necessary boundaries vary by the assessment issues.[45]

Table 4. Example score and rating calculation for CEEQUAL v6

Category	Category weighting, %	Credits available (max.)	Credits available (scoping)	Credits achieved	Credits achieved, %
Management	11%	550	492	411	83.5%
Resilience	12%	600	526	453	86.1%
Communities and stakeholders	11%	550	480	445	92.7%
Land use and ecology	12%	600	550	502	91.3%
Landscape and historic environment	9%	450	212	212	100%
Pollution	8%	400	369	340	92.1%
Resources					
Materials, including waste	16%	800	725	703	97.0%
Energy and carbon (operational)	4%	200	101	92	91.1%
Energy and carbon (construction)	5%	250	188	173	92.0%
Water use	4%	200	138	122	88.4%
Transport	8%	400	341	267	78.3%
TOTAL	100%	5000	4122	3720	90.2%
Innovation		500	-	-	2.00%
CEEQUAL score					92.2%
Minimum standards achieved					Yes
CEEQUAL rating					Outstanding

2.1.3. ISCA® RATING SCHEME (VERSION 1.2) [46]

Developed by the Infrastructure Sustainability Council of Australia (ISCA),[47] the IS rating scheme is Australia's comprehensive rating system for evaluating sustainability across

[45] Project boundaries are defined within the technical requirements of the scheme by one or more of the following:

- Explicit geographical, temporal, functional limits
- National or Global standards
- National industry or government best practice guidance
- Specific CEEQUAL methodologies
- Specific minimum requirements for content or activities
- Consultation with relevant stakeholders
- Deferral to the judgment of a suitably qualified professional
- The judgment of the CEEQUAL assessor and project team

[46] This is the current version of the Rating Scheme. ISv2.0 was released 1 July 2018 and is in beta testing, to participate as a pioneer or pilot. (https://www.isca.org.au/is_ratings)

[47] ISCA is a member-based not-for-profit public and private industry council. ISCA is the peak industry body for advancing sustainability outcomes in infrastructure. ISCA's mission is 'Improving the productivity & livability of industry & communities through sustainability in infrastructure

design, construction, and operation of infrastructure projects. It is an industry-compiled voluntary sustainability performance rating scheme for all infrastructure asset classes (transport, energy, water, communication, waste). The IS rating scheme has been developed with the assistance and participation of representatives from several organizations. ISCA and its' committees have vetted the views and opinions expressed. Since launching in 2012, over $60 billion in infrastructure and civil works projects or assets across Australia and New Zealand have either been certified or registered for an IS rating.

ISCA encourages all industry stakeholders to use the tool (e.g., owners, developers, designers, planners, legislators, constructors, operators, etc.) to evaluate sustainability initiatives and potential environmental, social, and economic impacts of infrastructure projects and assets.

According to the scheme's framework, the infrastructure project or asset is assessed in terms of how it performs in each of the following fifteen categories that are grouped into six themes: Management & Governance, Using Resources, Emissions Pollution & Waste, Ecology, People and Place, Innovation.

Themes	Categories	Abbreviation
Management & Governance	Management Systems	Man
	Procurement & Purchasing	Pro
	Climate Change Adaptation	Cli
Using Resources	Energy & Carbon	Ene
	Water	Wat
	Materials	Mat
Emissions, Pollution & Waste	Discharges to Air, Land & Water	Dis
	Land	Lan
	Waste	Was
Ecology	Ecology	Eco
People & Place	Community Health, Wellbeing & Safety	Hea
	Heritage	Her
	Stakeholder Participation	Sta
	Urban & Landscape Design	Urb
Innovation	Innovation	Inn

Each category is divided into several credits, each of which addresses a specific aspect of sustainability performance within that category. Each credit has a series of benchmark performance levels that define increasing levels of performance for that credit from Level 1 to Level 3. These three levels approximately correspond to 'Commended, 'Excellent,' and 'Leading' performance.[48]

(source: 2018 Infrastructure Sustainability Council of Australia (ISCA). IS Technical Manual Version 1.2. November 2018.

48 In some cases, not all of the three levels are used.

Each credit has a weight shown as the 'score possible.' The 'points per level' is the 'score possible' divided by the highest level available for that credit. Similarly, the 'points achieved' are the 'points per level' multiplied by the 'level achieved' (as assessed and verified). Each credit weight reflects the importance of the credit and, therefore, its relative contribution to the sustainability performance of the overall project or asset. The category score is simply the sum of the 'points achieved' for each credit, and the total score is simply the sum of the category scores, giving points on a 100-point scale. The rating level is assigned based on the overall score.

Score	Rating Level
< 25	Not eligible to apply for a certified rating
25 to <50	Commended
50 to <75	Excellent
75 to 100	Leading

The IS tool includes a weightings assessment tool that identifies each project/ asset's main sustainability issues to make custom adjustments to the default credit weightings. It highlights, thus, valuable areas of importance specific to operations, stakeholders, and context. For example, if an asset uses significant energy in operating (e.g., a railway) and also in construction (e.g., due to lots of earthmoving and tunneling) then 'Energy and Carbon' is likely to be an issue of high Materiality. Therefore, it is sensible to increase the weighting of the Energy and Carbon credits compared to less material issues.

It is worth mentioning that the IS tool has separate manuals for Design & Construction and Operations & Maintenance phases, resulting in different assessment requirements. For the needs of this research, it is essential to start from the early stages of project development. Therefore, this paper focuses on the analysis of the tool's Design& Construction stage's assessment requirements.

2.2. ANALYSIS OF THE CERTIFICATION SYSTEMS

The analysis of both CEEQUAL and ISCA rating schemes focused on the documentation requirements and performance indicators related to the triple-bottom-line assessment as well as the review of the credits associated with the lifecycle stages and the lifecycle impacts of the project.

The analysis followed a 5-step methodology:

- Identify general similarities and differences between CEEQUAL and ICSA as compared to Envision.
- Study of the relation of credits to the project lifecycle stages.[49]

[49] In the present analysis, the life stages of infrastructure as "product" or service are examined, and not the phases of the project development. For the sake of the hypothesis under examination, the tools' credits will be categorized based on the Lifecycle stages they apply to material production, construction, operation and maintenance, and end of life.

- Study of the relation of credits associated with the triple-bottom-line assessment, i.e., identification of requirements for firmly documented environmental, social, and economic impact.
- Study of the relation of credits associated with the impacts of LCA.
- Identify credits with quantitative indicators.
- Identify credits with documentation requirements according to global or national standards.

2.2.1 ENVISION®

Envision is a framework that guides the decision making toward sustainable project performance. It can be implemented at each phase of project development, planning, design, construction, operation, and maintenance, until the end of the project's useful life. The planning phase is where performance goals are set, negative and positive impacts are identified and measured, and mitigation strategies and sustainable actions are established for the entire lifecycle of the project. The design phase is where the planning decisions are embedded. All Envision credits refer to the planning and design of infrastructure projects, as these will define the performance during delivery, operation, and maintenance. "Users are also challenged to consider the project's end of useful life, such as how its materials can be disassembled and upcycled."[50]

The first stage of a project's lifecycle, the production of the materials stage, is part of the credits in the Resource Allocation category, which addresses materials and resources.

Credit 'RA1.1 Support Sustainable Procurement Practices,' which is part of the required documentation, directly refers to the LCA-related ISO and EPDs as examples of qualifying requirements. The credit assesses a project team's commitment to identifying and selecting manufacturers or suppliers that implement sustainable practices based on selection criteria focused on environmental practices and social responsibility. A project's level of performance in this credit is determined by the calculation of the percentage of the total project materials by cost, weight, or volume that meet the sustainable procurement policy/program requirements on social and environmental impacts (ranging from 5% to 50%). Additionally, an inventory for all materials being tracked for sustainable procurement practices is requested as documentation, including a description of the material and the manufacturer or supplier, along with evidence of the disclosure requirements, material/supplier tracking forms, spreadsheets, and receipts/invoices.

The second stage of a project's lifecycle, the construction stage, is the stage of the actual delivery of a planned project. Envision assesses the degree to which and how the planned sustainable strategies have been implemented through credits that directly refer to construction in various categories, such as 'QL1.6 Minimize Construction Impacts' or 'RA1.4 Reduce Construction Waste' or 'RA2.2 Reduce Construction Energy Consumption', and also

[50] Envision Manual V3

several other credits that assess strategies over the entire lifecycle of the project or refer to the construction stage through their documentation.

Similar to the construction stage, the third stage of a project's lifecycle, the operation stage, is addressed by credits that refer directly either to operations or to the entire lifecycle of a project. Operation is the stage of use and actual performance of a project, and the majority of the credits are related to it since planning and design mainly aim at the operation stage). Moreover, Envision requests evidence that the stated performance goals are being met through the entire LC of the project by measuring sustainable performance. The Envision framework provides key sustainability performance indicators that can be monitored over the project's life.

Finally, the last stage of a project's Lifecycle, the end-of-life stage, is addressed by the credit 'LD2.4 Plan for End of Life' in the Leadership category (see Envision tables in the Appendix).

Envision allows measuring the sustainability of infrastructure projects against well-defined targets and indicators. While not an LCA model, it includes LCA as one of many assessment methodologies it requires, with proper documentation, and encourages project teams to extend their assessment to account for social and economic sustainability. It is worth highlighting that, as part of its evaluation criteria for targeting higher levels of performance, the credit 'LD3.3 Conduct a Lifecycle Economic Evaluation' requires:

- mapping and quantification of the social and environmental impacts of the project, and
- quantification and measurement of the broader financial, social, and environmental benefits of the project, using triple bottom line cost-benefit analysis (TBL-CBA) or sustainable return on investment (SROI).

To further guide users in mapping the social and environmental impacts, the credit's evaluation criteria provide a list of potential impacts.

Finally, it is worth mentioning that multiple Envision credits formulate questions that make evident the connections between the three sustainability dimensions.

Envision does not offer a set of prescriptive measures. Instead, it provides industry-wide sustainability metrics for all types and sizes of infrastructure to help users assess and measure the extent to which their project contributes to conditions of sustainability across the full range of social, economic, and environmental indicators.[51] The majority of quantitative indicators (metrics) correspond to the Resource Allocation category, related to the resources (primary or recycled) used in a project and the resulting outputs (emissions, waste).

The connections of Envision credits to LCA, TBL categories, and lifecycle stages have been mapped in tables in the Appendix.

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[51] Envision Manual.

2.2.2 CEEQUAL

CEEQUAL is organized in eight Categories (Envision has five categories) and 30 Assessment Issues (Envision has 64 credits). Within its assessment issues and criteria, project teams can identify typical LCA impact categories (GHG Emissions, Energy, Water, Soil, Biodiversity, Resilience Value, Public Health), all project LC stages (materials production, construction, O&M, end of life) and the sustainability issues that cover the environmental, economic and social realms.

Most of the assessment issues take into consideration the impact categories. In contrast, most of the credits in the Leadership category are related to LCA categories, implying that decisions are made according to LCA values. As expected, the resources category is the most relevant to the LCA impacts, including two Assessment Issues directly asking for ISO LCA (7.3.1) and Environmental Product Declarations (EPDs) (7.3.2). Regarding LCA values, CEEQUAL also gives high importance to Resource Efficiency Strategy/Plan (7.1.1 & 7.1.7) and circular economy business models (7.4.1).

Regarding the project lifecycle stages, CEEQUAL deals with all. Still, the assessment has to be done at the construction stage. 60% of its criteria, 148 out of 248, are related to the construction stage, whereas the end of life is related only to 8%. 26% and 28% of the criteria are for the operation and materials production stages (see CEEQUAL tables in the Appendix).

The regular updating and upgrading of the system have led to a progressive widening of its scope. More specifically, its latest version 6, which has been studied in the current report, introduces critical technical changes, where significant developments have occurred in the last few years and related to the whole lifecycle of the assessed project. Indicatively:

- Resilience – new requirements relating to natural hazards, security, climate change adaptation, and future needs.
- Land use and ecology – a metric-based approach to quantifying change in ecological value.
- Resources – updated requirements for Lifecycle assessments in the Assessment Issue ‘7.3 Environmental Impact of Construction Products’

The Term Contracts version that accompanies the Scheme description and Assessment Process handbook recognizes environmental performance post-construction over several years.

The whole life sustainability of infrastructure projects is directly assessed through assessment issues such as:

- Environmental Management through EIAs (1.2)
- Whole life costing (1.5)
- Broader economics assessment (3.2)
- Broader social Impacts assessment (3.3)

- Resource strategy and environmental LCAs of construction products (7.1 & 7.3)

CEEQUAL can be seen to complement the planning system and the clients' financial and economic models. By promoting the development of appropriate strategies, and the use of the environmental and social best practices, and then measuring environmental and social performance, CEEQUAL is now a tool that assesses the full sustainability credentials (Environmental, Economic, Social) of projects and contracts. It provides visibility to the social part of sustainable development because the scheme assesses how well the project shows consideration to social issues, which are made more tangible and creditable. The scheme encourages project teams to give back to the community.

Similar to the other two systems, CEEQUAL also tends to give more emphasis to environmental issues and considerations than to social and economic factors. A percentage of 75% are Assessment Criteria, which are related mostly to environmental issues. 42% and 19% are related to social and economic issues, respectively. Through its recent update, the system has developed from a singular focus on environmental management to a more reliable and more balanced focus on environmental, social, and economic factors. New criteria covering the TBL have been introduced, including:

- Environmental: Carbon management in line with PAS 2080 in '7.2 Reducing whole life carbon emissions.'
- Economic: Business models for a circular economy in '7.4 Circular use of construction products.'
- Social: Ethical labor practices in '1.4 Staff and supply chain social governance'.

(see CEEQUAL tables in the appendix)

CATEGORY	CRITERIA WITH INDICATORS
1. Management	5
2. Resilience	1
3. Communities & Stakeholders	3
4. Land use & Ecology	4
5. Landscape & Historic environment	1
7. Resources	30
8. Transport	3

Throughout the project, CEEQUAL looks at a consistent set of indicators. The main focus is given to criteria with quantifiable evidence. A percentage of 57% of all categories of CEEQUAL Assessment Issues include quantitative indicators (17 issues & 47 criteria). The scheme helps to interrogate and understand why sustainability performance is better in one area/project than another, and it identifies where improvements can be made (see CEEQUAL tables in the Appendix).

CEEQUAL criteria were also filtered through the officially recognized standards, widely accepted guidelines, or policies. It is observed that the majority of the standards/guides (37 out of 64 standards) are global. The total number of Issues that require evidence through official standards, policies, or guides is 57, which is 76% of all CEEQUAL Assessment Issues. In many cases, these guides or standards appear not as mandatory but only as examples of a recognized framework to be followed. Twenty-seven of these guides are intended for UK projects only (see CEEQUAL tables in the Appendix).

CEEQUAL is being updated based on updated context. For example, in the criterion '1.5 Whole life costing', the whole life cost assessment of the project is asked to be in line with ISO 15686-5:2017, or country-specific equivalents. In criterion '7.2.1 Carbon Management', CEEQUAL asks for standard PAS2080 and gives specific guidance to achieve extra points.

Despite standards and national guides, 'CEEQUAL International for Projects' also undertakes weightings exercises to suit the target country's cultural influences on sustainability performance and the environmental conditions in the location of the project. In addition to the UK and Ireland, CEEQUAL is being used in Hong Kong, Sweden, and other Nordic Countries and the Gulf States Region.

Transportation infrastructure projects involve land use, long-term investment, and a vast amount of resources (mainly materials and energy use), having severe impacts on the environment and possibly dislocation of people. CEEQUAL assesses all types of civil infrastructure projects paying emphasis to the main factors of transportation projects, such as:

- durability,
- community impacts during construction and operation (e.g., noise, dust, emissions),
- safety,
- access & mobility,
- resource efficiency,
- waste management,
- lifecycle costs,
- procurement & construction methods (construction periods are essential in transportation projects to keep the traffic going),
- specific context constraints (e.g., environmental/habitats constraints, heritage constraints, landscape constraints, etc.).

Additionally, CEEQUAL contains a category called "Transport," which "encourages the effective management of transport impacts from all modes of transport both during construction and operation. Transport impacts considered within this assessment include the movement of construction materials and waste, construction workforce transport, as well as disruption to other users of the transport network during the life of the asset. An emphasis is placed on designing out transport impacts wherever possible and consultation with the local community to create opportunities for an integrated transport system."[52] For example, in the criterion '8.1 Relationship to the transport network,' the project provides improved levels of service. It extends to all modes in a way that delivers improved integration with the networks of vehicles (cars, buses, trucks), bicycles, pedestrian, fauna, rail, aviation, and water.

[52] CEEQUAL Version 6. International Projects Manual. p. 182.

2.2.3. IS RATING SCHEME

Being widely used in Australia as a tool for rating sustainable infrastructure assets and projects, the IS tool touches upon all LCA impact categories (GHG Emissions, Energy, Water, Soil, Biodiversity, Resilience Value, Public Health) that are by definition directly relevant to sustainability. Numerous credits take into consideration more than half of the impact categories. In contrast, most of the credits in the Management & Governance category are related to all the LCA categories, implying that decisions are made according to LCA values. (see IS Scheme tables in the Appendix)

Both sustainability principles and LCA tools aim towards infrastructure projects that cater for all stages of their lifecycle. Looking at the IS tool, it is observed that the LC stages that are mostly addressed through all 44 credits are Construction Stage and O&M. As for the first and last stages of a project's lifecycle, these are also addressed but through less than 50% of the credits. It is worth noting that all credits under the theme of Management and Governance are related to all of the lifecycle stages.

The IS Tool credits were also studied as per their relevance to the three pillars of sustainability: economy, society, and environment, i.e., for the triple-bottom-line principles (see IS Scheme tables in the Appendix). IS touches upon all of these areas, so what was instead investigated was the genre of evidence required to prove that these areas are addressed. The main focus was given to credits with the most objective indicators, i.e., either metric evidence or evidence supported through officially recognized standards, widely accepted guidelines, or policies. The total number of such credits is 31, a relatively large number revealing that the project's performance can be objectively assessed through 75% of the credits. Regarding the metric evidence, it seems that it is required in more than half of IS Tool credits (26 credits of the total 44, see IS Scheme tables in the Appendix).

The IS theme where the most metric indicators are required is Emissions Pollution & Waste. The other type of robust and objective indicators is official guides, standards, or policies that are necessary for some credits' documentation. These indicators have a specific and structured framework to be followed and, therefore, be used as a guide for assessment.

Regarding the official standards, it is observed that the majority of them are related to environmental performance rather than social or economic sustainability. The total number of credits that require evidence through official standards, policies, or guides is 24. In many cases, these guides or standards appear not as mandatory but only as examples of a recognized framework suggested to be followed, for instance, in credit "STA-2. Level of engagement," which refers to stakeholder engagement, it is mentioned that" Several mechanisms are available to support the incorporation of stakeholder participation into infrastructure development. The most widely recognized in Australia is the International Association of Public Participation (IAP2) spectrum of public engagement. The IAP2 identifies several levels at which stakeholders can participate in decisions and a range of techniques that can be used to foster that participation." This way, it suggests an ISCA accepted framework that applies nationally to Australian projects. More than half of these guides are intended for Australian projects only. However, there are also international guides suggested in almost half of the cases. UK guides are slightly mentioned, as well.

The IS Tool can be applied to all kinds of infrastructure, including transportation infrastructure. Still, it does not give clear guidance regarding the potential impacts of each project for the transportation infrastructure system. However, through the required evidence and guidance of certain credits, it encourages sustainable infrastructure strategies to improve community health and well-being and to promote sustainable urban planning. Hea-1 credit (Community health and well-being) promotes active transport and public transport through the following strategies:

Active transport	**Access to active transport facilities**	Provision or upgrading of, funding for, or maintained or enhanced access to: • Off-road paths or on-road lanes, paths, or shared roadways that connect logically to the existing pedestrian and cycle network and give pedestrians priority. • An infrastructure that doesn't create a barrier to walking or cycling. • Secure, undercover bicycle parking spaces and end-of-trip facilities • Accessible covered public transport shelters • Reduction in off-street parking supply in areas with good accessibility to public transport.
Public transport	**Access to public transport facilities**	Provision or upgrading of, funding for, or maintained or enhanced access to: • Public transport stops or stations • Accessible covered public transport shelters • Design to Disability Discrimination Act (DDA) and Accessibility Standards • Accessibility assessments are undertaken on the design, the as-built infrastructure and during operation

Sustainable transportation is also indirectly addressed in credit Urb-1 through sustainable urban design. This credit (Urban design) rewards the adoption of best practice urban design principles and refers to the Australian Urban Design Protocol (AUDP). This protocol includes, among others, guidance for physical connections through sustainable transportation.

2.3. CROSS-COMPARISON OF THE THREE CERTIFICATION SYSTEMS

The three project level rating systems aim to help the construction industry identify and quantify sustainable approaches that are beneficial to infrastructure projects. In addition to serving current needs, sustainability issues occur at the systems, industry, and project levels. Knowledge and understanding of the complexity of the systems, their interconnectedness, and the implications of decisions over the long term are essential in delivering sustainable development and affect the effectiveness of project-level tools and frameworks.

2.3.1 GENERAL OBSERVATIONS

There are commonalities among Envision, CEEQUAL, and IS to ensure and assess sustainability in infrastructure projects. They all include the main aspects of sustainability emphasizing particular criteria. Process and outcome assessments are often combined in these approaches, in the way in which they address the different sustainability needs that appear at various stages of the project's lifecycle. Furthermore, the importance given to management in the sustainability assessment is different.

All tools include materials and resource-efficient use, water, ecology, people and places, and land use. Also, climate change risk and adaptation actions and a focus on heritage and cultural aspects are included. All schemes also include elements such as quality of life and sustainable growth and development, reflecting their attention on the planning phase of the infrastructure project.

A high-level matching of the CEEQUAL and IS schemes with Envision categories is presented below. A general observation is that each of the Envision categories is related on average with three CEEQUAL categories and two of the IS themes based on the intents of the corresponding credits. It should be noted here that both CEEQUAL and IS rating schemes include an additional category named "Innovation," that can be related to any of the other categories/themes when the project or asset exceed any credit requirements. It is the equivalent to Envision innovation credits that appear in all Envision categories.

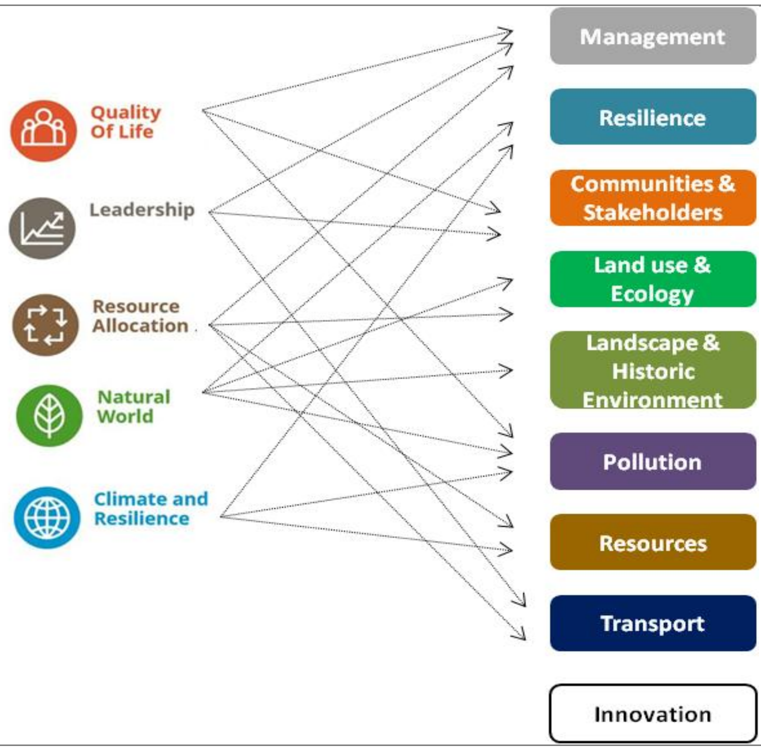

Fig.10: Correlation of Envision Categories (left) with CEEQUAL Assessment Issues (right)

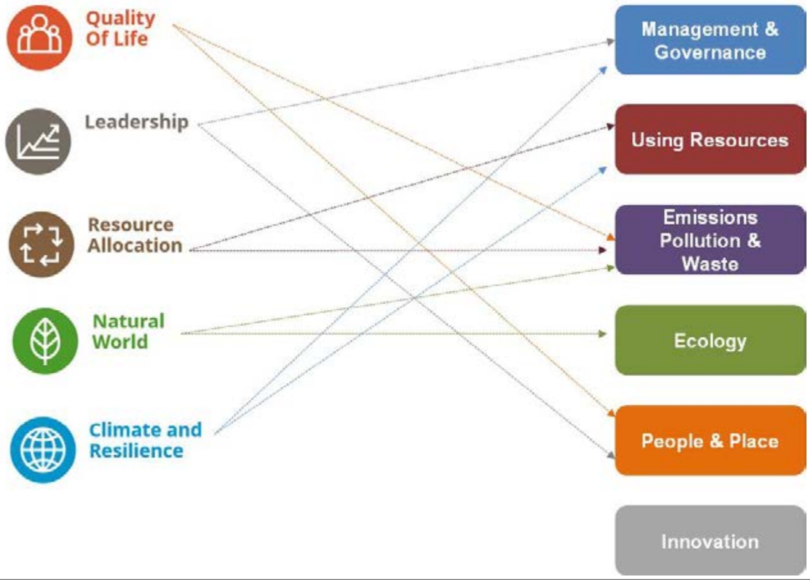

Fig.11: Correlation of Envision (left) Categories with IS themes (right)

At first glance, the IS rating scheme structure seems similar to Envision in terms of scale. Both tools have credits classified under five main themes (Envision themes are referred to as "categories') serving approximately the same sustainability objectives.[53] Also, the number of credits in IS and Envision is 44 and 64, respectively, both convenient numbers for handy assessment tools. CEEQUAL, on the other hand, is less compact. It organizes its 30 Assessment Issues, which can be related to the other systems' "credits," into 8 Categories (instead of 5 that IS and Envision count). Furthermore, CEEQUAL has the 248 Assessment Criteria, that address sustainability issues in a very analytical manner and sometimes are repeated based on whether their points were earned, for example, during the consideration/planning or implementation stages, or during project construction or operation.

Regarding the assessment methods, just like Envision, both CEEQUAL and IS include technical manuals with guidance and lists of evidence for each credit. In all tools, each credit has an aim and assessment criteria with the respective description. The difference between the tools is how they benchmark sustainability. Each of the IS credits has three benchmark performance levels instead of five levels that appear in the case of Envision, whereas in CEEQUAL, there are no levels, just different earning points, called "credits."

All three tools request evidence for all three sustainability pillars and all project lifecycle stages. The table below shows which of the main documents/proof are required by which assessment tool. "Main documentation" are documents that function as evidence to more than one credit/criterion. As a result, if a project team prepares these documents will save time and effort when aiming for a sustainability assessment and award.

Table 5. Main documentation required in each of the Certification systems

No	MAIN DOCUMENTATION			
	DOCUMENT	ENV	IS	CEEQ
1	Asset Management Plan (i.e., pavement management plan)	☑	☑	
2	Construction & Operation Community Impacts Assessments & Mitigation Plans (noise, vibration, dust, etc.)	☑	☑	☑
3	Construction Logistics Plan (CLP)	☑		☑
4	Construction Management Plan (including waste)	☑		☑
5	Contamination Prevention, Control & Action Plans for O&M	☑	☑	☑
6	Contractor Quality Control Plan	☑		
7	Corporate Responsibility Reports (environmental & social)			☑
8	Cost-Benefit Analysis (CBA)	☑	☑	
9	Cost-Effectiveness Analysis		☑	
10	Deconstruction Plan	☑	☑	
11	Ecological Assessment	☑	☑	☑
12	Ecological Management Plan	☑	☑	☑
13	Ecology Report		☑	
14	Economic impacts & benefits assessment			☑
15	Energy & Carbon Footprint Report		☑	
16	Environmental Impact Assessment (EIA)	☑	☑	☑
17	Environmental Management Plan (EMP) for the whole project LC	☑	☑	☑
18	Environmental Management System (EMS)			☑
19	Ethical Labor Sourcing Standard (ELS) self-assessment			☑
20	Ethical Trading Initiative (ETI) Base Code – Principles of the Implementation report			☑
21	GHG Emissions Assessment	☑	☑	☑
22	Habitats Assessment	☑	☑	☑
23	Hazard & Operability (HAZOP) Assessment			☑
24	Health & Safety Plan			☑
25	Health Impact Assessment (HIA)	☑	☑	☑
26	Heritage Management Plan		☑	☑
27	Landscape Character & Visual Impact Assessment	☑	☑	☑
28	Landscape Constraints Plan	☑		☑
29	Landscape Management Plan (LMP)		☑	☑
30	Landscape/Townscape Assessment & Plan	☑	☑	☑
31	Lifecycle Cost Assessment (LCCA)	☑		☑
32	Lifecycle Assessments (LCA)	☑	☑	☑
33	Maintenance & Monitoring Plans	☑	☑	☑
34	Materials Credentials Report (including Environmental Product Declarations (EPDs)	☑	☑	☑
35	Materials Resource Efficiency Plan			☑
36	Quality Control Plan	☑		
37	Remediation Strategy & Action Plan	☑	☑	☑
38	Resilience Plan	☑		☑
39	Resources Management Plan	☑	☑	☑
40	Resources Strategy Report (based on an LCA & the cradle-to-cradle principle)			☑
41	Risk Assessment		☑	☑
42	Site Suitability Study			☑
43	Social Impact Analysis / Assessment	☑		☑
44	Soil Management Plan		☑	☑
45	Stakeholder Engagement Plan	☑	☑	☑
46	Stormwater Pollution Prevention Plan	☑		
47	Sustainability Management Plan (high level/project-specific)	☑		
48	Sustainable Procurement Plan (including copies of the Procurement docs & contracts)	☑	☑	☑
49	Trade-off analysis	☑		
50	Transport Impact Assessment (TIA)	☑		☑

51	Value Engineering Reports	☑		☑
52	Waste Management & Monitoring Plan	☑	☑	☑
53	Water Management & Monitoring Plan	☑	☑	☑

As already mentioned, a crucial part of SLCA methodology is stakeholder engagement. Stakeholder engagement is one of the dimensions in which all three tools promote high performance: When an inclusive, representative group of stakeholders is engaged throughout the project, the results satisfy the broadest possible swath of the community. Project team collaboration with stakeholders also helps identify the most comprehensive practical array of sustainability alternatives for consideration, including byproduct synergies and social benefits. Specific credits are:

- Envision: LD1.3 Provide for Stakeholder Involvement
- CEEQUAL: 3.1 Consultation & engagement
- IS scheme: Sta-1 Stakeholder engagement strategy

To ensure early and sustained stakeholder engagement and involvement in project decision making, a significant number of the tools' credits rely on documentation from a robust stakeholder engagement process.

2.3.2 TRIPLE-BOTTOM-LINE RELATED FINDINGS

The environmental dimension prevails in the three systems. It is mostly considered through the GHG emissions, habitats and biodiversity preservation, pollution (air, lighting, noise, and water), energy consumption, climate risks (flooding), land use, and resource management. The three systems deal with the social dimension through general community issues such as stakeholders' engagement, public health, well-being, and heritage. Management covers aspects such as procurement, project and risk management, decision-making processes, and regulations and policies. Finally, the economic pillar focuses mainly on the whole lifecycle project costs, procurement practice, and resource efficiency.

Regarding weighting, all points awarded by the tools can be grouped into the TBL. "The average trend in the three systems reflects that Environment is the most relevant category with around two-thirds of the total score, while Society and Economy represent around 20% and 10% of points, respectively."[54] Despite CEEQUAL and IS requiring a higher score to reach the top level of achievement with 75%, Envision, which only needs 50% for top achievement, puts a strong focus on some criteria (e.g., restorative actions) that allocate points and thus the percentage more demanding. An indicator analysis of the tools suggests the balance across the TBL is similar to the three, with IS putting a stronger focus on performance-based measures than the other tools.

Similar to Envision, IS has a focus on stakeholder and community involvement in sustainability actions and decisions. CEEQUAL assesses how well the project shows

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[54] Jose Manuel Diaz-Saratoga, Daniel Jato-Espino, Badr Alsulami, Daniel Castro-Fresno. "Evaluation of existing Sustainable Infrastructure Rating 1 Systems for their application in developing countries". Article in Ecological Indicators 71:491-502. December 2016.

consideration to social issues by making them tangible and creditable. The scheme encourages projects to give back to the community.

From the economic perspective, more evidence/issues need to be added to all three tools related to projects' supportive role to sustainable growth and economic development, their financial viability, and their contribution to the reduction of poverty. The Envision rating system includes a Yes/No checklist to inform early thinking as well as a full rating tool that asks for the application of economic tools that calculate the return on investment, develop the business case and value externalities.

2.3.3 PROJECT LIFECYCLE

All three systems provide guidance and a good basis for integrating sustainability over the whole lifecycle of infrastructure projects (materials production, construction, operation, end of life). IS, in particular, contains a separate manual only for operation. The difference between the three tools is to what extent their criteria assess each lifecycle stage. Generally, all three give more emphasis at the construction stage, then at the operation and lastly at the materials production and the end of life. It is observed that the management issues that are emphasized in the three tools through specific categories called Management (IS & CEEQUAL) and Leadership (Envision) are broad and apply simultaneously at all the lifecycle stages of the projects. Procurement practices or stakeholders' engagement, for example, are assessed in these categories and are applicable to all lifecycle stages.

Currently, the broadening of the sustainability scope covered by the three tools and the consideration of the context of the project when addressing questions of sustainability, are two issues that are being addressed in the on-going development of the tools. With the release of new versions, it is evident that the tool developers have incorporated lessons learned from within their stable projects and extended their tools to account for technical clarifications, broader sustainability scope, and in some cases, extension across new infrastructure project types and scales and lifecycle stages.

2.3.4 ADDRESSING TRANSPORTATION INFRASTRUCTURE

The three assessment tools do not present specific manuals/guidance or particular sets of credits/indicators for specific infrastructure projects (i.e., transportation). They intend to be applied to all types of infrastructure projects using the same structure, guidance, and evidence. As a North American based tool and familiar to the research team, Envision was chosen as the basis to offer the integration of sustainability and lifecycle assessments to transportation infrastructure projects. The application of the proposed tool to transportation projects was requested by the sponsor of this research project. It can be considered as a first step, which will be followed by applications in other types of infrastructure projects to eventually lead to a general tool for all types of infrastructure projects.

CHAPTER 3.

INPUT FROM THE ONTARIO MINISTRY OF TRANSPORTATION’S WEST REGION

The Ontario Ministry of Transportation's West Region, provided documentation and insights at both the agency-level and at the project-level practice on the sustainability of transportation projects, based on years of cumulative experience and on-going research.

3.1. AGENCY-LEVEL PRACTICE – MTO'S WEST REGION

The Ontario Ministry of Transportation (MTO) is responsible for the construction and maintenance of highways and bridges in Ontario, which consists of about 40,000 km of highway lanes, 2,900 bridges, and 2,000 culverts which span over 3 meters. Among the 2,900 bridges, there are 1,060 bridges over water, 286 over railroads, and 1,508 highway bridges. Regional Structural Sections manage structures inventory with support from other Regional Sections, the Structural Standards and Specifications Office (previous Bridge Office), and the Investment Planning & Performance Office. The role of regional engineers includes activities such as inspection, identification of needs, prioritization, planning for rehabilitation and expansion, detailed design, construction, and maintenance.[55] Construction work in the 2000s focused mainly on rehabilitation.

MTO has a mandate to look into LCA. It recognizes LCA's value in infrastructure decision-making, such as the benchmarking pavement environmental performance, to help set GHG targets. It also considers making LCA a requirement in MTO design/bid/build procurement requirements, at least for major construction and reconstruction projects.[56]

3.1.1. ASSET MANAGEMENT

Though MTO does not officially undertake environmental LCA, the lifecycle of projects related issues are part of the decision-making process: the service life of the project and the estimated maintenance cycles during its life span for the desired level of serviceability, along with associated costs and impacts. The expected service life of an MTO typical bridge is 75 years. However, based on experience, Kris Mermigas, Head of Structural Standards and Specifications Office, explains the actual service life can reach up to 100 years using quality materials and construction methods, as proven by historical records and experience. Infrastructure deterioration is a function of design, material properties, traffic and climate-related degradation, and maintenance. High traffic volume, heavy trucks, freeze/thaw cycles, and exposure to salt for winter maintenance reduce a bridge's lifespan. It is worth noting that MTO bridges built between 1950 and 1980 have an average life span of 60 years, highlighting that enhanced strategies have prolonged the service life of newer bridges.

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55 Au, J., Mermigas, K., Brossard, J., Kroely, B., Schorn, S., and Akhtar, N. "Ministry of Transportation Ontario Bridge Management System 2018," paper for the 10th International Conference on Short and Medium Span Bridges, held in Quebec City, Canada in July 31 – August 3, 2018.

56 Athena Sustainable Materials Institute, the "LCA for Roadways and Bridges Roadmap for greater adoption of LCA as a decision-support tool," March 2018.

Routine maintenance is usually preventative maintenance and minor repair work carried out by bridge crews to prolong the bridge's life. Repairs are of two types, either routine structural repairs or emergency repairs.

Regular maintenance, repair, and rehabilitation can mostly offset the impacts of traffic volume, freeze/thaw cycles, and corrosion along with exposure to de-icing salt. A typical rehabilitation includes barrier replacement, concrete refacing at piers or abutments, bearing replacement, and reconstruction of the deck ends. In many cases, the construction duration of rehabilitation is almost the same as for a replacement. For small bridges, the cost of rehabilitation can be considerable due to fixed costs. The unit cost per m² of deck area for bridge rehabilitations in Ontario is approximately 27% of the cost of replacement.[57]

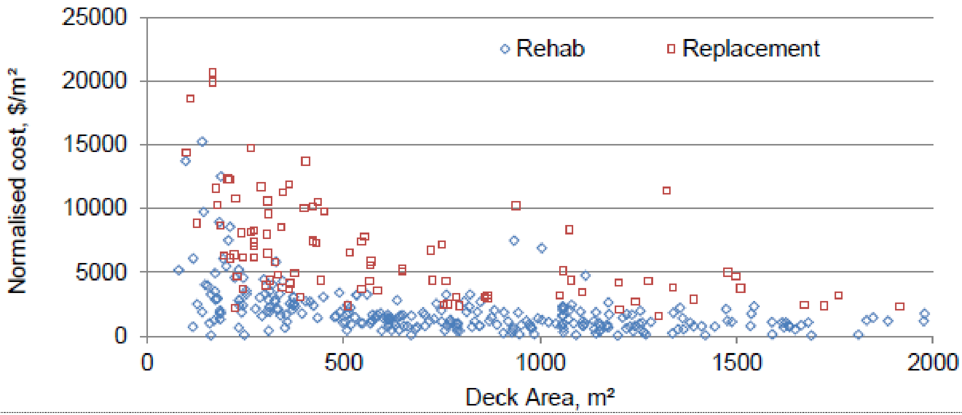

Fig.12: Cost of bridgework tendered 2009 to 2014 (costs are average of lowest three bidders, for bridges with less than 2000sqm) [58]

During its lifespan, a bridge undergoes a series of scheduled maintenance treatments:

- deck replacement: 50 years and aiming for 75 years for newer bridges,
- waterproofing replacement: 25-30 years,
- milling and replacing top asphalt surface: 15 years, and
- replacement of barrier wall: 40 years.

MTO has systems and procedures to ensure that the bridges within its highway system are safe and in a good state; bridge inspections are conducted. The required maintenance, repair, rehabilitation, and replacement work is implemented on a timely basis. A bridge's condition is monitored through biannual visual inspections, 'close-up' visual assessments of each critical element of a bridge to evaluate its material defects and performance deficiencies, based on a severity and extent philosophy of rating bridge elements, as documented in the Ontario Structure Inspection Manual (OSIM). [59] The elements that are

[57] Konstantinos Kris Mermigas, "Evolution of Bridge Practices in Ontario, Canada," Paper prepared for presentation at the Structures Session of the 2018 Conference of the Transportation Association of Canada, Saskatoon, SK

[58] Ibid.

[59] MTO Inspection Manual

rated are: the deck top, deck soffit, barrier wall, expansion joints, and concrete/steel beams. In some cases, sensors are attached to cracks and essential structural elements of the bridge and send real-time alarms.

If severe material defects or performance deficiencies in the individual elements of a bridge indicate that further investigation is required, detailed specialized studies follow.[60] Critical safety issues are flagged during inspections, and remedial work is carried out as soon as feasible.

To ensure a more efficient management of the inventory of provincial bridges and support the inspection process, MTO uses the Ontario Bridge Management System (OBMS) database. The system was developed based on a technology from the mid 90's and since 2018 has been replaced by a new commercial-off-the-shelf Bridge Management System by Sixense. Sixense's product, the ScanPrint® Infrastructure Management Solution (IMS), is web-based software that was configured to a final BMS solution that fulfills MTO processes. The system was set up with existing MTO legacy-data and contains basic inventory data, inspection data, work history data and documents such as photographs from inspections, reports and engineering drawings.

Inspection data are based on a visual condition state inspection as well as on the results of field-testing programs such as half-cell corrosion potential surveys. The behavior of the bridge components is based on Markovian deterioration models that can be modified through knowledge-based modification factors".[61] MTO has compiled an extremely valuable historical database of inspection reports. This database enables engineers to make predictions about structure needs, improve design and construction details based on performance, and in the event of an emergency, to quickly access detailed information on a structure or a group of similar structures.[62]

As of 2018 there were "over 2,000,000 records in the system with almost 517,000 inspection photos, 70,000 engineering drawings and 12,200 reports stored in the database." The information is easily searchable, viewed and filtered by users through a

[60] Thorough investigations include (source MTO Inspection Manual):
- a comprehensive, complete bridge condition survey
- non-destructive delamination survey of asphalt-covered decks
- substructure condition survey
- detailed coating condition survey
- underwater investigation
- fatigue investigation
- seismic investigation
- structural evaluation

[61] Paul D. Thompson, Tony Merlo (MTO) Brian Kerr, Alan Cheetham, Reed Ellis (Stantec), "The New Ontario Bridge Management System," TRB Transportation Research Circular 498,

[62] Au, J., Mermigas, K., Brossard, J., Kroely, B., Schorn, S., and Akhtar, N. "Ministry of Transportation Ontario Bridge Management System 2018," paper for the 10th International Conference on Short and Medium Span Bridges, held in Quebec City, Canada in July 31 – August 3, 2018.

user-friendly interface.[63] One of its key capabilities is that inspectors' recommendations for maintenance items can be tracked until completed.

The System contains physical and historical information of each bridge, such as length, number of spans, size of each bridge element, the results from inspections, rated from poor to excellent. Using this information, the System calculates a single value called the Bridge Condition Index, a measure of a bridge's overall structural condition and its remaining economic value expressed on a scale of 0 to 100. A Bridge Condition Index of 70 or above indicates that the bridge is in good condition.

Table 6. Bridge condition index

Rating	Maintenance schedule
Good: BCI Range 70 -100	Maintenance is not usually required within the next five years
Fair: BCI Range 60 -70	Maintenance work is usually scheduled within the next five years. This is the ideal time to schedule major bridge repairs to get the most out of bridge spending.
Poor: BCI Less than 60	Maintenance work is usually scheduled within one year.

In 2006, MTO developed a Bridge Priority Tool for major yearly bridge repairs and rehabilitation and standardized the different priority-setting methodologies used in various regions. The tool's development was part of a commitment that MTO made in response to a recommendation in the *Office of the Auditor General of Ontario*, as stated in the 2004 Annual Report. The tool calculates a Priority Index for each bridge by modifying the Bridge Condition Index value after examining the condition of five critical bridge elements: the deck top, deck soffit, barrier wall, expansion joints, and concrete/steel beams. Each of these critical elements is assigned a "need threshold" and a weight (the importance of the component to the entire structure). Bridges with a Priority Index of less than 70 are considered to be on the five-year rehabilitation list; bridges with a Priority Index of less than 60 are considered to be a "now need," which means they should be rehabilitated during the next construction season.

The Bridge Priority Tool also estimates the cost of future bridge repair and rehabilitation needs. Each of the province's regions is supposed to use these rankings to develop a five-year capital work plan for repair and rehabilitation work. These regional plans become part of the larger provincial work plan.[64]

It is interesting to explore further the decision-making process for MTO, the alternatives, and the trade-offs that MTO has to balance during this process to ensure a cost-effective

[63] Ibid.
[64] 2009 Annual Report of the Office of the Auditor General of Ontario

solution aligned with the Ministry's priorities. The focus will be given on some of MTO's top strategies with multiple benefits across categories, environmental, social, and economic:[65]

- Use of premium materials, redundant corrosion protection systems, and integral abutment jointless details to increase the durability of structures, extend service life, and minimize maintenance needs.
- Use of accelerated construction method, enabled by the use of prefabricated components that reduced construction impacts to the neighboring communities and increased work zone safety.

3.1.2. USE OF LIFECYCLE COSTING

MTO undertakes Life cycle Cost Analysis for its bridge projects. It has a guiding document for completing a financial analysis of alternatives for rehabilitation or replacement projects, the Structural Financial Analysis Manual (SFAM), last updated in 1993. The manual provides parameters for lifecycle cost analysis and cost/benefit analysis. SFAM aims to guide the selection of the most economical option for rehabilitation or replacement based on:

- Capital costs (replacement cost / rehabilitation cost)[66]
- Lifecycle (usually the time between two successive replacements or rehabilitations)
- Residual life (useful life at the end of the considered time- period.
- Future maintenance costs
- Estimated residual life without remedial work

The manual presents the available rehabilitation treatment options and associates them with costs and life spans, i.e., how long they extend the structure's useful life. However, according to Kris Mermigas, Head of Structural Standards and Specifications Office and Craig McLeod, Senior Structural Engineer, Regional Office's Structural Section: this LCC guidance "*is not calibrated to the way we make decisions. LCC is a cost-oriented document, strictly based on lowest present value of all future costs using an unfavorably high discount rate, which in reality suggests deferring work and spending less on the asset now, contrary to many sustainability objectives. This appears to be the main reason that LCCs are commonly omitted as the results don't align with the way we actually make decisions on infrastructure.*"

The document was created in a period of budget restraints, while, since 2014, there has been more public investment in infrastructure. With increased investment, the objective of infrastructure management has shifted to maximize the return on the investment, placing additional value on a bridge and extending its useful life. E.g., for structures that could undergo a significant rehabilitation but border on the need for replacement, the MTO considers replacement if there are clear benefits. Benefits include reduced risk of unknown

65 These strategies were among the ones implemented on the small replacement bridge project that will be used to cross-examine the proposed by the research framework.

66 Includes the engineering design cost, the construction cost, including traffic and environmental protection costs and miscellaneous costs such as demolition/ right-of-way/ approaches/ utilities/ stream diversion/ detours etc.

conditions (associated with an existing structure), the longer service life of the asset, less future traffic disruption, less total traffic disruption over a given Lifecycle, design for durability, e.g., integral abutment details, corrosion protection, and premium materials), potential geometric improvements to the roadway alignment, and the potential for functional enhancements.[67]

3.1.3. MATERIAL SELECTION TO REDUCE INFRASTRUCTURE DEGRADATION

Top priorities of the MTO are the safety of the traveling public and the safety of workers during construction and the quality of construction. These are directly connected to infrastructure degradation, service life, and maintenance schedules and associated costs.

MTO's practice in terms of specifying properties of materials is risk-based to provide confidence in the performance of materials and products. Quality assurance is an inherently scalable activity driven by, among other considerations, an organization's tolerance for risk, material/product variability, and cost. However, practices acceptable for one may not be suitable for another, e.g., the use of stainless-steel reinforcement is not an obvious choice for all.

Bridge longevity is integral to bridge design practices in Ontario based on lessons learned through a history of rehabilitation and legacy.[68] MTO makes a conscious choice of enhanced durability of materials to reduce the risk of short- and long-term failures that could lead to increased maintenance costs, service interruptions, and safety hazards; however, avoiding disproportionate, unnecessary costs.

The requirement for bridge deck waterproofing since 1978 is an example of how lessons learned have helped MTO to produce better quality bridges. MTO realized that the exposed concrete bridge decks, as practiced until then, resulted in delamination and spalling on bridge decks due to high chloride content from de-icing salt. The service life of bridges has been significantly prolonged.

[67] Konstantinos Kris Mermigkas, "Evolution of Bridge Practices in Ontario, Canada," Paper prepared for presentation at the Structures Session of the 2018 Conference of the Transportation Association of Canada, Saskatoon, SK

[68] MTO Inspection Manual

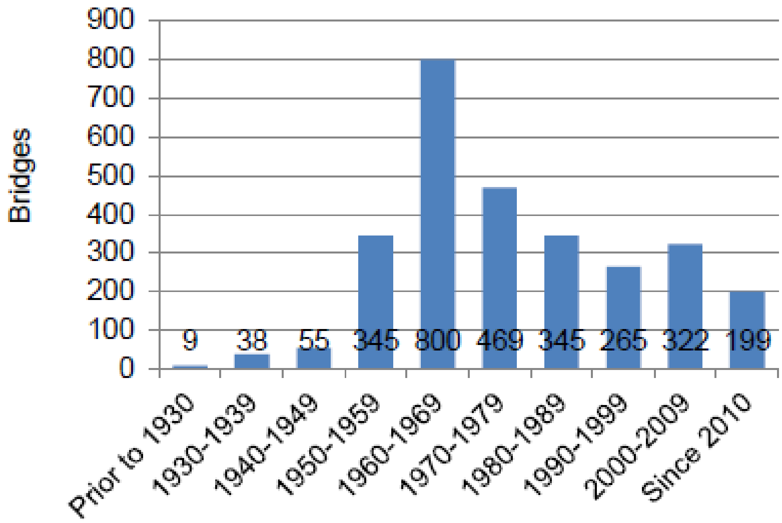

Fig.13: A decade of Construction of Ontario's provincial bridges (2016 data) [69]

MTO's Materials Engineering and Standards office has high standards in terms of materials, compared to common practices. According to Mermigas, *"we are going from the base that we are familiar with, and we are adding to this, we do not want to create a problem that does not exist."*

MTO's Materials Engineering and Research Office (MERO):

- ensures that quality materials and products are used,
- facilitates the use of innovative materials and processes,
- provides material standards, policies, and guidelines for acceptable performance, and
- provides specialized laboratory testing and technical expertise.

Premium stainless-steel reinforcement and Glass Fiber Reinforced Polymer Reinforcement (GFRP) are examples of MERO's Concrete section research to improve corrosion resistance. By specifying stainless steel, the intent is to achieve a long maintenance-free period. It is also the preferred option for bridges that are not easily accessible for future maintenance, such as in high traffic areas, as rehabilitation requires the closure of lanes and road shoulders to traffic.[70] Although there is a premium[71] in stainless-steel compared to black or

[69] Konstantinos Kris Mermigkas, "Evolution of Bridge Practices in Ontario, Canada," Paper prepared for presentation at the Structures Session of the 2018 Conference of the Transportation Association of Canada, Saskatoon, SK.

[70] Ministry of Transportation Materials Engineering and Research Office Concrete Section, guidelines for inspection and acceptance of stainless-steel reinforcement on the contract site, June 5, 2001

[71] The cost per ton for stainless rebar is $13,500, while for midgrade rebar is $10,725 and for black rebar is $2,250

epoxy-coated reinforcing steel, it is cost-effective over the long term because of less corrosion.[72]

MTO has used stainless steel reinforcement since 1996. After an experimental stage where its effectiveness was demonstrated, stainless steel reinforcement was used in concrete structures on corridors with high traffic volumes. The policy introduced in 2000 extended the use of stainless-steel reinforcement to structural components with the most severe exposures in terms of likelihood of corrosion damage, such as in exposed concrete splash zone or tidal zone. The corrosion protection policy prescribes the minimum level of detailing for durability on conventional bridges and always includes waterproofing of bridge decks.

The two grades of stainless-steel permitted in Ontario for all directly exposed areas are 316LN stainless and duplex 2205. Other grades are used as part of the corrosion protection policy for components that are not directly exposed to chlorides. For example, Duplex 2304, a medium grade steel, is used because of the construction joints in the deck as a result of the modular construction method.

Due to the additional cost of premium reinforcement, it is used selectively to avoid disproportionate and unnecessary expenses. So, a typical two-lane rural highway bridge may not get it. "*These strategies were developed based on lifecycle financial analysis. Given the higher unit price of Premium Reinforcement, the Ministry uses it judiciously and only in those components for which a lifecycle benefit can be demonstrated.*"[73]

The example of the replacement of the Bayfield River bridge demonstrates that the use of higher-grade reinforcement resulted in a reduced thickness of the bridge deck, thus reducing the quantity of materials and the requirements for future maintenance, with both environmental and cost benefits.

A 2018 study provides reasonable optimism that the current waterproofing system **ensures a service life of 100 years for bridges constructed after the 1980s.**[74] MTO studied the performance of hot poured bituminous membrane to waterproof bridge decks, using chloride profiles from condition surveys of 53 bridges built between 1973 and 1986. The study proves that it meets the MTO's expectations for preventing corrosion of reinforcing steel. The study showed, at a 95% confidence interval, that the concentration of chlorides at the minimum cover to reinforcement (50 mm depth) will not exceed the threshold for the initiation of corrosion at the end of the third cycle of rehabilitation, 75 to 100 years from initial construction. For steel bridges, **MTO has had a good experience with**

72 Ministry of Transportation Materials Engineering and Research Office Concrete Section, guidelines for inspection and acceptance of stainless-steel reinforcement on the contract site, June 5, 2001

73 MTO Structural Manual, September 2016.

74 Bridges in Ontario, built between 1950 and 1980, have an average lifespan of 60 years.

weathering steel for at least 50 years. The formulations followed technical reviews in Canada and the USA, changed in the 90s to address shortcomings.

Through the mid-90s, high strength concrete was encouraged, but the net effect on durability was considered questionable due to early age shrinkage and premature cracking. Currently, MTO's specifies 30 MPa concrete, with lower permeability, which is achieved through additives that reduce the water content. Ultra-high-performance concrete (UHPC) is useful for joining precast components, a weak link of older prefabricated bridges.

Regarding **asphalt,** in March 2017, MTO increased the specification requirements for pavement compaction and pavement smoothness. MTO considers pavement smoothness to be a critical factor that benefits comfort, improves the environment (less fuel consumption), and extends the road's life.[75] According to MTO's research, the increase in asphalt compaction is expected to increase by 10% to 30% the pavement life. The 25% reduction in recycled engine oil, determined by the ash content, will decrease the risk of cracking during cold temperatures. MTO, through its pavement design standards, makes projects more durable and thus more sustainable. These practices allow MTO to use less energy, emit fewer greenhouse gases, and use fewer raw materials.[76]

It is worth noting that MTO suspended the use of recycled asphalt pavement in the top layer of pavement where long-lasting pavement is required, with the justification that highways that last longer have a positive effect on environmental sustainability and generate fewer greenhouse gases.[77]

3.1.4. STRUCTURAL SYSTEMS TO REDUCE INFRASTRUCTURE DEGRADATION – INTEGRAL ABUTMENTS

Over the last two decades, MTO has issued guidelines to increase the use of structural continuity and jointless details in new construction and rehabilitation to improve durability. Through the 1990s, standards were introduced for integral abutments, semi-integral abutments, and flexible links slabs between simply-supported spans.

Jointless details are currently integral to bridge design in Ontario, and the use of integral abutments in bridges is the first preference for bridges that meet the specifications.[78] More than half of Ontario's bridges are rigid frames or incorporate integral or semi-integral abutments, integral piers, or link slabs. Experience indicates that integral abutments and rigid frame bridges have the lowest maintenance and rehabilitation costs, due to the elimination of costly and maintenance-prone expansion joints and bearings. Moreover,

[75] Ministry of Transportation— Road Infrastructure Construction Contract Awarding and Oversight Follow-Up on VFM Section 3.10, 2016 Annual Report.

[76] MTO, Sustainability Insight.

[77] Provincial Highways Management Division, Ministry of Transportation, Action Plan for Highway Construction Contracts and Oversight, February 17, 2017

[78] There are certain constraints with the feasibility of incorporating integral abutments such as skew, length, and others.

they have a lower initial cost than conventional abutments because of simpler formwork and no bearings. They also perform better in earthquakes.

The design of integral abutments has been evaluated in terms of performance through systematic visual monitoring. The encouraging results give confidence that bridges with less than 100m in length have performed well. The benefits of the method can be summarized as:

- less construction cost than conventional abutments,
- less construction time because of fewer concrete pours,
- less material, single rows of piles because of less bending in the abutments, and less overall materials,
- zero- maintenance since there are no replaceable bearings and joints.
- more durable, efficient structural System,
- more resilient, because of structural continuity.

3.1.5. INNOVATIVE STRATEGIES - ACCELERATED BRIDGE CONSTRUCTION

Accelerating bridge construction (ABC) on-site is a current focus for MTO. Canada's weather window for in-situ construction varies between 5 months in Northern Ontario to 8 months in southern Ontario. These constraints make schedule critical, and a single-construction period for a project is highly desirable. Many of the typical small to medium-sized bridge replacement projects require a full season to complete—the construction duration doubles or triples when the bridge is in use.

The concept of ABC initiated when several bridges on Highway 401 were identified as condition deficient and functionally obsolete, and a rigorous bridge replacement strategy had to be set. In partnership with Stantec and other contractors, MTO developed a method for accelerated bridge construction called Get in-Get out Bridge or GiGo Bridge. The GiGo Bridge concept is an ABC technique for replacing bridges. Stantec held a Value Engineering Workshop and a GiGo bridge workshop to identify innovative strategies for removing and replacing bridges fast. They were able to minimize the duration of construction and the associated traffic disruptions. The initial GiGo Bridge concept was developed in advance of the workshop, using a prototype site at an interchange location. Workshop attendees included MTO representatives, construction specialists, and engineers from Stantec. The workshop, and a follow-up meeting with contractor representatives, resulted in several modifications and refinements to the preliminary concept.

The concept requires bridge components to be prefabricated, shifting a substantial portion of the work into the winter months. Additional benefits of GiGo include shorter disruptions to traffic, and fewer idling cars emissions, as well as enhanced safety since workers have less contact with traffic during the project. Depending on the availability of a detour, there can be a full-closure of the bridge that results in an accelerated and more effective project. However, in the case of long detour alternatives, staged construction is opted to maintain accessibility and reduce traffic delays.

Prefabrication, the prerequisite of ABC techniques, includes superstructure and substructure components. The precast superstructure (supermodules) benefit most from accelerated bridge construction, at a marginal cost increase compared to traditional practices. The Westminster Drive Underpass over Highway 401, a two-lane bridge with integral abutments and integral pier, was constructed in 40 days and cost 29% more than a nearby bridge replacement with conventional methods, which took a year and a half. The concept is simple, scalable, offers the fewest cast-in-place connections relative to other prefabricated systems, has the potential to capture structural efficiency of shored construction, can be standardized, and does not sacrifice aesthetics compared to conventional construction in Ontario.[79] Precast abutments and piers mimic the cast-in-place process. The advantage of precast substructures is even more noticeable in locations with no available local ready-mix concrete. Up to date, MTO has already completed seven projects through ABC construction.[80]

3.2. THE BAYFIELD RIVER BRIDGE REPLACEMENT PROJECT

A small-scale routine project of the MTO's West Region, the Bayfield River bridge replacement project, was selected to serve as a case study to:

- provide an insight into the context of sustainability practice in transportation projects in Canada,
- identify the environmental, social, and economic impacts of transportation projects and present priorities, needs and strategies, and potential areas for improvement in managing inevitable trade-offs in the Lifecycle performance of assets,
- calibrate a sustainability rating system's methodology in terms of how LIFECYCLE stages and TBL impacts of a transportation project are captured, and finally
- calibrate the proposed Sustainability Lifecycle model, providing both input and an example of the use of the proposed model.

The implemented sustainable strategies are highlighted by MTO, revealing the agency's stated priorities and potential areas for improvement.

[79] Konstantinos Kris Mermigkas, "Evolution of Bridge Practices in Ontario, Canada," Paper prepared for presentation at the Structures Session of the 2018 Conference of the Transportation Association of Canada, Saskatoon, SK.

[80] D'Andrea, M., Young, W. and Andrew Turnbull, "Westminster Drive Underpass – Accelerated Bridge Construction using GiGo (Get In-Get Out) bridge concept," paper published in Resilient Infrastructure, June 1–4, 2016

Fig.14: The original Bayfield River bridge

Fig.15: The new Bayfield River bridge

3.2.1. PROJECT DESCRIPTION

The bridge is located south of Clinton at the municipal boundary between Bluewater and Central Huron, Ontario. The 87-yrs old (constructed in 1931) two-span bridge on Highway 4, a two-lane rural highway, was replaced in 2019. It was a complete replacement in the same location, with all new structural components.

The new structure is a 40m single-span steel box girder bridge with a 200 mm thick concrete deck. The substructure consists of precast integral abutments on steel H-piles (HP 310 x 110) and precast cantilevered wing walls. The superstructure consists of four (4) 1500mm deep steel box girders spaced at 3.8m. Open steel railings are proposed for aesthetic purposes. The replacement bridge requires approximately 0.470m of grading to accommodate the profile raise (0.69m profile raise at the south abutment, 1.27m at the north abutment).

	Existing bridge	**New bridge**
Span	two-span	Single-span
Overall structure width	11.532 m	14.960 m
Length	32.5 m	40.0 m
Roadway width	9.402 m	
Width of lane	3.65 m	3.75 m
Width of shoulder	1.3 -3.0	2.0- 2.5 m
Sidewalk width	1.2 m	2.0 m

Old bridge Condition – Need for replacement

In 1994, 1996, and 2011, the original bridge had undergone structural rehabilitation, which included concrete repairs, the addition of a 60 mm thick concrete overlay with a new 90 mm asphalt, and a waterproofing system.

Based on the 2014 Ontario Structure Inspection Manual, the old structure was generally in fair condition with deterioration, including wide cracks, severe scaling, spalls, and delamination on the soffit, girders, barrier walls, abutment walls, piers wing walls. The 2014

Bridge Condition Index (BCI)[81] was 60.65, a measure of the bridge's overall structural condition and its remaining economic value. It is a marginal 'fair rating", meaning that maintenance work should be scheduled within the next five years, "the ideal time to schedule major bridge repairs to get the most out of bridge spending."

The Replacement Project – Top Multi-benefit Design and Construction Strategies

In 2016, when the replacement of the bridge was planned, the bridge was already 85 years old. The replacement was justified to ensure public safety. As part of the replacement project, there were certain features incorporated into the design and construction that best reflect the agency's concerns and priorities when delivering a project of this scale and type, as well as the agency's and project team's innovative approach. The strategies were highlighted during the discussion with the representatives of the Bridge Office, as their "top multi-benefit' strategies.

These strategies are a mix of both agency-wide established strategies as well as innovative approaches that have been pilot-tested and proven successful, as described in the previous section of the report. The specific project strategies aim to examine more in detail the agency's decision-making process and balancing trade-offs.

- **Optimize the design and sizing of bridge components** to reduce the quantity of materials by replacing the 2-span original bridge with a single-span bridge
- **Use of integral abutment with jointless details** to maximize structure resilience with a more durable, continuous structural system and, at the same time, reduce future maintenance needs, a zero-maintenance solution. Moreover, this technique has multi-benefits, as described in the previous section of the report, such as:
    - shorter construction time,
    - a smaller quantity of materials.
- **Use of accelerated bridge construction (ABC)** to reduce construction duration, minimize public disruption, and avoid project construction carry-over beyond one construction season. The Bayfield River Bridge is the fourth accelerated bridge construction project to be completed using the (Get in-Get out) GiGo Bridge model, an ABC technique for replacing bridges to enable ABC construction two basic strategies were adopted:
    - Use of prefabricated components in the superstructure and substructure. Utilizing additional precast elements (Integral abutments, wing walls, full-depth deck panels, and approach slabs) helped to expedite construction further.
    - Offline construction staged method was opted to prefabricate a lot of the work (deck and supermodule sections) off-site in the winter months (construction season

[81] See "MTO's connection of bridge condition and maintenance schedule and costs" section of this document.

shutdown[82]) on a temporary construction staging area, so during the summer construction season works would be able to fit in within a single season. The availability of land adjacent to the site reduced the need for long routes from an off-site location to the worksite

The ABC method addressed constructability and safety concerns associated with maintaining a grade separation over winter that would require additional temporary construction barriers and provide solutions for pedestrian crossing. ABC has a premium **of approximately 10%** of the construction cost because of the required heavier machinery for the supermodules. Based on the 40m span of the bridge (41m girder length), the approximate weight of each of the two-girder supermodules is 125 tons. A heavy-lift sub-contractor is required to transport and place the supermodule sections, with a multiple 300 to 600-ton cranes.

- **Staged construction** was opted to avoid full-closure of the rural highway. Using a two-stages construction, one 4m lane, two-way traffic was maintained at all times to avoid a long detour. Traffic in each of the two stages shifted traffic to one side of the structure while the other was being replaced. "The ability to maintaining at least one single lane of traffic during peak hours was vital to the arterial route."[83] The Bayfield River project is the first GiGo Bridge to be completed under staged construction. Since it was built in stages, it did not take full advantage of the ABC technique and resulted in a higher cost (less efficient construction of the deck and concrete placement and the need for temporary abutments and foundations in the staging area to construct these elements). The longer construction duration (construction duration doubles or triples when traffic on the bridge is maintained)[84] was mitigated through other strategies, and mainly the decision to build a single-span bridge, instead of the original two-span with a pier in the middle.
- **Providing for transport ease** in the hauling of large prefabricated components by setting maximum dimensions (4.1 m) for the precast abutment and wing wall units that optimized weight.
- **Replacement of the 2-span original bridge with a single-span bridge** to reduce the quantity of materials, as well as in-water works. A trade-off analysis was performed of the single vs. two-span design summarizing the benefits of the single-span option in terms of environmental impact, construction duration, traffic control, constructability, and risk and cost. With a pier in the river, in-water works would be required for the removal of the existing foundation and the construction of a new foundation and pier. With the single span construction, the team opted to remove the existing pier footing down to the streambed level. In this way, the cofferdam works were limited, as

[82] In Canada, from December to end of March there is a construction shutdown for the cold weather conditions.

[83] Bluewater Municipality

[84] Mark D'Andrea, Wade Young and Andrew Turnbull, Westminster Drive Underpass – Accelerated Bridge Construction Using GiGo (Get In-Get Out) Bridge Concept, paper in Resilient Infrastructure, June 1–4, 201

compared to excavating below streambed, while also restoring the natural streambed of the river and it put the potential species at risk relocation off the critical path schedule. The avoided river works and the associated environmental restrictions for species at risk[85] enabled construction to be completed in one step. At the same time, while a 2-span bridge would require a 3-seasons construction (a full advanced-work primary construction year and a follow-on year). It is worth noting that the preliminary design was initially considering a 2-span bridge. However, the detailed design discarded this option. The estimated working days for 2-spans were 207 vs. 115 for a single span. Benefits of opting for a single-span bridge alternative included:

  - reduced risk of design delay from drilling and foundation investigation,
  - less materials,
  - optimization of precast elements, and
  - better hydraulic performance

- **Redundant corrosion protection system** through a combination of strategies that makes the team confident that the protection system will last the bridge's design life:
  - Use of weathering steel girders; atmospheric corrosion-resistant steel is recommended as the minimum soffit elevation is more than 2.5 m over the mean water level.
  - Local coating in areas that have the potential to have a runoff between them, thus expectations are that there will zero-maintenance on the bridge's structural steel for its service life.
  - Deck waterproofing system, hot rubberized asphalt (90mm), waterproofing membrane, and protection board (10mm) was recommended for the bridge deck and approach slabs. A special type of waterproofing system is required when a sidewalk extends over the exterior web of the exterior girder due to experience with leaking inside of the box girders. The structural manual specifies the "Eliminator" waterproofing system to be a suitable product. The waterproofing system used under the sidewalk ended up being BDM (Bridge Deck Membrane) by Bridge Preservation.
  - Premium reinforcing was used (following the MTO Structural manual): Stainless steel reinforcing was preferred in areas where bar bending is required or where significant future spalling repairs are anticipated, such as curb faces, or in locations where crack control is especially important, such as the top of concrete sidewalks.
  - Use of stainless steel (Duplex 2304 a medium grade steel) in the deck because of the construction joints, as a result of the modular construction method. The project team described this as the most significant material enhancement in the project, given that the cost of the premium stainless steel is approximately four times that of "black" reinforcement, and was likely not required due to the presence of the waterproofing on the deck. A cost analysis was performed to

[85] In-water works are restricted to occur between July 16th and September 14th of any year to protect sensitive life stages and/or processes of migratory and resident fish.

understand the additional cost of using in the entire deck as opposed to a combination of localized use of higher-grade steel and black. The extra cost was within 10% and allowed for use in the whole deck. The use of stainless enabled the reduction of total deck thickness from 225mm to 200mm, optimizing the use of the material and facilitating the transport of supermodules.

- Since an open railing barrier system was used, the one area that might be a risk is the exterior face of the girders; as de-icing material from the deck can go over the barrier onto the exterior face and bottom flange of the closed-box exterior girders. A premium metalizing coating system was used for the exterior face of the exterior web and the bottom flange.

Through the combination of the above strategies, the design of the bridge resulted in a structure of maximized resilience with fatigue provisions for 75 years or longer, as well as a zero-maintenance bridge, expected to require minimum maintenance, annual bridge washing, and replacement of waterproofing at 25-30 years. The above confirm the choice of replacing the bridge instead of performing a major rehabilitation.

There was a strategic effort by MTO to offset the cost premium of some of the implemented strategies, such as accelerated construction, use of premium materials, and staged construction through:

- A Technically Preferred Alternative Assessment for the accelerated construction technique was performed by the Detail Design Consultant, and the lower cost and fewer working days options were justified.
- Reduced project management costs by doing in-house contract administration and inspection. MTO typically retains a contract administrator, or construction manager, for inspection and administration of each contract. As a result, there is a cost associated with having those people on staff and working through an additional half a year on either end if this had been extended. The project management contract administration cost was easily quantified at $360,000.
- In the trade-off analysis of comparing the single vs. two-span design options, it was calculated that the single-season construction had a savings of $50,000.
- Avoided costs from future rehabilitations. The cost of rehabilitation is a major challenge for the agency, given it is a labor-intensive operation in general, and those types of costs have escalated faster than other types of cost. To better understand the avoided costs associated with a major rehabilitation project, the rehabilitation of 1996 was used as an example, in combination with a more recent similar scope rehabilitation project, MTO’s Highway 6 Rocky Saugeen River Bridge project of 2014. Both were used to assess the effort, costs, and impacts associated with this type of rehabilitation. Avoided costs were calculated to be $1,350,000 and are associated with 85 working days for deferring the full replacement of the superstructure project for ten years. In comparison, the cost of the replacement

project was $3,700,000 for a new maintenance-free bridge, with a life expectancy of at least 75 years.

Apart from the above, which are representative of the project optimized engineering and construction, there were additional design and construction strategies contributing to minimizing the impact on the affected communities:

- Increased capacity with a wider section - Design standards require 3.75 m lane widths when traffic volumes increase, which is expected within the design life of the new bridge structure.
- Improvements to the horizontal alignment of the bridge to match the existing urban section at the connecting link with curb and gutter.
- Sufficient capacity to meet the community’s infrastructure needs of today and tomorrow, following the Bluewater Municipality strategic plan.
- Increased sidewalk width on the west side of the new bridge.
- Addition of sidewalk along the west side of Highway 4, north (within connecting link) and south of the bridge. The existing site does not have pedestrian access on the approaches to the bridge, with pedestrians using the boulevard and sidewalk on the west side of the bridge to cross the river. The capital costs for the construction of the sidewalk, illumination, and maintenance, including winter maintenance, were agreed to be shared between the MTO and the Municipalities of Bluewater and Central Huron.
- Increased shoulder width on both sides of the new bridge - Design standards require a 2.5 m shoulder for a rural arterial with the Highway 4 traffic volumes. The east side of Highway 4 will have a 2.5 m paved shoulder on the south approach and across the bridge. The shoulder adjacent to the sidewalk across the bridge will be 2.0 m on the west side, corresponding to design standards for shoulders across a bridge between the lane and sidewalk. The 2.0 m west shoulder will also accommodate future staging and maintenance.
- Improvements to the vertical alignment of Highway 4 for further improved drivability and sightlines.
- Provision for a future bicycle lane.[86] There is a bicycle route under consideration on Highway 4 to connect with existing and future bicycle routes.

Regarding the construction impacts:

- The option for ABC and offline- construction staged limited method disruption to the public to a minimum total of six full road closures for the demolition of the

[86] Huron County Transportation Demand management plan on a Pilot / Demonstration Project: Active Transportation Connection (Clinton, ON):
An Active Transportation connection could be considered for implementation along the London Road / Highway 4 South corridor in Clinton, ON. More specifically, the facility is proposed to be implemented between the Downtown center of Clinton and the Health and Library Complex. The facility could be either an on-road bikeway or a shoulder pedestrian and bike trail creating a key connection for commuters and recreational pedestrian and cyclists throughout Clinton.

existing bridge and installation of the new bridge sections (supermodules). The supermodules of the bridge were pre-built in a contractor work area near the site and subsequently transported to the site and lifted into place overnight. Closures took place over-night on non-Statutory/Civic Holiday weekdays.

- Construction noise mitigation through alternative methods of removal of the old bridge (saw-cutting bridge into segments) and transfer cut sections onto trailers to demolish at an off-site location.
- No exceedance of local noise by-laws for the daytime construction (i.e., pile driving, saw cutting, etc.), as this work is non-continuous and not anticipated to exceed 75-80dB. A noise exemption was early requested only for the six nights of full closure required.[87]
- The construction of the supermodules in the temporary yard achieved the GiGo Bridge goal of enhancing safety in the work zone by removing construction activities away from the highway. Construction personnel noted that forming and placing reinforcing steel for the supermodules was straight-forward at the temporary yard; there was easy site access, no traffic, and no concerns with dropping materials onto a roadway or the river below.[88]

Finally, there were environmentally sustainable practices:

- The single-span new bridge did not need a pier in the water. The removal of the existing pier was scheduled when the water level was low, so there was no in-water work. So, the impact on surface waters and related habitats was minimized.
- The removal of the pier improved hydraulic performance.
- The removal of the existing pier resulted in a net-gain of available habitat (benthic habitat). It impacted approximately 80m2 of land situated within the watercourse. Before the installation of a sandbag stream diversion and short-term de-watering of the pier work zone, the existing rainbow mussels were relocated as per DFO and ESA requirements.[89] Restoration of vegetation removals was also incorporated.
- Drainage improvements: One of the reasons for the bridge replacement was a deficiency in hydraulic capacity. Design standards for a rural arterial road require conveyance for the 50-year design storm and freeboard and vertical clearance greater than 1.0 m at the lowest soffit elevation. These criteria were satisfied by raising the road profile and extending the structure. Conveyance requirements for the 100-year design storm and regulatory design events were also met with

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87 In November 2016 MTO requested for exemption to Noise By-law No. 21-2005 for six nights in 2019 to permit 24-hour continuous construction operations on the London Road (Hwy 4) Bridge over the Bayfield River. It was also mentioned “The MTO prefers to have all noise exemptions in place prior to tendering the project in the upcoming months. The specific dates are unknown at this time and are largely dependent on the selected contractor’s schedule.”

88 D’Andrea et al.

89 In-water work will require permits under the Endangered Species Act and the Species at Risk Act from the Ministry of Natural Resources and Forestry and the Department of Fisheries and Oceans Canada, respectively, due to the presences of a SAR mussel species (Rainbow Mussel).

additional climate change considerations incorporated in the calculations.[90] Other drainage improvements included replacement of catch basins, maintenance holes, storm sewer and outlets, drainage, and ditch modifications as required on the bridge approaches.

3.2.2. ANALYSIS OF IMPLEMENTED DESIGN AND CONSTRUCTION STRATEGIES IN TERMS OF SUSTAINABILITY PERFORMANCE

The objective of this research is to develop a Sustainability Lifecycle Tool, and the decision was made to be part of the Envision framework. So, Envision was used by the research team to analyze the sustainability performance of the replacement project. The Envision Pre-Assessment Checklist was used, given that it allows to quickly identify if a project addresses the sustainability criteria. It is worth noting that the pre-assessment was performed retrospectively for the replacement project as an auxiliary tool of the research and did not aim to represent the project's complete sustainable performance. At the time of the project, the project team had not considered pursuing an Envision accreditation, and part of the required documentation to support implemented actions was not produced. Therefore, the presented pre-assessment was based on limited documentation provided, standard documents already part of the project delivery. An example is the Resource Allocation category results that do not reflect the actual agency's practice. Many of the required by Envision strategies are by-default practices of the agency that were not tracked or quantified to prove the Envision process.

The results of the pre-assessment (not endorsed by the Institute for Sustainable Infrastructure) are summarized in the following Table, showing that bridge design features and design and construction strategies account for social, environmental, and economic dimensions of sustainability:

Table 7. Envision scoring for the Bayfield river bridge

Quality of Life	97	168	57.7%
Leadership	90	182	49.5%

[90] As per the MTO Climate Change Consideration, a ratio of 1.07 has been applied to the flows generated by the MNR Multiple Regression Method (OFAT3) in the design. This ratio is applied to ensure that the bridge can accommodate the projected rainfall values for the year (2093) corresponding to the end of the Design Service Life of the structure (75 years). Hydrologic analyses using various empirical methods to compare the peak flows to the MTO Unified Ontario Flood Method (UOFM) were completed by the detail design contractor and determined that the UOFM mean quantile value for the design flow is lower than one or more of the empirical methods.

Resource Allocation	15	98	15.3%
Natural World	104	182	57.1%
Climate and Resilience	75	174	40.5%
score	**381**	**804**	**47.4%**

The score is approximate and indicates a project that achieves a Gold Envision award.[91] However, more important, it indicates at a high-level, that the project strategies address all categories of impact. A more detailed study of the results per credit is presented in the Appendix. A cross-comparison with the core strategies of the project, as highlighted by the MTO team, were linked with the Envision credits they respond to, shown in the following Table 2.

Table 8. Bayfield bridge replacement core project strategies related to Envision credits

CORE STRATEGIES	RELATED ENVISION CREDITS
Bridge replacement vs. rehabilitation	QL1.2 QL1.4 QL2.1 **LD2.3** **LD2.4** LD3.1 LD3.3 CR1.1 CR1.2 CR2.5
Single-span vs. original two-span	NW1.2 NW3.1 NW3.2 NW3.3 LD3.3 CR1.1 CR2.2 CR2.3 CR2.5
Use of Integral abutment	QL1.6 **LD2.3** **LD2.4** LD3.3 CR1.1 CR1.2 CR2.2 CR2.3 CR2.4 CR2.5
Redundant corrosion protection system (use of premium materials)	LD2.3 LD2.4 LD3.3 CR1.1 CR2.3 CR2.5
Construction quality	LD2.3 LD2.4 LD3.3 CR1.1 CR1.2 CR2.5
Correction of horizontal alignment	QL1.2 CR2.6
Correction of vertical alignment & embankment widening	QL1.2 NW3.3 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
Widening of the highway section	QL1.2 QL2.1 LD2.3 LD3.1
Increased sidewalk width	QL1.2 QL2.1 QL2.3 LD1.3
Extension of the sidewalk beyond project limit	QL1.2 QL2.3 LD3.1
Provision for a future bicycle lane	QL2.1 QL2.2 QL2.3 CR2.6
Salvage of old structure parts	RA1.2 RA1.4 CR1.1
ABC construction	QL1.2 QL1.6 LD3.1 LD3.2 LD3.3 RA2.2
Use of prefabricated components	QL1.3 QL1.6 LD3.2 RA2.2

[91] For some credits there is no available information. Nevertheless, the focus is on core strategies, which were thoroughly documented. So, the missing information does not alter the overall take-aways of the process.

Performance of selected works off-site during a seasonal shutdown	QL1.3	QL1.6	LD3.3	
Staged construction	QL1.3	QL1.6	LD3.1	LD3.3
Use of ready-mix plant near worksite (15 min)	RA2.2	CR1.1		

Moreover, the alignment of results with the team's expectations of the project's performance indicates that the Envision rating system captures the nature of transportation projects. More specifically:

Agency-level practice and commitment, e.g., on addressing sustainability through the priority on durability and quality of materials and the entire structure, were captured by both the Leadership and Climate & Resilience categories. This conscious choice of MTO, introduced in its specifications, highlights an approach of addressing sustainability through securing a longer useful life and resilience for projects, avoiding future rehabilitation needs and the associated effort, cost, and environmental and user impact. At the same time, certain credits of both categories revealed the potential of strengthening the case of MTO projects. More specifically:

- Leadership's LD3.3 credit for lifecycle economic evaluation captured agency's efforts to offset initial costs to allow for the incorporation of sustainability strategies that add value to a project; the approach to go beyond initial costs to whole-life cost savings while considering community impacts. Moreover, it highlighted the potential of quantifying both cash and non-cash costs and benefits.
- Climate & Resilience's CR1.1 and CR2.2 credits for the reduction of net embodied carbon and emissions revealed a gap. Though basic strategies of the credit, such as the use of less materials, use of durable materials, etc. were integral to the project, it did not qualify for points in these credits because of not being adequately documented and quantified by the team. MTO described the lack of in-house capacity and resources to perform LCAs as the constraint in demonstrable results in this area. This is an area that Envision® and the proposed Sustainability Lifecycle model could contribute to strengthening the case of the projects.

The Quality of Life category has a focus on public safety, community mobility, and access, as well as construction impacts, which are core issues of transportation projects. So, Quality of Life category captured both agency and project level priorities and concerns, as well as project-level capacity improvements and enhancements within and beyond the project's boundary.

The Natural World category captured the efforts of minimizing the impact on surface water and habitats during construction works, as well as the long-term enhancement of natural processes.

Some Envision credits were identified as out-of-scope for the scale and type of the project. These credits were excluded from the assessment as not applicable.

3.2.3. KEY TAKE-AWAYS FOR THE DEVELOPMENT OF THE PROPOSED MODEL

MTO and its project-specific practices highlight areas of focus for transportation projects:

- The need for longer-lived materials to address sustainability through durability, reducing future rehabilitation and replacement works, and the associated emissions and disruption to the community. This approach is based on research, but also studies of the actual performance of realized projects. Experience-based lessons learned to provide the necessary input and guidance for site-specific and need-specific practices.
- The importance of maintaining projects to a state of good repair for public safety, but also broader sustainability and resilience performance.
- The socioeconomic impacts of construction works (whether new construction, major rehabilitation, or replacement of a transportation project) and how through construction management methods or innovative construction methods, these impacts can be minimized.
- The multi-benefit nature of strategies applied in transportation projects and the need to be captured, quantified to support the sustainability business case of projects.
- The ability to offset costs through a combination of strategies, schedule efficiencies, and the importance of long-term lifecycle perspective.

Regarding the capability of a rating system (more specifically Envision) to capture the issues related to a transportation project, and a bridge, in particular, the outcome proved satisfactory.

An area for potential enhancement identified through the analysis is evaluating future impacts of agency strategies. It was observed that the Envision Checklist does not fully capture the impacts related to future replacement works. These impacts are within the boundary of assessment of LD2.3 and CR2.5 credits. These credits award the minimization of future rehabilitation or replacement needs by extending the project's service life, therefore the avoidance of construction works and their associated impacts; however, the two credits do not assess or quantify the performance on specific future impacts such as disruption of access, construction noise, construction safety, construction energy, waste or water consumption, as in the case of the Envision credits that refer directly to construction works:

- QL1.3 Improve construction safety
- QL1.6 Minimize construction impacts
- RA1.4 Reduce construction waste
- RA2.2 Reduce construction energy consumption
- RA3.3 Reduce construction water consumption

The above-listed credits collectively capture the full short-term impacts of construction works. However, future construction impacts are out of their boundary of assessment.

In terms of economic impacts, the LD3.3 credit captures both the immediate costs (capital cost) and whole-life economic costs and benefits (O&M, rehabilitation cost, replacement cost, residual value, and revenues). However, the economic impact is not the only motivation for adopting specific strategies, but rather a balance of social and environmental impacts as well, as in MTO. The CR1.1 credit, as already mentioned, captures the project's materials and processes' whole-life embodied carbon.

Therefore, a gap is identified in assessing the full social and environmental impacts of the reduction of maintenance works during the lifecycle of a project that affects the multi-criteria analysis on specific strategies.

To further strengthen the case of sustainable projects, the tool aims to provide this additional capability of accounting for social, environmental, and economic impacts both in the short-term and the long-term to:

- guide across complex trade-off analysis of strategies
- make evident and quantifiable implications of strategies in the future and thus,
- enable more informed decisions.

PART II

PROPOSED MODEL FOR THE LIFECYCLE SUSTAINABILITY ASSESSMENT OF INFRASTRUCTURE PROJECTS – PILOT APPLICATION ON TRANSPORTATION

CHAPTER 4.

SYNTHESIS OF THE RESEARCH OUTCOMES

4.1 SUMMARY OF THE RESEARCH OUTCOME

The scope of the present research is to develop a **Lifecycle Sustainability Tool** by integrating the Lifecycle Assessment (LCA) and the sustainability assessment of projects.

Input from the Literature review on LCA:

- Though LCAs are an essential tool to understand a project's environmental footprint, they do not cover the full range of sustainability. The LCA method does not incorporate non-cash or external costs, or other benefits that the projects may bring. On the other hand, traditional financial models do not include the social or environmental benefits of projects. There is a gap for multi-criteria analysis, instead of a mono-criterion analysis.
- There is a need for LCA to follow an adaptable framework allowing quantifiable flows to be evaluated. A setting of a broader boundary, including the Lifecycle stages, is missing, along with a broader scope of LCA indicators for additional quantitative considerations in environmental LCAs.
- A prior report developed by Athena Institute reaffirmed that the constraints and gaps identified in the literature review are present in the Canadian practice of LCA.

Input from the sustainability rating systems analysis:

Part of the analysis focused on identifying LCA-specific components (i.e., impacts, Lifecycle stages) and explored whether they are being accounted for in the rating systems (Envision®, ISCA, SEEQUAL).

- A sustainability framework, by definition, accounts for the environmental, social, and economic aspects of a project. In contrast, LCA –as explained in the identified gaps – accounts only for either environmental or economic impacts. Therefore, the studied sustainability frameworks consider relevant trade-offs and issues in the context of sustainability that an LCA does not provide.
- The sustainability frameworks consider the entire lifecycle of a project.
- The sustainability frameworks propose a shift of focus from monetary to the total value.
- LCA, due to its highly technical and labor- and data-intensive process, is a tool that cannot be effectively applied by agencies in-house. For a public agency to perform LCAs in-house requires a certain capacity building and resources that have been constraints for LCA's broader use.
- A straight-forward, easy-to-use model is required.

Input from MTO West Region's Structural Standards and Specifications Office and Regional Office's Structural Section and the bridge case study:

- MTO's West Region provided insight on actual transportation projects, priorities & concerns. The main concerns are the choice of replacement or major rehabilitation, durability, impacts of construction (disruption of access), materials, and costs, and cost offsetting.

- The sustainability rating systems sufficiently capture the nature of sustainable transportation strategies and the areas of priority and concern, as proven in the application of Envision® to the specific project selected as a case study.

4.2. THE BASIS OF THE PROPOSED MODEL

The overall research findings led to the development of a proposed model to assist the decision-making process in improving the long-term sustainability of transportation infrastructure projects.

A sustainability assessment framework was chosen to be used as the basis for the proposed model for addressing the identified gaps in the sustainability of LCA, instead of using the ISO LCA methodology.

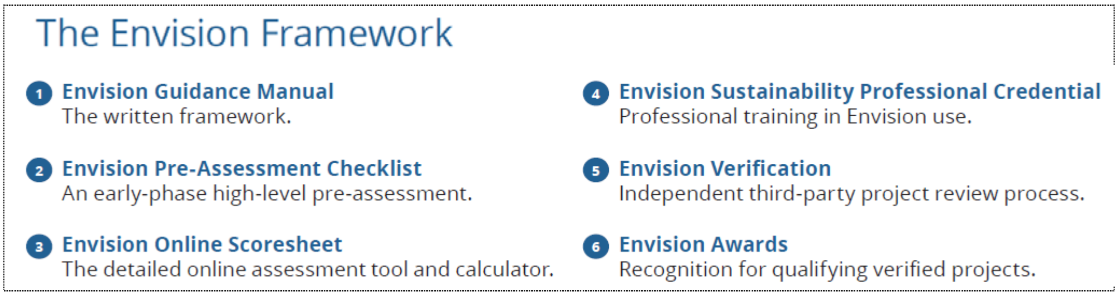
The research team is most familiar with the Envision® framework. Prof. Pollalis was actively involved in its development at the Zofnass Program at Harvard University. Thus, Envision was selected to be the basis of the model for "Lifecycle Sustainability" of transportation projects. The model addresses (1) transportation projects and (2) Lifecycle considerations and (3) the needs of transportation agencies for prioritizing strategies based on triple bottom line impacts and for weighting potential trade-offs.

The proposed model is different from the "Lifecycle Sustainability Assessment (LCSA) initiative by UNEP/SETAC," which is referred to in the literature review. UNEP's LCSA is defined as the combination of Environmental, Economic, and Social LCAs, therefore, of existing standalone LCA techniques: "*Combining (environmental) LCA, S-LCA, and LCC contributes to an assessment of products, providing more relevant results in the context of sustainability*." The framework used for LCSA is the ISO standard LCA methodology.

It is essential to highlight the functions of an ISO LCA that the proposed model does not support. LCA, through the extraction of information from available extensive databases and their incorporation within its supporting software, performs calculations and provides a final quantified outcome of the analysis. Furthermore, the ISO LCA is a complementary tool to be used for assessment at a higher level of sustainable performance in specific areas, such as carbon footprint, GHG emissions, as well as in the form of EPDs. The proposed model offers multi-level guidance for a holistic LIFECYCLE sustainability assessment of a project that results in an increased awareness of associated impacts, trade-offs, and potential strategies for improvement. However, it does not prescribe an exact path to sustainability. It is up to the decision-maker to determine the outcome of the analysis based on priorities and needs.

4.3. RELATION OF THE PROPOSED MODEL TO THE ENVISION® FRAMEWORK

The proposed model is based on the Envision® framework, which has been developed by the Zofnass Program at Harvard and the Institute for Sustainable Infrastructure.



The present research proposes **an additional tool for self-assessment within the Envision® framework:** the "Sustainability Lifecycle tool." The Sustainability Lifecycle tool is an Envision-based tool customized for transportation projects that **highlights indicators specific to Lifecycle stages and the Triple Bottom Line**, which indicators are already included in Envision. Moreover, the tool does not aim to substitute the Envision Guidance manual but be used in combination with it.

It is an added self-assessment support tool containing greater detail than the Pre-assessment Checklist (where Envision criteria are presented as YES/NO answers) but with less detail than the Envision Online Scoresheet that constitutes the detailed full Envision assessment.

The Sustainability Lifecycle tool (referred to hereafter as the 'tool') uses the Envision methodology, approach, and structure and follows the **64 credits organized in 5 Impact Categories and 14 subcategories.** It is a filtering and interpretation of the Envision Manual, extracting and highlighting selective information within the Envision credits.

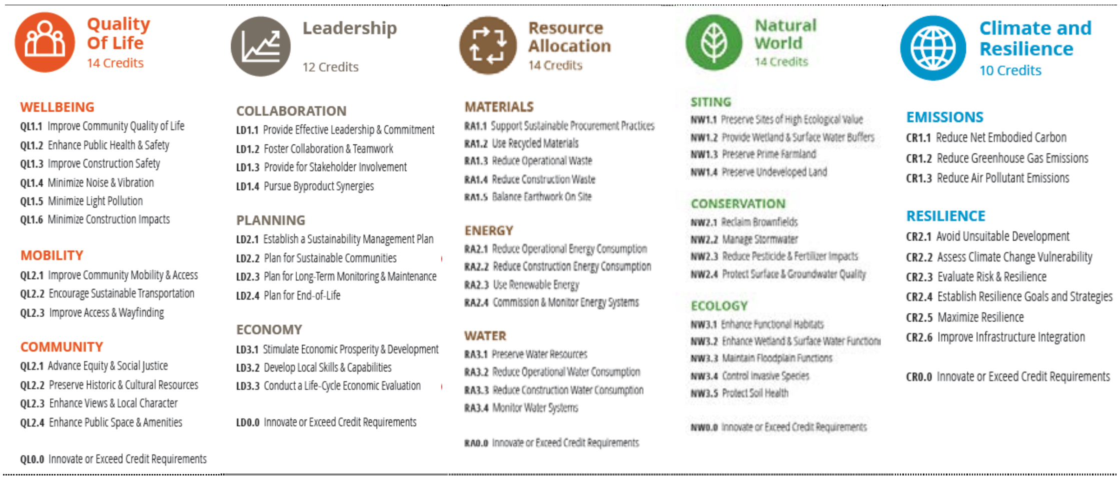


Fig.16: Sixty-four credits organized in five Impact Categories and fourteen subcategories

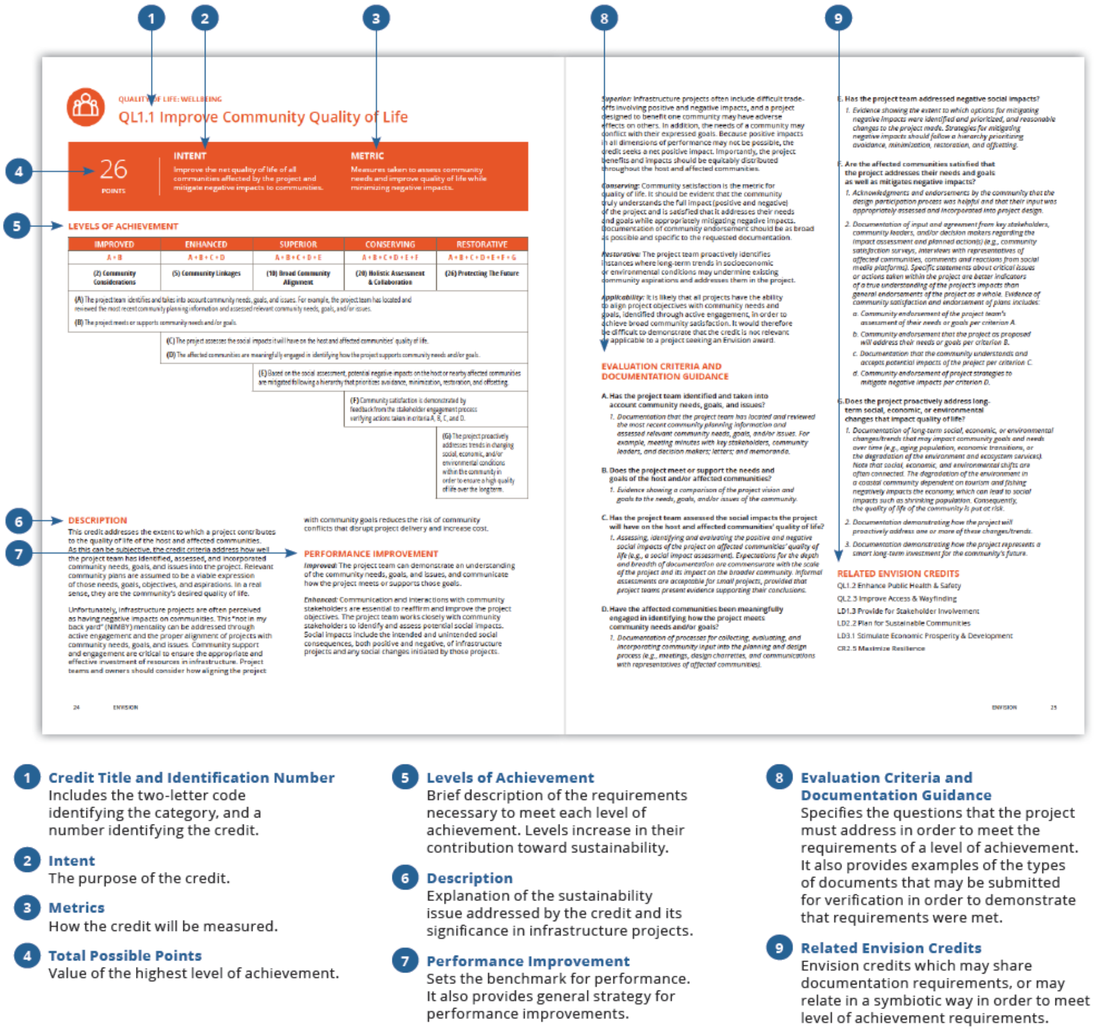


Fig.17: Example of credit presentation within the Envision Guidance Manual

As already discussed in the analysis of the Envision Rating Tool section of the report, Envision assesses sustainable performance both for:

- all the Lifecycle stages of a project: material production, construction, operation and maintenance, and end-of-life; and
- the Triple bottom line impacts (environmental, social, and economic).

The tool aims to make more evident these connections, which already exist within Envision. It isolates relevant information from the 'intent,' 'description,' 'performance improvement' and 'evaluation criteria' that describe each credit and develops the so-called **'performance indicators'** and **metrics.** Additionally, it applies a new coding to each credit focused on **TBL impacts** and **lifecycle stages.**

To better approximate a Lifecycle Assessment and provide guidance on how to improve Lifecycle stage-specific and impact-specific sustainability performance, as well as provide a transportation focus (research objectives), it incorporates input from:

- literature Review on infrastructure LCA and transportation infrastructure LCA,
- analysis of existing sustainability assessment frameworks,
- literature review on sustainable transportation infrastructure, and
- input from the MTO West Region's Structural Standards and Specifications Office and Regional Office's Structural Section and a representative project.

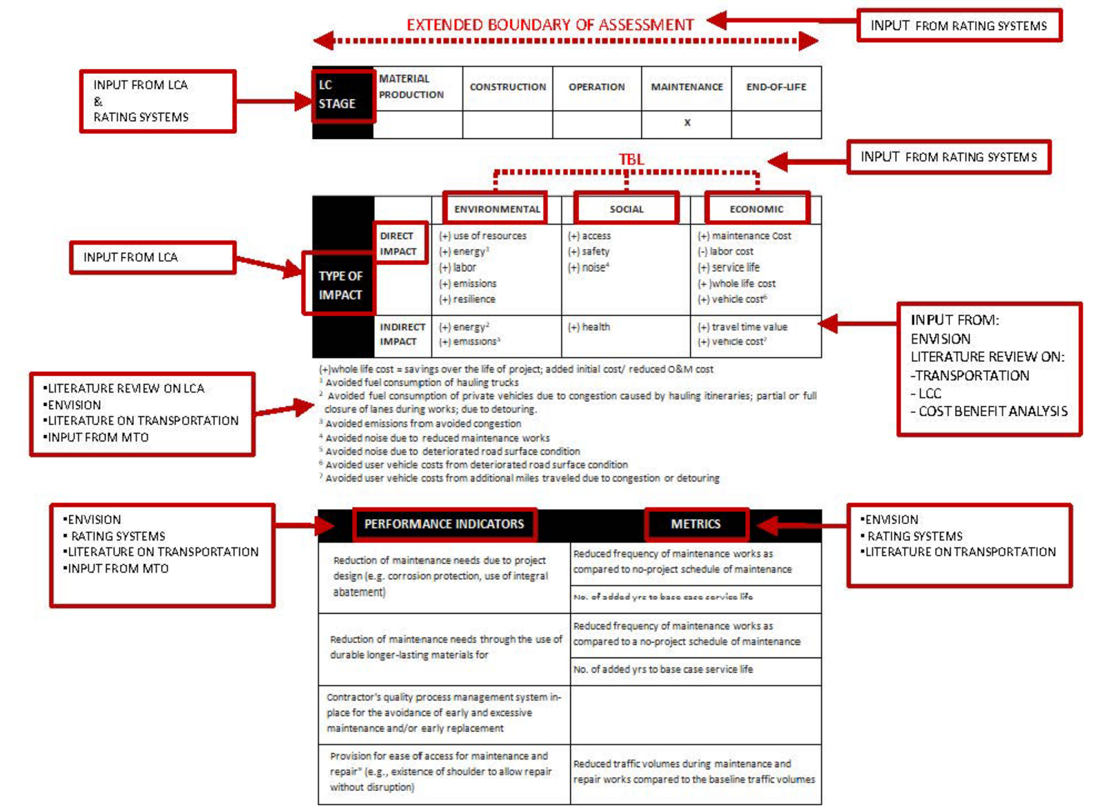


Fig.18: Diagram showing the inputs of the tool

In the process of applying it, the proposed tool redirects to the Envision® manual for detailed descriptions of credits, examples of strategies and best-practices, etc. However, it does not include the project's performance with the Envision levels of achievement and the associated pointing system as determined by the specific documentation requirements for each credit and level of achievement.

CHAPTER 5.

THE PROPOSED MODEL BASED ON THE ENVISION® FRAMEWORK

5.1. OVERVIEW

5.1.1 TOOL STRUCTURE

The **Sustainability Lifecycle Tool** is based on an extensive background table, structured according to Envision's five impact categories and credits, which contains multiple levels of information for each Envision credit:

- performance indicators,
- type of indicator,
- metric,
- lifecycle stage,
- TBL impact,
- direct and indirect impact (positive/negative).

The information results from the Envision framework, the literature review, the study of other sustainability rating systems for infrastructure, and input from the MTO.

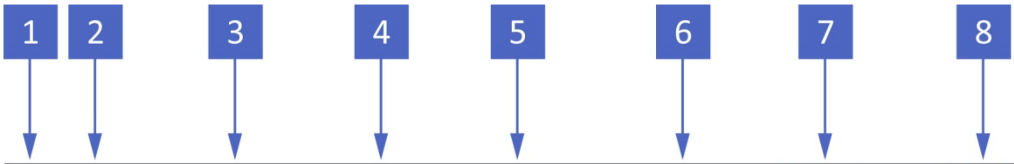
The tool is presented by four supporting tables:

- lifecycle table,
- TBL impact table,
- lifecycle grouping table,
- TBL impact grouping table,

and a datasheet for each Envision credit (the Indicator and Impact Datasheet).

The supporting tables interpret the Envision credits through the lens of the lifecycle stages and the TBL impact and group them accordingly. The Indicator & Impact Datasheet is the primary reference document that provides guidance for assessing and enhancing the sustainable performance of transportation projects. The Indicator & Impact Datasheet constitutes the foundation of the Sustainability Lifecycle tool manual, presenting the tool's content.

LIFECYCLE TABLE	Envision credits are linked to lifecycle stages
TBL IMPACT TABLE	Envision credits are linked to Environmental, Social and Economic impacts (direct and indirect)
LIFECYCLE GROUPING	Envision credits are grouped based on the lifecycle stage they refer to. This Table enables the lifecycle- specific focus. e.g., identify the credits and indicators that relate only to a single-stage, such as the construction stage
TBL IMPACT GROUPING	Envision credits are grouped based on the triple bottom line impact they address. This Table enables Social or Environmental or Economic- specific focus. e.g., identify the credits and indicators that relate only to Social impact, to strengthen a project team's case for community-focused projects.
INDICATOR & IMPACT DATASHEET	The main reference document that assigns performance indicators and metrics to each Envision credit.



ENV CREDITS	LC STAGE	PERFORMANCE INDICATORS	INDICATOR TYPE	METRICS	TBL-direct	TBL-indirect	DIRECT IMPACT SOC	DIRECT IMPACT ENV	DIRECT IMPACT ECON	INDIRECT IMPACT SOC	INDIRECT IMPACT ENV	INDIRECT IMPACT ECON
RA1.1 Support Sustainable Procurement Practices	MATERIAL PRODUCTION	% of the total project materials by cost, weight, or volume that meet sustainable procurement policy/program requirements on social and environmental impacts.	numeric	% Over the total quantity of materials	SOCIAL/ ENVIRONMENTAL	ENVIRONMENTAL	safety equity				embodied energy embodied water/ embodied carbon climate change	
	MATERIAL PRODUCTION	% of materials sourced from manufacturers/ suppliers that implement sustainable practices	target	At least 5% of all project materials, supplies, and equipment meet the sustainable procurement policy/program requirements. Examples of qualifying requirements include but are not limited to: •Environmental management systems consistent with ISO (International Organization for Standardization) 14001 •Product-specific type III Environmental Product Declaration (EPD) conforming to ISO 14025, 14044. •Third-party verified sustainability program (e.g., Forest Stewardship Council (FSC), Green Seal, EcoLogo, Underwriters Laboratory, National Biosolids Partnership (NBP), Concrete Sustainability Council (CSC), etc.) •Third-party verified corporate sustainability report consistent with the Global Reporting Initiative (GRI) Sustainability Report or equivalent.	ENVIRONMENTAL / SOCIAL	ENVIRONMENTAL	safety equity				embodied energy/ embodied water/ embodied carbon/ climate change	
RA1.2 Use Recycled Materials	MATERIAL PRODUCTION/ CONSTRUCTION/ MAINTENANCE	% of project materials that are reused or recycled	target	At least 5% (by weight, volume, or cost) of recycled materials including materials with recycled content and/or reused existing structures or materials.	ENVIRONMENTAL /ECONOMIC-AGENCY			waste/ materials energy	capital cost(materials cost/ hauling&fuel cost/ waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	MATERIAL PRODUCTION/ CONSTRUCTION/ MAINTENANCE		target	at least 25% (by volume) of any existing structures and materials have been retained and used within the project as opposed to being demolished and crushed or disposed.	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ENVIRONMENTAL/ ECONOMIC		waste materials energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	MATERIAL PRODUCTION/ CONSTRUCTION/ MAINTENANCE	% of offsite material with reclaimed/recycled content	taget	at least 20% (by volume) of materials from offsite with reclaimed/recycled content (excluding bulk fill and sub-base)	ENVIRONMENTAL /ECONOMIC-AGENCY			waste materials energy			embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	MATERIAL PRODUCTION/ CONSTRUCTION/ MAINTENANCE		target	at least 40% (by volume) of bulk fill and sub-base material from off site with reclaimed/recycled content	ENVIRONMENTAL /ECONOMIC-AGENCY			materials energy	capital cost(materials cost/ hauling&fuel cost labor cost)		embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	MATERIAL PRODUCTION/ MAINTENANCE	% of reuse of existing pavement materials by weight or cost (such as hot mix asphalt (HMA), portland cement concrete (PCC), unbound granular base material, stabilized base material, reinforced concrete, structural steel, and timber) during rehabilitation works	target	at least 50% of pavement reused through one or/more of the folllowing methods: -Surface treatments -Overlay / Mill and Fill -Hot-in-place recycling - Cold-in-place recycling(CIR) -Full depth reclamation(FDR) - Crack and Seat of PCC pavements - Rubblization of PCC pavements	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ENVIRONMENTAL/ ECONOMIC		waste materials energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	MATERIAL PRODUCTION/ CONSTRUCTION/ MAINTENANCE	On-site use of demolition arisings	target	At least 25% demolition arisings are reused	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ENVIRONMENTAL/ ECONOMIC		waste materials energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
RA1.3 Reduce Operational Waste	OPERATION	Percentage of total operational waste or byproducts diverted from disposal	target	divert at least 25% of operational waste. (Diversion may be a combination of waste reduction measures and/or sourcing waste to other facilities for recycling or reuse)	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ENVIRONMENTAL/ ECONOMIC-USER		waste materials energy	O&M cost (waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
RA1.4 Reduce Construction Waste	CONSTRUCTION/ MAINTENANCE	% (by volume) of total construction waste diverted from disposal	target	at least 25% of waste materials are recycled, reused, and/or salvaged during construction	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ ENVIRONMENTAL/ECONOMIC-USER		waste materials energy	capital cost (waste cost labor cost)	noise/ health	embodied carbon/energy / emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	CONSTRUCTION/ MAINTENANCE	Reduced(by volume) surplus materials (ordered and not used) over the total volume of materials ordered	target		ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ ENVIRONMENTAL/ECONOMIC-USER		materials energy	capital cost	noise/ health	embodied carbon/energy / emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	CONSTRUCTION/ MAINTENANCE	% (by volume)of surplus materials beneficially reused	target	At least 50% of surplus materials beneficially re-used (or stored for re-use), no or minimal unused materials.	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ ENVIRONMENTAL/ECONOMIC-USER		waste materials energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost)	noise/ health	embodied carbon/ energy/emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
RA1.5 Balance Earthwork On Site	CONSTRUCTION/ MAINTENANCE	% of excavated material reused/retained on-site	target	At least 30%	ENVIRONMENTAL /ECONOMIC-AGENCY		access noise	waste materials (soil) energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost)	noise/ health	embodied carbon/ energy/ emissions climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	CONSTRUCTION/ MAINTENANCE	% of excavated material moved off-site / reused to other nearby projects	target	Excavated material moved off site and/or fill brought onto the site does not exceed 70% of total site soil handling.	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ ENVIRONMENTAL/ECONOMIC-USER	access noise	waste materials (soil) energy	capital cost(materials cost/ hauling&fuel cost waste cost labor cost0	health	embodied carbon/ energy/ emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost
	CONSTRUCTION/ MAINTENANCE	Destination of materials and proximity to site	target	100% of fill and excavated materials are sourced or reused within a maximum distance of 25 mi/40 km of the site.	ENVIRONMENTAL /ECONOMIC-AGENCY	SOCIAL/ ENVIRONMENTAL/ECONOMIC-USER	access noise	energy	capital cost (hauling&fuel cost)	health	embodied carbon/ energy/emissions/ climate change/resource depletion	travel time value/ vehicle cost/ fuel cost

1. **ENVISION CREDITS**
2. **LIFECYCLE STAGE**
3. **PERFORMANCE INDICATORS**
4. **INDICATOR TYPE**
5. **METRICS**
6. **TBL IMPACTS** (Direct/ Indirect)
7. **DIRECT IMPACTS** (Social/ Environmental/ Economic)
8. **INDIRECT IMPACTS** (Social/ Environmental/ Economic)

Fig.19: The complete Sustainability Lifecycle tool (example: part of Resource Allocation credits)

Table 9. Supporting lifecycle stages Table

	LIFECYCLE PROJECT STAGES				
	MAT	CON	OPE	MAIN	END
QL1.1			■		
QL1.2			■		
QL1.3		■		■	■
QL1.4			■		
QL1.5			■		
QL1.6		■		■	■
QL2.1			■		
QL2.2			■		
QL2.3			■		
QL3.1			■		
QL3.2			■		
QL3.3		■	■	■	■
QL3.4			■		
LD1.1		■	■	■	■
LD1.2		■	■	■	■
LD1.3		■	■	■	■
LD1.4	■	■	■	■	■
LD2.1		■	■	■	■
LD2.2			■		
LD2.3	■	■	■	■	■
LD2.4	■				■
LD3.1	■	■	■	■	■
LD3.2		■	■	■	■
LD3.3	■	■	■	■	■
RA1.1	■				
RA1.2	■	■		■	■
RA1.3			■		
RA1.4		■		■	■
RA1.5		■		■	■
RA2.1			■		
RA2.2		■		■	■
RA2.3			■		
RA2.4			■		
RA3.1			■		
RA3.2			■		
RA3.3		■		■	■
RA3.4			■		
NW1.1		■	■	■	■
NW1.2			■		
NW1.3		■	■	■	■
NW1.4		■	■	■	■
NW2.1		■	■		
NW2.2		■	■	■	■
NW2.3		■	■	■	■
NW2.4		■	■	■	■
NW3.1			■		
NW3.2		■	■	■	■
NW3.3			■	■	■
NW3.4		■	■	■	■
NW3.5		■	■	■	■
CR1.1	■	■	■	■	■
CR1.2			■		
CR1.3		■	■	■	■
CR2.1			■		
CR2.2			■		
CR2.3			■		
CR2.4			■		
CR2.5	■	■	■	■	■
CR2.6			■		

Table 10. Supporting TBL Impacts table

	TBL IMPACTS			
	ENV	SOC	ECON	
			AGEN	USER
QL1.1		■	░	░
QL1.2	■	■	░	■
QL1.3	■	■	■	■
QL1.4	■	■	■	░
QL1.5	■	■	■	■
QL1.6	■	■	■	■
QL2.1	■	■	■	■
QL2.2	■	■	■	■
QL2.3	■	■	■	■
QL3.1		■	■	■
QL3.2		■	░	
QL3.3	■	■	■	░
QL3.4	■	■	■	░
LD1.1	■	■	■	■
LD1.2	■	■	■	░
LD1.3		■	░	░
LD1.4	■	░	■	░
LD2.1	■	■	■	■
LD2.2	■	■	■	■
LD2.3	■	■	■	■
LD2.4	■	■	■	■
LD3.1		■		■
LD3.2		■	░	░
LD3.3	■	■	■	■
RA1.1	░	■	■	░
RA1.2	■	░	■	■
RA1.3	■	░	■	■
RA1.4	■	░	■	■
RA1.5	■	■	■	■
RA2.1	■	■	■	■
RA2.2	■	■	■	■
RA2.3	■	■	■	■
RA2.4	■		■	
RA3.1	■	░	░	░
RA3.2	■	░	■	░
RA3.3	■	░	■	■
RA3.4	■	░	■	░
NW1.1	■	░	░	░
NW1.2	■	░	░	░
NW1.3	■	░	░	░
NW1.4	■	■		■
NW2.1	■	■	■	■
NW2.2	■	■	■	■
NW2.3	■	■	■	░
NW2.4	■	■	■	░
NW3.1	■	■	■	■
NW3.2	■	░	■	░
NW3.3	■	■	■	░
NW3.4	■	░	■	░
NW3.5	■	░	■	░
CR1.1	■	░	■	
CR1.2	■	░	■	
CR1.3	■	░	■	
CR2.1	■	■	■	■
CR2.2	■	■	■	■
CR2.3	■	■	■	■
CR2.4	■	■	■	■
CR2.5	■	■	■	░
CR2.6	■	■	■	░

Table 11. Lifecycle Grouping

LC PROJECT STAGE	ENVISION RELATED CREDITS
DESIGN & MATERIAL PRODUCTION	LD1.4 LD2.3 LD2.4 LD3.1 LD3.3
	RA1.1 RA1.2
	CR1.1 CR1.3 CR2.5
CONSTRUCTION	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.2 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
OPERATION	QL1.1 QL1.2 QL1.4 QL1.5 QL2.1 QL2.2 QL2.3 QL3.1 QL3.2 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.2 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.3 RA2.1 RA2.3 RA2.4 RA3.1 RA3.2 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
MAINTENANCE	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
END-OF-LIFE	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD2.4 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.2 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5

Table 12. TBL Grouping

TBL IMPACTS	ENVISION RELATED CREDITS
ENVIRONMENTAL	QL1.2 QL1.3 QL1.4 QL1.5 QL1.6 QL2.1 QL2.2 QL2.3 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.4 LD2.1 LD2.2 LD2.3 LD2.4 LD3.3
	RA1.1 RA1.2 RA1.3 RA1.4 RA1.5 RA2.1 RA2.2 RA2.3 RA2.4 RA3.1 RA3.2 RA3.3 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
SOCIAL	QL1.1 QL1.2 QL1.3 QL1.4 QL1.5 QL1.6 QL2.1 QL2.2 QL2.3 QL3.1 QL3.2 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.2 LD2.3 LD2.4 LD3.1 LD3.2 LD3.3
	RA1.1 RA1.2 RA1.3 RA1.4 RA1.5 RA2.1 RA2.2 RA2.3 RA3.1 RA3.2 RA3.3 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
ECONOMIC	QL1.1 QL1.2 QL1.3 QL1.4 QL1.5 QL1.6 QL2.1 QL2.2 QL2.3 QL3.1 QL3.2 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.2 LD2.3 LD2.4 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.3 RA1.4 RA1.5 RA2.1 RA2.2 RA2.3 RA2.4 RA3.1 RA3.2 RA3.3 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6

INDIRECT DIRECT

Table 13. Indicator & Impact Credit Datasheet

CREDIT: QL1.1 Improve Community Quality of Life

The credit assesses the net quality of life of all communities affected by the project and mitigates negative impacts on communities.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Wellbeing (+) Community satisfaction (+) Inclusivity		
	INDIRECT IMPACT			(+) Delay cost	(+) Economic prosperity

SOCIAL	• Improved living standards, needs fulfillment (indicator 1) • Increased community satisfaction of alignment of project and community goals and needs; and how input was incorporated into the design of the project (indicator 2) • Inclusion of all related stakeholders in the decision-making process and understanding of the full implications of the project positive and negative (indicator 1&2)
ECON	• Avoided costs due to delays in project delivery due to public opposition, or extended approval processes (indicator 2) • Improved socioeconomic conditions due to job growth, capacity building, productivity, business attractiveness, and livability (indicator 1)

	PERFORMANCE INDICATORS	METRICS
1		
2		

5.1.2 CONTENTS OF THE TABLE

The Table for each credit presents all the information included in the **Sustainability Lifecycle Tool** for the respective credit:

- A brief description of the credit's assessment 'boundary,' what it assesses, what it addresses.
- The lifecycle stage to which the credit refers, defining the boundary of the credit's assessment.
- What type of impact (environmental, social, economic) the credit assesses.
- The distinction of related to the credit impacts into direct and indirect impacts.
- List of key performance indicators & associated metrics.

- Breakdown of key performance indicators & associated metrics including transportation specific guidance where needed

LIFECYCLE STAGE

The lifecycle stages are:

- Design & Material Production[92]
- Construction
- Operation (including routine re-occurring maintenance, upkeeping)
- Maintenance (including minor and major rehabilitation)[93]
- End-of-life (replacement/decommissioning & deconstruction).

Given that in transportation projects, it is not common to decommission and deconstruct a project, end-of-life mainly refers mainly to project replacement at the end of its useful life.

By assigning lifecycle stages to credits, the tool aims to easily track sustainable actions-strategies per lifecycle stage and, at the same time, provide the boundary for implementation of each strategy. In other words, it guides on how to improve project performance at the corresponding stage of the life of the project.

The majority of credits apply to more than one lifecycle stage, as in the case of credits, including strategies to be implemented 'during construction works.' Since the construction works occur at the initial construction stage and the maintenance and end-of-life, these credits apply to all three life cycle stages (see, e.g., credit QL1.6 of the Tool manual). Also, credits referring mainly to operation may include a construction (see, e.g., credit QL3.3 of the Tool manual).

TYPE OF IMPACT

The tool has pre-established a set of **TBL-related impacts** that the credits assess. The impacts aim to represent the **impact and damage categories** of a Lifecycle Impact Assessment (LCIA),[94] providing additional links beyond an initial obvious assessment level.

Therefore, within the Sustainability Lifecycle tool, impacts are distinguished into direct and indirect. Direct impacts represent the immediate impacts of strategies (midpoint). Indirect impacts represent damages (endpoint), incremental impacts of a strategy within the same category of impact, as well as multiple benefits or trade-offs. The distinction aims to

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92 In ISO- LCA methodology, the first stage of the product life cycle is 'Material Production.' Given that the current framework is oriented towards infrastructure projects, the stage is converted to 'Design & Material Production' to also account for all design-led strategies with impact on materials production, such as optimizing the use of materials through project sizing, material selection, etc.

93 This stage does not include routine recurring maintenance, which is accounted in Operation (O&M), but rather minor or major rehabilitation that involves significant construction works.

94 As already mentioned in the literature review, through the LCIA phase of the LCA, a project's 'environmental interventions' are linked to impact categories (midpoint approach) and damage categories (endpoint approach).

facilitate comparisons and trade-offs among different planning/product alternatives, simplify the LCA process for decision-makers, and enable benchmarking.

The added feature of the tool as compared to an LCIA is that the TBL-related impacts sum up impacts and damages from Environmental, Social, and Economic-LCAs to expand the scope of assessment and approximate a Sustainability-LCA.
The tool's pre-established impacts are shown below:

SOCIAL	ENVIRONMENTAL	ECONOMIC	
		AGENCY	USER
Access	Materials	Capital (initial)cost	Travel time value
Safety	Energy	O&M cost	Vehicle cost
Health	Embodied energy	Rehabilitation cost	Fuel cost
Noise	Water	Replacement cost	Fare cost
Light pollution	Water quality	Residual value	Accident cost
Community satisfaction	Embodied water	Revenues	Health cost
Inclusivity	Air quality	Delay cost	Job creation
Equity	Waste	Liability claim/Penalty cost	Economic prosperity
Sense of place	Soil quality	Noise cost	Resilience value
Wellbeing	Emissions	Restoration cost	Ecosystem services value
Livability	Embodied carbon	Resilience value	
Integration	Ecosystem quality	Ecosystem services value	
Capacity building	Resource depletion		
Social resilience	Land occupation		
	Climate change		
	Ecological Resilience		

(+) positive impact
(-) negative impact
e.g. (+) cost = reduced or avoided cost / (-) cost = added cost.
(+) energy = energy reduction / (-) energy=increased energy use or energy wastage

Social Impacts:

Access=access to key community activities (job, education, healthcare, etc.)

Safety = exposure to the risk of accident (during operations or construction works) for public/ safety for workers; the level of stress for users; premature mortality due to accidents

Health = project's impact on human health (air-, water-, noise- prone diseases and premature mortality)

Noise= community disturbance caused by project-generated noise (operational or during construction and maintenance works)

Light pollution= impact of excessive, misdirected, or obtrusive artificial outdoor light (during operations or during construction and maintenance works)

Community satisfaction= Project approval by the affected by the project community as reflected in positive feedback

Inclusivity=inclusion of people who might otherwise be excluded or marginalized (minority groups) and inclusion of all related stakeholders in the decision-making process

Equity=equal and without prejudice treatment of all individuals affected by the project (communities) and involved in the project delivery (project team, workforce), as well as fair distribution of benefits and burdens and funding

Sense of place= heritage & cultural identity

Wellbeing= Given that human wellbeing is a broad concept with numerous interpretations that lacks a universally acceptable definition, as part of this research entails living standards, needs fulfillment, human comfort, freedom of choice, ride quality, visual comfort (removal of eyesores); and workers comfort. Though not a quantifiable impact, it is used to highlight the project's contribution to relevant themes.

Livability=contribution to the creation of livable communities

Integration= operational relationships and functional integration of the project into connected, efficient, and diverse infrastructure systems beyond its boundary

Capacity building= Skill and knowledge expansion (for the workforce, community), awareness building and behavioral change

Social Resilience= avoided loss of life, loss of health, loss of assets due to acute shocks and chronic stresses and avoided impact on the community due to loss of service; as well as adaptation to demographic shifts

<u>Environmental Impacts:</u>

Materials= use of primary materials

Energy= fuel & electricity use; depending on the credit could refer to fuel use of equipment/ vehicles. Energy could refer to the fuel consumption by private vehicles (e.g. due to congestion). In this case it appears as an indirect environmental impact.

Embodied energy= embodied energy of materials, equipment and fleet vehicles (from cradle to gate)

Water = quantity of freshwater used during construction works and O&M, as well as embodied water of materials

Water quality= contamination of wetlands, surface water bodies, and groundwater, acidification, eutrophication of water bodies

Embodied water= embodied water of materials, equipment, and fleet vehicles (use of water from cradle to gate)

Air quality= emission of air pollutants: particulate matter (including dust), volatile organic compounds (VOC), etc.

Waste= waste generation during construction or replacement works and project operations

Soil quality= disturbance of soil health and functionality (e.g., water holding capacity, nutrient retention capability, and erosion prevention capability

Emissions= GHG emissions; depending on the credit could refer to emissions by the project's operations or emissions by on-site energy use during construction works emissions refer directly to 'Climate change.' Emissions also refer to emissions by private vehicles (e.g. due to congestion created by the project).

Embodied carbon= embodied carbon of materials, equipment, and fleet vehicles (from cradle to gate, therefore including emissions during material extraction and production; equipment/vehicle manufacture; fuel production; supply chain.
Ecosystem quality= ecosystem degradation, biodiversity loss, loss of habitat connectivity (and in some cases wildlife-vehicle collisions)
Resource depletion =intensification of raw materials extraction, freshwater (surface and groundwater) as a result of materials, water used by the project
Land occupation= area of land (undeveloped) permanently or temporarily occupied and converted to accommodate the project, or temporary construction works, as well as land to accommodate waste produced (landfill)
Climate change= project's contribution (exacerbation or mitigation) to climate change
Ecological resilience= Project's contribution to the potential degradation of ecosystems

<u>**Economic impacts:**</u>

Economic impacts are added or reduced costs for/by incorporating a sustainable feature and implementing a sustainable strategy. In line with Lifecycle Costing and Cost-Benefit Analysis, methodologies costs are distinguished in agency and user costs.

For the agency:

Capital cost= initial capital/ investment cost (including preliminary engineering, contract administration, initial construction, construction supervision & administrative costs)
O&M cost= recurring operational & routine maintenance cost
Rehabilitation cost= cost or avoided costs of major rehabilitation
Replacement cost = cost or avoided costs of replacement of the project/ end-of-life cost
Revenues= streams of income due to service provision, pricing schemes in-place, by-product synergies with external groups, carbon credits trade.
Delay cost= avoided cost due to delays in project delivery due to public opposition, or extended approval processes
Liability claim/Penalty cost= avoided potential cost of liability claims (e.g., in the case of an accident) and cost of potential penalties for exceedance of regulation limits (e.g., noise, air quality, water quality, etc.)
Noise cost= avoided cost for passive noise mitigation (e.g.) Sound Insulation schemes for affected residences.
Restoration cost= cost of restoration or clean-up of a natural system in the case of an environmental incident during construction and operation.
Resiliency value= value of protection from the effects of future/repeat disasters; such as avoided future cost of repair, of displacement, or cost of loss of service that may create a financial downturn or slowdown for the organization
Ecosystem services value= impact on natural capital and avoided costs for substituting natural control processes (availability of clean air, fresh water, reduced risk of flooding or drought) with engineered controls

Moreover, a further breakdown of capital, O&M, rehabilitation, and replacement costs is provided for additional and more specific data on the source of cost:

- Land acquisition cost (for temporary staging area)
- Materials cost (for acquisition)
- Labor cost
- Schedule efficiency cost (avoided cost through optimized work completion)
- Hauling & fuel cost
- Waste cost

This additional information, in the form of notes, can provide a better account for trade-offs for the consideration of alternatives (Lifecycle Costing).

For the user:

Travel time value= avoided cost of time spent on transport. It includes costs to businesses of the time their employees and vehicles spend on travel and costs to consumers of personal (unpaid) time spent on travel. Therefore, it translates time loss, e.g., due to congestion into productivity for individuals and businesses. A person's time value is determined by the average income level and working hours)

Vehicle cost= avoided vehicle operating cost due to increased miles traveled (affected by vehicle type, age, and condition of road surface condition)

Fuel cost= avoided cost of excess fuel consumption due to stop-and-go traffic flow during congestion & due to surface roughness and deflection of the road surface (which is a function of design and maintenance)

Fare cost= the impact of the project on the affordability of service

Accident cost= avoided cost of accidents (vehicle repair or medical cost)

Health cost= avoided medical cost of illness

Job creation= direct or indirect jobs created as a result of the project (construction, O&M, supply chain)

Economic prosperity=project's contribution to socioeconomic conditions of the affected community through attractiveness to businesses, workforce, etc., and user's productivity through increased capacity, improved level of service, etc.

Resiliency value= value of protection from the effects of future/repeat disasters, such as avoided loss of life, loss of health, damage or loss of property; and loss of productivity due to disruption of service

Ecosystem services value=impact on natural capital, a community asset, given that the preservation of ecological functions is necessary for human needs fulfillment (availability of clean air, fresh water, reduced risk of flooding or drought, stabilization of local and regional climates, control on the range and transmission of certain diseases; provisioning of food; visual comfort, recreation, etc.)

In addition, the Sustainability Lifecycle tool aims to map and highlight the inherent linkages between certain types of impacts across the impact categories (environmental, social, and economic) revealing thus the indirect impacts of sustainable strategies as described below:

<u>Incremental impacts</u>

Incremental impacts are the indirect impacts of a sustainable feature and an implemented or not strategy within the same category of impact (environmental, social, or economic). For example:

- A project's 'energy' use, whether fuel or electricity, produces 'emissions' during fuel combustion or electricity generation and leads to 'Climate change.'
- The use of 'materials' contributes to 'resource depletion.' Additionally, it includes an added 'capital cost' for the acquisition of materials.
- 'Access' contributes to 'wellbeing.'
- 'Waste' generation related environmental impacts are: 'land occupation' (landfill), 'water quality,' 'embodied energy' (fuel consumption for waste hauling; energy for waste treatment, landfill), and related 'embodied energy, water and carbon.'

Indirect benefits/ multiple benefits:

Indirect benefits or multiple benefits are indirect impacts of an implemented or not strategy across different categories of impact. For example:

- 'Community satisfaction' and 'inclusivity' provide the agency with the 'license to operate' and have as an indirect economic impact 'Delay cost,' avoided agency costs from delays in project delivery in the case of community opposition.
- 'Safety' is closely related to 'health' and is associated with a 'Accident cost,' avoided cost of accidents for users (vehicle repair or medical cost) and avoided cost of liability claim due to an accident for the agency.

Trade-offs:

Trade-offs are the indirect impacts that represent the positive and negative impacts of a strategy (implemented or not) within the same category of impact.

- When the indirect impact belongs to the same category of impact, trade-offs are indicated by a '(+-)' pre-mark before a specific impact. For example, (+-) capital cost, highlights simultaneous costs and benefits in different areas that capital cost entails. A strategy, for instance, may require a higher cost of materials due to premium quality but less cost of labor.
- When the indirect impact refers to a different impact category, the trade-offs are indicated with different pre-marks in each category. For example, a strategy with (+) energy and (-) safety would mean that the strategies for minimizing electricity for lighting needs result in insufficient nighttime safety for the public.

For both cases, trade-offs are captured and concretized based on the notes that accompany the impact table in the datasheet.[95]

The Lifecycle dimension of impacts

[95] This is done because the impact table within the manual summarizes impacts of various indicators (strategies) and requires a further explanation. To fully address this point and given that in the excel that forms the basis of the tool, impacts are assigned per indicator, the automatization of the tool is suggested as a next step (see relevant section of the report)

The impacts finally include the project's lifetime dimension. They can be initial, short-term, but also future, long-term, or recurring short-term impacts. The tool tries to capture and account for both the initial and future impacts of a project, which is more evident in the case of direct economic impacts for the agency, as shown in the table below:

LIFECYCLE STAGE	**DESIGN & MATERIAL PRODUCTION**	**CONSTRUCTION**	**OPERATION**	**MAINTENANCE**	**END-OF-LIFE**
IMPACT	capital cost		O&M cost Revenues	rehabilitation cost	Replacement cost Residual value
TIME	**INITIAL SHORT-TERM**		**FUTURE**		
			long-term	recurring short-term	

Although credit and its strategies correspond to a specific lifecycle stage of the project (e.g., to improve sustainable performance during operation), the listed related impacts not only focus on operation but also refer to other lifecycle stages to provide a complete overview of what are the strategy's implications and enable, e.g., choosing between alternative strategies.

This way, a decision-maker that navigates the tool in search of sustainable strategies can be aware of the impacts of implementing a strategy for future stages of the project. Strategies inevitably entail future social and environmental impacts. However, they have not been listed as in the case of economic impacts.[96]

By assigning attributes across all categories of impact to credit, the decision-maker can track strategies that represent 'win-win' situations, discard strategies that don't address an impact category of his priority or identify a strategy that has to be incorporated in the project to strengthen its case, concerning a not-yet-addressed category (environmental, social or economic).

The type of assessment that has to be performed for evidence of positive impact is determined within the Envision manual in the section of the documentation. Therefore, the tool redirects to the Envision manual for guidance on which documents support the assessment process. It is worth noting that guidance on documents required can help project teams identify gaps in their documenting process of strategies they may already implement but do not formally provide evidence.

PERFORMANCE INDICATORS

The performance indicators are consistent with the Envision evaluation criteria that define the type of required evidence and documentation. Same with Envision evaluation criteria, the indicators include both qualitative and quantitative requirements. However, <u>while the</u>

[96] The way that the tool accounts for future social and environmental impacts, as well as user-related impacts, is presented in Section 5.1.5.

evaluation criteria are framed as questions, the performance indicators are more focused and straightforwardly formulated, aiming to assist in high-level evaluations of sustainability features and strategies for decision making.

Types of performance indicators:

- **Numeric**: Quantifiable Performance indicators
- **Target**: A specified outcome with discrete, quantifiable levels. The minimum value is defined as acceptable, the baseline (e.g., the project reduces energy use by 15%).
- **Process**: Indicators describing a process conducted or a commitment made to accomplish a stated objective (e.g., the project team has a comprehensive sustainability management plan).
- **Yes/No:** An action is taken, or an outcome achieved (e.g., the project is not located on a sensitive site).
- **Strategy**: Indicators suggesting commonly known sustainable strategies and practices

The list of performance indicators functions as a set of guidelines or strategies and, therefore, will be referred to as strategies in the tool's presentation.

Table 14. Example of the Indicator & Impact Datasheet

CREDIT: RA1.4 Reduce Construction Waste

The credit assesses how the project diverts construction and demolition waste streams from disposal to recycling and re-use.

LIFECYCLE STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials (+) Land occupation		(+-) Capital cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost
	INDIRECT IMPACT	(+) Energy (+) Embodied carbon (+) Embodied energy (+) Embodied water (+) Emissions (+) Climate change (+) Resource depletion (+) Ecological resilience	(+) Noise (+) Safety (+) Health	(+) Ecosystem services value	(+) Ecosystem services value

ENVIR	• Reduced waste to be managed or sent to landfill; land occupation; reduced impact on water quality and ecosystems (indicators 1-3) • Reduced embodied energy and carbon of transport of waste. (indicators 1-3) It is determined by: - volume and types of construction waste - no. of routes based on hauling truck volume capacity - waste destination and proximity to the site (recycling facility, landfill, contractor's yard) • Reduced use of materials due to minimization of surplus materials (indicators 2, 3) • Reduced primary materials purchased (by other projects) through re-use (indicators 1-3) • Avoided fuel combustion and associated emissions by private vehicles due to stop-and-go traffic trends that tend to increase fuel combustion (fewer hauling routes of waste to landfill - less congestion)
SOCIAL	• Reduced risk of car crash accident due to reduced hauling trucks traffic (indicators 1-3)
ECON	• Capital cost savings due to avoided costs for surplus materials; avoided waste hauling costs (cost of labor and fuel) and fees for landfills, recovery facilities, etc. (indicators 1-3) • Added cost due to additional effort for waste management at source (indicators 1,3) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to construction traffic (less hauling of waste to landfill) (indicators 1-3) • Reduced impact on natural capital due to less land occupied for landfill, soil contamination and associated avoided costs for community and agency (indicators 1-3)

	PERFORMANCE INDICATORS	METRICS
1	% (by volume) of total construction waste diverted from disposal	At least 25% of waste materials are recycled, re-used, and salvaged in construction
2	Reduced (by volume) surplus materials (ordered and not used) over the total volume of materials ordered	
3	% (by volume) of surplus materials beneficially re-used	At least 50% of surplus materials are beneficially re-used (or stored for re-use), no or minimal unused materials.

5.1.3 KEY CREDITS

The tool demarcates a set of Envision credits as 'key credits.' The six key credits within the **Sustainability Lifecycle Tool** are the following:

- LD1.3 Provide For Stakeholder Engagement
- LD3.1 Stimulate Economic Prosperity
- LD3.3 Conduct A Lifecycle Economic Evaluation
- CR1.1 reduce net embodied carbon
- CR2.2 Reduce GHG Emissions
- CR2.5 Maximize Resilience

KEY CREDIT

CREDIT: CR1.1 Reduce Net Embodied Carbon

The credit assesses how the project reduces the impacts of material extraction, refinement/ manufacture, and transport over the project life.

LC STAGE	MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Climate change		(-) O&M cost (+) Revenues	
	INDIRECT IMPACT	(+) Embodied carbon	(+) Health	(+) Penalty cost	

- Reduced contribution to climate change by the project over its lifetime
- Increased O&M cost due to the cost premium for the purchase of RECs; carbon credits within a cap-and-trade program
- Increased revenues through generation and sale of carbon credits within a cap-and-trade program
- Avoided cot of penalty due to exceedance of allowed carbon limits

PERFORMANCE INDICATORS	METRICS
Documentation of the primary materials for construction and ongoing operation of the project over its life, by type, quantity (including frequency of use over project life). Estimation of the embodied carbon of materials (based on readily available public information such as regional, national, or global averages) Identification of the select materials that collectively will make up over 80% of the total estimated embodied carbon of the project.	
Mapping (Index and quantification) of the embodied carbon of materials - primary contributors to carbon intensity- over the life of the project (construction and operations) Calculations include: • Embodied carbon of production, including raw material extraction, refinement, and manufacture. • Embodied carbon of transporting materials to the project site. • The replacement, repair, or refurbishment of materials over the life of the project. Embodied carbon data may come from the manufacturer, reputable databases, reputable embodied energy software, or from project team calculations. If the source or specific type of materials is not known at the time of assessment, calculations may present a range of values or rely on likely material choices. (Calculations should be in tons CO2)	IMPACT FOR FILTERING: "INDIRECT ENVIRONMENTAL IMPACT"="EMBODIED CARBON" Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on embodied carbon. The index of filtered credit indicators can provide the basis for an **informal** CARBON-LCA.
% of reduction in net embodied carbon of materials (Calculations should compare total carbon intensity of materials for the project against the total carbon	At Least 5% Reduction in net embodied carbon of materials as compared to a base case

The key credits include indicators that request input from other Envision credits. The credits which provide input are identified through search/filtering based on specific impacts. The impacts to be filtered are provided within each key credit datasheet. The key credit indicator that requires filtering of impacts is highlighted (with grey) in the datasheet, and in the column 'metrics' provides the 'impact or list of impacts for filtering.'

The key credits play a particular role within the Sustainability Lifecycle tool because they highlight and materialize suggestions made within the Envision Manual.

KEY CREDIT LD1.3 PROVIDE FOR STAKEHOLDER ENGAGEMENT

The LD1.3 credit addresses an essential notion of social sustainability within Envision, community, and stakeholder engagement. As explicitly pointed out within the Envision guidance manual, *"when an inclusive, representative group of stakeholders is engaged throughout the project, the results satisfy the community's broadest possible swath and lead to social prosperity."*

Several Envision credits refer to these aspects that are essential for decision-makers when addressing the social impacts of sustainable infrastructure projects. However, the relevant assessment's nature is often qualitative and subjective, so Envision relies on community engagement support of the project to demonstrate a positive impact.

The following levels of stakeholder participation (defined by Envision key credit LD1.3) provide an objective assessment of the community engagement:

- active engagement (inform)
- direct engagement (consult)
- community involvement (involve)
- community Satisfaction (support)
- stakeholder partnerships (one or more stakeholders engaged as partners).

Within the Sustainability Lifecycle tool, the key credit LD1.3 enables a full index of all strategies that require:

- Community support through the filtering of all Envision credits and relevant indicators that have: 'DIRECT SOCIAL IMPACT' = 'COMMUNITY SATISFACTION.'

Therefore, LD1.3 is the key credit that indicates how to link sustainable strategies with social performance, reflected in positive community feedback.

KEY CREDIT LD3.1 STIMULATE ECONOMIC PROSPERITY

The Envision credit LD3.1 aims to capture a project's contribution to the long-term economic prosperity of the community and explores the added benefits of sustainability strategies. Aims to highlight how infrastructure can contribute to socioeconomic vitality by driving livability and community attractiveness to businesses and the workforce, therefore offsetting investment costs.

Within the Sustainability Lifecycle tool, the key credit LD3.1 enables a full index of all strategies with a positive or negative impact on:

- The prosperity of the community through the filtering of all Envision credits and relevant indicators that have: 'INDIRECT IMPACT' = 'ECONOMIC PROSPERITY'; and
- The productivity of the user through the filtering of all Envision credits and relevant indicators that have: 'DIRECT ECONOMIC IMPACT ON USER' ='TRAVEL TIME VALUE.'

Through the suggested process, the index of filtered credit indicators can provide the basis for quantification of community economic benefits and user productivity benefits.

Therefore, LD3.1 is the key credit that indicates how to link sustainable strategies with socioeconomic performance, economic benefits for the community, and the user.

KEY CREDIT LD3.3 CONDUCT A LIFECYCLE ECONOMIC EVALUATION

Envision credits of the Quality of Life, Resource Allocation, Natural World, and Climate & Risk categories consider social and environmental project strategies across the full lifecycle of a project. Although Envision does not assess a project in terms of monetary value, cost implications of strategies are often mentioned in the description of credits, such as cost savings, or trade-offs of upfront capital costs and longer-term anticipated operational savings. Instead, Envision suggests that planning decisions should go beyond the return on investment and upfront capital costs (often key drivers of decisions) and account for "the lifecycle costs of the project, risks, and uncertainty, or the broader outcomes that impact the environment and society." Envision guides the user to "quantify these soft benefits and broader outcomes such that owners are less likely to overlook the sustainable returns on investment, such as lower utility costs, operations, and maintenance costs, or lower replacement costs."

More specifically, the LD3.3 credit rewards teams that perform a Lifecycle Cost analysis to identify the total economic impacts of the project over its entire life and provide additional insight into decision-making on alternatives. Part of the evaluation criteria for credit LD3.3 target higher levels of performance:

- mapping and quantification of the social and environmental impacts of the project, and
- quantification and measurement of the broader financial, social, and environmental benefits of the project, using triple bottom line cost-benefit analysis (TBL-CBA) or sustainable return on investment (SROI).

The Envision manual suggests an indicative list of topics to project teams to guide and **structure** the social and environmental impacts that can be monetized, e.g., *reductions in mortality, injuries; benefit to low- and moderate-income households; productivity improvements; resiliency value, etc.* Therefore, LD3.3 is the credit that links sustainable strategies with financial costs or benefits.

What the Sustainability Lifecycle tool additionally offers is the capability to easily map sustainable project features and strategies to facilitate the performance at three levels of economic analysis:

Level 1: Lifecycle Cost Analysis (LCCA). The tool maps all sustainable project features and strategies with positive or negative economic direct impact (added or reduced cost for/by incorporating a sustainable feature and implementing a sustainable strategy) for the agency over its entire lifecycle; a mono-criterion analysis.

The Sustainability Lifecycle tool enables a full index of strategies with a positive or negative impact on agency through filtering of all credits and relevant indicators with '**DIRECT ECONOMIC IMPACT FOR THE AGENCY**':
<u>Agency direct costs:</u> - Capital cost - O&M cost - Replacement or Major rehabilitation cost - Residual value - End-of-Life cost - Revenues The index of filtered credits and relevant indicators can provide the basis for the LCCA.

<u>Level 2: Lifecycle Cost/Benefit Analysis.</u> The tool maps all sustainable project features and strategies with a positive or negative impact on both the user and the agency, a two-criteria analysis.

The Sustainability Lifecycle tool enables a full index of project features and strategies with a positive or negative economic impact on agency and user through filtering of all credits and relevant indicators with '**DIRECT ECONOMIC IMPACT' FOR THE 'AGENCY' & 'DIRECT ECONOMIC IMPACT" FOR THE 'USER'**:	
<u>Agency direct costs:</u> - Capital cost - O&M cost - Replacement or Major rehabilitation cost - End-of-Life cost - Residual value - Revenues	<u>User costs (cost of service-related impacts):</u> • Travel time value • Vehicle cost • Fuel cost • Fare cost • Accident cost

<u>Level 3: Sustainability Cost-Benefit Analysis.</u> The tool maps all project strategies with social and environmental impacts that have quantifiable cost and benefits for both the agency and the user (community), a multi-criteria analysis.

The Sustainability Lifecycle tool enables a full index of project features and strategies with positive or negative economic impact through filtering of all credits and relevant indicators with '**DIRECT' & 'INDIREC T' 'ECONOMIC IMPACT' for THE 'AGENCY' & THE 'USER'**:	
<u>Agency direct costs:</u> • Capital cost • O&M cost • Replacement (or Major rehabilitation) cost • End-of-life cost • Residual value • Revenues	<u>User costs (cost of service-related impacts):</u> • Travel time value • Vehicle cost • Fuel cost • Fare cost • Accident cost

Agency indirect costs (cost of social & environmental impacts)	User indirect benefits (cost of broader social & environmental impacts)
• Delay cost • Liability claim/Penalty cost • Noise cost • Restoration cost	• Health cost • Job creation • Economic prosperity
The index of filtered credit and relevant indicators can provide the basis for the Sustainability Cost-Benefit Analysis, a sustainability multi-criteria cost-benefit analysis.	

As already mentioned, the Sustainability Lifecycle tool by assigning direct and indirect impacts on credits makes evident the cost-related information already included in the description of multiple credits.

KEY CREDIT CR1.1 REDUCE NET EMBODIED CARBON

The Envision credit CR1.1 assesses the extent to which a project reduces the net embodied carbon of materials used in construction and operations works and suggests a list of strategies that could contribute to less embodied carbon as guidance:

a. Sizing the project to require less material;
b. Designing the project to use less material;
c. Choosing materials that have lower embodied carbon;
d. Reducing material needed for repair and maintenance;
e. Reducing material waste during construction;
f. Reducing material waste during operation;
g. Sourcing local materials to reduce transportation emissions;
h. Utilizing lower-carbon transportation modes.[97]

As part of the assessment criteria, a mapping (Index and quantification) of the embodied carbon of materials - primary contributors to carbon intensity- over the life of the project is requested.

Within the Sustainability Lifecycle tool key credit, CR1.1 provides the capability to group all credits and relevant indicators that have a positive or negative impact related to:

- Net embodied carbon by performing the search/filtering: 'INDIRECT ENVIRONMENTAL IMPACT' = 'EMBODIED CARBON.'

The index of filtered credit indicators can provide the basis for an informal carbon-LCA to assess the project's contribution (exacerbation or mitigation) to climate change.

KEY CREDIT CR2.2 REDUCE GHG EMISSIONS

Similar to key credit CR1.1, the key credit CR1.2 provides the capability to create a full index of all project strategies that have a positive or negative impact on GHG emissions. The filtering of impacts that has to be performed is an INDIRECT ENVIRONMENTAL IMPACT' =

[97] Envision Guidance Manual

'EMISSIONS.' The index of filtered credit indicators can provide the basis for an informal GHG emissions-LCA to assess the project's contribution (exacerbation or mitigation) to climate change.

KEY CREDIT CR2.5 MAXIMIZE RESILIENCE

The CR2.5 credit assesses the extent to which the project has the ability to withstand potential future short-term and long-term hazards through durability, adaptive capacity, system recovery in the case of failure scenarios; as well as response to future needs (e.g., growing population, demand) and changes.

The credit requests the "inclusion of methods of measurement and quantification of the benefits of increased resilience through the objective measure (e.g., cost savings, improved service, etc.) to support their implementation on the project and benefit the knowledge and understanding of the broader resilience for the community."

Within the Sustainability Lifecycle tool, the key credit CR2.5 provides the capability to create a full index of all project strategies that have a positive or negative impact on:

- Resilience through the filtering of all credits that have 'INDIRECT ECONOMIC IMPACT' ='RESILIENCE VALUE.' The resulting index can help to further quantification requested by Envision.

5.1.4. THE ROLE OF KEY CREDITS

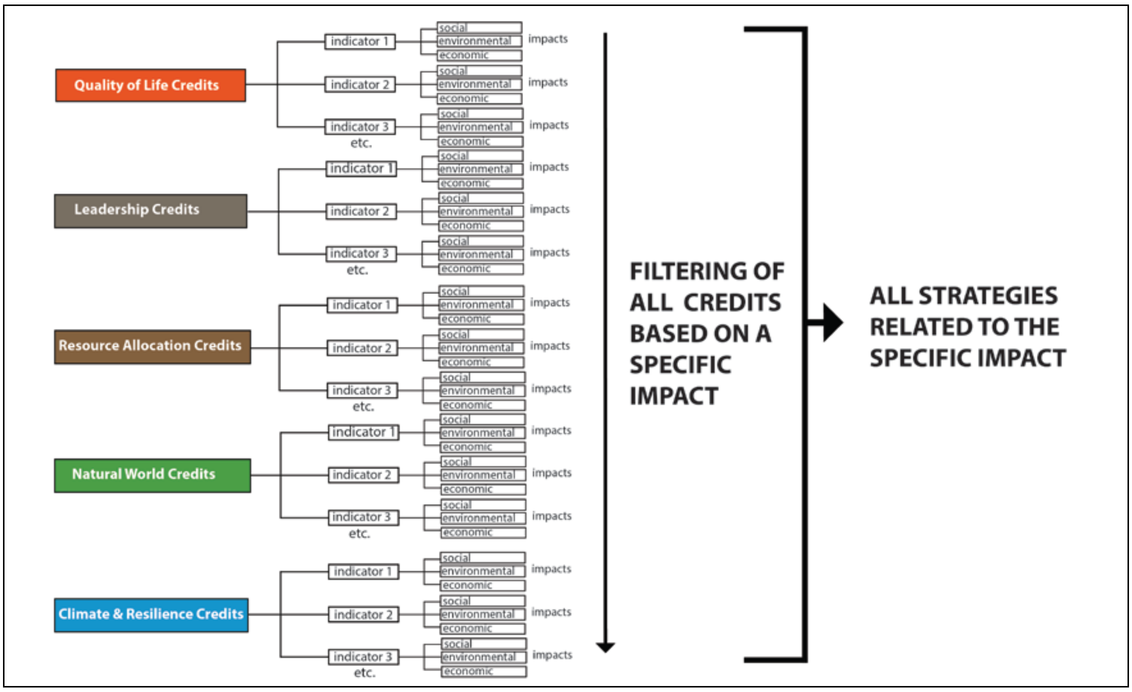
Overall, the key credits explicitly refer to core impacts, which are at the center of the research and aim to provide a basis for their quantification: impact on the community, cost, climate change and resilience against future uncertainty.

Table 15. Overview of the impacts, captured by six key credits

		PROPOSED IMPACT FILTERING	
KEY CREDITS	**TBL CATEGORY**	**TYPE OF IMPACT**	**IMPACT**
LD1.3 Provide For Stakeholder Engagement	SOCIAL	'DIRECT SOCIAL IMPACT'	COMMUNITY SATISFACTION
LD3.1 Stimulate Economic Prosperity	ECONOMIC	INDIRECT ECONOMIC IMPACT'	ECONOMIC PROSPERITY
	ECONOMIC	INDIRECT ECONOMIC IMPACT for USER	TRAVEL TIME VALUE
LD3.3 Conduct A Lifecycle Economic Evaluation	ECONOMIC	'DIRECT ECONOMIC IMPACT for 'AGENCY'	ALL
	ECONOMIC	DIRECT ECONOMIC IMPACT' for 'AGENCY' & 'DIRECT ECONOMIC IMPACT" for 'USER'	ALL
	ECONOMIC	DIRECT' & 'INDIRECT' 'ECONOMIC IMPACT' for 'AGENCY' and 'USER'	ALL
CR1.1 Reduce net	ENVIRONM	INDIRECT ENVIRONMENTAL IMPACT	EMBODIED

embodied carbon	ENTAL		CARBON
CR2.2 Reduce GHG Emissions	ENVIRONM ENTAL	INDIRECT ENVIRONMENTAL IMPACT'	EMISSIONS
CR2.5 Maximize Resilience	ECONOMIC	INDIRECT ECONOMIC IMPACT'	RESILIENCE VALUE

Moreover, the key credits aim to familiarize the user with a core capability of the Sustainability Lifecycle tool, the capability to perform filtering of the various impacts linked to credits and related strategies. Thus, the user decision-maker has the option to include his additional indicators, customized based on his needs: e.g. 'Identify all indicators/strategies with a positive impact on 'SAFETY.' Therefore, the user can focus on certain areas of interest.



This filtering and the resulting grouping of indicators based on an attribute/impact of the user's preference can form the basis for a further quantification and potential monetization of costs and benefits, given that each indicator is assigned a cash cost for the agency and the user. Some costs can be calculated based on budget item lists, experience-based assumptions, and others, such as resilience value and ecosystem services value, which are more complex. However, they can be approximated to be taken into account in the decision-making process. For example, resilience value requires the inclusion of the additional factor of risk, the probability of an impact, which are already captured in the Envision resilience subcategory.

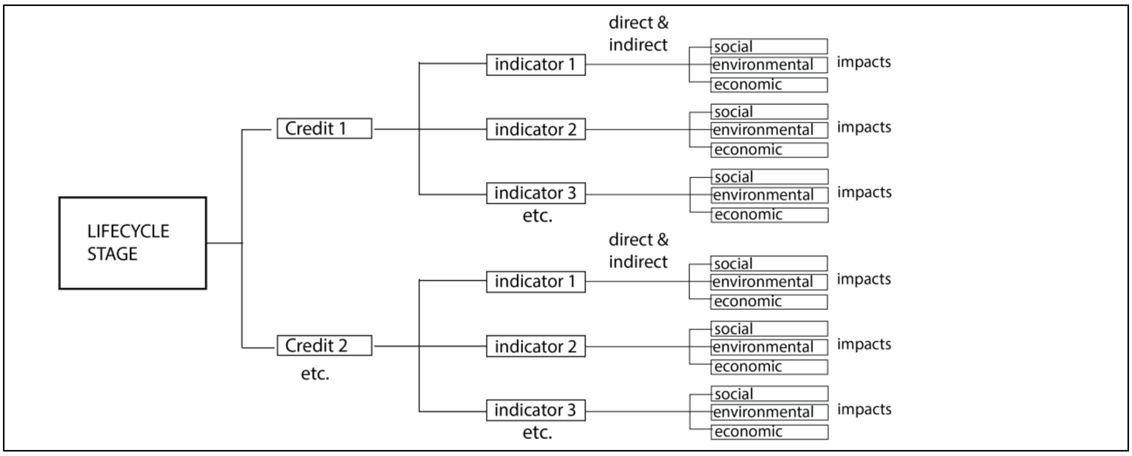
Finally, it is important to highlight that the tool, in trade-offs of a strategy or combination of strategies, does not perform a calculation of a net benefit or net cost. However, negative impacts tend to increase following the mitigation hierarchy: from avoidance to minimization to abatement and offsetting. This is a core strategy of the Envision Guidance that the tool aligns with and makes it evident:

- *Avoidance*: Measures taken to avoid creating impacts from the outset
- *Minimization*: Measures taken to reduce the duration, intensity or extent of impacts that cannot be avoided
- *Abatement*: Measures taken to rehabilitate degraded ecosystems
- *Offsetting*: Measures taken to compensate for any residual adverse impacts

5.1.5. THE LIFECYCLE DIMENSION OF THE TOOL

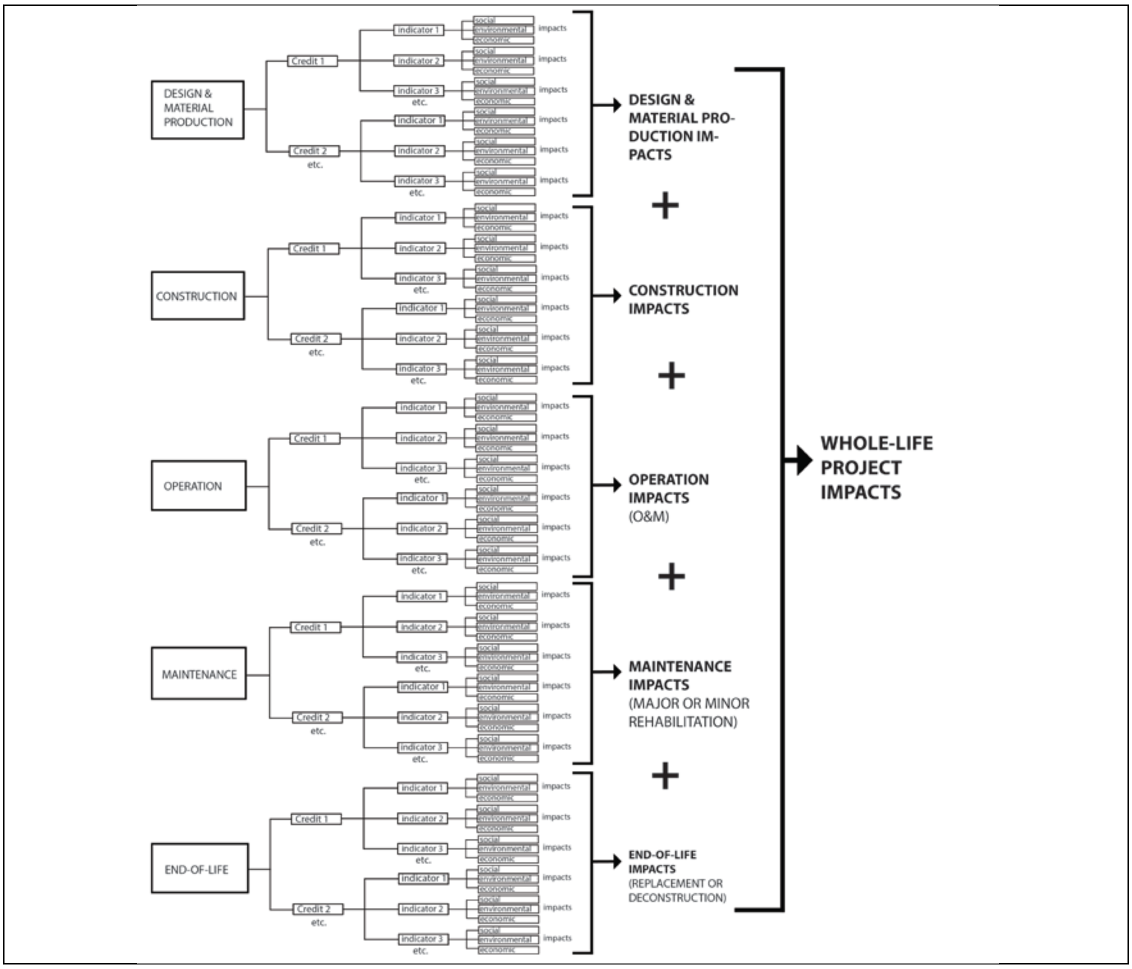
One of the significant enhancements to the Envision framework and multi-criteria analysis that the tool offers is the potential to account for whole-life (initial and future) social, environmental, and economic impacts. The tool provides two potential ways to perform this lifecycle assessment.

The first way is to utilize the tool for each lifecycle stage separately. As already presented, the Lifecycle Grouping Table groups the credits based on the lifecycle stage they refer to, the stage they aim to enhance in terms of sustainable performance. The generic structure of this reading of the tool is presented in the diagram below:

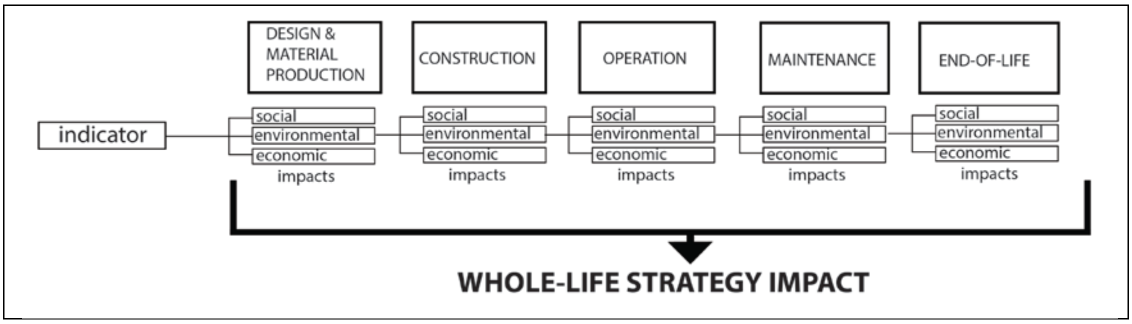


Through this process, the indicators/ strategies are connected to impacts in the context of each lifecycle: construction impacts, operation impacts, maintenance impacts, etc. For example, the 'QL1.6 Minimize construction impacts' credit indicators, when within the Maintenance lifecycle stage, can indicate future rehabilitation impacts and guide future strategies to minimize rehabilitation impacts.

The sum of all different lifecycle impacts provides **a whole-life impact assessment of the project** strategies:



A second alternative way to account for future impacts of project strategies is by focusing on the lifecycle dimension of the impacts. **This provides a complete reading of all impacts per strategy both in the short-term and long-term**:



As already mentioned, this reading is more straightforward for direct economic impacts for the agency, given that costs tend to be classified according to life cycle stages: capital (initial) cost, O&M cost, rehabilitation cost, replacement cost, residual value. In the case of social impacts (such as disruption of access, noise, safety, light pollution) or environmental impacts (such as the use of materials, waste, energy, water consumption), the distinction per lifecycle would require an additional classification of impacts to short-term (or initial) and long-term (or future), or the assignment of another attribute to each impact. E.g. 'rehabilitation works energy,' or 'replacement works disruption of access.' To avoid extensive lists, the distinction of impacts into short-term and long-term is provided as part of the XLS version of the tool. The manual is highlighted within the tool as part of the description of the impact that supplements the 'type of impact' table under the label 'initial' or 'future' 'construction works-related impacts.' The impacts captured are both the significant impacts of construction works and their associated/ indirect impacts, as presented in detail in construction-specific Envision credits, QL1.3, QL1.6, RA1.4, RA2.2, and RA3.3 and summarized in Table 9.

Given that construction works in transportation projects (whether new construction, rehabilitation, or replacement) include features and processes with significant impacts, initial and future construction works impacts are being accounted for if relevant to a specific strategy.

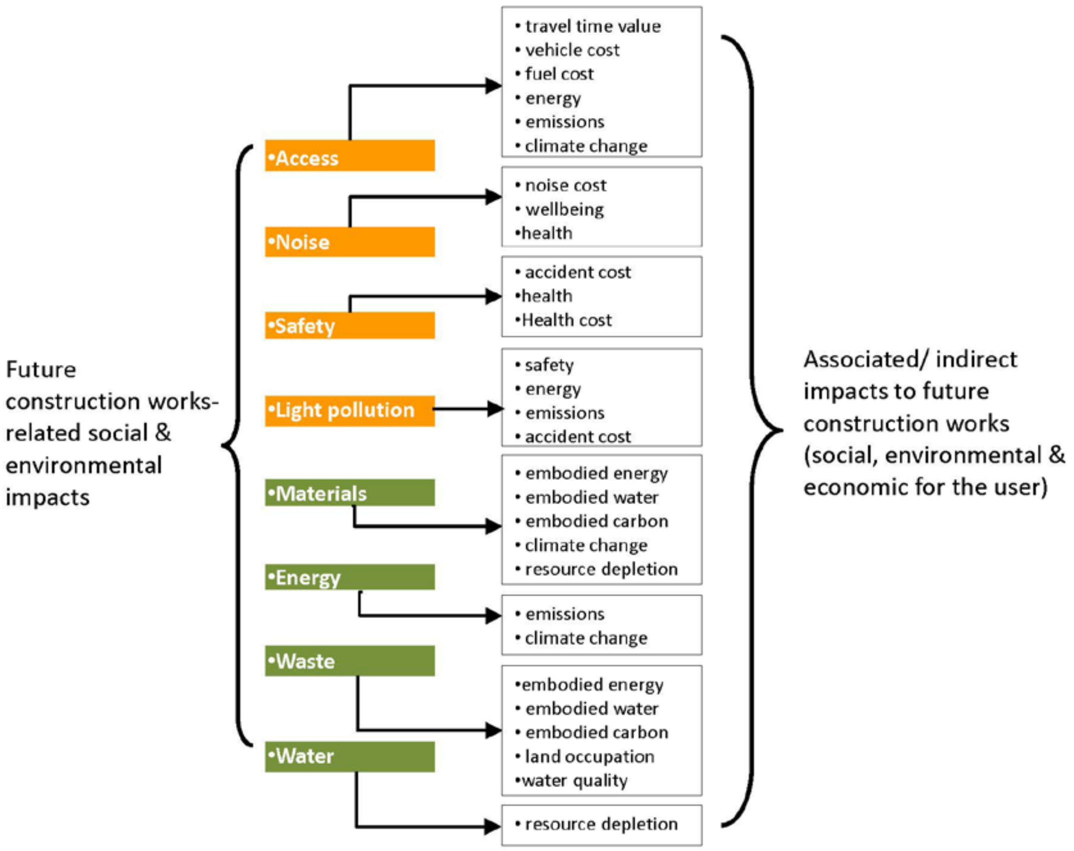


Fig.20: Future construction works-related impacts

Such function provides the capability to efficiently address the gap identified during the Bayfield River bridge replacement project analysis. A representative example of the importance of such capability is the case of lifecycle impacts of strategies that extend a project's service life and thus minimize future rehabilitation and replacements works, such as:

- use of premium materials for a redundant corrosion protection system
- design for structure durability (e.g., use of integral abutments)
- improved durability through construction quality
- extension of the project’s service life through repurposing, adaptability for increased capacity, etc.

In the following table, a detailed list of all impacts related to the use of premium materials (e.g., stainless steel) for corrosion protection is presented to highlight the importance of whole-life impacts accounting for adopting a strategy:

Table 16. Example of lifecycle impacts of strategies that contribute to minimization/ avoidance of future maintenance needs

SOCIAL IMPACT	ASSOCIATED IMPACT	IMPACT DESCRIPTION	IMMEDIATE/ INITIAL	FUTURE
(+) access	(+) travel time value (+) vehicle cost (+) fuel cost (+) energy (+) emissions (+) climate change	Avoided disruptions of access/ closure due to reduced maintenance needs; avoided construction traffic		Recurring for period of works
		Avoided fuel consumption by private vehicles due construction traffic or detouring and associated emissions		
		Avoided cost of lost productivity, vehicle operating costs and fuel cost due to avoided disruption of access and construction traffic		
(+) safety	(+) health (+) health cost	Increased safety due to durable structures		Long-term
	(+) accident cost	Increased safety due to avoided construction works and related traffic Avoided cost of accidents for public (vehicle repair or medical cost)		Recurring short-term
(+) noise	(+) noise cost (+) wellbeing (+) health (+) ecosystem quality	Avoided construction worksite noise for future maintenance; construction traffic noise		Recurring for period of works
		Avoided operational noise/ vibration due to state of good repair	Long-term	Long-term
		Avoided cost for passive noise mitigation (e.g.) Sound Insulation schemes for affected residences	Long-term	Long-term
		Avoided potential health impact from increased noise levels Positive impact on habitats as increased noise levels disturb their equilibrium		Long-term
(+) light pollution	(+) safety (+) energy (+) emissions (+) accident cost (+) ecosystem quality	Avoided energy consumption due to light wastage during nighttime works and associated emissions Positive impact on habitats as light pollution disturbs their equilibrium Avoided nighttime works and exposure of drivers to accidents due to intrusive light		Recurring for period of works

ENVIRONMENTAL IMPACT	ASSOCIATED IMPACT	IMPACT DESCRIPTION	INITIAL/ IMMEDIATE	FUTURE
(+) materials	(+) embodied energy (+) embodied water (+) embodied carbon (+) climate change (+) resource depletion	Reduced material use due to optimizing size of structures due to the redundant corrosion system/ premium materials	Short-term	
		Reduced use of materials (permanent) due to avoided replacement works through design, longer-lived materials		Recurring short-term
		Reduced use of temporary material for replacement works (equipment, safety barriers/ temporary signage, noise barriers etc.)		Recurring short-term
		Reduced embodied energy, water and carbon of materials due to avoided maintenance needs; avoided hauling routes		Recurring short-term
(+) energy	(+) emissions (+) climate change	Avoided construction worksite energy consumption and associated emissions		Recurring short-term
(+) waste	(+) embodied energy (+) embodied water (+) embodied carbon (+) land occupation (+) water quality	Reduced construction waste due to avoided rehabilitation or replacement works		Recurring short-term
		Reduced embodied energy, water and carbon of construction waste Reduced land occupation for landfilling Improved water quality		
(+) water	(+) resource depletion	Avoided construction water consumption Reduced contribution to depletion of resources		Recurring short-term
ECONOMIC IMPACT	**ASSOCIATED IMPACT**	**IMPACT DESCRIPTION**	**IMMEDIATE/ INITIAL**	**FUTURE**
(-) capital cost		Added capital cost for more durable materials (premium) and structures	Short-term	
		Reduced capital cost for labor or transport of heavier components (for downsized structures)	Short-term	
(+) rehabilitation cost		Avoided future rehabilitation cost due to longer-lived structures and materials		Recurring short-term
(+) replacement cost		Avoided future replacement cost due to longer-lived structures and materials		Recurring short-term
(+) residual value		Increased residual value		future

5.2. THE MANUAL OF THE SUSTAINABILITY LIFECYCLE TOOL

	QUALITY OF LIFE
Purpose	QL1.1 Improve Community Quality of Life QL1.2 Enhance Public Health & Safety QL1.3 Improve Construction Safety QL1.4 Minimize Noise & Vibration QL1.5 Minimize Light Pollution QL1.6 Minimize Construction Impacts
Wellbeing	QL2.1 Improve Community Mobility QL2.2 Encourage Sustainable Transportation QL2.3 Improve Access & Wayfinding
Community	QL3.1 Advance Equity & Social Justice QL3.2 Preserve Historic & Cultural Resources QL3.3 Enhance Views & Local Character QL3.4 Enhance Public Space & Amenities

PURPOSE

CREDIT: QL1.1 Improve Community Quality of Life

The credit assesses the net quality of life of all communities affected by the project and mitigates negative impacts on communities.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Wellbeing (+) Community satisfaction (+) Inclusivity		
	INDIRECT IMPACT		(+) Social resilience	(+) Delay cost	(+) Economic prosperity

SOCIAL	• Improved living standards, needs fulfillment (indicator 1) • Increased community satisfaction of alignment of project and community goals and needs; and how input was incorporated into the design of the project (indicator 2) • Inclusion of all related stakeholders in the decision-making process and understanding of the full implications of the project positive and negative (indicator 1&2)
ECON	• Avoided costs due to delays in project delivery due to public opposition, or extended approval processes (indicator 2) • Improved socioeconomic conditions due to job growth, capacity building, productivity, business attractiveness, and livability (indicator 1)

	PERFORMANCE INDICATORS	METRICS
1	Extent of assessment of community needs and extent of incorporation into the project	Achieve at least 'community considerations' level at Envision's proposed assessment levels: • 'Community considerations': Consideration of community needs and goals (through review of recent community planning) and communication of how the project meets or supports these goals) • 'Community linkages': Assessment of social impacts and engagement of the community in identifying how the project supports community needs and goals (e.g., meetings, design charrettes, and communications with representatives of affected communities) • 'Broad Community Alignment': Mitigation of negative impacts (Net positive impact) and community input incorporated into project design • 'Holistic Assessment & collaboration': Endorsements by the community that the design participation process was helpful and that their input was appropriately assessed and incorporated into project design (e.g., community satisfaction surveys, interviews with representatives of affected communities, comments, and reactions from social media platforms) • 'Protecting the future': Project identifies long-term social, economic, or environmental changes/trends that may impact community goals and needs and proactively addresses one or more of these changes/trends)
2	Community satisfaction and endorsement of plans expressed by a positive feedback	Positive community feedback with at least 65% support* regarding the assessment of their needs or goals **(Stakeholders could be included in setting and measuring of percentage targets)*
		Positive community feedback with at least 65% support that the project as proposed will address their needs or goals
		Positive community feedback with at least 65% support regarding understanding and acceptance of potential impacts of the project
		Positive community feedback with at least 65% support regarding project strategies to mitigate negative impacts

CREDIT: QL1.2 Enhance Public Health & Safety

The credit assesses how the project protects and enhances community health and safety during operation.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water quality (+) Air quality (+) Ecosystem quality[98]	(+) Wellbeing (+) Health (+) Safety (+) Equity (+) Inclusivity		(+) Accident cost
	INDIRECT IMPACT		(+) Social resilience	(+) Liability claim cost	(+) Health cost
SOCIAL	• Reduction in respiratory diseases, allergens, etc. through the project's avoidance or minimization of critical health (water quality, air quality, and ecosystem quality; increased physical fitness; and improved access to healthcare services (indicators 1-4) • Reduction in premature mortality, injuries, etc. due to the avoided risk of accidents (indicator 5) • Proportionate distribution of health and safety mitigation measures to all most impacted communities (indicator 6)				
ECON	• Avoided cost of potential liability claims (e.g., in the case of an accident related to the project) (indicators 1-6) • Avoided healthcare cost (indicators 1-5) • Avoided cost of accidents (vehicle repair or medical cost) (indicator 1-5)				

	PERFORMANCE INDICATORS	METRICS
1	Compliance with all relevant health and safety regulations and laws as an overarching prerequisite	
2	Exceedance of minimum legal health and safety requirements through health and safety improvements within the project boundary	
3	Avoidance or minimization of health and safety risks through strategic project siting	
4	Extent (area of impact) of health and safety improvements	Area of impact of improvements: • Critical improvements within the project boundary (project operations) • Additional improvements to the project's immediate surroundings (e.g., protected areas or elevated walkways for pedestrians, clear lines of sight to traffic, improved lighting, etc.). • Additional improvements to the broader host or affected communities (e.g., reduced pollution in surface waters, higher water quality, better air quality, access to healthy activities, access to health

[98] The mentioned impacts are indicative and limited to typical critical risks to human health and safety, as the range of impacts are dependent of the exact nature of the project

		services, etc.)
5	Increased crash prevention and reduced crash severity through design	• Reduced vehicle, bicyclist or pedestrian collisions per mile traveled • Reduced no. of vehicle/ bicycle or pedestrian fatalities • Reduced no. of vehicle/ bicycle/ pedestrian severe injuries • Reduced no. of near misses reported (as compared to pre-project conditions)
6	Environmental justice - Proportionate distribution of health and safety mitigation measures to all most impacted communities	

CREDIT: QL1.3 Improve Construction Safety

The credit assesses how the project addresses safety procedures for onsite workers and public, personnel training and development, and site and information security.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(-) Land occupation (-) Energy	(+) Health (+) Safety (+) Wellbeing	(+-) Capital cost	(-) Travel time value (-) Vehicle cost (-) Fuel cost (+) Accident cost
	INDIRECT IMPACT	(-) Emissions (-) Embodied energy (-) Embodied carbon (-) Embodied water (-) Climate change	(+) Noise	(-) restoration cost	(+) Health cost

ENVIR	• Avoided harmful emissions on the construction site due to paving process controls, reduced asphalt fumes, prefabrication (indicators 5-7) • Additional (temporary) land occupation and need for availability of parcel near the construction site (indicator 7) • Additional fuel consumption for the hauling of components assembled or prefabricated off-site (indicator 7) • Increased emissions due to potential routes from the temporary yard to the site and the prefabrication location (indicator 7) • Increased embodied energy, water and carbon in the case of prefabricated components (indicator 7)
SOCIAL	• Improved comfort for workers (indicators 1, 2) • Improved safety and health conditions for both public and workers through less exposure to risks (indicators 1-7) • Reduced noise levels due to works performed off-site (indicator 7)

ECON	• Capital cost savings through schedule efficiency, and avoided cost of labor, the result of standardization of construction site works and avoided time lost due to job site incidents (indicators 1-7); schedule efficiency due to works performed in a temporary yard; prefabrication (indicator 7) • Added capital cost for implementing better health and safety standards (indicators 1-6); added cost of a temporary yard (acquisition, preparation, and potential post-construction restoration); added cost for hauling components from off-site location (hauling &fuel); added cost of prefabrication. (indicator 7) • Avoided cost of job site accidents; and public accidents (indicators 1, 2, 4 & 7) • Added restoration cost for temporary staging area/ construction yard after the finalization of works (indicator 7) • Added cost of lost productivity, vehicle operating costs and fuel cost due to construction site-related traffic congestion from off-site location to work site (indicator 7)

	PERFORMANCE INDICATORS	METRICS
1	Level of construction company's job site safety as determined by DART (Days Away, Restrictions, or Transfers) rates (DART rates are the calculation of the number of recordable incidents per 100 full-time employees that resulted in lost or restricted days or job transfer due to work-related injuries or illnesses)	
2	Development of construction safety procedures after identifying and assessing onsite hazards (e.g., associated with using new materials, technologies, and/or methodologies)	
3	Introduction of safety and/or security competency training programs, either online or in-person, for field personnel	
4	Standardization of job-site activities	
5	Reduced workers exposure to emissions from construction materials, asphalt fumes	At least 90% of the hot mix asphalt (HMA) placed using a certified emission controls paver
		50% of the total project pavement (hot mix asphalt or Portland cement concrete) to comprise by the reduced temperature mix (50°F less) by weight
6	Reduced workers exposure to emissions from non-road construction equipment	At least 15% of the fuel consumed by non-road construction equipment from a source other than fossil fuel (biofuel or biofuel blend)
7	Reduction of workers exposure to street traffic through performance of selected works off-site • use of temporary construction yard (preferably near the site) • use of prefabricated materials	

CREDIT: QL1.4 Minimize Noise and Vibration

The credit assesses how the project addresses noise and vibrations during project operations.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER

<table>
<tr><td rowspan="2">IMPACT ASSESSED</td><td>DIRECT IMPACT</td><td>(-) Materials</td><td>(+) Noise
(+) Wellbeing
(+) Community satisfaction</td><td>(-) Capital cost
(-) Rehabilitation cost
(-) Replacement cost</td><td></td></tr>
<tr><td>INDIRECT IMPACT</td><td>(-) Embodied energy
(-) Embodied carbon
(-) Embodied water
(-) Emissions
(-) Climate change
(-) Resource depletion
(+) Ecosystem quality
(+) Ecological resilience</td><td>(+) Health
(+) Social resilience</td><td>(+) Noise cost
(+) Delay cost</td><td>(+) Health cost</td></tr>
<tr><td>ENVIR</td><td colspan="5">• Additional use of materials for noise mitigation elements (noise barriers) and the associated embodied energy, water, and carbon. (indicator 2)
• Additional future construction works-related impacts (materials, energy, waste, water and associated indirect impacts) for the rehabilitation or replacement of the typically shorter-service-life quiet pavements. (indicators 2,3)
• Positive long-term impact on habitats as increased noise levels disturb their equilibrium (indicators 1-4)</td></tr>
<tr><td>SOCIAL</td><td colspan="5">• Reduced community disturbance by operational noise (indicators 1-4)
• Community satisfaction with engagement process for awareness of targets, mitigation strategies, and noise impacts (indicator 5)
• Avoided potential health impact from increased noise levels (indicators 1-4)
• Additional future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for the rehabilitation or replacement of the typically shorter-service-life quiet pavements. (indicators 2,3)</td></tr>
<tr><td>ECON</td><td colspan="5">• Added capital (initial) cost of materials, labor, hauling & fuel for noise mitigation measures (indicator 2)
• Added rehabilitation cost or replacement cost of the typically shorter-life quiet pavements; (indicator 3) and/or the rehabilitation or replacement works of noise mitigation elements. (indicator 2)
• Avoided cost for passive noise mitigation (e.g.) Sound Insulation schemes for affected residences. (indicator 1-4)
• Avoided costs due to delays in project delivery due to public complaints (indicator 5)
• Additional future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for the rehabilitation or replacement of the typically shorter-service-life quiet pavements. (indicators 2,3)
• An overall observation is that a negative impact on capital cost, materials, emissions, etc. increases significantly from avoidance to minimization to abatement. (indicator 2)</td></tr>
</table>

<table>
<tr><th colspan="2">PERFORMANCE INDICATORS</th><th>METRICS</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Level of exceedance of existing or adopted target noise levels accounting for all potential noise generation sources related to operations (targets are the maximum acceptable noise levels for the receiving communities and should include existing ambient noise levels)
A typical noise goal might be to not exceed the background noise level by more than five dBA. There may be different noise goals for different locations, times of day, receiver types and activities</td><td>No exceedance of target noise levels (Exceedances are measured noise levels greater than two dBA)</td></tr>
<tr><td>No recurring or major exceedances of noise goals as determined based on relevant regulations and the advice of a qualified acoustic specialist
• Recurring exceedances are defined as more than two exceedances of a similar nature within 12 months.
• Major exceedances are defined as exceeding noise goals or objectives by more thaten10 dBA</td></tr>
<tr><td>2</td><td>Implementation of noise reduction measures (Measures may include:
• Siting strategies, e.g., relocating noise generation</td><td>Noise reduction ability of implemented measures (dB) as compared to not implementing measures.</td></tr>
</table>

	sources away from populated areas • Noise abatement at source, e.g., through the use of quieter equipment, use of quieter pavement, (in the case of bridges) elimination of bridge expansion joints through structural continuity • Receptor abatement (e.g., use of noise barriers/ buffers)	
3	Reduced tire/pavement noise through quiet pavement, e.g., open graded friction course (Noise reduction ability of open graded pavement surfaces is generally reported in 3-9 dBA range)	At least 75% of trafficked lane pavement surface areas where speed exceeds 30 mph surfaced with quiet pavement that produces tire pavement noise levels at or below: • 99 dB for speed limit 55 mph or more • 91 dB for speed limit 30 to 54 mph
4	Level of exceedances of vibration goals	No recurring or major exceedances of vibration goals for human comfort criteria. • Recurring exceedances are defined as more than two of a similar type within 12 months. • Major exceedances are defined as more than doubling the vibration goals.)
5	Community awareness of targets, mitigation strategies and noise impacts through stakeholder engagement process	At least 'Active engagement (inform)' level of stakeholder participation according to EnvisionV3 Manual Levels of stakeholder participation: • Active engagement (inform) • Direct engagement (consult) • Community involvement (involve) • Community Satisfaction (support) • Stakeholder partnerships (one or more stakeholders engaged as partners)

CREDIT: QL1.5 Minimize Light Pollution

The credit assesses how the project reduces backlight, uplight, and glare without jeopardizing safety during operations.

LC STAGE	**DESIGN & MATERIAL PRODUCTION**	**CONSTRUCTION**	**OPERATION**	**MAINTENANCE**	**END-OF-LIFE**
			X		

TYPE OF IMPACT ASSESSED		**ENVIRONMENTAL**	**SOCIAL**	**ECONOMIC**	
				AGENCY	USER
	DIRECT IMPACT	(+) Materials (+) Energy (-) Waste	(+) Light pollution (+-) Safety	(+-) Capital cost (+) O&M cost	(+-) Accident cost
	INDIRECT IMPACT	(+) Ecosystem quality (+) Emissions (+-) Embodied energy (+-) Embodied carbon (+-) Embodied water (+-) Climate change (-) Water quality (+) Ecological resilience	(+) Health (+) Wellbeing (+) Social resilience		(+) Health cost

ENVIR	• Reduced use of materials due to minimized lighting needs (new construction) (indicators 3, 4) • Additional waste generated by removal of excess existing luminaires; and associated embodied energy, water and carbon from its disposal; negative impact on water quality from its disposal. (indicator 6) • Reduced electricity consumption due to minimized lighting needs; low-energy luminaires; and avoidance of light wastage (indicators 1-6) • Positive impact on habitats as light pollution disturbs their equilibrium (indicators 1-6) • Reduced embodied energy and carbon due to less materials (indicators 3, 4) • Increase in embodied energy and carbon due to waste generated (rehabilitation/ retrofit project) (indicators 6) • Reduced emissions due to less electricity purchased from grid, therefore less need for energy generation (indicators 1-6) Maximized performance when strategies are under a more comprehensive review of lighting needs.
SOCIAL	• Potential trade-off between sufficient light levels and uniformity necessary for human nighttime safety and minimum lighting needs (indicator 4)
ECON	• Capital cost savings due to reduced purchased materials (indicators 3, 4) • O&M cost savings (electricity cost) due to reduced electricity consumption (indicators 1-6) • Added capital cost of removal of excess existing luminaires (indicator 6) • Potential accident cost depending on the proper or not balance of human nighttime safety and minimum lighting needs (indicator 4)

	PERFORMANCE INDICATORS	METRICS
1	Perform BUG (Backlight, Uplight, and Glare) rating for each luminaire	
2	Reduction of backlight, uplight, and glare (BUG)	Lighting does not exceed maximum backlight, uplight, and glare requirements for lighting zones (based on Model Lighting Ordinance methodology)
3	Lighting pollution reduction through the following strategies as prioritized: a. Avoidance: identifying where lighting may not be needed. b. Minimization: determining the minimum lighting necessary to meet safety and performance requirements. c. Protection: restricting light spillage to sensitive areas or directing light only to where it is needed. d. Offsetting: compensating for lighting in one location by removing lighting in another location.	
4	Establishment of minimum lighting needs to meet safety and energy performance requirements (sufficient light levels and uniformity necessary for human nighttime safety and low-energy and avoidance of light wastage)	Not to exceed minimum lighting needs
5	Minimization of upward light spill(uplight) by use of Dark-sky compliant (or equivalent) Luminaire types	Luminaire type restricts light emission to below 90 degrees
6	Reduction of overall existing lighting levels through: • Retrofit of existing luminaires and/or • Removal of excess existing lighting no longer needed	At least 10% reduction of lighting levels

CREDIT: QL1.6 Minimize Construction Impacts

The credit assesses how many temporary impacts to the community associated with construction works are addressed through the construction management plan.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(-) Materials (+) Air quality (+-) Energy (+) Emissions	(+-) Noise (+) Safety (+-) Access (+) Light pollution (+) Wellbeing (+) Inclusivity (+) Community satisfaction	(+-) Capital cost	(+-) Travel time value (+-) Vehicle cost (+-) Fuel cost (+-) Accident cost
	INDIRECT IMPACT	(+-) Energy (-) Embodied energy (-) Embodied carbon (-) Embodied water (+-) Emissions (+-) Climate change (+) Ecosystem quality (+) Water quality (-) Resource depletion	(+) Health (+) Wellbeing (+) Noise (+-) Safety	(+) Noise cost (+) Liability claim cost (+) Penalty cost (+) Delay cost (+) restoration cost	(+) Health cost

ENVIR	
	• Added use of materials for safety barriers/ temporary signage in the case of staged construction and detour; and associated embodied energy, water and carbon (indicators 7, 8) • Reduced energy and fuel consumption due to properly-sized equipment, avoided idling; and associated emissions (indicator 3) • Reduced embodied energy and carbon due to avoided truck routes (indicator 5) • Increased electricity and fuel consumption on the construction site due to longer construction duration; and associated emissions (indicator 8) • Avoided fuel combustion by private vehicles and emissions due to stop-and-go traffic trends (during construction congestion traffic that tend to increase fuel consumption and thus produce more emissions) (indicator 5, 8 &14) • Increased fuel consumption by private vehicles due to detouring; and associated emissions (indicator 6, 7, 8) • Positive impact on habitats due to reduced noise (increased noise levels disturb their equilibrium) (indicators 2, 3) • Increased water quality due to avoided incidents of debris into water course (indicator 9)

SOCIAL	• Disruption of access due to full closure; days of full closure (indicator 6); for heavy freight trucks that are not allowed to cross a bridge due to weight limitations (indicator 8) • Reduced disruption of access due to improved construction logistics (indicator 5); less construction duration through accelerated construction and works performed off-site (indicators 9,10) • Increased safety for public and workers through less exposure to risk of accident due to safety measures (indicator 4); full closure, work off-site; (indicators 6, 9&14) with exception workers safety in the case of staged construction (indicator 8) • Increased safety for drivers due to control of distracting light during nighttime works (indicator 11) • Reduced disturbance of surrounding residences from distracting light during nighttime works (indicator 11) • Positive impact on human health due to reduced noise (body's acute stress response to noise raises blood pressure and heart rate among other consequences) (indicators 2, 3) • Decreased long-term noise impact due to less duration; noise controls; (indicators 2, 3) with the exception of short-term noise generation in the case of saw-cutting existing structures to be removed into segments for transfer and demolishment off-site (indicator 14) • Increased traffic noise in other areas beyond the immediate affected area of by project due to detouring (indicator 7); decreased noise due to avoided congestion through optimized construction logistics, not full disruption of access (indicators 5, 8 & 10)
ECON	• Added capital cost of temporary materials for staged construction and detour (indicators 7& 8); of accelerated construction (prefabrication, cost of acquisition of temporary yard, preparation and potential restoration cost; transport cost of heavier components, skilled labor) (indicator 9&10); schedule efficiency cost of staged construction due to inefficient work sequencing (indicator 8) • Added capital cost for contractor of noise control at source (cost increases in accordance to strategy hierarchy: from avoidance to abatement) (indicator 3) • Capital cost savings due to schedule efficiency through construction logistics (indicator 5); accelerated construction (indicators 9&10); full closure (efficient work sequencing as compared to staged construction) (indicator 6) • Avoided cost of accidents for public (vehicle repair or medical cost) and for workers (indicators 4, 6, 11, 12) • Avoided cost of delay of project delivery in the case of construction season constraints (indicators 9&10) • Avoided cost of environmental incident and restoration cost through works off-site (e.g. avoided incident of debris into water course) (indicators 9&14) • Avoided agency cost of penalty for exceedance of noise regulations; and avoided potential liability claim cost (e.g. result of noise complaints) (indicators 2, 3, 12, 15 &16) • Avoided cost for passive noise mitigation (e.g.) Sound Insulation schemes for affected residences (indicators 2,3, 12) • Avoided cost of delay due to construction carry-over; (indicators 9&10) jobsite accidents; (indicators 4, 5& 15); complaints (indicator 16). • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to optimized construction logistics, not full disruption of access (indicators 5, 8 & 10) • Added cost of lost productivity, vehicle operating costs and fuel cost due to full-closure; detouring; construction site-related traffic congestion (indicator 7,8) • Increased community satisfaction due to notification and timely response to complaints (indicator 16)

	PERFORMANCE INDICATORS	**METRICS**
1	No. of addressed construction impacts (and to what extend)	Address one, two, three or all types of the following construction impacts: • Noise • safety/wayfinding for public • disruption of access/mobility • distracting or intrusive lighting in work zone
2	Level of exceedance of existing or adopted target noise levels (continuous or non-continuous) for construction period	Noise level at any residential premises not to exceed background noise by: • 10 dB(A) or more for up to 18 months after project commencement • 5 dB(A) or more after 18 months during daytime hours (and beyond normal working hours)

		Noise not above background levels inside any adjacent residence during nighttime
		No. of days with works undertaken outside of normal working hours
		No. of days that required noise exemption for nighttime construction works
3	Reduced construction noise through noise control strategies, such as: • minimum distance from sensitive receptors, (e.g. site access roads and noisy plant as far as possible from residential areas) • new engine technology (low-noise emitting equipment) • properly sized equipment and plant on-site • avoided prolonged idling of equipment and • noise transmission reduction (screening, enclosure or silencing of noise sources)	
4	Increased safety for vulnerable road users through management of worksite access and egress routes for delivery trucks	
5	Minimized disruption from construction traffic (delivery trucks for hauling of materials and waste) upon the transport network through improved construction logistics	
6	Reduced interruption of service (full-closure)	• No. of days with planned full-closures (short and/ or long duration) • Total hours of full closures
7	Provision of alternative access during construction works through the minimum possible detour	Additional miles of detour
8	Implementation of partial closure of service- staged construction	Number of lanes open in each direction during work zone
		Added working days as compared to full-closure due to inefficiency of work sequencing
		Avoided days of full disruption due to staged construction
9	Reduced construction duration through performance of selected works off-site	Any reduction of no. of working days as compared to a base case (Base case can be a similar scope and scale construction project)
10	Reduced construction duration through accelerated construction	
11	Control of distracting or intrusive lighting in work zone	No. exceedance of minimum lighting requirements for nighttime work zone based on activities performed
12	Level of exceedance of vibration goals for high risk activities (such as rolling for compaction) for structural damage of structures	No. exceedance of vibration goals for structural damage to buildings and structures.
13	Control of dust and odors produced in work zone	
14	Reduced dust production through performance of selecting works off-site (e.g. saw-cutting into segments for removal of existing structures, transfer and demolishment off-site)	
15	Implementation of feedback mechanisms and performance monitoring and reporting for construction impacts	
16	Efficiency of implemented feedback mechanisms and performance monitoring and reporting for construction impacts	• No. of complaints resolved in a timely-manner • Time for resolution of construction incidents

WELLBEING

CREDIT: QL2.1 Improve Community Mobility & Access

The credit assesses the extent to which the project broadens mode choices, reduces commute times, reduces vehicle distance traveled, and improves levels of service.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(-) Materials (-) Energy	(+) Community satisfaction (+) Inclusivity (+) Integration (+) Access (+) Wellbeing (+) Equity	(-) Capital cost (+-) O&M cost (+-) Rehabilitation cost (+-) Replacement cost (+) Residual value (+) Revenues	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+-) Accident cost (+) Fare cost
	INDIRECT IMPACT	(+) Energy (+-) Emissions (-) Embodied energy (-) Embodied water (-) Embodied carbon (+-) Climate change (+) Resource depletion (+) Ecosystem quality	(+-) Safety (+-) Health (+) Social resilience	(+) Delay cost (+) Resilience value	(+-) Health cost (+) Job creation (+) Economic prosperity (+) Resilience value

ENVIR	• Increased initial use of materials for additional fleet for higher service coverage; and associated embodied energy, water and carbon (indicators 3, 5, 6, 7, 8,9 &10) • Increased electricity consumption for lighting/signal needs of corridors and increased fuel consumption for additional fleet; and associated emissions (indicators 3, 5, 6, 7, 8,9 &10) • Reduced fuel consumption by private vehicles from avoided idling of vehicles, as well as discouraged private vehicle use through multi-modal options; and associated emissions (indicators 3, 5, 6, 7, 8, 9, 10 &11) • Increased initial use of materials (permanent) and initial construction works- related impacts (materials (temporary), energy, water, waste and associated indirect impacts) for higher capacity systems (wider, extended corridors) (indicators 3, 5, 6, 7 &9) • Avoided future use of materials (permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for the replacement or major rehabilitation for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7 &9)

SOCIAL	• Improved living standards, needs fulfillment, human comfort, freedom of choice and ride quality (indicators 3, 5, 6, 7, 8, 9, 10 &11) • Improved access due to increased system capacity, less miles travelled, traffic management, multi-modal options that reduce congestion (indicators 3, 6, 7, 8, 9, 10 &11) • Improved safety due to vehicle mileage reductions that generally cause proportional or greater reductions in total crash damages; due to reduced congestion that tends to reduce crashes; however, increased speed increases crash severity (indicators 3, 4, 5 &11) • Increased initial construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for higher capacity systems (wider, extended corridors (indicators 3, 5, 6, 7 &9) • Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for replacement or major rehabilitation for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7 &9) • Increased equity, less dependence on privately owned vehicles (indicator 7) • Improved integration through consistency with local and regional plans (indicator 2) • Increased social resilience through adaptation to demographic shifts and growth in demand (indicator 6)
ECON	• Added capital cost and O&M cost for higher capacity (materials for higher capacity through wider, extended corridors, labor etc.); for additional fleet for improved service (fuel cost, repair, labor) (indicators 3, 5, 6, 7, 8,9 &10) • Added replacement cost and/ or major rehabilitation cost for higher capacity corridors (indicators 3, 5, 6, 7, 8,9 &10) • Avoided future replacement or major rehabilitation cost for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7, 8, 9 &10) • Increased residual value (indicators 3, 6, 7, 8 & 9) • Increased resilience value due to redundancy of options of transportation modes; accommodation of future projected growth (indicators 6 &8) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to more connections; reduced miles traveled; less congestion; reduced commute times and delays (indicators 3, 5, 7, 8, 9, 10 &11) • Increased initial construction works-related impacts (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for higher capacity systems (wider, extended corridors) (indicators 3, 5, 6, 7 &9) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for replacement or major rehabilitation for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7, 8, 9 &10) • Increased short-term jobs created for construction/ replacement due to increased capacity; additional long-term jobs created due to increased coverage (for operation of fleet etc.) (indicators 3, 6, 7, 8, 9, 10 &11) • Economic prosperity due to improved accessibility to jobs; attractiveness to businesses; new jobs created for construction and O&M due to the project (indicators 3, 5, 6, 7, 8, 9, 10 &11)

	PERFORMANCE INDICATORS	METRICS
1	Input provided from community and key stakeholders regarding improved access (e.g. from public officials and operators of adjacent facilities, amenities or transportation hubs)	At least 'Active engagement (inform)' level of stakeholder participation (See credit QL1.4)
2	Planning is consistent with local and regional transportation plans	
3	Increased system capacity to reduce congestion and avoid overloading of structural capacity of pavement	• Reduced Volume-to-capacity ratio • Improved traffic flow per capita • Reduced ratio of average peak travel time to an off-peak (free-flow) standard
4	Implemented strategies to reduce accident rate	
5	Reduced vehicle distance traveled	Average person miles of travel

6	System capacity planning addresses projected growth in commercial, industrial, and/or residential demand	
7	Increased coverage of public transportation service	Households with walking distance to a bus route less than 0.4 km (0.25 mi) or 5-minute walk
8	Multiple options of transportation modes are included	Increase in no. of mode options to the modal split
9	Intelligent Transportation Systems are incorporated to increase system efficiency	
10	Improved level of service (reliability)	• Reduced commute times • Reduced travel delay • % of user days/year without service interruptions
11	Incentivized mobility management to shift travel from peak to off-peak (e.g. congestion pricing, dynamic pricing, incorporation of HOV toll lanes)	

CREDIT: QL2.2 Encourage Sustainable Transportation

The credit assesses how the project addresses the need to expand sustainable transportation choices including active, shared, and/or mass transportation, as a way to increase health, reduce emissions, improve air quality, and increase community development.

LC STAGE	**DESIGN & MATERIAL PRODUCTION**	**CONSTRUCTION**	**OPERATION**	**MAINTENANCE**	**END-OF-LIFE**
			X		

TYPE OF IMPACT ASSESSED		**ENVIRONMENTAL**	**SOCIAL**	**ECONOMIC**	
				AGENCY	USER
	DIRECT IMPACT	(-) Materials (+-) Energy	(+) Access (+) Wellbeing (+) Livability (+) Safety (+) Equity (+) Integration	(+) Revenues (-) Capital cost (-) O&M cost (+-) Rehabilitation cost (+-) Replacement cost (+) Residual value	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Accident cost (+) Fare cost
	INDIRECT IMPACT	(+) Energy (+-) Emissions (+-) Climate change (-) Embodied carbon (-) Ecosystem quality (-) Resource depletion	(+) Health (+) Noise (+) Safety (+) Livability (+) Social resilience	(+) Resilience value	(+) Health cost (+) Job creation (+) Economic prosperity (+) Resilience value

ENVIR	• Increased use of materials for additional fleet for higher-frequency routes, higher service coverage; and associated embodied energy and carbon (indicators 3&17); for amenities (shelters, secure lockers etc. ITS systems) (indicators 10, 11& 14) • Increased electricity consumption for lighting/signal/ ITS systems needs of corridors and increased and fuel consumption for additional fleet (indicators 5, 8, 10, 11, 12,14 & 15) • Reduced fuel consumption by fleet and associated emissions through the use of lower carbon modes (indicators 1,19) • Reduced fuel consumption by private vehicles due to mass/ shared transportation; and associated emissions (indicators 1, 2, 4, 5, 7, 8, 9, 13, 14, 16 & 17) • Increased initial use of materials (permanent) and initial construction works- related impacts (materials (temporary), energy, water, waste and associated indirect impacts) for higher capacity corridors (indicators 5, 6, 7, 8, 9 &17) • Avoided future use of materials and future construction works-related impacts (materials, energy, waste, water and associated indirect impacts) for replacement or major rehabilitation cost for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 5, 6, 7, 8, 9 &17)
SOCIAL	• Improved access due to increased system capacity, less miles travelled, traffic management, multi-modal options that reduce congestion (indicators 3, 5, 6, 7, 8, 9, 10,11, 14,15 &17) • Improved safety due to exclusive pedestrian/ bicycle paths; ITS systems; less miles traveled (indicators 6, 8, 9 &17) • Reduced respiratory diseases due to reduced pollutant emissions and increased physical fitness; less stress for cyclists, pedestrians (indicators 1, 2, 4, 16 &19) • Increased livability due to increased accessibility by pedestrians/ cyclists (indicators 1, 2, 4, 5, 6, 9, 12 &17) • Increased initial construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for higher capacity corridors (indicators 5, 6, 7, 8, 9 &17) • Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for replacement or major rehabilitation cost for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7, 8, 9 &17)
ECON	• Added capital cost and O&M cost for higher capacity (materials for higher capacity through wider, extended corridors, labor etc.); for additional fleet for improved service (fuel cost, repair, labor) (indicators 3, 5, 6, 7, 8, 9, 10,11, 14,15 &17) • Added replacement cost or major rehabilitation cost for higher capacity corridors (indicators 3, 5, 6, 7, 8, 9, 10,11, 14, 15 &17) • Avoided future replacement or major rehabilitation cost for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7, 8, 9 &17) • Increased residual value (indicators 3, 5, 6, 7, 8, 9, 10,11, 14,15 &17) • Increased revenues from increased use of mass transportation due to quality of service, proximity, (indicators 1, 2, 3, 4, 5, 7, 13, 15, 16, 17 &18) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to higher frequency routes; less commute time; more connections; reduced miles traveled; ITS systems; less congestion (indicators 1,2,4, 5, 7, 8,9, 13, 14, 16, 17 &18) • Increased initial construction works-related impacts (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for higher capacity corridors (indicators 5, 6, 7, 8, 9 &17) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for replacement or major rehabilitation cost for expansion/widening due to redundant capacity and less road damage due to less burden on the road structure and thus less degradation (indicators 3, 5, 6, 7, 8, 9 &17) • Increased short-term jobs created for construction/ replacement due to increased capacity; additional long-term jobs created due to increased coverage (for operation of fleet etc.) (indicators 3, 5, 6, 7, 8, 9, 10,11, 14,15 &17) • Economic prosperity due to improved accessibility to jobs; (indicators 2, 4 &18) increased attractiveness to businesses due to livability, connections (indicators 1, 2, 4, 5, 6, 9, 12, 16 &17) • Increased resilience value due to redundancy of options; accommodation of future projected growth; promotion of zero or low carbon alternatives for transport; climate change mitigation (indicators 3-17 &19)

	PERFORMANCE INDICATORS	METRICS
1	Increased pedestrian proximity and accessibility to active, shared, and/or mass transportation	The % of residences located within walking distance (0.5 mi/0.8 km, or a 10-minute walk) from mass transportation is increased compared to pre-project conditions
2	Increased proximity between households and jobs	Increased no. of jobs accessible within a 30-min transit commute on avg. for households
3	Increased high-frequency transit routes	• No. of 24hrs around high-frequency routes • No. of 7am to 10 pm high-frequency routes • No. of rush hours high-frequency routes
4	Increased pedestrian proximity to high-frequency transit routes	% of population within 0.5 mile of high-frequency transit route
5	Extended network of active transportation	Miles of pedestrian/bicycle facilities
6	Enhanced width and condition of bicycle and pedestrian facilities	
7	Enhanced HOV access within the ROW by incorporating carpool lane for HOV (or HOV toll lanes)	Miles of dedicated HOV lanes
8	Enhanced physical characteristics (roadway structure dimensions or form) for mass transportation that provide: • queue jump lanes for transit vehicles; • dedicated transit access within the ROW, such as on-street bus lane • expressway bus lane; • exclusive mass transit access within the ROW, such as at-grade or grade-separated transit ways	
9	Increased sidewalk connections and bike facility connections	Miles of sidewalk connections and bike facility connections
10	Increased transit stops with bicycle parking, bicycle sharing stations, secure bike lockers along a corridor	% of transit stops with bicycle parking, bicycle sharing stations, secure bike lockers along a corridor
11	Extended use of shelters in bus stops along a corridor	% of bus stops with shelters along a corridor
12	Extended network of well-lit and clearly visible pathways	Miles of well-lit and clearly visible pathways
13	Increased access to mode share	% of stations with access to mode share
14	Extended use of ITS in transit and HOV facilities	% of transit and HOV facilities with ITS (passenger information amenities (maps, schedules, real-time signage)
15	Provision for access to new park & ride lots in strategic locations	
16	Inclusion of programs that encourage use of mass transportation (Subsidized fare programs, emergency ride home services, coordination with ride-sharing companies, off-board ticketing, real-time arrival information, or mobile apps)	
17	Contribution to integrated overall efficiency and level of service of active, shared, or mass transportation network for the community or region (e.g. creation of new connections, rehabilitation/repurpose of unused, underused, or previously disconnected pathways, bikeways, rail, and/or other modes)	
18	Reduced time spent commuting for work or school during peak periods	Average time per trip spent commuting for work or school during peak periods via transit vs. private vehicles
19	Increased use of lower-carbon transport modes (e.g. electricity-, natural gas- powered)	% of fleet with low-carbon technologies

CREDIT: QL2.3 Improve Access & Wayfinding

The credit assesses how the project provides safe and appropriate access to users of all ages and abilities, and wayfinding measures so they can safely access the site and/or clearly and easily navigate around it.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(-) Materials	(+) Access (+) Safety (+) Wellbeing (+) Health	(-) Capital cost (-) O&M cost (-) Rehabilitation cost (-) Replacement cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Accident cost
	INDIRECT IMPACT	(+) Energy (+) Emissions (+-) Climate change (-) Embodied energy (-) Embodied carbon (-) Resource depletion	(+) Livability (+) Social resilience	(+) Resilience value	(+) Health cost (+) Resilience value (+) Economic prosperity

ENVIR	• Increased use of materials for wayfinding measures and safety measures (indicators 1, 4, 5, 6,7 &8) • Reduced fuel consumption by private vehicles due to less miles travelled through route directness; avoided errors in route selection etc.; and associated emissions (indicators 1, 2, 3, 4 & 5) • Increased initial use of materials (permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for the rehabilitation or replacement of wayfinding measures and safety measures (indicators 5, 6,7 &8) • Avoided future use of materials and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for replacement or major rehabilitation for expansion/ widening due to less miles traveled thus less degradation (indicators 1-8)
SOCIAL	• Improved access due to direct routes, avoided errors in route selection etc. (indicators 1, 2, 3) • Less disturbance to community due to direct routes, avoided errors in route selection etc. (indicators 1, 2, 3) • Improved safety due to signage/ wayfinding measures for proper use of different corridors; traffic calming measures; physical separation of pedestrian/ cycling paths from road traffic (indicators 1, 4, 5, 6,7 &8) • Additional future construction works-related impacts to the community (access, noise, safety, light pollution and associated indirect impacts) for the rehabilitation or replacement of wayfinding measures and safety measures (indicators 5, 6,7 &8) • Avoided future construction works-related impacts to the community (access, noise, safety, light pollution and associated indirect impacts) for replacement or major rehabilitation for expansion/ widening due to less miles traveled thus less degradation (indicators 1-8) • Reduced respiratory diseases due to reduced pollutant emissions and increased physical fitness; less stress for cyclists, pedestrians (indicators 1, 4, 5, 6,7 &8) • Increased livability due to increased accessibility by pedestrians/ cyclists (indicators 1, 4, 5, 6,7 &8) • Increased social resilience due to emergency preparedness (indicator 2)

ECON	• Added capital cost and O&M cost for higher capacity (materials for wayfinding measures and safety measures) (indicators 1, 4, 5, 6,7 & 8) • Added replacement cost or major rehabilitation cost for wayfinding measures and safety measures (indicators 1, 4, 5, 6,7 & 8) • Avoided future replacement or major rehabilitation cost for expansion/widening due to less miles traveled thus less degradation (indicators 1-8) • Increased initial construction works-related impacts (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for wayfinding measures and safety measures (indicators 5, 6,7 & 8) • Additional future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for the rehabilitation or replacement of wayfinding measures and safety measures (indicators 5, 6,7 & 8) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for replacement or major rehabilitation for expansion/ widening due to less miles traveled thus less degradation (indicators 1-8) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to direct routes, improved orientation and recognition of destination for users, easy route selection, tolerance for error (indicators 1, 2, 3 & 4) • Avoided cost of accident (indicators 1-8) • Increased resilience value for agency and community due to emergence preparedness (indicator 2) • Economic prosperity due to attractiveness to businesses, result of ease of access, livability (indicators 1, 2, 3 4 &6)

	PERFORMANCE INDICATORS	METRICS
1	Provision of clear wayfinding measures for orientation, route selection, route control and recognition of destination for both regular vehicular and pedestrian traffic	
2	Emergency preparedness (signage and route directness for access and egress of emergency personnel, users, and occupants)	
3	Increased tolerance for error through flexibility in route selection	
4	Clear signage and wayfinding techniques (for access roads, bikeways, or pedestrian paths) to facilitate their proper use	
5	Increased no. of safe and accessible street-crossing opportunities for pedestrians (universal access curb cuts, pedestrian crossing signs, and high-visibility crosswalks and no. of eliminated at-grade crossings at heavy traffic roads	• No. of street crossings for pedestrians per mile of road • No. of street crossings for pedestrians with universal access curb cuts • No. of street crossings with pedestrian crossing signs • No. of eliminated at-grade crossings at heavy traffic roads
6	Use of traffic-calming measures in areas with heavy pedestrian or bicycle traffic	
7	Improved pedestrian path safety (e.g. physical barriers between sidewalks and street traffic exceeding 40 mph speed)	Miles of pedestrian pathways with physical barriers
8	Improved bike lane safety (e.g. separating bike lanes from street traffic)	Miles of pedestrian lanes separated from street traffic

COMMUNITY

CREDIT: QL3.1 Advance Equity and Social Justice

The credit assesses how the project ensures that equity and social justice are fundamental considerations within project processes and decision making.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Equity (+) Inclusivity (+) Access (+) Wellbeing (+) Community satisfaction	(+) Revenues	(+) Fare cost
	INDIRECT IMPACT				(+) Economic prosperity

SOCIAL	• Increased social justice through equal distribution of social, environmental and economic benefits (indicators 1-5) • Improved community satisfaction due to inclusion of historically underrepresented communities; social justice (indicators 1,3 &4)
ECON	• Improved affordability of service for all (indicators 4&5) • Increased revenues due to use of service by portions of population it was prior not affordable to (indicators 4&5) • Economic prosperity due to improved accessibility to jobs, increased attractiveness to businesses through improved accessibility, regeneration of neighborhoods etc. (indicators 1 -5)

	PERFORMANCE INDICATORS	METRICS
1	High rate of participation and/or inclusion of underrepresented communities in stakeholder engagement to promote equity and social justice	
2	Organizations involved in the project have institutional policies to commit to nondiscrimination (policy of active diversity and inclusion or policy of pay equity may be also required)	
3	Increase of historically transportation-disadvantaged population served (aiming to correct an existing or historic injustice or imbalance)	Ratio of vulnerable populations and non-vulnerable populations within service area that live within 0.5 mile of a high frequency transit stop
4	Consideration of the portion of household income devoted to public transport by lower income households	
5	No. of participants in a low-income fare program as a percentage of low-income riders	

CREDIT: QL3.2 Preserve Historic and Cultural Resources

The credit assesses how the project preserves or restores significant historical and cultural sites and related resources.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Sense of place (+) Community satisfaction		
	INDIRECT IMPACT			(+-) Delay cost	

SOCIAL	• Enhanced relation of the community with the place due to preserved heritage and cultural identity resources (indicators 1&2) • Increased community satisfaction due to engagement (indicator 2)
ECON	• Avoided costs due to delays in project delivery because of opposition (indicators 1&2) • Added cost due to potential longer approval processes that extend schedule through stakeholder engagement (indicator 1&2)

	PERFORMANCE INDICATORS	METRICS
1	Preservation of historic and/or cultural resources (registered heritage assets) that may be impacted by the project	
2	Preservation of historic and/or cultural resources (unregistered heritage assets) that are identified as important parts of the community culture and maybe impacted by the project	At least 'Direct engagement (consult)' level of stakeholder participation (See credit QL1.4)

CREDIT: QL3.3 Enhance Views & Local Character

The credit assesses how the project preserves or enhances the physical, natural, and/or community character of the project site and its surroundings.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Ecosystem quality	(+) Sense of place (+) Wellbeing (+) Community satisfaction	(-) Capital cost	

	INDIRECT IMPACT			(+) Delay cost (+) Liability claim cost (+) Restoration cost	

SOCIAL	• Enhanced relation of the community with the place due to preserved local view resources (indicator 1) • Increased community satisfaction and project endorsement due to alignment with community values (indicator 2)
ECON	• Added cost of protection measures during construction in case of proximity to a character feature (indicator 3) • Avoided costs of delays in project delivery due to public opposition, and/ or accidental damage or removal or character features (indicators 2&3) • Avoided cost of restoration of accidental damage or removal of a character feature (indicator 3) • Avoided cost of potential liability claims in case of accidental damage or removal of a character feature (indicator 3)

	PERFORMANCE INDICATORS	METRICS
1	Protection or enhancement of local landscape and visual factors (view resources)	
2	Preservation and enhancement strategies regarding views and local character are informed by the stakeholder consultation process	At least 'Direct engagement (consult)' level of stakeholder participation (See credit QL1.4)
3	Increased level of protection against accidental damage or removal of character features, high-value landscapes, or landscape features during construction works	

CREDIT: QL3.4 Enhance Public Space and Amenities

The credit assesses how the project improves amenities and publicly accessible spaces to enhance community livability.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(-) Materials	(+) Wellbeing (+) Community satisfaction (+) Livability	(-) Capital cost (-) O&M cost (+-) Rehabilitation cost (+-) Replacement cost (+) Residual value	
	INDIRECT IMPACT	(-) Embodied energy (-) Embodied carbon (-) Embodied water (-) Climate change (-) Resource depletion	(+) Safety		(+) Economic prosperity

ENVIR	• Increased initial use of materials for enhancement of existing amenities and new amenities; and associated embodied energy, water and carbon (indicators 1&2) • Increased initial construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for enhancement of existing amenities and new amenities (indicators 1&2) • Avoided future construction works-related impacts (materials, energy, waste, water and associated indirect impacts) for the rehabilitation or replacement of degraded existing amenities (indicator 2)
SOCIAL	• Increased livability due to provision/ enhancement of amenities (indicators 1&2) • Increased safety and sense of safety due to livability; regeneration of previously degraded or unusable amenities (indicator 1& 2) • Increased community satisfaction and project endorsement due to alignment with community needs (indicator 3) • Increased initial construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for enhancement of existing amenities and new amenities (indicators 1&2) • Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for the rehabilitation or replacement of degraded amenities (indicator 2)
ECON	• Added capital cost, O&M cost, for new amenities and enhancement of existing, or offsetting in the case of loss of existing amenity (indicators 1 &2) • Added future rehabilitation and replacement cost for new assets or offsetting in the case of loss of existing amenity (indicators 1 &2) • Reduced rehabilitation and replacement cost for existing enhanced amenities (indicator 2) • Increased residual value due to new assets, enhancement of existing, upgrade of previously degraded ones (indicators 1 &2) • Potential increase of land and property value due to new assets to community; regeneration of previously degraded or unusable amenities (indicators 1 &2) • Increased initial construction works-related impacts (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for enhancement of existing amenities and new amenities (indicators 1&2) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for the rehabilitation or replacement of degraded amenities (indicator 2)

	PERFORMANCE INDICATORS	METRICS
1	No net loss in quantity or quality (may include offsetting) of existing public amenities (offsets must be of similar or better type and quality and serve the same community)	
2	Net benefit in quantity or quality of existing public amenities through at least one of the following strategies: • Enhancement of existing public amenities • New public amenities (not previously available) added • New assets to community • Restoration of previously degraded or unusable amenities	
3	Preservation and enhancement strategies regarding public space and amenities are informed by the stakeholder consultation process	At least 'Direct engagement (consult)' level of stakeholder participation (See credit QL1.4)

LEADERSHIP

Collaboration	LD1.1 Provide Effective Leadership & Commitment LD1.2 Foster Collaboration & Teamwork LD1.3 Provide for Stakeholder Involvement LD1.4 Pursue Byproduct Synergies
Planning	LD2.1 Establish a Sustainability Management Plan LD2.2 Plan for Sustainable Communities LD2.3 Plan for Long-Term Monitoring & Maintenance LD2.4 Plan for End-of-Life
Economy	LD3.1 Stimulate Economic Prosperity & Development LD3.2 Develop Local Skills & Capabilities LD3.3 Conduct a Lifecycle Economic Evaluation

COLLABORATION

CREDIT: LD1.1 Provide Effective Leadership & Commitment

The credit assesses the degree to which the project owner and the project team provides effective leadership and commitment to achieve general, and project-specific, sustainability commitments and instituted sustainability management policies.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Capacity building		
	INDIRECT IMPACT				(+) Economic prosperity
	Direct and indirect impacts depend on specific objectives and targets set, however effective leadership and commitment are a precondition for potentially enhanced performance across all categories.				

Apart from objective- and target-specific environmental, social and economic impacts result of effective leadership commitment:	
SOCIAL	• Increased capacity building through dissemination of best practice (indicator 5)
ECON	• Economic prosperity through wider adoption of scalable sustainable solutions enabled by dissemination of best practice (indicator 5)

	PERFORMANCE INDICATORS	METRICS
1	Project-specific commitment to address social, environmental, and economic aspects clearly articulated in project chartering session and/or contract documents	
2	Project- or program-specific or agency/department-wide commitment for improved sustainable performance with clear objectives and targets supported by a sustainability management policy	
3	Revisited statements and review of progress against targets	
4	Corporate-level sustainability commitment (embedded into business strategy) for key project team members	
5	Communication and effective dissemination of best practice (e.g. briefing sheets internally published or in industry publications, presentations to other companies or professional bodies, involvement with universities)	

CREDIT: LD1.2 Foster Collaboration & Teamwork

The credit assesses the breadth and inclusivity of interdisciplinary and collaborative meetings and the resulting project sustainability performance enhancements.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Materials (+) Energy (+) Water (+) water quality (+) Waste	(+) Inclusivity (+) Integration	(+) Capital cost (+) O&M cost (+) Rehabilitation cost (+) Replacement cost (+) Residual value	
	INDIRECT IMPACT	(+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Emissions (+) Resource depletion (+) Climate change (+) Ecosystem quality	(+) Wellbeing (+) Health (+) Social resilience	(+) Resilience value	(+) Resilience value

ENVIR	• Optimized use of materials, energy, water and reduced waste through early consideration of construction, O&M phases; on-going collaboration and experts' feedback on the design; waste and associated net embodied energy, water and carbon (indicators 1,2,3) • Avoided future use of materials(permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for rehabilitation or replacement works (indicators 1,2,3 & 4)
SOC	• Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for rehabilitation or replacement works (indicators 1,2,3 & 4)
ECON	• Reduced whole-life costs through early consideration and experts' feedback on the design for optimized materials' use, improved constructability; schedule and labor efficiency; energy and water efficiency during operations; improved durability and extended useful life (indicators 1,2,3 & 4) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for rehabilitation or replacement works (indicators 1,2,3 & 4) • Increased residual value of the asset due to improved design, construction quality, durability (indicators 1,2,3) • Increased resilience value for the agency and the community through ability to withstand short-term and long-term due to durability (indicators 1,2,3)

	PERFORMANCE INDICATORS	METRICS
1	Early collaboration meeting for definition of project sustainability goals (initial kick-off meeting with project staff at all levels)	
2	On-going collaboration meetings focused on sustainability throughout design development with a broad set of participants to enable a whole-systems design approach, rather than sustainability add-ons	No. of sustainability-focused meetings (beyond the kick-off meting) held over design development, at which frequency and no. of participants from different disciplines

3	Collaboration meetings that specifically included stakeholders from later construction, operations, and/or maintenance phases for whole-life approach	No. of whole-life-approach-focused meetings and no. of participants from different disciplines
4	Efficient communication through reporting and project tracking mechanisms (e.g. flowcharts, checklists, progress status reports, IT platforms for collaboration and data integration)	

KEY CREDIT

CREDIT: LD1.3 Provide for Stakeholder Involvement

The credit assesses the early and sustained stakeholder engagement and involvement in project decision making.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Inclusivity (+) Equity (+) Capacity building	(+) Delay cost	(+) Economic Prosperity
	INDIRECT IMPACT		(+) Community satisfaction		

- Indirect and direct impacts of this credit are the sum up of impacts from credits QL1.1, QL1.4, QL 2.1, QL3.2, QL3.3, QL 3.4

	PERFORMANCE INDICATORS	METRICS
1	Level of stakeholder engagement/ stakeholder participation in the decision making	At least 'Direct engagement (consult)' level of stakeholder participation Levels of stakeholder participation: • Active engagement (inform) • Direct engagement (consult) • Community involvement (involve) • Community Satisfaction (support) • Stakeholder partnerships (one or more stakeholders engaged as partners
		IMPACT FOR FILTERING: 'COMMUNITY SATISFACTION'
2	Effectiveness of community engagement process	% of the population of each identified demographic group within the affected community that has been outreached
		% of the population of each identified demographic group within the affected community that has participated
3	% of Client-identified partnership links implemented during construction works (e.g. with local schools, community groups, or other organizations that could benefit from an exchange of skills or donation of surplus material or knowledge)	At least 25% of stakeholder partnership links implemented by the contractor

CREDIT: LD1.4 Pursue byproduct Synergies

The credit assesses how the project critically reconsiders whether traditional waste streams can be beneficially reused and the extent to which the project team works with external groups to find beneficial use of waste, excess resources, or capacity.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials (+) Land occupation		(+) O&M cost	
	INDIRECT IMPACT	(+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Climate change (+) Resource depletion (+) Ecosystem quality (+) Ecological resilience	(+) Noise (+) Wellbeing (+) Health (+) Social resilience	(+) Noise cost (+) Resilience value	(+) Health cost (+) Economic prosperity
ENVIR	• Reduced waste and associated embodied energy, water and carbon through beneficial reuse by nearby facilities and land occupation for landfilling (indicators 1-5) • Reduced land occupation for landfilling through waste diversion (indicators 1-5)				
ECON	• Reduced O&M costs for primary materials through collaboration and negotiation with nearby facilities for supply of their by-products or discarded materials for use on the project (indicators 1-5) • Increased resilience value through the future security of supply of beneficial operational resources (indicators 1-5) • Wider community prosperity through shared benefits; sharing economy (indicators 1-5)				

	PERFORMANCE INDICATORS	METRICS
1	Assessment of the availability and viability of beneficial reuse of excess resources (e.g. waste materials, land area/space, or management/personnel capacity)	
2	Reuse for project's waste or excess resources to support natural systems or use of natural systems for processing project waste	
3	Increased collaboration with external groups to find beneficial use of project by-products (project's waste streams or excess resources) off-site or incorporating off-site waste or excess resources into the project	
4	Short-term and/or long-term incorporation of at least one by-product synergy or reuse into the project	
5	Full-engagement of the project to in a "circular economy" system: the majority of its operational waste is beneficially reused OR the majority of its operational resources are sourced from external waste streams. Use of one or more of the following business models: [99] (i) On-demand, (ii) Dematerialization,	

[99] Source: BS 8001:2007 Framework for implementing the principles of the circular economy in organizations – Guide.

	(iii) Product Lifecycle extension/reuse, (iv) Recovery of secondary raw materials/ by-products, (v) Product as a service/product–service system (PSS), (vi) Sharing economy and collaborative consumption	

PLANNING

CREDIT: LD2.1 Establish a Sustainability Management Plan

The credit assesses if the project created a project sustainability management plan that can manage the scope, scale, and complexity of a project seeking to improve sustainable performance.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	Direct and indirect impacts depend on specific objectives and performance targets set, however by definition ensures enhanced performance across all categories.			
	INDIRECT IMPACT				

	PERFORMANCE INDICATORS	METRICS
1	Clear definition and assignment of roles & responsibilities to key project members for addressing sustainability	
2	Development of a sustainability management plan, or adoption of existing sustainability management plans or policies sufficient to address project sustainable performance and community needs	
3	Quantifiable sustainability targets for construction with reference to timescales (e.g. achieving/exceeding water quality targets, targets for completion of work elements to avoid 'closed' seasons, such as nesting birds, and demonstrate that the targets were regularly monitored)	
4	Measurable environmental targets for key sub-contractors e.g. waste produced, number of environmental incidents	
5	Measurable sustainability targets for operation to be monitored/ measured against (e.g. % of waste produced during the 1st year of O&M is to be recovered through re-use, recycling or composting)	
6	Periodic revision of the sustainability management plan and progress towards targets set	
7	% of Implemented sustainability enhancements	At least 25% enhancements implemented over the initial targets set

CREDIT: LD2.2 Plan for Sustainable Communities

The credit assesses the degree to which project selection/identification includes sustainability performance assessments and is part of a larger sustainable development plan.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	Direct and indirect Impacts are determined by the specific sustainability goals and performance targets set as part of the sustainability management plan.			
	INDIRECT IMPACT				

	PERFORMANCE INDICATORS	METRICS
1	The potential sustainability impacts were considered during project selection/ identification	
2	Project alternatives were evaluated and considered to choose the right project (consideration given to the relative sustainability of a 'no build' scenario)	
3	Overall community sustainability is considered (e.g. will the project lead to density or urban sprawl)	
4	Investment in comprehensive sustainability plans to leverage the co-benefits and efficiencies of integrated systems	

CREDIT: LD2.3 Plan for Long-Term Monitoring and Maintenance

The credit assesses how the project puts in place plans, processes, and personnel sufficient to ensure that long-term sustainable protection, mitigation, and enhancement measures are incorporated.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+-) Materials (+) Energy (+) Water (+) Land occupation	(+) Access (+) Safety (+) Noise (+) Light pollution (+) Inclusivity	(-) Capital cost (-) O&M cost (+) Rehabilitation cost (+) Replacement cost (+) Residual value	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Accident cost
	INDIRECT IMPACT	(+) Energy (+-) Emissions	(+) Wellbeing (+) Health	(+) Resilience value	(+) Health cost (+) Resilience

		(+-) Embodied energy (+-) Embodied water (+-) Embodied carbon (+-) Climate change (+) Ecosystem quality (+) Resource depletion	(+) Social resilience		value

ENVIR	• Reduced use of materials due to avoided replacement works through design, longer-lived materials, construction quality; and associated reductions in embodied energy, water and carbon of materials (indicators 2,3, 4 &9) • Reduced construction site fuel and electricity consumption due to avoided rehabilitation or replacement works; and associated emissions (indicators 2,3, 4 &9) • Reduced construction waste due to avoided rehabilitation or replacement works (indicators 2,3, 4 &9) • Reduced construction water production (indicators 2,3, 4 &9) • Additional use of materials for widening road section to accommodate shoulder for easy maintenance access and associated increase in embodied energy and carbon of materials (indicator 6) • Avoided fuel consumption by private vehicles due to under-maintained surfaces; due to avoided construction traffic or detouring; and associated emissions (indicators 2,3,4, 5, 6 &9) • A potential trade-off in this area could be, for example in the case of more-durable paint systems that implicate environmentally damaging treatments (indicator 3)
SOCIAL	• Wellbeing represents better ride quality due to properly maintained surfaces (adequate surface roughness) (indicator 5) • Increased safety for workers through availability of shoulder for work (indicator 6) • Increased safety for public due to regular inspections and timely performance of necessary works (indicators 1 &8); due to avoided future rehabilitation and replacement works (indicators 2,3, 4 &9) • Avoided disruptions of access due to reduced maintenance needs (indicator 2, 3, 4 &9); availability of space for performance of works and avoidance of closures (indicator 6) • Reduced noise levels as a result of properly maintained surfaces (adequate surface roughness), given that under-maintenance increased noise levels at the tire/ pavement contact) (indicator 5); avoided noise from maintenance works due to low-maintenance design and longer life materials (indicators 2, 3, 4 &9)
ECON	• Avoided future replacement cost due to longer-lived structures and materials; construction quality (indicators 2,3, 4, 6 &9) • Added capital cost for more durable materials (premium) (indicators 2, 3 &9); for widening road section to accommodate shoulder for easy maintenance access (indicator 6); for construction quality process (indicator 4) • Added O&M cost for widening road section to accommodate shoulder for easy maintenance access (indicator 6) • Avoided cost of user vehicle operating costs due to under-maintained surfaces (indicators 5 &8) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to avoided disruption of access and construction traffic (indicators 2, 3, 4, 6 &9) • Improved resilience value for both the agency and the community through improved condition of assets to withstand short-term and long-term risks (indicators 2, 3, 4, 8 &9); development of long-term plan (indicator 7)

	PERFORMANCE INDICATORS	METRICS
1	Development of asset management systems for effective prioritization and timely performance of works	
2	Reduction of maintenance needs through project design (e.g. redundant corrosion protection, use of integral abatement)	
3	Reduction of maintenance needs through the use of durable longer-lasting materials	
4	Contractor's quality process management system for avoidance of early and excessive maintenance and/or early replacement (e.g. inadequate asphalt compaction as a factor for decreased stiffness,	

	reduced fatigue life, accelerated aging/ decreased durability, rutting, raveling, and moisture damage)	
5	Maintenance for adequate surface roughness for improved ride quality	
6	Provision for ease of access for maintenance and repair" (e.g. existence of shoulder to allow repair without disruption)	
7	Development of comprehensive on-going maintenance plan that addresses at a minimum: responsible parties/organizations, standards, schedule, methods to be used and funding source(s)	
8	Developed schedule of project condition inspection	
9	Increased total percentage of pavement surface area for regularly trafficked lanes designed for long-life	At least of 75% of pavement area is designed for long life (minimum 40-year design life)

CREDIT: LD2.4 Plan for End of Life

The credit assesses the degree to which the project team analyzes, and communicates with stakeholders, the end-of-life impacts, cost, and value.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X				X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials (+) Energy (+) Land occupation	(+) Access (+) Safety (+) Noise (+) Light pollution (+) Inclusivity (+) Capacity building	(-) capital cost (+) Replacement cost (+) End-of-life cost (+) Residual value	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Accident cost
	INDIRECT IMPACT	(+) Energy (+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Emissions (+) Climate change (+) Water quality (+) Ecosystem quality	(+) Social resilience	(+) Resilience value	(+) Resilience value
ENVIR	• Reduced future use of materials due to extended useful life of project through durability, provision for expansion or repurpose; and associated embodied energy and carbon (indicators 1,2,3 &5) • Reduced future construction waste due to extended useful life of project through durability, state of good repair, provision for expansion, or repurpose; and associated embodied energy and carbon; land occupation (landfill); impact on water quality and ecosystem quality (indicators 1,2,3 &5) • Reduced future construction energy consumption due to avoided replacement, expansion works through extended useful life; and associated emissions (indicators 1,2,3&5) • Reduced future construction water consumption due to avoided replacement, expansion works through extended useful life (indicators 1,2,3&5) • Reduced user fuel consumption due to state of good repair of road surface (indicator 1)				

SOCIAL	• Community awareness building through engagement and communication on end of life options of the project (indicator 6) • Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for replacement works (indicators 1,2,3 &5)
ECON	• Increased capital cost for durable materials (indicator 1); prefabricated units (indicator 5) • Avoided replacement costs in the case of repurpose/ reconfiguration (avoided waste hauling costs (cost of labor and fuel) and fees for landfills, recovery facilities etc.) (indicators 2 &3) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for replacement works (indicators 1,2,3 &5) • Reduced end-of-life cost due to easy disassembly into components for reuse (indicator 5) • Increased residual value due to state of good repair, durability (indicator 1) • Improved resilience value for both the agency and the community through improved condition of assets, durability to withstand short-term and long-term risks and adaptability (indicators 1,2,3)

	PERFORMANCE INDICATORS	METRICS
1	Extension of project's useful life through durability and state of good repair	No. of added years to base case service life
2	Extension of project's useful life by providing flexibility for reconfiguration, future expansion (Relevant future demands, loads, or other requirements on the infrastructure system have to estimate over the anticipated project life)	
3	Extension of project's useful life by providing opportunities to repurpose the project after end-of-life	
4	Analysis of estimated end-of-life costs and salvage value associated with deconstruction, decommissioning, or replacement.	
5	% by volume of components or prefabricated units that can be easily separated on future disassembly/ de-construction into material types suitable for recycling or reuse	At least 15% (The volume of materials that contribute to 80% of the total by value should be used as a basis for the calculations)
6	Proactive stakeholder engagement in end-of-life planning to communicate with community end-of-life options for the project	

ECONOMY

KEY CREDIT

CREDIT: LD3.1 Stimulate Economic Prosperity and Development

The credit assesses how the project supports economic prosperity and sustainable development, including job growth, capacity building, productivity, business attractiveness, and livability.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Capacity building		(+) Travel time value

			(+) Inclusivity		(+) Job creation
	INDIRECT IMPACT		(+) Wellbeing (+) Social resilience	(+) Resilience value	(+) Economic prosperity (+) Resilience value
SOCIAL	• Increased local capacity building through involvement and creation of various job types (indicators 1-4)				
ECON	• Reduced productivity loss due to improved operating capacity, mobility (indicator 6) • Increased economic prosperity through job creation; business and workforce attractiveness; property value due to improved operating capacity, mobility, amenities (indicators 1-6) • Increased resilience value for both the agency and the community through local economic prosperity; and security of skilled workforce in the long-term (indicators 1-6)				

	PERFORMANCE INDICATORS	**METRICS**
1	Creation of new direct and indirect short-term jobs	No. and duration of fulltime equivalent (FTE) jobs by type during design and construction
2	Creation of new direct and indirect long-term jobs	No. and duration of fulltime equivalent (FTE) jobs by type during O&M
3	Level of support of local employment	% of jobs occupied by residents over the total jobs created
4	Level of involvement of local firms	% of involvement of local firms (identified as viable) over the total firm applications or quotations received
5	Increased host community attractiveness to businesses and workforce through improved operating capacity, mobility, amenities and equity	**IMPACT FOR FILTERING: 'INDIRECT ECONOMIC IMPACT ON USER' ='ECONOMIC PROSPERITY'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive impact on attractiveness to businesses and workforce. The index of filtered credit indicators can provide the basis for quantification of economic benefits to the community.
6	Productivity benefits delivered through travel time savings as a result of the project	**IMPACT FOR FILTERING: 'DIRECT ECONOMIC IMPACT ON USER' ='TRAVEL TIME VALUE'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on productivity. The index of filtered credit indicators can provide the basis for quantification of productivity benefits.

CREDIT: LD3.2 Develop Local Skills & Capabilities

The credit assesses how the project expands the knowledge, skills, and capacity of the community workforce to improve their ability to grow and develop.

LC STAGE	**DESIGN & MATERIAL PRODUCTION**	**CONSTRUCTION**	**OPERATION**	**MAINTENANCE**	**END-OF-LIFE**
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Capacity building		
	INDIRECT IMPACT		(+) Social resilience	(+) Resilience value	(+) Job creation (+) Economic prosperity (+) Resilience value

ECON	
	• Economic prosperity due to skills and capacity building on sustainable methods, technologies and increased empowerment and competitiveness of local workforce and economically depressed communities for future job opportunities (indicators 1-4) • Increased resilience value for the agency due to future security of skilled labor force; and for the community due to competitiveness, awareness (indicators 1-4)

	PERFORMANCE INDICATORS	METRICS
1	Inclusion of training programs for expanding knowledge, skills and capacity of local workforce during project delivery (designers, contractors, subcontractors or operators)	
2	Inclusion of training programs targeted on identified skill or capability gaps in the community workforce during project delivery (e.g. inexperience in deploying sustainable technologies, best practices, or new methods)	
3	Delivery of training, education, or skill development programs after project delivery (e.g. community education and/or awareness training programs)	
4	Inclusion of training programs specifically targeted to economically depressed, underemployed, or disadvantaged communities	

KEY CREDIT

CREDIT: LD3.3 Conduct a Lifecycle Economic Evaluation

The credit assesses how the project utilizes economic analyses to identify its full economic implications and its broader social and environmental benefits.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT			Capital cost O&M cost Rehabilitation cost Replacement cost Residual value Revenues	Travel time value Vehicle cost Fuel cost Fare cost Accident cost

	INDIRECT IMPACT			Penalty cost Delay cost Liability claim cost Noise cost Restoration cost Resilience value	Health cost Job creation Economic prosperity Resilience value

The impacts assessed depend on the type of Economic analysis performed:

- Level 1 Lifecycle Cost Analysis (LCCA): positive or negative economic direct impact (added or reduced cost for/by incorporating a sustainable feature and implementing a sustainable strategy) for the agency.
- Level 2 Lifecycle Cost/Benefit Analysis: positive or negative impact on both the user and the agency
- Level 3 Sustainability cost-benefit analysis: social and environmental impacts that have quantifiable cost and benefits for both the agency and the user (community

	PERFORMANCE INDICATORS	**METRICS**
1	Development of a Lifecycle cost analysis (LCCA) for the whole project including at minimum: • Project/ investment cost (capital costs) • Replacement costs • Annual or recurring O&M costs • Residual value • Adding financial benefit streams that offset costs, such as revenues (including assumptions, data sources, and methodology)	**IMPACT FOR FILTERING: 'DIRECT ECONOMIC IMPACT FOR THE AGENCY'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on the project costs for the agency. The index of filtered credit indicators can provide the basis for the LCCA.
2	Use of LCCA to compare and assess alternatives for at least one major design component	
3	Development of a Lifecycle Cost/Benefit analysis for the whole project including agency and user costs.	**IMPACT FOR FILTERING: ' DIRECT' 'ECONOMIC IMPACT' FOR THE 'AGENCY' & THE 'USER'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative economic direct impact on both the agency and the user. The index of filtered credit indicators can provide the basis for the Lifecycle Cost Benefit Analysis.
4	Mapping (Index and quantification) of social, environmental, and financial costs and benefits of the project.	**IMPACT FOR FILTERING: ' DIRECT' & 'INDIRECT' 'ECONOMIC IMPACT' FOR THE 'AGENCY' & THE 'USER'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative economic direct and indirect impact on both the agency and the user. The index of filtered credit indicators can provide the basis for the Sustainability Cost/Benefit Analysis.
5	Expansion of LCCA into a comprehensive Sustainability Cost Benefit Analysis based on monetizing the identified social, environmental, and financial costs and benefits	
6	Use of the Sustainability Cost Benefit Analysis to compare and assess alternatives for at least one major design component	

RESOURCE ALLOCATION

Materials	RA1.1 Support Sustainable Procurement Practices RA1.2 Use Recycled Materials RA1.3 Reduce Operational Waste RA1.4 Reduce Construction Waste RA1.5 Balance Earthwork On Site
Energy	RA2.1 Reduce Operational Energy Consumption RA2.2 Reduce Construction Energy Consumption RA2.3 Use Renewable Energy RA2.4 Commission & Monitor Energy Systems
Water	RA3.1 Preserve Water Resources RA3.2 Reduce Operational Water Consumption RA3.3 Reduce Construction Water Consumption RA3.4 Monitor Water Systems

MATERIALS

CREDIT: RA1.1 Support Sustainable Procurement Practices

The credit assesses how the project develops sustainable procurement policies and programs to source materials and equipment from manufacturers and suppliers that implement sustainable practices.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X				

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT		(+) Safety (+) Equity	(-) Capital cost	
	INDIRECT IMPACT	(+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Climate change (+) Water quality (+) Ecosystem quality (+) Resource depletion (+) Ecological resilience	(+) Social Resilience	(+) Ecosystem services value	(+) Economic prosperity (+) Ecosystem services value

ENVIR	• Reduced embodied energy, embodied water and carbon of materials through sourcing from environmentally qualified manufacturers/ suppliers; and reduced contribution of the project to climate change (indicators 1,2) • Contribution to ecological resilience through reduced impact on ecosystems (indicators 1,2)
SOCIAL	• Reduced exposure of workers and public to hazardous and pollutant materials (indicators 1,2) • Improved equity through support to companies that comply with standards: against anti-competitive behavior (e.g. against monopoly); flow of capital among different stakeholders and main economic impacts of an organization throughout society; fair labor and ethical practices etc. (indicators 1,2)
ECON	• Added capital cost for the purchase of materials (indicators 1,2) • Improved economic prosperity through support to companies that comply with standards: against anti-competitive behavior (e.g. against monopoly); flow of capital among different stakeholders and main economic impacts of an organization throughout society; fair labor and ethical practices etc. (indicators 1,2) • Reduced impact on natural capital through sustainable procurement practices and associated avoided costs for community and agency (indicators 1,2)

	PERFORMANCE INDICATORS	METRICS
1	Increased % of the total project materials by cost, weight, or volume that meet sustainable procurement policy/ program requirements on social and environmental impacts.	% over the total quantity of materials
2	% of materials sourced from manufacturers/ suppliers that implement sustainable practices	At least 5% of all project materials, supplies, and equipment meet the sustainable procurement policy/program requirements. Examples of qualifying requirements include but are not limited to:

		• Environmental management systems consistent with ISO (International Organization for Standardization) 14001 • Product-specific type III Environmental Product Declaration (EPD) conforming to ISO 14025, 14044. • Third-party verified sustainability program (e.g., Forest Stewardship Council (FSC), Green Seal, EcoLogo, Underwriters Laboratory, National Biosolids Partnership (NBP), Concrete Sustainability Council (CSC), etc.) • Third-party verified corporate sustainability report consistent with the Global Reporting Initiative (GRI) Sustainability Report or equivalent.

CREDIT: RA1.2 Use Recycled Materials

The credit assesses how the project reduces the use of virgin natural resources and avoids sending useful materials to landfills by specifying reused materials, including structures, and material with recycled content.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials (+) Land occupation		(+-) Capital cost (-) Rehabilitation cost (-) Replacement cost (-) Residual value	(+) Travel time value (+) Vehicle cost (+) Fuel cost
	INDIRECT IMPACT	(+) Energy (+) Embodied energy (+) Embodied water (+) Embodied carbon (+-) Emissions (+) Climate change (+) Ecosystem quality (+) Resource depletion (+) Ecological resilience	(+) Noise (+) Access (+) Health	(+) Ecosystem services value	(+) Ecosystem services value

ENVIR	• Reduced use of primary materials through on-site reuse or recycling; use of off-site recycled-content materials; and associated embodied energy, water and carbon (indicators 1-4) • Reduced waste through reuse or recycling; and associated embodied energy and carbon; land occupation (landfill); water quality (indicators 1, 3 &4) • Avoided increased fuel combustion and emissions by private vehicles due to avoided stop-and-go traffic trends (fewer hauling routes, less congestion) (indicators 1, 3 &4) • Additional future use of materials (permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for the rehabilitation or replacement due to less durable and typically shorter-service-life recycled content materials (indicators 1-4)

SOC	• Additional future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for the rehabilitation or replacement of the typically shorter-service-life recycled content materials (indicators 1-4)
ECON	• Capital cost savings due to avoided purchase of new materials; avoided hauling cost for materials and waste (cost of labor and fuel); fees for landfills, recovery facilities etc. (indicators 1, 3 &4) • Added capital cost due to additional effort for reuse on-site/ cost of additional specialized equipment for pavement reuse (indicators 1, 3 &4) • Added future rehabilitation cost or replacement cost due to shorter service life of recycled-content materials/ recycled structures (indicators 1-4) • Reduced residual value due to shorter life components (indicators 1-4) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to construction traffic (less hauling from off-site locations, less hauling of waste to landfill) (indicators 1, 3 &4) • Reduced impact on natural capital through reduced consumption of primary resources, less land occupied for landfill, soil contamination and associated avoided costs for community and agency (indicators 1-4) • Additional future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for the rehabilitation or replacement of the typically shorter-service-life recycled content materials (indicators 1-4)

	PERFORMANCE INDICATORS	METRICS
1	% of project materials that are reused or recycled	At least 5% (by weight, volume, or cost) of recycled materials including materials with recycled content and/or reused existing structures or materials.
		At least 25% (by volume) of any existing structures and materials have been retained and used within the project as opposed to being demolished and crushed or disposed.
2	% of offsite material with reclaimed/recycled content	At least 20% (by volume) of materials from offsite with reclaimed/recycled content (excluding bulk fill and sub-base)
		At least 40% (by volume) of bulk fill and sub-base material from off site with reclaimed/recycled content
3	% of reuse of existing pavement materials by weight or cost (such as hot mix asphalt (HMA), Portland cement concrete (PCC), unbound granular base material, stabilized base material, reinforced concrete, structural steel, and timber) during rehabilitation works [100]	• At least 50% of pavement reused through one or/more of the following methods: • Surface treatments • Overlay / Mill and Fill • Hot-in-place recycling • Cold-in-place recycling (CIR) • Full depth reclamation (FDR) • Crack and Seat of PCC pavements - Rubberization of PCC pavements
4	On-site use of demolition arisings	At least 25% demolition arisings are reused

CREDIT: RA1.3 Reduce Operational Waste

The credit assesses how the project reduces operational waste and diverts waste streams from disposal to recycling and reuse.

LC	DESIGN & MATERIAL	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE

[100] Not appropriate for construction of an entirely new roadway or bridge replacement.

STAGE	PRODUCTION				
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Land occupation (+) Materials		(+-) O&M cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost
	INDIRECT IMPACT	(+) Energy (+) Embodied energy (+) Embodied carbon (+) Emissions (+) Climate change (+) Water quality (+) Ecosystem quality (+) Resource depletion (+) Ecological resilience	(+) Noise (+) Health	(+) Ecosystem services value	(+) Ecosystem services value
ENVIR	• Reduced waste to be managed or sent to landfill; and associated embodied energy and carbon; land occupation; reduced impact on water quality and ecosystems • Reduced use of materials (by other facilities) where waste or byproducts can be used as resource • Avoided increased fuel combustion and emissions by private vehicles due to stop-and-go traffic trends (fewer hauling routes)				
ECON	• O&M cost savings from avoided hauling cost for waste (cost of labor and fuel); fees for landfills, recovery facilities etc. • Added O&M cost for waste management at source if sourced to other facilities for recycling or reuse • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to construction traffic (less hauling of waste to landfill) • Reduced impact on natural capital due to less land occupied for landfill, soil contamination and associated avoided costs for community and agency				

	PERFORMANCE INDICATORS	METRICS
1	Percentage of total operational waste or byproducts diverted from disposal	Divert at least 25% of operational waste. (Diversion may be a combination of waste reduction measures and/or sourcing waste to other facilities for recycling or reuse)

CREDIT: RA1.4 Reduce Construction Waste

The credit assesses how the project diverts construction and demolition waste streams from disposal to recycling and reuse.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials (+) Land occupation		(+-) Capital cost	(+) Travel time value (+) Vehicle cost

					(+) Fuel cost
	INDIRECT IMPACT	(+) Energy (+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Emissions (+) Climate change (+) Resource depletion (+) Ecological resilience	(+) Noise (+) Safety (+) Health	(+) Ecosystem services value	(+) Ecosystem services value

ENVIR	• Reduced waste to be managed or sent to landfill; land occupation; reduced impact on water quality and ecosystems (indicators 1-3) • Reduced embodied energy and carbon of waste. (indicators 1-3) It is determined by: - volume and types of construction waste - no. of routes based on hauling truck volume capacity - waste destination and proximity to site (recycling facility, landfill, contractor's yard) • Reduced use of materials due to minimization of surplus materials (indicators 2, 3) • Reduced primary materials purchased (by other projects) through reuse (indicators 1-3) • Avoided increased fuel combustion and emissions by private cars due to stop-and-go traffic trends (fewer hauling routes) (indicators 1-3)
SOCIAL	• Reduced risk of car crash accident due to reduced hauling trucks traffic (indicators 1-3)
ECON	• Capital cost savings due to avoided costs for surplus materials; avoided waste hauling costs (cost of labor and fuel) and fees for landfills, recovery facilities etc. (indicators 1-3) • Added cost due to additional effort for waste management at source (indicators 1,3) • Potential trade-off with schedule efficiency (e.g. delay due to lack of availability of material vs. surplus that is being wasted) (indicator 2) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to construction traffic (less hauling of waste to landfill) (indicators 1-3) • Reduced impact on natural capital due to less land occupied for landfill, soil contamination and associated avoided costs for community and agency (indicators 1-3)

	PERFORMANCE INDICATORS	METRICS
1	% (by volume) of total construction waste diverted from disposal	At least 25% of waste materials are recycled, reused, and/or salvaged during construction works
2	Reduced (by volume) surplus materials (ordered and not used) over the total volume of materials ordered	
3	% (by volume) of surplus materials beneficially reused	At least 50% of surplus materials beneficially re-used (or stored for re-use), no or minimal unused materials.

CREDIT: RA1.5 Balance Earthwork On Site

The credit assesses how the project minimizes the movement of soils and other excavated materials off site to reduce transportation and environmental impacts.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+) Materials	(+) Access	(+) Capital cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost
	INDIRECT IMPACT	(+) Energy (+) Embodied energy (+) Embodied carbon (+) Emissions (+) Climate change (+) Resource depletion	(+) Noise (+) Safety (+) Health		

ENVIR	• Reduced material use and/or waste; and associated embodied energy and carbon (indicators 1, 2) • Reduced embodied energy and carbon due to shorter hauling routes (indicator 3) • Avoided fuel consumption and emissions from increased fuel combustion due to avoided stop-and-go traffic trends (fewer and shorter hauling routes) (indicators 1, 2 &3) • Reduced land occupation for storage of excessive soil (indicators 1, 2)
SOCIAL	• Reduced risk of car crash accident due to reduced and shorter hauling trucks traffic (indicators 1, 2 & 3) • Reduced noise from hauling truck routes (indicators 1, 2 &3)
ECON	• Capital cost savings due to avoided soil purchase, hauling to/from off-site location (indicators 1, 2 & 3) • Avoided cost of lost productivity, vehicle operating costs and fuel cost due to construction traffic (fewer and shorter hauling routes to/ from site) (indicators 1, 2 & 3)

	PERFORMANCE INDICATORS	METRICS
1	% of excavated material reused/retained on-site	At least 30%
2	% of excavated material moved off-site / reused to other nearby projects	Excavated material moved off site and/or fill brought onto the site does not exceed 70% of total site soil handling.
3	Use of locally sourced fill materials and proximity of destination of excavated materials to site	100% of fill and excavated materials are sourced or reused within a maximum distance of 25 mi/40 km of the site.

ENERGY

CREDIT: RA2.1 Reduce Operational Energy Consumption

The credit assesses how the project conserves energy by reducing overall operational energy consumption throughout the project life.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Energy	(+) Light pollution	(-) Capital cost (+) O&M cost	(-) Accident cost
	INDIRECT IMPACT	(+) Emissions (+) Climate change (+) Ecosystem quality	(-) Safety (+-) Health		(+) Health cost

ENVIR	• Reduced electricity use due to energy efficient lighting (e.g. light emitting diodes (LEDs) technology), signals, ITS systems; reduced fuel consumption through fuel-efficient fleet; and associated reduction in emissions (indicators 1, 2)
SOCIAL	• Reduced light pollution (indicator 1) • Potential trade-off in the case of insufficient luminance for nighttime safety in favor of conserving energy (indicator 1)
ECON	• Added capital cost of energy efficient fixtures (indicator 2) • Reduced O&M cost (electricity and fuel cost) (indicators 1, 2)

	PERFORMANCE INDICATORS	METRICS
1	% of reduced operational energy as compared to an appropriate base case (Accepted methodologies for establishing baseline performance data are explained in detail in the Envision manual and include existing conditions, a seriously considered alternative, standard practice, or a comparable existing project/facility) If annual energy consumption varies, the project team submits the range of estimated performance over the project life. Relevant indicators: • Amount of estimated operational energy purchased from the grid • Amount of estimated operational energy generated on site • Amount of fuels used on-site	At least 10% reduction
2	Reduced lifetime energy consumption through use of energy efficient lighting systems	At least 20% of total luminaires installed with energy efficient fixtures (Energy Star 2009 compliant)

CREDIT: RA2.2 Reduce Construction Energy Consumption

The credit assesses how the project conserves resources and reduces greenhouse gases and air pollutant emissions by reducing energy consumption during construction works.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE

		X		X	X

				ECONOMIC	
		ENVIRONMENTAL	SOCIAL	AGENCY	USER
TYPE OF IMPACT ASSESSED	DIRECT IMPACT	(+) Energy	(+) Safety (+) Health (+) Capacity building	(+-) Capital cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Accident cost
	INDIRECT IMPACT	(+-) Embodied energy (+-) Embodied carbon (+) Emissions (+) Climate change (+) Ecological resilience	(+) Noise		(+) Health cost

ENVIR	• Reduced electricity for worksite and fuel consumption for equipment due to efficiency and reduction measures; reduced embodied energy and carbon through reduced no. of deliveries, on-site trucking, on-site reuse and short destinations for sourcing of materials (indicators 2, 3, 4, 5,7, 10) • Reduced emissions due to lower emission equipment; less fuel combustion (indicator 2); less demand for grid electricity • Reduced emissions related to workforce moves to/from the site by private vehicle (indicators 2, 3, 4) • Increased embodied energy, water and carbon in the case of prefabrication (indicator 10,11)
SOCIAL	• Reduced noise levels due to avoided idling of equipment, reduced on-site trucking (indicator 10) • Reduced risk of car crash accident due to reduced hauling trucks traffic (indicator 10) • Improved health due to less exposure of workforce to emissions (indicators 2, 3, 4, 5, 10 & 11) • Increased potential for awareness and behavioral change for workforce and use of public transport (indicator 6)
ECON	• Added capital cost for high- technology equipment; equipment compatible with alternative fuel or electrified, on-site renewable generation; prefabrication; accelerated construction method (indicators 2, 3, 4, 5, 8, 9) • Cost savings at electricity and fuel cost through improved logistics, reduction and efficiency (indicators 2, 3,4,5, 7 &10) • Avoided loss of productivity, vehicle operating cost and fuel cost, due to less construction traffic related to workforce moves (indicators 6, 10)

	PERFORMANCE INDICATORS	METRICS
1	Reduced energy consumption during construction works through implementation of reduction strategies	Two or more reduction strategies of the following are implemented Envision approved strategies: • Tier IV emission standard construction equipment or Tier III with Best Available Technology (BAT) (fuel efficient equipment) for non-road equipment fleet greater than 50 horsepower • Alternative fuels in heavy equipment such as biodiesel • Hybrid or fully electric project vehicles • Electrified equipment (vs. gas or diesel engines) • Use of public transport for workforce moves through employee commuting programs with incentives, e.g. shuttles to transit, ride-share programs, biking facilities, etc.) • Reduced purchased energy for workstations (construction trailer/office energy)

		• Purchase green power (RECs) for workstation energy consumption • Offset electrical consumption by on-site renewable energy generation (e.g., solar panels on trailer complex, solar-powered temporary light plant, solar-powered cameras and variable message sign boards) • Reduce overall fuel consumption through improved planning and logistics
2	% of Tier IV emission standard construction equipment or Tier III with Best Available Technology (BAT) over the total equipment fleet	At least 75% of non-road equipment fleet greater than 50 horsepower OR 75% of total operating hours associated with fuel efficient technology equipment
3	Hybrid or fully electric project vehicles over the total fleet	At least 50% of fleet
4	% of use of alternative fuels in heavy equipment such as biodiesel	At least 5% alternative fuels use over total fuel consumption
5	% of electrified equipment over the total equipment fleet	At least 20% of equipment
6	% of reduced fuel consumption by avoided Workforce vehicle/transportation movements to and from site through use of public transport Other relevant indicators: • Reduced miles travelled by workforce due to use of public transport • % of number of total recorded local public transportation mode uses over the total number of workforce transportation movements • Total distance traveled by workforce to and from site (total distance of each round trip) • Total number of recorded workforce vehicle/transportation movements to and from site • Average distance travelled per person to and from site	Any % reduction compared to the baseline
7	% of reduced purchased energy for workstations (construction trailer/office energy)	30% reduction for two of the following: (1) lighting; (2) HVAC; (3) plug loads
8	Purchased green power (RECs) as a percentage of total workstation energy consumption	For 30% of workstation energy consumption
9	% of electrical consumption offset by on-site renewable energy generation	At least 5% on-site renewable energy generation
10	% of reduction of overall fuel consumption through improved planning and logistics. Specific strategies may include: i. Reduce number of deliveries; ii. Reduce idle times; iii. On-site reuse of soils or other materials to decrease truck traffic to and from site iv. Reduce on-site trucking – proper logistics planning such as staging material near installation location; v. Schedule acceleration without additional resource consumption; vi. Waterborne/rail transportation of materials versus trucking (third-party distribution or logistics); vii. On-site plants (concrete plant/asphalt plant) instead of trucking material to the site; and	10% reduction in fuel consumption (through one strategy or combination of strategies)

	viii. Prefabrication of design elements.	
11	Increased volume of components constructed off site	% (by volume) of components constructed off site over the total volume of all materials incorporated in permanent works

CREDIT: RA2.3 Use Renewable Energy

The credit assesses how the project meets operational energy needs through renewable energy sources.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
TYPE OF IMPACT ASSESSED	**DIRECT IMPACT**	(+) Energy (-) Materials	(+) Capacity building	(+) Capital cost (+-) O&M cost	
	INDIRECT IMPACT	(+) Ecosystem quality (-) Embodied energy (-) Embodied water (-) Embodied carbon (+) Emissions (+-) Climate change (+) Resource depletion	(+) Health	(+) Resilience value	(+) Economic prosperity (+) Resilience value

ENVIR	• Reduced energy purchased from grid • Added initial use of materials for renewable facilities components (e.g. solar panels etc.) and associated embodied energy, water and carbon
ECON	• Added capital cost for on-site renewable energy generation facilities; fleet compatible with renewable fuels or electric vehicles; charging stations for electrical vehicles • Added O&M cost for renewable fuel for fleet; for maintenance of on-site renewable generation facilities; cost premium of the purchase of RECs • Reduced O&M cost for electricity purchased from grid and excess energy returned to grid. • Support of the energy renewable market; less demand thus less need for larger central generation plant, less dependency on oil imports etc. • Increased resilience value for both agency and community through security of the availability of future resources for operations; no full dependence on non-renewable sources; and avoided associated costs

	PERFORMANCE INDICATORS	METRICS
1	% of energy needs (electricity and fuel) from renewable sources (Projects may only count Renewable Energy Credits (RECs) purchased or under contract at the time of assessment) Relevant indicators: • % of renewable energy generated and used on-site • % of renewables returned to grid • % of renewable energy purchased in fuels • % of renewable energy purchased from the grid through a direct purchase agreement (e.g., renewable energy power purchase agreement)	At least 5% of energy needs (electricity and fuel) from renewable sources. (the resulting overall percentage of renewable energy to total energy consumption)

CREDIT: RA2.4 Commission & Monitor Energy Systems

The credit assesses how the project ensures efficient functioning and extends useful life by specifying commissioning and monitoring of energy systems.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Energy (-) Materials		(+-) Capital cost (+) O&M cost (+) Replacement cost	
	INDIRECT IMPACT	(+) Emissions (+) Ecosystem quality (-) Embodied energy (-) Embodied water (-) Embodied carbon (+-) Climate change			
ENVIR	• Added use of materials for monitoring devices; and associated embodied energy, water and carbon (indicator 1)				
ECON	• Added capital cost for monitoring equipment and software and commissioning; cost of high-resolution monitoring (indicator 1) • Reduced O&M cost due to efficient electricity use enabled by monitoring equipment and software (allowing operators to identify efficiency loss and identify high-energy processes and target them for reduction) (indicator 1, 3); by incorporating the most useful energy-efficient techniques and equipment; by properly performing energy systems and controls • Avoided cost of early replacement of energy systems due to extended life of equipment (indicator 2) • Avoided cost of replacement of energy systems due to avoidance of installation errors or degradation of energy systems enabled by commissioning (indicator 2)				

	PERFORMANCE INDICATORS	METRICS
1	Energy monitoring capability for primary project functions (Equipment and/or software are incorporated in the design to allow detailed monitoring of performance)	Monitoring accounting for at least 50% of energy use/consumption
2	Extent of commissioning of energy systems	Commissioning accounting for at least 50% of the total energy consumption/generation
3	% of the recommended energy consumption reduction in operations achieved	At least 10% reduction of the recommended energy consumption
4	% of potential renewable / low-carbon / 0-carbon energy identified that has been implemented	Implementation of at least 10% of the potential renewable / low-carbon / 0-carbon energy identified

WATER

CREDIT: RA3.1 Preserve Water Resources

The credit assesses how the project assesses and reduces the negative net impact on fresh water availability, quantity, and quality at a watershed scale to positively impact the region's water resources.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water (+) Water quality			
	INDIRECT IMPACT	(+) Resource depletion (+) Ecosystem quality (+) Ecological resilience	(+) Health	(+) Penalty cost (+) Restoration cost (+) Resilience value (+) Ecosystem services value	(+) Resilience value (+) Ecosystem services value

ENVIR	• Reduced impact on freshwater quantity, quality (indicators 1-5)
ECON	• Increased resilience value and ecosystem services value[101] for both agency and community through security of future freshwater availability for operations; and avoided associated costs (indicators 1-5) • Avoided cost of penalty and/or restoration of water contamination incident (indicators 1-5)

	PERFORMANCE INDICATORS	METRICS
1	Estimated water usage and wastewater generation over the life of the project (gallons/liters).	
2	No net impact is expected by project's water usage on the quantity and availability of fresh surface water and groundwater supplies (requires identification of source of water used)	
3	No net impact is expected by project's water usage on generation of wastewater (requires identification of destination of wastewater)	
4	No net impact is expected by the project on watershed water quality	
5	Watershed improvements: improved water quality, better hydrologic connectivity, or water storage and availability.	

[101] In this case resilience value and ecosystem services value coincide

CREDIT: RA3.2 Reduce Operational Water Consumption

The credit assesses how the project reduces overall water consumption while encouraging the use of greywater, recycled water, and stormwater to meet water needs.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water		(+) O&M cost (-) Capital cost	
	INDIRECT IMPACT	(+) Resource depletion (+) Ecosystem quality	(-) Safety (-) Health		
SOC	• Potential negative effect on workplace health and safety by the use of non-potable water (management of any risks arising from use, handling, storage and transport of water) (indicator 3)				
ECON	• Added cost for the implementation of water conservation and reduction measures (indicators 1-3) • Reduced O&M cost for water (indicators 1-3)				

	PERFORMANCE INDICATORS	METRICS
1	% reduction of annual potable water consumption over the life of the project over the industry baseline (without conservation & reduction measures)	At Least 25% annual reduction in potable water use over the industry baseline
2	% of water use reduction over the industry baseline (potable and non-potable)	At least 20% reduction of potable and non-potable if: annual potable reduction= 50% -->overall potable &non-potable =20% if: annual potable reduction=75%--> overall potable & non-potable=30% if: annual potable reduction= 95% -->overall potable & non-potable=40% if: annual potable reduction= 100% -->overall potable & non-potable=50%
3	% of potable water substituted by non-potable	Any incremental improvement possible

CREDIT: RA3.3 Reduce Construction Water Consumption

The credit assesses how the project reduces potable water consumption during construction works through a number of strategies.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water (+) Embodied water (+) Waste		(+-) Capital cost	(-) Accident cost
	INDIRECT IMPACT	(+) Resource depletion (+) Ecosystem quality (+) Climate change	(-) Safety (-) Health		(-) Health cost
SOCIAL	• Potential negative effect on workplace health and safety by the use of non-potable water (management of any risks arising from use, handling, storage and transport of water) (indicators 10,11)				
ECON	• Added capital cost for the implementation of water conservation and reduction measures (indicators 1, 2, 3, 5, 6,7,9, 10 & 11); added capital cost for the purchase of lower-embodied water materials (indicator 8) • Reduced capital cost for water (indicators 1, 2, 3, 4, 5, 6,7,9, 10 & 11)				

	PERFORMANCE INDICATORS	METRICS
1	Reduced potable water during construction works through implementation of conservation strategies (Reduction percentage of potable water consumption for each strategy as compared to not implementing the strategy over the construction duration)	One or more conservation strategies of the following are implemented during construction works Envision approved strategies: • High-efficient fixtures in construction trailers or offices • Leakage reduction / Leak detection • Reduced embodied water of materials by reducing waste material • Alternatives for dust suppression such as dry agents • Alternatives for curing concrete • Alternatives for truck tire wash stations • Reduced embodied water through material selection • Stormwater harvesting • Greywater or wastewater effluent reuse • Dewatering reuse
2	% of reduced water usage through high-efficient fixtures in construction trailers or offices	40% reduction (as compared to not implementing the strategy over the construction duration)
3	Reduced water usage through leakage reduction / leak detection	
4	% of reduced embodied water of materials by reducing waste material	At least 10% reduction in material quantities entering the site as new material
5	% of reduced water usage through alternatives for dust suppression such as dry agents	At least 50% reduction
6	% of reduced water usage through alternatives for curing concrete	At least 50% reduction
7	% of reduced water usage through alternatives for truck tire wash stations	At least 50% reduction
8	% of reduced embodied water through material selection (permanent and temporary materials)	At least 25% reduction
9	% of reduced water usage through stormwater harvesting	At least 40% reduction
10	% of reduced water usage through greywater or wastewater effluent reuse	At least 40% reuse
11	% of reduced water usage through dewatering reuse	At least 40% reuse/recycling

CREDIT: RA3.4 Monitor Water Systems

The credit assesses how the project improves operational performance through the extent and capability of water monitoring equipment and inclusion of response plans.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water (+) Water quality		(+) O&M cost (+-) Capital cost	
	INDIRECT IMPACT	(+) Resource depletion (+) Ecosystem quality (+) Ecological resilience	(+) Health	(+) Penalty cost (+) Restoration cost (+) Resilience value	

ENVIR	• Reduced water consumption through efficiency (e.g. irrigation based on needs); detection of leaks (indicators 1, 3,4) • Improved water quality through leak detection (indicator 3)
ECON	• Added capital cost for monitoring equipment and software and commissioning; cost of high-resolution, or real-time monitoring (indicators 1, 3,4) • Reduced O&M cost due to efficient water use enabled by monitoring equipment and software (allowing operators to identify efficiency loss and identify high-energy processes and target them for reduction); avoided labor effort for leak detection (indicators 1-4) • Avoided cost of penalty and/or restoration of water contamination incident (indicators 1, 3,4) • Resilience value for the agency as provision against future more strict regulations on water wastage and water quality (indicators 1, 3,4)

	PERFORMANCE INDICATORS	METRICS
1	Improved operational performance (quantity or quality) by including water monitoring capabilities for all primary project functions	Accounting for at least 50% of water consumption
2	Ease of accessibility of installed water sub-meters	
3	Reduced leakage through real-time monitoring capability for leak detection	
4	Improved water quality through real-time monitoring capability for leak detection	

NATURAL WORLD

Siting	NW1.1 Preserve Sites of High Ecological Value NW1.2 Provide Wetland & Surface Water Buffers NW1.3 Preserve Prime Farmland NW1.4 Preserve Undeveloped Land
Conservation	NW2.1 Reclaim Brownfields NW2.2 Manage Stormwater NW2.3 Reduce Pesticide & Fertilizer Impacts NW2.4 Protect Surface & Groundwater Quality
Ecology	NW3.1 Enhance Functional Habitats NW3.2 Enhance Wetland & Surface Water Functions NW3.3 Maintain Floodplain Functions NW3.4 Control Invasive Species NW3.5 Protect Soil Health

SITING

CREDIT: NW1.1 Preserve Sites of High Ecological Value

The credit assesses how the project avoids placing temporary works on a site that has been identified as being of high ecological value.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Air quality (+) Ecosystem quality		(-) Capital cost	
	INDIRECT IMPACT	(+) Ecological Resilience	(+) Health (+) Wellbeing (+) Sense of place	(+) Ecosystem services value	(+) Ecosystem services value

ENVIR	• Preservation of ecosystem services (availability of clean air, freshwater, reduced risk of flooding or drought, stabilization of local and regional climates, control on the range and transmission of certain diseases; provisioning of food; visual comfort, recreation, etc.) (indicators 1-5)
SOCIAL	• Improved wellbeing and health through preservation of ecological functions necessary for needs fulfillment (indicators 1-5) • Improved sense of place through preservation of existing natural features (indicators 1-5)
ECON	• Added capital cost in the case of offsetting disturbed habitats and enhancements (indicators 1, 3, 5); long-term monitoring (indicator 4) • Avoided impact on natural capital stock and avoided costs for substituting natural control processes with engineered controls (indicators 1-5)

	PERFORMANCE INDICATORS	METRICS
1	No net impact on area of high ecological value through the following strategies: • through avoidance (improved siting of project) • through minimization (establishment of buffer areas) • through restoration (enhancement of degraded habitat) • through offsetting (creation of new habitats off-site or on-site with area equal or exceeding the area disturbed by the project)	
2	No net impact of construction activities on the capacity of ecological sites (e.g. avoiding proximity of temporary works)	
3	Change in ecological value as a result of the project (using a calculation methodology implemented by a Suitably Qualified Ecologist; e.g. GN36 BREEAM,	Levels of change: • Minimizing loss of ecological value (75-94%) • No net loss of ecological value (95-104%)

	CEEQUAL, and HQM Ecology Calculation Methodology – Route 2 builds on the 'Defra biodiversity metric' or an agreed equivalent)	• Net gain of ecological value (105-109%) • Significant net gain of ecological value (110% or more)
4	Monitoring ecological management/ Long-term management of biodiversity	
5	% Enhancement of ecological value of the site (comparison of pre- and post- development condition (using an "Ecological Impact Assessment" or similar)	The ecological value of infrastructure site is enhanced Enhancements beyond 20% may be awarded innovation points.

CREDIT: NW1.2 Provide Wetland & Surface Water Buffers

The credit assesses how the project protects, buffers, enhances, and restores wetlands, shorelines, and waterbodies by providing natural buffer zones, vegetation, and soil-protection zones.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Ecosystem quality			
	INDIRECT IMPACT	(+) Resource depletion (+) Climate change (+) Ecological Resilience	(+) Health (+) Wellbeing (+) Sense of place	(+) Penalty cost (+) Ecosystem services value	(+) Ecosystem services value
SOCIAL	• Improved wellbeing and health through preservation of ecological functions necessary for needs fulfillment (availability of clean air, freshwater, reduced risk of flooding or drought, stabilization of local and regional climates, control on the range and transmission of certain diseases; visual comfort, recreation, etc.) (indicators 1-3) • Improved sense of place through preservation of existing natural features (indicators 1-3)				
ECON	• Avoided impact on natural capital stock and avoided costs for substituting natural control processes with engineered controls (indicators 1-3) • Avoided penalty cost for potential freshwater contamination (indicators 1-3)				

	PERFORMANCE INDICATORS	METRICS
1	Establishment of appropriate protective buffer type and sufficient width around wetlands and water bodies on or near the site. (Appropriateness of the proposed buffer type and width based on site conditions including soil type, slope, land use, and vegetation mix)	Managed vegetated zones or natural buffer zones around at least 90% of wetlands and waterbodies on site. Envision minimum buffer width requirement is 50 ft/15 m
2	Minimization of area around wetlands requiring engineered controls	No exceedance of 10% of the total area
3	Consideration of the cumulative impacts of acidification and/or eutrophication of the water bodies in the project design	

CREDIT: NW1.3 Preserve Prime Farmland

The credit assesses how the project identifies and protects soils designated as prime farmland, unique farmland, or farmland of importance.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Land occupation (+) Ecosystem quality	(+) Health (+) Wellbeing (+) Sense of place	(-) capital cost	
	INDIRECT IMPACT	(+) Ecological resilience	(+) Social resilience	(-) restoration cost	(+) Economic prosperity (+) Ecosystem services value

SOCIAL	• Improved wellbeing and health through preservation of ecological functions necessary for needs fulfillment (availability of clean air, freshwater, reduced risk of flooding or drought, stabilization of local and regional climates, control on the range and transmission of certain diseases; visual comfort, recreation, etc.) (indicators 1-3) • Improved sense of place through preservation of existing natural features (indicators 1-3)
ECON	• Added capital cost for offsetting disturbed areas of prime farmland (indicator 2); for restoring temporarily disturbed land (indicator 3) • Economic prosperity through provision of food and resources (indicators 1-3) • Avoided impact on natural capital stock and increased resilience for the community due to long-term food security, needs fulfillment, economic prosperity (indicators 1-3)

	PERFORMANCE INDICATORS	METRICS
1	% of farmland avoided or preserved during development	Less than 10% Disturbance
2	Area permanently disturbed by the constructed project is mitigated through offsetting. (offset must equal or exceed area disturbed)	
3	Area temporarily disturbed by construction restored to a level that does not decrease the prior capacity of land. (During construction works no soils will be stripped from these areas)	100% of area restored

CREDIT: NW1.4 Preserve Undeveloped Land

The credit assesses how the project conserves undeveloped land by being located on previously developed land.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Land occupation (+) Soil health (+) Materials	(+) Safety (+) Wellbeing (+) Equity		(+) Accident cost
	INDIRECT IMPACT	(+) Ecosystem quality (+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Climate change (+) Ecological resilience	(+) Health		(+) Job creation (+) Economic prosperity (+) Ecosystem services value

ENVIR	• Reduced undeveloped land occupation (indicators 1,2) • Improved soil health through avoided undeveloped land occupation (indicators 1,2) • Reduced use of materials through potential reuse of existing structures or materials; and associated embodied energy, water and carbon (indicator 1)
SOCIAL	• Improved visual comfort through the removal of eyesores (indicator 1) • Improved health and safety for nearby communities (indicator 1) • Improved equity through regeneration of degraded/derelict assets within communities (indicators 1-3)
ECON	• Economic prosperity through regeneration of degraded/ unused brownfields; increased land value (indicator 1) • Avoided impact on natural capital stock through preservation of soil quality and related regulating services (indicator 1,2)

	PERFORMANCE INDICATORS	METRICS
1	% of the project area that is on previously developed land (this credit considers all previously developed land as grayfields. This includes contaminated sites referred to as “brownfields". However, historically developed sites returned to a natural state do not qualify as previously developed)	At least 25% of the project area on previously developed land
2	Reduced temporary land take of construction works	% of Land take of completed permanent works over the temporary land take of construction works

CONSERVATION

CREDIT: NW2.1 Reclaim Brownfields

The credit assesses if the project reclaims a brownfield location and the extent of its remediation.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X		

TYPE OF IMPACT		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT	(+) Land occupation	(+) Safety	(-) Capital cost	(+) Accident cost

ASSESSED	**IMPACT**	(+) Soil health (+) Water quality	(+) Health		
	INDIRECT IMPACT	(+) Ecosystem quality (+) Resource depletion (+) Ecological resilience		(+) Penalty cost	(+) Health cost (+) Job creation (+) Economic prosperity (+) Ecosystem services value
ENVIR	• Reduced undeveloped land occupation (indicator 1) • Improved soil health through remediation of contaminated land (indicator 2) • Reduced human exposure to health hazards (indicator 1,2)				
ECON	• Added cost of implementing active or passive remediation (indicator 2) • Economic prosperity through regeneration of historically and economically disadvantaged communities; increased property values due to removal of eyesores; job creation (indicator 1,2) • Avoided cost of healthcare (indicator 2) • Avoided cost of penalty for unsafe conditions for the intended use, groundwater pollution incidents etc. (indicator 2) • Enhancement of natural capital stock in the case of restoration to a natural state (indicator 2)				

	PERFORMANCE INDICATORS	METRICS
1	Reuse of former brownfield previously remediated or contained	
2	Extent of mitigation of exposure to contamination of site classified as brownfield and is known to contain contamination	As a minimum, site remediation to safe levels for human exposure for the intended use has to be performed Extent of remediation of brownfield site: • Minimum capping and remediation to safe levels for human exposure for the intended use • Passive remediation to gradually remove contamination (natural attenuation in the ground) • Active remediation (trap and remove contamination) or a combination of active and passive remediation to remove contamination • Active remediation or a combination of active and passive remediation to restore the entirety of site soils and/or groundwater back to regional background or unrestricted use levels.

CREDIT: NW2.2 Manage Stormwater

The credit assesses the degree to which the project infiltrates, evapotranspirates, reuses, and/or treats stormwater while not exceeding rate or quantity runoff targets.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water quality	(+) Safety (+) Health	(+) Capital cost (+) O&M cost	(+) Accident cost

	INDIRECT IMPACT	(+) Ecosystem quality (+) Resource depletion (+) Ecological resilience	(+) Social Resilience	(+) Penalty cost (+) Resilience value	(+) Health cost (+) Resilience value (+) Ecosystem services value

ECON	• Cost savings by addressing stormwater outside wastewater treatment facilities (indicators 1-6) • Avoided burden on combined sewage systems, or overflows and associated impact on community or need for systems expansion and associated costs for expansion of capacity (indicators 1-6) • Increased resilience value for the agency and the community against increasingly unpredictable precipitation rates with impact on service, property damage etc. and associated costs (indicators 1-6) • Avoided impact on natural capital (given that increased surface runoff typically leads to increased stream and channel erosion, downstream flooding, and concentration of pollutants to surface water) (indicators 1-6)

	PERFORMANCE INDICATORS	METRICS
1	increased % of stormwater detained and treated in relation to relevant requirements for storm events (85th, 90th and/or 95th percentile local 24-hour storm event)	At least 100% of the 85th percentile local 24-hour event detained and treated Ensure compliance with local requirements if stricter
2	increased % of stormwater infiltrated, evapotranspirated and/or reused in relation to relevant requirements for storm events	At least 100% of the 85th percentile local 24-hour event infiltrated, evapotranspirated and/or reused
3	Rate or quantity of runoff for the relevant 2-, 5-, 10-, 25-, 50-, and/or 100-year 24-hour rainfall event relative to the existing condition (greenfield, grayfield, or brownfield)	No exceedance (as a minimum for the 2yr 24-hr rainfall event) Ensure compliance with local requirements if stricter (increased levels of performance are linked with rainfall events)
4	Implementation of erosion, sedimentation, and pollutant control during construction works and compliance with all regulations pertinent to stormwater management	
5	Increased % of pervious hardscape	
6	Minimization of soil compaction to preserve natural infiltration capacity	

CREDIT: NW2.3 Reduce Pesticide & Fertilizer Impacts

The credit assesses how the project reduces non-point-source pollution by reducing the quantity, toxicity, bioavailability, and persistence of pesticides and fertilizers.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water quality (+) Materials (+) Soil quality	(+) Health	(+-) Capital cost (+) O&M cost	
	INDIRECT IMPACT	(+) Ecosystem quality (+) Embodied energy	(+) Sense of place	(+) Resilience value	(+) Resilience value

		(+) Embodied carbon (+) Embodied water (+) Climate change (+) Ecosystem resilience		(+) Ecosystem services value	(+) Ecosystem services value
ENVIR	• Improved water quality through avoidance of contamination of surface water through avoided overuse of fertilizers and pesticides (indicators 1,2,3 & 5); run-off controls (indicator 4) • Reduced embodied energy, water and carbon through reduction in fertilizers or pesticides (indicators 1,2,3 & 5)				
SOCIAL	• Reduced impact on health from improper application of pesticides (indicators 1,2,3 & 5) • Increased sense of place through the use of native plant species, rather than exotic species (indicator 2)				
ECON	• Added capital cost for integrated pest management; run-off controls (indicators 4, 5) • Reduced O&M cost for fertilizers and pesticides and associated labor; for maintenance of soil tolerant and pest resistant vegetation; less plant replacement needs (indicators 1,2,3 & 5) • Reduced cumulative impact on natural capital and associated costs of substituting regulating ecosystem services (pest regulation is a natural service) (indicators 1-5)				

	PERFORMANCE INDICATORS	METRICS
1	Application control of fertilizers or pesticides on site during construction works (limited to the eradication of invasive species) and during the initial stage of operation (limited to vegetation establishment)	
2	Reduced pesticide and fertilizer application rates or no use through the use of soil tolerant and pest resistant plant species, native species	
3	Reduced pesticide and fertilizer toxicity, persistence and bioavailability	
4	Implementation of run-off controls	
5	Development of an integrated pest management approach and natural fertilizer management approach (e.g. composting) that eliminate pesticide and chemical fertilizer use	

CREDIT: NW2.4 Protect Surface and Groundwater Quality

The credit assesses how the project preserves water resources by preventing pollutants from contaminating surface water and groundwater and monitoring impacts during construction works and operations.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER

IMPACT ASSESSED	**DIRECT IMPACT**	(+) Water quality	(-) Noise	(+-) Capital cost (-) Rehabilitation cost (-) Replacement cost	(-) Travel time value (-) Vehicle cost (-) Fuel cost
	INDIRECT IMPACT	(+) Ecosystem quality (+) Resource depletion (-) Embodied energy (-) Embodied carbon (-) Emissions (-) Climate change	(+) Health (+) Wellbeing	(+) Restoration cost (+) Delay cost (+) Resilience value (+) Ecosystem services value	(+) Health cost (+) Ecosystem services value
ENVIR	• Improved water quality through the prevention of leaks, spills and other sources of contamination during operations and construction works; through controls, avoidance of in-water works (indicators 1-11) • Increased embodied energy and carbon for transport in the case of performance of selected works offsite (indicator 8)				
ECON	• Added cost for runoff interceptors and drainage systems (capital cost, rehabilitation or replacement cost) (indicator 2); monitoring • Added capital cost for protection measures against debris in water courses (indicator 7) • Added capital cost (hauling & fuel cost, labor cost) for transport to off-site location (indicator 8) • Avoided cost of delay due to avoided environmental incidents; limitations in permitted seasons for in-water works (indicators 7, 8, 9 &11) • Avoided cost of cleanup in the case of water contamination incident (indicators 1-11) • Avoided healthcare cost (indicators 1-11)				

	PERFORMANCE INDICATORS	METRICS
1	No creation of new direct pathway for surface and ground water contamination through spill and leak diversion systems, spill prevention plans and cleanup	
2	Provision of runoff interceptors and drainage channels for pollutants in stormwater runoff or ice melt, potential spills, and leakage	
3	Use of natural systems to capture or prevent potentially polluting substances leakage	
4	Surface water and/or groundwater quality monitoring or contaminant source monitoring of receiving waters (in terms of pollutant loading, biological impact, water temperature, and the impact on receiving water flow)	
5	Overall improvement of water quality on site, or in the watershed, compared to the pre-existing baseline	
6	Improved quality of stormwater runoff through infiltration (e.g. use of permeable pavement)	Treat at least 50% of the 90th percentile average annual rainfall event post-construction runoff volume to 25 mg/L concentration of total suspended solids or less
7	Prevention or minimization of potential impacts of water pollution during construction works. (e.g. measures to prevent leakage of pollutants into a watercourse or the sea (bunding, appropriate storage, spill kits, and/or emergency response plans, run-off containing high volumes of silt and poor site management)	• No. of recorded environmental incidents • No. of recorded near misses • Stockpiles located in a distance > 10 meters of a watercourse
8	Minimization of potential impacts on surface water and/or groundwater quality through performance of selected works off-site (e.g. demolition of existing structures)	

9	Minimization of in-water works during construction works through design optimization	Reduced no. of in-water working days
10	Prevention or minimization of potential impacts of water pollution in operation. (Actions include: the location of storage for fuels, chemicals or other potentially - polluting substances away from sensitive areas, and inclusion of interceptors and drainage channels.)	
11	Monitoring water quality during construction works (visual inspection of watercourses is a standard industry practice)	

ECOLOGY

CREDIT: NW3.1 Enhance Functional Habitats

The credit assesses how the project preserves and improves the functionality of terrestrial (land) habitats.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Ecosystem quality (-) Materials (-) Energy (-) Waste (-) Water	(+) Safety	(-) Capital cost (-) O&M cost (-) Rehabilitation cost (-) Replacement cost (+) Residual value	(+) Vehicle cost (+) Accident cost
	INDIRECT IMPACT	(+) Ecological resilience (-) emissions (-) Embodied energy (-) Embodied water (-) Embodied carbon (-) climate change (-) Resource depletion	(+) Health (+) Wellbeing	(+) Resilience value (+) Ecosystem services value	(+) Health cost (+) Ecosystem services value

ENVIR	• Preservation of ecosystem services (availability of clean air, freshwater, reduced risk of flooding or drought, stabilization of local and regional climates, control on the range and transmission of certain diseases; provisioning of food; visual comfort, recreation, etc.) (indicators 1, 3) • Increased protection of fauna through reduced wildlife-vehicle collisions (indicator 2) • Increased use of materials for initial construction of dedicated wildlife crossings; and associated embodied energy, water and carbon (indicator 2) • Increased use of energy for initial construction of dedicated wildlife crossings and associated emissions (indicator 2) • Additional future use of materials (permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for rehabilitation or replacement works (indicator 2)
SOC	• Reduced risk of wildlife-vehicle collisions for drivers (indicator 2) • Additional future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for rehabilitation or replacement works (indicator 2)
ECON	• Added capital cost, O&M cost; rehabilitation or replacement cost in the case of dedicated wildlife crossings (indicator 2) • Additional future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for rehabilitation or replacement works (indicator 2) • Avoided cost of accident, vehicle repair cost and healthcare cost due to wildlife-vehicle collisions (indicator 2) • No impact on natural capital and associated costs of substituting ecosystem processes with engineered controls (indicators 1, 3)

	PERFORMANCE INDICATORS	METRICS
1	No net impact on habitat quality, quantity, and connectivity (includes offsetting, new habitat creation to compensate for loss)	
2	Provision for local wildlife protection (Structures or facilities that support local wildlife but do not in themselves create a self-supporting habitat). (e.g. artificial bat roosting boxes, bird nesting opportunities, artificial badger sets or otter holts, dedicated wildlife crossings (overpasses or underpasses), green roofs and walls)	
3	Degree of habitat connectivity maintained or enhanced (low, moderate or high degree) High connectivity: Native vegetation in good condition >100m wide that forms a sole link between other native vegetation in good condition. Moderate connectivity: Low condition native vegetation >100m wide or native vegetation in good condition 50-100m wide that forms part of a sole link between other vegetation in good condition. Low connectivity: Low condition native vegetation >100m wide or native vegetation in good condition >50m wide that is part of one of several links to other native vegetation in good condition (source: IS tool)	The existing degree of habitat connectivity should be at least maintained (offsetting allowed).

CREDIT: NW3.2 Enhance Wetland & Surface Water Functions

The credit assesses how the project maintains and restores the ecosystem functions of streams, wetlands, waterbodies, and their riparian areas.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water quality (+) Ecosystem quality (+) Resource depletion		(+-) Capital cost (+-) O&M cost	
	INDIRECT IMPACT	(+) Ecological resilience	(+) Health (+) Wellbeing	(+) Restoration cost (+) Resilience value (+) Ecosystem services value	(+) Economic prosperity (+) Resilience value (+) Ecosystem services value

ENVIR	• Improved water quality and aquatic species diversity (indicators 1-4)
SOC	• Increased recreational value, visual comfort due to more visible and natural water flow (indicators 1-4)
ECON	• Capital and O&M cost savings due to reduced need for engineered sediment controls (indicators 1-4) • Added capital cost and O&M cost of protection measures (indicator 3) • Avoided delay cost during construction works associated with environmental incidents (indicator 2) • Avoided cost of remediation of water quality (indicator 1, 2) • Increase in property value of the site and surrounding area (indicators 1-4) • No impact and enhancement of natural capital and avoided associated future costs (indicators 1-4) • Increased resilience value for the agency and the community through security of availability of water resources (indicators 1-4)

	PERFORMANCE INDICATORS	METRICS
1	No net loss in quantity or quality of existing wetlands and surface waters	
2	Minimized disturbance to existing natural wetland and surface water functions through active protection strategies, controls, safeguards, or other measures during construction works[102]	Active protection of at least one of the four wetland and surface water ecosystem functions: • hydrologic connection • water quality • aquatic/riparian habitat, and • sediment transport/ sedimentation
3	Compensation for unavoidable losses in wetland and surface water functions through mitigation measures: • removal of existing sources of sediment obstruction or sedimentation • removal of structures that drain wetlands and/or reconnection or diversion of appropriate sources of groundwater or surface waters • mitigation of existing obstructions to habitat connectivity such as dams, roadway structures	
4	Reduced need for engineered sediment controls	

[102] Increased sediment loading in rivers and stream due to exposed soils and sediment in run-off from construction sites results to sediment loading in nearby streams and outfalls.

CREDIT: NW3.3 Maintain Floodplain Functions

The credit assesses how the project preserves floodplain functions by limiting development and impacts of development in the floodplain.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Materials (+) Energy (+) Water quality (+) Ecosystem quality	(+) Safety	(+) Rehabilitation cost (+) Replacement cost (+) Residual value	
	INDIRECT IMPACT	(+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Emissions (+) Climate change (+) Ecological resilience	(+) Health (+) Access (+) Social resilience	(+) Resilience value (+) Ecosystem services value	(+) Health cost (+) Economic prosperity (+) Resilience value (+) Ecosystem services value

ENVIR	• Reduced future use of materials(permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for rehabilitation or replacement works (indicators 1-7) • Reduced worksite energy consumption due to avoided construction works (indicators 1-7)
SOCIAL	• Increased safety through flood protection; avoided structural degradation of structures (indicators 1-7) • Reduced future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for rehabilitation or replacement works (indicators 1-7)
ECON	• Reduced rehabilitation and replacement cost due to reduced corrosion and structural degradation of structures (indicators 1-7) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for rehabilitation or replacement works • No impact on natural capital (flood protection, climate regulation etc.) and associated costs of substituting ecosystem processes with engineered controls (indicators 1-7) • Increased resilience against short-term and long-term flooding hazards and avoided costs of property loss, life loss, loss of service; and avoided associated costs (indicators 1-7)

	PERFORMANCE INDICATORS	METRICS
1	Relation to the 100-year or design floodplain (whichever is more stringent). Projects are encouraged to use existing information.	• Above the 100-year flood levels • Above flood of record levels plus 3 feet/1 meter (If the 100-year flood is not demarcated)
2	% of net quantity of natural/vegetated zones within the floodplain maintained	At least 75% of natural/vegetated area maintained within the floodplain
3	% of existing vegetated areas retained after development OR no project development within the floodplain.	At least 25% of existing vegetation retained
4	Preservation of floodplain conveyance and floodplain storage capacity for project with large sites (i.e., the project does not shift net storage capacity from lower to higher elevations, thereby removing	Both • Floodplain conveyance maintained above the 10-year flood; and • Floodplain storage maintained below the 10-

	storage capacity from higher-frequency floods).	year flood
5	Maintained or increased floodplain storage capacity	
6	Maintain pre-development floodplain infiltration	% of area of impervious surfaces, vegetated zones and soil protection zones as compared to predevelopment
7	Enhanced habitat such as riparian buffers within and along waterways in the floodplain	

CREDIT: NW3.4 Control Invasive Species

The credit assesses how the project uses appropriate noninvasive species, and controls or eliminates existing invasive species.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Water quality (+) Soil quality (+) Ecosystem quality		(+-) O&M cost (-) Capital cost	
	INDIRECT IMPACT	(+) Climate change (+) Embodied energy (+) Embodied carbon (+) Ecological resilience	(+) Health (+) Sense of place	(+) Resilience value (+) Ecosystem services value	(+) Health cost (+) Resilience value (+) Ecosystem services value
ENVIR	• Reduced fertilizer use and associated embodied energy and carbon (indicators 1-5) • Improved soil quality and water quality (indicators 1-5)				
ECON	• Added capital cost (labor) for eradication of invasive species and controls (indicators 2,3 &5) • Long-term O&M cost savings due to avoided labor and cost for treatment or eradication of invasive species (indicators 1-5)				

	PERFORMANCE INDICATORS	METRICS
1	Use of landscaping best practices to prevent unintentional introduction of known invasive species to the local context (e.g. use of species that are known to be non-invasive)	
2	Eradication or control of existing invasive species populations before construction	
3	Establishment and implementation of control program for minor infestations of invasive species on site throughout construction.	
4	Protection against future infestations by supporting the establishment of native and/or noninvasive species	
5	Long-term controls are in place through a minimum three-year management plan to prevent the introduction or reintroduction of invasive species and	

	perform follow-up control actions if populations persist.	

CREDIT: NW3.5 Protect Soil Health

The credit assesses how the project preserves the composition, structure and function of site soils.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Soil quality (+) Ecosystem quality		(+-) Capital cost	
	INDIRECT IMPACT	(+) Emissions (+) Embodied carbon (+) Ecological resilience	(+) Health	(+) Delay cost (+) Restoration cost (+) Ecosystem services value	(+) Health cost (+) Ecosystem services value
ECON	• Added cost of labor for soil management; controls and treatments (indicators 2-5) • Capital cost savings for additional purchase of topsoil through reuse on-site (indicator 3) • Avoided cost of schedule delay due to environmental incidents during construction works; cost of remediation (indicators 1, 2, 4 &5) • No impact on natural capital and avoided cost of substituting regulating services with engineered controls (indicators 1-5)				

	PERFORMANCE INDICATORS	METRICS
1	Limited soil disturbance either through project design or construction management	
2	Establishment and implementation of a soil management plan	
3	Beneficial re-use of topsoil (at appropriate thickness and in places where required) [103]	Topsoil is correctly stored in stockpiles no higher than 2 meters to avoid compaction
4	Restoration of post-construction vegetated areas on site for appropriate soil type, structure, and function	At least 95% of post-construction vegetated areas restored OR 95% of all topsoil (by volume) retains its productivity and is beneficially re-used on or nearby to the project.
5	Land contamination remediation options/solutions with long-term effectiveness (i.e. Use of soil (bio) treatment centers)	

[103] Topsoil is an organic material and is only re-used beneficially if layers are not applied too deep as this would destroy its structure.

CLIMATE AND RESILIENCE

Emissions	CR1.1 Reduce Net Embodied Carbon CR1.2 Reduce Greenhouse Gas Emissions CR1.3 Reduce Air Pollutant Emissions
Resilience	CR2.1 Avoid Unsuitable Development CR2.2 Assess Climate Change Vulnerability CR2.3 Evaluate Risk and Resilience CR2.4 Establish Resilience Goals and Strategies CR2.5 Maximize Resilience CR2.6 Improve Infrastructure Integration

EMISSIONS

KEY CREDIT

CREDIT: CR1.1 Reduce Net Embodied Carbon

The credit assesses how the project reduces the impacts of material extraction, refinement/ manufacture, and transport over the project life.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Embodied carbon		(-) O&M cost (+) Revenues	
	INDIRECT IMPACT	(+) Climate change	(+) Health	(+) Penalty cost	
ENVIR	• Reduced contribution to climate change by the project over its lifetime (indicators 1-5)				
ECON	• Increased O&M cost due to the cost premium for the purchase of RECs; carbon credits within a cap-and-trade program (indicators 4, 5) • Increased revenues through generation and sale of carbon credits within a cap-and-trade program (indicator 5) • Avoided cost of penalty due to exceedance of allowed carbon limits (indicator 4)				

	PERFORMANCE INDICATORS	METRICS
1	Documentation of the primary materials for construction and ongoing operation of the project over its life, by type, quantity (including frequency of use over project life) Estimation of the embodied carbon of materials (based on readily available public information such as regional, national, or global averages) Identification of the select materials that collectively will make up over 80% of the total estimated embodied carbon of the project.	
2	Mapping (Index and quantification) of the embodied carbon of materials - primary contributors to carbon intensity- over the life of the project (construction and operations) Calculations include: • Embodied carbon of production, including raw material extraction, refinement, and manufacture. • Embodied carbon of transporting materials to the project site. • The replacement, repair, or refurbishment of materials over the life of the project. Embodied carbon data may come from the manufacturer, reputable databases, reputable	**IMPACT FOR FILTERING: 'INDIRECT ENVIRONMENTAL IMPACT' ='EMBODIED CARBON'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on embodied carbon. The index of filtered credit indicators can provide the basis for an **informal** CARBON-LCA.

	embodied energy software, or from project team calculations. If the source or specific type of materials is not known at the time of assessment, calculations may present a range of values or rely on likely material choices. (Calculations should be in tons CO_2)	
3	% of reduction in net embodied carbon of materials (Calculations should compare total carbon intensity of materials for the project against the total carbon intensity of the baseline. (Calculations should be in tons CO_2)	At Least 5% Reduction in net embodied carbon of materials as compared to a base case
4	Reduced net embodied carbon through carbon offsetting	No. of carbon credits purchased within a cap-and-trade program
5	Generation of carbon credits (e.g. through the use of low carbon transportation fuels) and sale of carbon credits[104]	No. of carbon credits generated No. of carbon credits sold (purchased by others within a cap-and-trade program)

KEY CREDIT

CREDIT: CR1.2 Reduce Greenhouse Gas Emissions

The credit assesses how the project reduces greenhouse gas emissions during the operation of the project, reducing project contribution to climate change.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Emissions		(-) Capital cost	
	INDIRECT IMPACT	(+) Climate change	(+) Health	(+) Penalty cost	

ENVIR	• Reduced contribution to climate change by the project over its lifetime (indicators 1-3)
SOCIAL	• Reduced respiratory diseases due to better air quality (indicators 1-3)
ECON	• Added capital cost for carbon sequestration strategies (indicator 3) • Avoided penalty cost for exceeding relevant mandatory limits (indicators 1-3)

[104] The case of LA METRO that generates carbon credits through the use of low carbon transportation fuels such as electricity and renewable natural gas. Metro conducts periodic solicitations for the sale of these carbon credits including Low Carbon Fuel Standard (LCFS) credits and Renewable Identification Numbers (RINs).

	PERFORMANCE INDICATORS	METRICS
1	Mapping (Index and quantification) of the total annual greenhouse gas emissions over the life of the project (direct and indirect greenhouse gas emissions and sequestration associated with project operations)	**IMPACT FOR FILTERING: 'INDIRECT ENVIRONMENTAL IMPACT' ='EMISSIONS'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on GHG emissions. The index of filtered credit indicators can provide the basis for **an informal** GHG EMISSIONS-LCA.
2	% of reduction in operational greenhouse gas emissions (all sources of emissions from facilities, processes, or vehicles owned or controlled within the project boundary, as well as indirect emissions from the off-site generation of energy used by the project.)	At least 10% reduction in total CO2e as compared to a base case footprint (where a demand or volume increase is anticipated over the life of the project emissions reductions can be calculated on a per unit basis e.g. passenger miles traveled)
3	Reduced operational greenhouse emissions through carbon sequestration (e.g. CO2 offset potential of streetscape)	

CREDIT: CR1.3 Reduce Air Pollutant Emissions

The credit assesses how the project reduces emissions of air pollutants: particulate matter (including dust), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and volatile organic compounds.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Air quality		(-) Capital cost	
	INDIRECT IMPACT	(+) Climate change	(+) Health	(+) Penalty cost	

SOCIAL	• Reduced respiratory diseases due to better air quality (indicators 1-5) • Improved health for workers through less exposure to harmful substances (indicator 2)
ECON	• Added cost of capture and sequestration strategies (indicator 5) • Avoided cost of penalty due to no compliance to air quality standards and regulations (indicators 1-5)

	PERFORMANCE INDICATORS	METRICS
1	Compliance with all applicable air quality standards and regulations for air pollutants as an overarching prerequisite	
2	Reduction of air pollutants compared to baseline	No exceedance of the 95th percentile,

		OR Represent the lowest levels possible compared to projects of similar type or elimination of all air pollutant sources, choice of a non-polluting alternative, OR At least a 98% net reduction in air pollution emissions compared to the baseline
3	Level of exceedance of air emission or air quality goals[105]	No recurring or major exceedances of air emission or air quality goals. • Recurring exceedances are defined as more than two of a similar type within a 12-month period • Major exceedances are defined as exceeding the air emission or air quality goals by more than 50%."
4	Limited use or controlled exposure to volatile organic compounds through the use of coatings and other treatments (during temporary and permanent works) that are specified as Low-VOC and/or biodegradable	At least 10% use of Low-VOC and/or biodegradable coatings
5	Net positive impact on air pollutants (through direct removal of existing air pollutant sources or capture and sequestration of air pollutants)	

RESILIENCE

As stated in the Envision Manual, the following credits of the Subcategory Resilience have a strong correlation that is worth highlighting:

CR2.1 Avoid Unsuitable Development
CR2.2 Assess Climate Change Vulnerability; [106]
CR2.3 Evaluate Risk and Resilience;
CR2.4 Establish Resilience Goals and Strategies; and
CR2.5 Maximize Resilience.

Credits CR2.1 and CR2.2 can be considered subcomponents of the broader credit CR2.3 given that site-prone hazards and climate change are overarching threats to projects. Furthermore, credit CR2.3 forms the foundation (and a requisite) for credits CR2.4 and

[105] Goals: Air emission or air quality goals are typically based on nationwide air quality objectives regional objectives. They should be based on relevant regulations and the advice of a qualified air quality specialist.

[106] Hazards/threats are events that have the potential to cause damage or harm, whether naturally occurring (hazards) or human-induced (threats). Vulnerability is a condition whereby a threat has the potential to disrupt or damage a project or system. Risk is the probability of a threat exploiting a vulnerability and the associated impacts and consequences. For example, flooding might be a threat to a project, critical systems located below flood levels would be vulnerable to that threat, and risk would be an evaluation of the probability and severity of a flood event as a factor of the associated losses if the critical systems were flooded. (source: Envision Manual)

CR2.5. Therefore, credits CR2.1-CR2.4 establish consecutive steps of risk evaluation towards maximized resilience.

Envision suggests a standard methodology for risk evaluation to be used across credits:

- Establish the boundary and scope of the assessment
- Understanding of objectives and performance goals of the project and related systems.
- Identification of natural hazards and human-induced threats
- identification of vulnerabilities of the critical functions and dependencies of the asset and its primary components
- evaluation of project risk by determining the likelihood/probability of a threat/hazard occurring

Additionally, to rewarding the development or not of a comprehensive risk evaluation. Envision rewards the extent of the scope and the comprehensiveness of the assessment:

- only project and site assessment
- expansion to system assessment: interdependencies of the project and its associated/connected infrastructure system/network
- expansion to community risk assessment: interdependencies of the project, its associated/connected infrastructure system/network, and broader community.

CREDIT: CR2.1 Avoid Unsuitable Development

The credit assesses how the project minimizes or avoids development on sites prone to hazards.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	Direct and indirect Impacts are determined by the nature of project-specific site-related hazards.			
	INDIRECT IMPACT				

	PERFORMANCE INDICATORS	METRICS
1	Assessment of siting alternatives that avoid or minimize hazard exposure and/or project alternatives less vulnerable to site hazards, to identify the lowest risk alternative Potentially adverse sites include but are not limited to: • Steep slopes (> 20 degrees) • Permafrost • Adverse geology (e.g., risk of liquefaction,	

	subsidence, or sinkholes) • Flood-prone areas • At-risk coastline (coastal surges, coastal erosion)	
2	Assessment of project potential to exacerbate site hazards to identify and implement mitigation measures of project's impact	
3	Strategic retreat from hazard-prone areas, removing structures, development, or activities from areas prone to damage or at risk of future damage	

CREDIT: CR2.2 Assess Climate Change Vulnerability

The credit assesses how the project develops a comprehensive climate change vulnerability assessment.

LC STAGE	**DESIGN & MATERIAL PRODUCTION**	**CONSTRUCTION**	**OPERATION**	**MAINTENANCE**	**END-OF-LIFE**
			X		

TYPE OF IMPACT ASSESSED		**ENVIRONMENTAL**	**SOCIAL**	**ECONOMIC**	
				AGENCY	USER
	DIRECT IMPACT **INDIRECT IMPACT**	Direct and indirect Impacts are determined by threats and hazards identified in a comprehensive climate change vulnerability assessment and their likelihood/ probability of occurring. However, the overall impact is on resilience: loss of life, loss of health, damage or loss of assets and/ or loss of operating time, loss of service, ecological resilience; and the associated resilience value, the avoided cost to the agency and the community through protection against risks.			

	PERFORMANCE INDICATORS	**METRICS**
1	Development of comprehensive threat/hazard identification study, or assessment due to climate change (e.g. climate threat analysis) based on the Envision-suggested standard methodology or consultation of an existing one. (The assessment should account for climate change's impact on the frequency, duration, and severity of threats/hazards and should specifically address changing design variables.)	
2	Determination of vulnerabilities and increased risk to the project due to climate change. (if key design variables or performance standards would be impacted over the life of the project under changing operating conditions)	
3	Determination of vulnerabilities and increased risk to the project's connected infrastructure system due to climate change	
4	Determination of vulnerabilities to community systems due to climate change (other assets, community, environment that would be impacted if the asset was to fail)[107]	

[107] Community systems can include:

CREDIT: CR2.3 Evaluate Risk and Resilience

The credit assesses how the project conducts a comprehensive, multi-hazard risk and resilience evaluation.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	The exact direct and indirect Impacts are determined by the risks identified in a comprehensive multi-hazard risk evaluation. However, the overall impact is resilience: loss of life, loss of health, damage or loss of assets and/ or loss of operating time, loss of service), ecological resilience; and the associated resilience value, the avoided cost to the agency and the community through protection against risks.			
	INDIRECT IMPACT				

	PERFORMANCE INDICATORS	METRICS
1	Development of a comprehensive multi-hazard risk assessment based on the Envision-suggested standard methodology. (the assessment could account for risks other than catastrophic events, e.g. crime/vandalism or personal injury)	
2	Determination of vulnerabilities and increased risk to the project's connected infrastructure system due to threats/hazards	
3	Determination of vulnerabilities and increased risk to community systems due to threats/hazards	

CREDIT: CR2.4 Establish Resilience Goals and Strategies

The credit assesses how the project supports increased project and community resilience through the establishment of clear objectives and goals.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

- physical systems like energy, water, transportation, communication systems, waste removal, and/or food supply.
- Non-physical systems like emergency services, funding, regulations, workforce, and/or community/political support.
  According to CEEQUAL as a minimum should include:
- 'one tier up or down' dependencies (i.e. parts of the system that, if impacted, would have a direct effect on the asset such as the energy supply or communication system)

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	Direct and indirect Impacts are determined by the specific resilience goals of the project and risk management strategies set, informed by a comprehensive and thorough risk evaluation. However, overall there is an associated resilience value, the avoided cost to the agency and the community through protection against risks			
	INDIRECT IMPACT				

	PERFORMANCE INDICATORS	METRICS
1	Development of comprehensive and thorough risk evaluation (CR2.3) as prerequisite	
2	Establishment of quantifiable resilience performance goals of the project and the owner's acceptable level of risk based on the results of a comprehensive and thorough risk evaluation (prerequisite)	
3	Development of risk management strategies that meet project performance goals and budget, and increase project resilience based on the proposed prioritization according to risk reduction potential and any extenuating factors (cost, availability, reliability, effectiveness, etc.): • Eliminate/Avoid potential threat. • Accommodate the threat through durable and adaptable design • Minimize the impact of a failure through redundant/ diverse design and preparedness • Restore quickly from losses through recovery/ response • No action: likelihood and impacts are deemed an acceptable risk.	
4	Level of stakeholder engagement in the resilience goal setting process and development of strategies	

KEY CREDIT

CREDIT: CR2.5 Maximize Resilience

The credit assesses the degree to which the project incorporates elements that increase durability, the ability to withstand hazards, and extend useful life.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
	X	X	X	X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Materials (+) Resource depletion (+) Ecosystem quality	(+) Access (+) Safety (+) Health (+) Capacity building	(-) Capital cost (+) O&M cost (+) Rehabilitation cost (+) Replacement cost (+) Residual value	
	INDIRECT IMPACT	(+) Ecological Resilience	(+) Wellbeing (+) Social resilience	(+) Resilience value	(+) Economic prosperity (+) Resilience value

ENVIR	• Improved capacity building through measurement and quantification of resilience benefits for further community resilience and preparedness (indicator 11) • Reduced initial use of materials and associated embodied energy, water and carbon due to the potential for downsizing structures through the use of durable materials and structures (indicators 3,4) • Avoided future use of materials (permanent) and future construction works-related impacts (materials (temporary), energy, waste, water and associated indirect impacts) for rehabilitation or replacement works due to durability (indicators 3, 4); adaptability (indicators 5, 6)
SOC	• Avoided future construction works-related impacts (access, noise, safety, light pollution and associated indirect impacts) for rehabilitation or replacement works due to durability (indicators 3, 4); adaptability (indicators 5, 6)
ECON	• Added capital cost for durable materials and structures (indicators 3, 4); adaptability (indicators 5, 6); system recovery/ response mechanisms (indicator 7) • Reduced O&M, rehabilitation or replacement cost due to durability (indicators 3, 4); adaptability (indicators 5, 6) • Avoided cost of repair of damage, lost revenues due to operating time loss, loss of service; displacement due to system recovery, adaptability, redundancy and durability (indicators 1-10) • Avoided cost of productivity for the community due to failure of systems; lost operating time; avoided cost of damage loss of property (indicators 1-10) • Avoided future construction works-related impacts for user (travel time value, vehicle, fuel cost, accident cost and associated indirect impacts) for the rehabilitation or replacement due to durability (indicators 3, 4); adaptability (indicators 5, 6)

	PERFORMANCE INDICATORS	METRICS
1	Development of comprehensive and thorough risk evaluation and strategies (CR2.3 & CR2.4.) as prerequisite	
2	Adoption of a comprehensive approach to implementing resilience strategies. Strategies include one or more of: • Reflectiveness (learning and improving) • Resourcefulness (resource efficiency, innovation) • Inclusivity (shared action and responsibilities) • Integration (of diverse systems, institutions, and people) • Robustness (durability, quality construction) • Redundancy (diversity, fault tolerance) • Adaptability (flexibility, changeability)	
3	Exceedance of minimum requirements, regulations, or standard practice for project durability (materials, structure, construction quality)	
4	Maximized durability for project elements where failures or degradation are most likely to occur. (taking into consideration anticipated impacts on durability by future demand, loads up until project's end-of-life)	
5	Increased operational tolerance for adaptation to long-terms changes	
6	Increased physical adaptability such as reconfiguration, repurposing, self-regulating, or self-repairing systems.	
7	Development of operational guidance including thresholds and indicators to trigger deployment of adaptation strategies at appropriate times	
8	Establishment of system recovery target times and service levels in the event of hazards	
9	Monitoring of the implementation of resilience strategies throughout construction and establishment of key performance indicators to be used to measure and	

	manage initiatives.	
10	Incorporation of resilience strategies into O&M of the project through systems in place to maintain, grow, learn, and continually improve resilience capabilities (e.g. "plan, do, check, act").	
11	Inclusion of methods of measurement and quantification of the benefits of increased resilience through objective measure (e.g., cost savings, improved service) to support their implementation on the project and benefit the knowledge and understanding of the broader resilience for the community.	**IMPACT FOR FILTERING: 'INDIRECT ECONOMIC IMPACT' FOR 'THE AGENCY' & 'THE USER'='RESILIENCE VALUE'** Through this filtering the Sustainability LC tool enables a full index of strategies with positive or negative impact on social and economic resilience for the agency and the user. This index could assist in determining reductions in: - magnitude of losses - probability of occurrence - recovery time

CREDIT: CR2.6 Improve Infrastructure Integration

The credit assesses how the project enhances the operational relationships and strengthens its functional integration into connected, efficient, and diverse infrastructure systems.

LC STAGE	DESIGN & MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
			X		

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Materials (+) Energy	(+) Integration	(+) Capital cost (+) O&M cost (+) Rehabilitation cost (+) Replacement cost (+) Revenues	
	INDIRECT IMPACT	(+) Embodied energy (+) Embodied water (+) Embodied carbon (+) Emissions (+) Climate change	(+) Social resilience	(+) Resilience value	(+) Economic prosperity (+) Resilience value
ENVIR	• Reduced use of materials through avoidance of duplicated system components (indicators 1, 2 &3) • Reduced operational energy use through efficiency (indicators 1-4) • Avoided construction energy use through avoided construction, rehabilitation and replacement works of duplicated system components to provide redundancy (indicators 1, 2 &3)				
ECON	• Whole-life cost savings due to efficiency redundancy without additional use of materials for duplicated systems but rather through systems integration and multifunctional components; monitoring of performance; shared costs through cross-sector programs (indicators 1, 2 &3) • Increased resilience against short-term and long-term flooding hazards through redundancy; avoidance of cascading failures and avoided costs of property loss, life loss, loss of service; and avoided associated costs for the agency and the community (indicators 1-4)				

	PERFORMANCE INDICATORS	METRICS
1	Internal systems integration and coordination for efficiency and redundancy (multi-functional system components rather than duplicated components)	
2	External systems integration for improved efficiency, redundancy, or system diversity of a larger infrastructure system beyond the project boundary	
3	Community/Network Integration for improved efficiency, redundancy, or system diversity (e.g. part of a larger program, policy, or initiative to improve cross-sector performance and sustainability)	
4	Information integration (integrated monitoring or data gathering systems in order to improve performance during operations)	

CHAPTER 6.

APPLICATION OF THE SUSTAINABILITY LIFECYCLE TOOL ON A TRANSPORTATION PROJECT

The main reason to use the **Sustainability Lifecycle Tool** is for an early assessment of how the project addresses sustainability at:

a. each of the stages of the lifecycle of the project (lifecycle stages)
b. each of the three pillars of sustainability (TBL), environmental, social, economic

The MTO's bridge replacement project presented in a previous part of the report, which also helped calibrate the tool in its development process, will serve as an example of using the supportive tables and datasheets of the tool.

<u>The application of the tool is presented in the following steps:</u>
Step 1: Apply the Envision Checklist to identify core sustainability strategies.
Step 2: Link core sustainability strategies with specific Envision credits.
Step 3: Use of the Lifecycle Table and TBL tables (tool's supporting tables) for the identified strategies.
Step 4: Use the Envision Checklist score to identify low-score Envision credits and potential areas for improvement.
Step 5: Use of the Sustainability Lifecycle Tool in the chosen area(s) of improvement.
Step 6: Use the Envision Manual for guidance on the required documentation, best practice strategies, and higher levels of achievement.

The steps of the process reaffirm that the proposed tool can be an integral part of the Envision framework.

STEP 1: APPLYING THE ENVISION CHECKLIST TO IDENTIFY CORE SUSTAINABILITY STRATEGIES

The first step of the assessment is to identify the most important sustainability strategies of the project. It is suggested to use the Envision Pre-assessment checklist to identify the project's sustainable strategies.[108] The Checklist provides a quick, approximate overall picture of the sustainable performance of the project across the different Envision categories of impact. It assesses if the project addresses the full range of sustainability criteria and to what extent. It is an Excel-based tool to support the incorporation of Envision early in project planning and in the conceptual design phase. Envision criteria are presented as yes/no questions, and therefore its results do not directly correspond to Envision rating system scores, but rather serve as an estimate of the potential score a project may achieve should it proceed through third-party verification.

[108] In many cases, decision makers or project managers may be able to identify the core sustainability strategies of the project without the use of the Envision Checklist. However, this step is essential for high level decision making even without the Checklist.

In the case of the Bayfield Bridge, the application of the Checklist was based on available information regarding the project's sustainability strategies[109] (Section 3.2.2).

Quality of Life	97	168	57.7%
Leadership	90	182	49.5%
Resource Allocation	15	98	15.3%
Natural World	104	182	57.1%
Climate and Resilience	75	174	43.1%
score	**381**	**804**	**47.4%**

The core strategies relate to most YES answers in the Checklist.

The core strategies identified for the Bayfield Bridge through the Checklist are the following:

- bridge replacement vs. rehabilitation,
- single-span bridge versus the previous two-span bridge,
- use of integral abutments,
- redundant corrosion protection through the use of premium materials (stainless steel on splash zones, premium reinforcing steel on bridge deck),
- correction of horizontal alignment,
- correction of vertical alignment and embankment widening,
- widening of the highway section next to the bridge (both lane width and inclusion of shoulders),
- increased sidewalk width (on community request),
- extension of the sidewalk beyond the project limits,
- provision for a future bicycle lane,

[109] The information for the Bayfield Bridge project was provided in order to summarize its main sustainability strategies but not to support any evidence required for Envision ratings. In this sense, the information provided was relatively limited, therefore some of the unaddressed credits are also a function of unavailable information. The case study does not aim to assess or rate the actual sustainable performance of the project. The Envision checklist is used to facilitate the research objectives showing how the framework can be applied in sustainable projects at the stages of decision making. Given that the focus is given on core strategies that were thoroughly documented, the missing information does not alter the overall take-aways of the process.

- salvage of parts of the old bridge structure,
- ABC construction,
- use of prefabricated components,
- performance of selected works off-site (temporary staging area adjacent to the site)
- staged construction,
- Use of ready-mix concrete plant in close proximity to the site (15 mins drive).

STEP 2: LINKING CORE SUSTAINABILITY STRATEGIES WITH SPECIFIC ENVISION CREDITS

This is an important step for every project team that chooses to use the tool. The sustainability strategies of the project should be approximately linked to the Envision credits. This provides a first high-level overview of strategies with multiple benefits across impact categories. More importantly, this link, in turn, enables the use of the Sustainability Lifecycle Tool for further and more detailed lifecycle stages and TBL impact assessment.

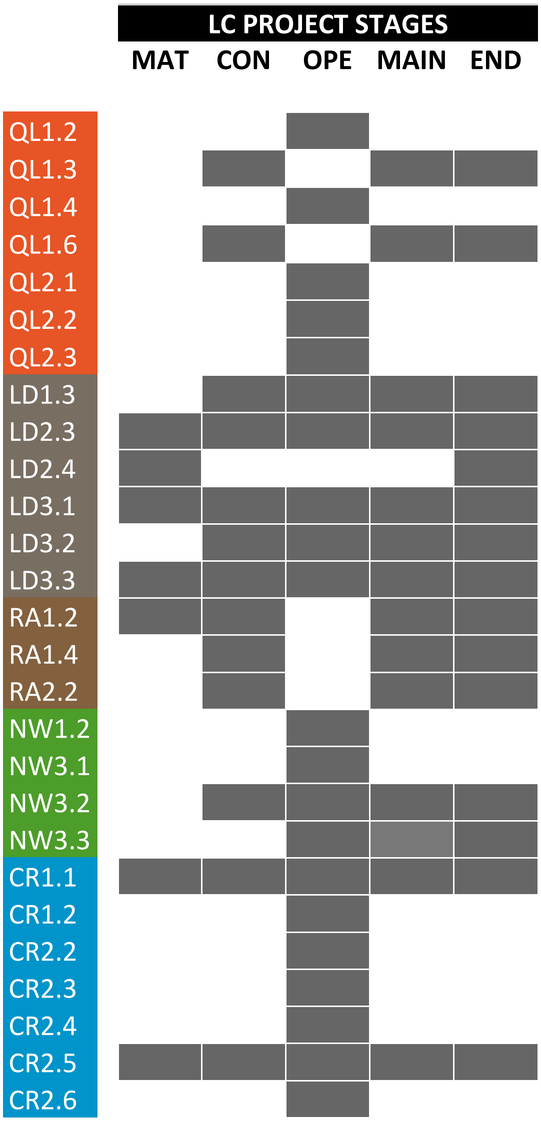
CORE STRATEGIES	RELATED ENVISION CREDITS									
Bridge replacement vs. rehabilitation	QL1.2	QL1.4	QL2.1	**LD2.3**	**LD2.4**	LD3.1	LD3.3	CR1.1	CR1.2	CR2.5
Single-span vs. original two-span	NW1.2	NW3.1	NW3.2	NW3.3	LD3.3	CR1.1	CR2.2	CR2.3	CR2.5	
Use of Integral abutment	QL1.6	**LD2.3**	**LD2.4**	LD3.3	CR1.1	CR1.2	CR2.2	CR2.3	CR2.4	CR2.5
Redundant corrosion protection system (use of premium materials)	LD2.3	LD2.4	LD3.3	CR1.1	CR2.3	CR2.5				
Construction quality	LD2.3	LD2.4	LD3.3	CR1.1	CR1.2	CR2.5				
Correction of horizontal alignment	QL1.2	CR2.6								
Correction of vertical alignment & embankment widening	QL1.2	NW3.3	CR2.2	CR2.3	CR2.4	CR2.5	CR2.6			
Widening of the highway section	QL1.2	QL2.1	LD2.3	LD3.1						
Increased sidewalk width	QL1.2	QL2.1	QL2.3	LD1.3						
Extension of the sidewalk beyond project limit	QL1.2	QL2.3	LD3.1							
Provision for a future bicycle lane	QL2.1	QL2.2	QL2.3	CR2.6						
Salvage of old structure parts	RA1.2	RA1.4	CR1.1							
ABC construction	QL1.2	QL1.6	LD3.1	LD3.2	LD3.3	RA2.2				
Use of prefabricated components	QL1.3	QL1.6	LD3.2	RA2.2						
Performance of selected works off-site during a seasonal shutdown	QL1.3	QL1.6	LD3.3							
Staged construction	QL1.3	QL1.6	LD3.1	LD3.3						
Use of ready-mix plant near worksite (15 min)	RA2.2	CR1.1								

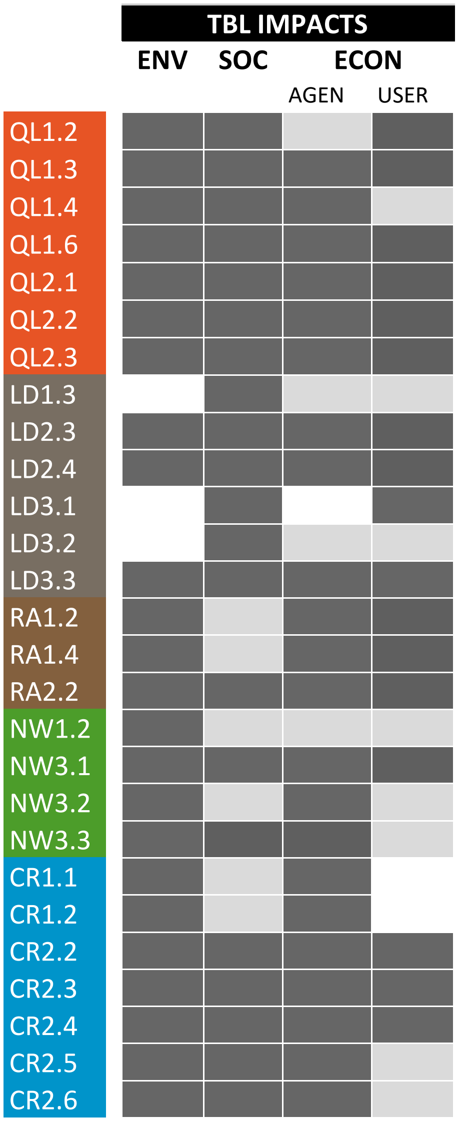
To a certain degree, the table presents the Envision credits that are addressed through the sustainable strategies of the project.

Through these credits, the tool will assess the sustainable strategies in relation to the TBL pillars and the lifecycle stages, with the respective supporting tables.

STEP 3: USE OF THE LIFECYCLE TABLE AND THE TBL TABLE FOR THE IDENTIFIED STRATEGIES

The corresponding supporting tables of the tool are used only for the credits related to the identified strategies, as shown below:





However, these tables do not represent the level of sustainable performance, but rather the extent to which the mentioned areas of interest are addressed.

In Step 3, all life cycle stages and all TBL impact categories are being considered through the identified strategies.

STEP 4: USING THE ENVISION CHECKLIST SCORE TO IDENTIFY LOW-SCORE ENVISION CREDITS AND POTENTIAL AREAS FOR IMPROVEMENT

The purpose of using the Checklist score is not to judge the performance but rather to identify areas of improvement. The results of the checklist application for the Bayfield Bridge replacement, shown below, indicate that the project can achieve a Gold award level. The scores per core strategy were isolated in the following table to provide an insight on their contribution to achieving each credit:

Table 17. Envision estimated score related to credits/ strategies

QL		LD		RA		NW		CR	
QL1.2	60%	LD1.3	17%	RA1.2	25%	NW1.2	80%	CR1.1	0%
QL1.3	36%	LD2.3	100%	RA1.4	0%	NW3.1	11%	CR1.2	0%
QL1.4	83%	LD2.4	57%	RA2.2	33%	NW3.2	100%	CR2.2	70%
QL1.6	100%	LD3.1	100%			NW3.3	79%	CR2.3	69%
QL2.1	100%	LD3.2	25%					CR2.4	40%
QL2.2	100%	LD3.3	71%					CR2.5	77%
QL2.3	100%							CR2.6	72%

STEP 5: USE OF THE SUSTAINABILITY LIFECYCLE TOOL IN THE CHOSEN AREA(S) OF IMPROVEMENT

At this point, the project team may want to make different types of improvements in several areas. Three hypothetical scenarios of improvements are considered:

- **Scenario A:** The focus is on enhancing the performance in the Envision credits with low scores.
- **Scenario B:** The focus is on the maintenance stage (minor or major rehabilitation) for improving its performance within the specific project stage.
- **Scenario C:** The focus is on the impact of the construction works across all TBL impact categories.

SCENARIO A: FOCUS ON ENHANCING THE PERFORMANCE IN THE ENVISION CREDITS WITH LOW SCORES

The identified credits are sorted based on their score in the Envision checklist:

Table 18. Credits with the lowest Envision scores are identified

	LC PROJECT STAGES					TBL IMPACTS				ENV SCORE
	MAT	CON	OPE	MAIN	END	ENV	SOC	ECON		
								AGEN	USER	
RA1.4										0%
CR1.1										0%
CR1.2										0%
NW3.1										11%
LD1.3										17%
LD3.2										25%
RA1.2										25%
RA2.2										33%
QL1.3										36%
CR2.4										40%
LD2.4										57%
QL1.2										60%
CR2.3										69%
CR2.2										70%
LD3.3										71%
CR2.6										72%
CR2.5										77%
NW3.3										79%
NW1.2										80%
QL1.4										83%
QL1.6										100%
QL2.1										100%
QL2.2										100%
QL2.3										100%
LD2.3										100%
LD3.1										100%
NW3.2										100%

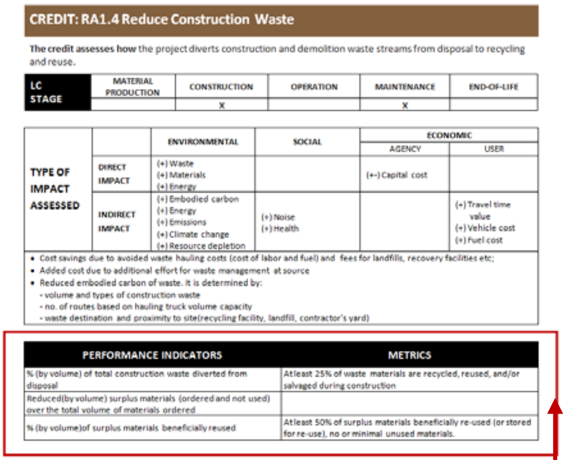
There are five credits with zero score in the Envision checklist, despite being related to the project's sustainable strategies. This may be due to the absence of the required documentation or the lack of the appropriate evidence required in Envision. For a better understanding of the shortcomings for these credits, the project team is able to use the Sustainability Lifecycle Tool manual (datasheets) to:

- identify sustainability indicators that were accounted in the project but need to be properly documented,

- identify sustainability indicators that can possibly be addressed in the project to enhance its performance.

For the latter, the team is directed to use the Sustainability Lifecycle Tool and the Envision Manual.

Among the five credits with 0% scoring, ‘RA1.4 Reduce Construction Waste’ has been selected as an example to show potential improvements through the use of the RA1.4 datasheet below:



CREDIT: RA1.4 Reduce Construction Waste

The credit assesses how the project diverts construction and demolition waste streams from disposal to recycling and reuse.

LC STAGE	MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	

		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
TYPE OF IMPACT ASSESSED	DIRECT IMPACT	(+) Waste (+) Materials (+) Energy		(+-) Capital cost	
	INDIRECT IMPACT	(+) Embodied carbon (+) Energy (+) Emissions (+) Climate change (+) Resource depletion	(+) Noise (+) Health		(+) Travel time value (+) Vehicle cost (+) Fuel cost

- Cost savings due to avoided waste hauling costs (cost of labor and fuel) and fees for landfills, recovery facilities etc;
- Added cost due to additional effort for waste management at source
- Reduced embodied carbon of waste. It is determined by:
  - volume and types of construction waste
  - no. of routes based on hauling truck volume capacity
  - waste destination and proximity to site(recycling facility, landfill, contractor's yard)

PERFORMANCE INDICATORS	METRICS
% (by volume) of total construction waste diverted from disposal	Atleast 25% of waste materials are recycled, reused, and/or salvaged during construction
Reduced(by volume) surplus materials (ordered and not used) over the total volume of materials ordered	
% (by volume)of surplus materials beneficially reused	Atleast 50% of surplus materials beneficially re-used (or stored for re-use), no or minimal unused materials.

Table 19.

CREDIT RA1.4 REDUCE CONSTRUCTION WASTE DATASHEET

Study indicators and related metrics as presented in the credit datasheet:

	PERFORMANCE INDICATORS	METRICS
1	**% (by volume) of total construction waste diverted from disposal**	At least 25% of waste materials are recycled, reused, or salvaged during construction works
2	**Reduced (by volume) surplus materials (ordered and not used) over the total volume of materials ordered**	
3	**% (by volume) of surplus materials beneficially reused**	At least 50% of surplus materials are beneficially reused (or stored for reuse), no or minimal unused materials.

The sustainability strategy of the project, which is related to RA1.4 is the salvage and reuse of parts of the old bridge structure, a strategy also related to the credit’ RA1.2 Use Recycled Materials.’ Considering that this strategy implies reduced construction waste (through reuse), it can be assumed that the indicators shown above have the potential to be properly addressed and meet the targets. The project team can perform the appropriate calculations to see if the targeted performance can be therefore achieved.

Similarly, the rest of the credits of a low Envision score can also be studied through their corresponding indicators, which are included in the datasheets.

SCENARIO B: FOCUS ON THE MAINTENANCE STAGE (MINOR OR MAJOR REHABILITATION)

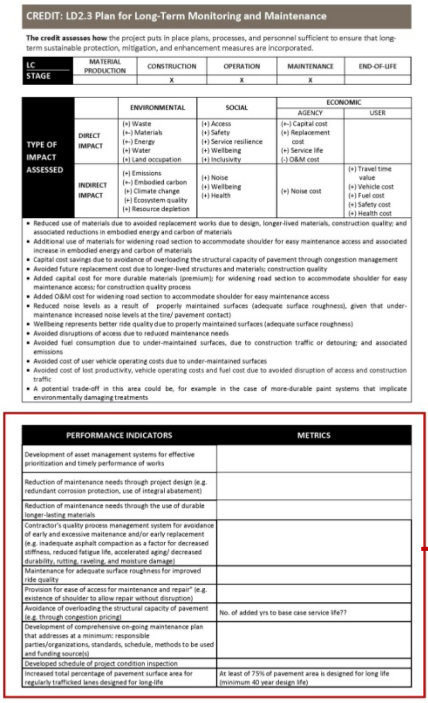
Assuming that the project team wants to focus on improvements in the maintenance stage, the lifecycle grouping table can be used.

LC PROJECT STAGE	ENVISION RELATED CREDITS
DESIGN & MATERIAL PRODUCTION	LD1.4 LD2.3 LD2.4 LD3.1 LD3.3
	RA1.1 RA1.2
	CR1.1 CR1.3 CR2.5
CONSTRUCTION	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.2 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
OPERATION	QL1.1 QL1.2 QL1.4 QL1.5 QL2.1 QL2.2 QL2.3 QL3.1 QL3.2 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.2 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.3 RA2.1 RA2.3 RA2.4 RA3.1 RA3.2 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
MAINTENANCE (minor or major rehabilitation)	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 **RA1.4** RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
END-OF-LIFE	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD2.4 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5

The credits that address the maintenance stage are identified in this table. Among these credits, the ones that are already linked with sustainable strategies of the project can be tracked by cross-comparing this table with the first table presented on the Strategies linked to the Envision credits. The identified credits are highlighted below.

MAINTENANCE (minor/ major rehabilitation)	**QL1.3** **QL1.6** QL3.3
	LD1.1 LD1.2 **LD1.3** LD1.4 LD2.1 **LD2.3** **LD3.1** **LD3.2** **LD3.3**
	RA1.2 **RA1.4** RA1.5 **RA2.2** RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 **NW3.2** **NW3.3** NW3.4 NW3.5
	CR1.1 CR1.3 **CR2.5**

The identified credits represent the credits with a high potential of performance improvement in the maintenance phase since they are already linked with some of the project's sustainable strategies. Therefore, the study of the corresponding indicators through the datasheet should follow, as shown below, as an example, for credit' LD2.3. Plan for long-term monitoring & maintenance'. Similarly, more credits will lead to more sustainable indicators to address.



CREDIT: LD2.3 Plan for Long-Term Monitoring and Maintenance

The credit assesses how the project puts in place plans, processes, and personnel sufficient to ensure that long-term sustainable protection, mitigation, and enhancement measures are incorporated.

LC STAGE	MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X	X	X	

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC	
				AGENCY	USER
	DIRECT IMPACT	(+) Waste (+-) Materials (+-) Energy (+) Water (+) Land occupation	(+) Access (+) Safety (+) Service resilience (+) Wellbeing (+) Inclusivity	(+-) Capital cost (+) Replacement cost (+) Service life (-) O&M cost	
	INDIRECT IMPACT	(+) Emissions (+-) Embodied carbon (+) Climate change (+) Ecosystem quality (+) Resource depletion	(+) Noise (+) Wellbeing (+) Health	(+) Noise cost	(+) Travel time value (+) Vehicle cost (+) Fuel cost (+) Safety cost (+) Health cost

- Reduced use of materials due to avoided replacement works due to design, longer-lived materials, construction quality; and associated reductions in embodied energy and carbon of materials
- Additional use of materials for widening road section to accommodate shoulder for easy maintenance access and associated increase in embodied energy and carbon of materials
- Capital cost savings due to avoidance of overloading the structural capacity of pavement through congestion management
- Avoided future replacement cost due to longer-lived structures and materials; construction quality
- Added capital cost for more durable materials (premium); for widening road section to accommodate shoulder for easy maintenance access; for construction quality process
- Added O&M cost for widening road section to accommodate shoulder for easy maintenance access
- Reduced noise levels as a result of properly maintained surfaces (adequate surface roughness), given that under-maintenance increased noise levels at the tire/ pavement contact)
- Wellbeing represents better ride quality due to properly maintained surfaces (adequate surface roughness)
- Avoided disruptions of access due to reduced maintenance needs
- Avoided fuel consumption due to under-maintained surfaces, due to construction traffic or detouring; and associated emissions
- Avoided cost of user vehicle operating costs due to under-maintained surfaces
- Avoided cost of lost productivity, vehicle operating costs and fuel cost due to avoided disruption of access and construction traffic
- A potential trade-off in this area could be, for example in the case of more-durable paint systems that implicate environmentally damaging treatments

PERFORMANCE INDICATORS	METRICS
Development of asset management systems for effective prioritization and timely performance of works	
Reduction of maintenance needs through project design (e.g. redundant corrosion protection, use of integral abatement)	
Reduction of maintenance needs through the use of durable longer-lasting materials	
Contractor's quality process management system for avoidance of early and excessive maitenance and/or early replacement (e.g. inadequate asphalt compaction as a factor for decreased stiffness, reduced fatigue life, accelerated aging/ decreased durability, rutting, raveling, and moisture damage)	
Maintenance for adequate surface roughness for improved ride quality	
Provision for ease of access for maintenance and repair" (e.g. existence of shoulder to allow repair without disruption)	
Avoidance of overloading the structural capacity of pavement (e.g. through congestion pricing)	No. of added yrs to base case service life??
Development of comprehensive on-going maintenance plan that addresses at a minimum: responsible parties/organizations, standards, schedule, methods to be used and funding source(s)	
Developed schedule of project condition inspection	
Increased total percentage of pavement surface area for regularly trafficked lanes designed for long-life	At least of 75% of pavement area is designed for long life (minimum 40 year design life)

Table 20.

CREDIT LD2.3 PLAN FOR LONG-TERM MONITORING & MAINTENANCE DATASHEET

	PERFORMANCE INDICATORS	METRICS	MTO PROJECT
1	Development of asset management systems for effective prioritization and timely performance of works		YES
2	Reduction of maintenance needs through project design (e.g., redundant corrosion protection, use of integral abatement)		YES
3	Reduction of maintenance needs through the use of durable longer-lasting materials		YES
4	Contractor's quality process management system for avoidance of early and excessive maintenance or early replacement (e.g., inadequate asphalt compaction as a factor for decreased stiffness, reduced fatigue life, accelerated aging/ decreased durability, rutting, raveling, and moisture damage)		YES
5	Maintenance for adequate surface roughness for improved ride quality		YES
6	Provision for ease of access for maintenance and repair" (e.g., shoulder to allow repair without disruption)		YES
7	Development of a comprehensive on-going maintenance plan that addresses at a minimum: responsible parties/organizations, standards, schedule, methods to be used and funding source(s)		YES
8	Developed schedule of project condition inspection		YES
9	Increased total percentage of pavement surface area for regularly trafficked lanes designed for long-life	At least of 75% of pavement area is designed for long life (minimum 40-year design life)	NO

The "MTO PROJECT" column represents the project team's (in this case, MTO) notes regarding the project's response with respect to the indicators. It is evident that the large majority of the indicators have been addressed (marked with "YES"). They are strategies that are being implemented successfully on an agency-level and have been incorporated into the specific bridge replacement project. Only one indicator is not addressed. The decision-maker can thus decide whether it is worth spending more time on this credit or move on with other maintenance credits that might be underperforming. The tool again contributes to quick and general observations and decisions before examining the areas of interest in more detail.

SCENARIO C: FOCUS ON THE IMPACT OF CONSTRUCTION WORKS (NOISE)

The Sustainability Lifecycle Tool can be used to assess and enhance project performance in a selected area or multiple areas of impact (direct or indirect), during a selected lifecycle stage. By performing multiple filtering of the credits, the project team can identify the strategies with, for example, 'NOISE' impact, both direct and indirect, of the 'CONSTRUCTION' stage activities.

The first step of the process is the use of the tool's LC GROUPING TABLE to identify credits related to the 'CONSTRUCTION STAGE.'

LC PROJECT STAGE	ENVISION RELATED CREDITS
DESIGN & MATERIAL PRODUCTION	LD1.4 LD2.3 LD2.4 LD3.1 LD3.3
	RA1.1 RA1.2
	CR1.1 CR1.3 CR2.5
CONSTRUCTION	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.2 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
OPERATION	QL1.1 QL1.2 QL1.4 QL1.5 QL2.1 QL2.2 QL2.3 QL3.1 QL3.2 QL3.3 QL3.4
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.2 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.3 RA2.1 RA2.3 RA2.4 RA3.1 RA3.2 RA3.4
	NW1.1 NW1.2 NW1.3 NW1.4 NW2.1 NW2.2 NW2.3 NW2.4 NW3.1 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.2 CR1.3 CR2.1 CR2.2 CR2.3 CR2.4 CR2.5 CR2.6
MAINTENANCE (minor or major rehabilitation)	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD3.1 LD3.2 LD3.3
	RA1.2 **RA1.4** RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5
END-OF-LIFE	QL1.3 QL1.6 QL3.3
	LD1.1 LD1.2 LD1.3 LD1.4 LD2.1 LD2.3 LD2.4 LD3.1 LD3.2 LD3.3
	RA1.2 RA1.4 RA1.5 RA2.2 RA3.3
	NW1.1 NW1.3 NW1.4 NW2.2 NW2.3 NW2.4 NW3.2 NW3.3 NW3.4 NW3.5
	CR1.1 CR1.3 CR2.5

Next, the user should refer to the respective credit datasheets to identify credits with 'DIRECT' and 'INDIRECT'' SOCIAL IMPACT' = 'NOISE,' as indicated in the 'TYPE OF IMPACT ASSESSED' section of the datasheet.

Table 21. EXAMPLE OF CREDIT QL1.6 MINIMIZE CONSTRUCTION IMPACTS DATASHEET

		ENVIRONMENTAL	SOCIAL	ECONOMIC: AGENCY	ECONOMIC: USER
TYPE OF IMPACT ASSESSED	DIRECT IMPACT	(-) Materials (+) Air quality (+-) Energy (+) Emissions	(+-) Noise (+) Safety (+-) Access (+) Light pollution (+) Wellbeing (+) Inclusivity (+) Community satisfaction	(+-) Capital cost	(+-) Travel time value (+-) Vehicle cost (+-) Fuel cost (+-) Safety cost
	INDIRECT IMPACT	(-) Embodied energy (-) Embodied carbon (-) Embodied water (+-) Emissions (+) Climate change (+) Ecosystem quality (+) Water quality (-) Resource depletion	(+) Health (+) Wellbeing (+) Noise (+-) Safety	(+) Noise cost (+) Liability claim cost (+) Penalty cost (+) Delay cost	(+) Health cost

The result of the 'NOISE' filtering is nine credits that refer to noise directly and indirectly:

CONSTRUCTION NOISE RELATED CREDITS	**QL1.3**	**QL1.6**	QL3.3							
	LD1.1	LD1.2	LD1.3	**LD1.4**	LD2.1	**LD2.3**	LD3.1	LD3.2	LD3.3	
	RA1.2	**RA1.4**	**RA1.5**	**RA2.2**	RA3.3					
	NW1.1	NW1.3	NW1.4	NW2.1	NW2.2	NW2.3	**NW2.4**	NW3.2	NW3.4	NW3.5
	CR1.1	CR1.3	CR2.5							

The next step is to collect all indicators of these 9 credits; 53 indicators in total. Through the use of notes[110] in the datasheet, the user can discard the indicators with no 'NOISE' impact.

Table 22. EXAMPLE OF CREDIT QL1.6 MINIMIZE CONSTRUCTION IMPACTS DATASHEET

CREDIT: QL1.6 Minimize Construction Impacts

The credit assesses how many temporary impacts associated with construction are addressed through the construction management plan.

LC STAGE	MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END-OF-LIFE
		X		X	X

TYPE OF IMPACT ASSESSED		ENVIRONMENTAL	SOCIAL	ECONOMIC – AGENCY	ECONOMIC – USER
	DIRECT IMPACT	(-) Materials (+) Air quality (+-) Energy (+) Emissions	(+-) Noise (+) Safety (+-) Access (+) Light pollution (+) Wellbeing (+) Inclusivity (+) Community satisfaction	(+-) Capital cost	(+-) Travel time value (+-) Vehicle cost (+-) Fuel cost (+-) Safety cost
	INDIRECT IMPACT	(-) Embodied energy (-) Embodied carbon (-) Embodied water (+-) Emissions (+) Climate change (+) Ecosystem quality	(+) Health (+) Wellbeing (+) Noise (+-) Safety	(+) Noise cost (+) Liability claim cost (+) Penalty cost (+) Delay cost	(+) Health cost
		(+) Water quality (-) Resource depletion			

- Added use of materials for safety barriers/ temporary signage in the case of staged construction and detour and associated embodied energy, water and carbon;
- Disruption of access due to full closure; days of full closure; for heavy freight trucks that are not allowed to cross a bridge due to weight limitations
- Reduced disruption of access due to improved construction logistics
- Increased safety for public and workers through less exposure to risk of accident due to full closure, work off-site; with exception workers safety in the case of staged construction
- Reduced energy and fuel consumption due to properly-sized equipment, avoided idling; and associated emissions
- Reduced embodied energy and carbon due to avoided truck routes
- Reduced emissions from increased fuel combustion due to avoided stop-and-go traffic trends (during construction congestion traffic that tend to increase fuel consumption and thus produce more emissions)
- Increased fuel consumption by private vehicles due to detouring; and associated emissions
- Decreased noise impact due to less duration; noise controls; with the exception of short-term noise generation in the case of saw-cutting existing structures to be removed into segments for transfer and demolishment off-site
- Positive impact on habitats due to reduced noise (increased noise levels disturb their equilibrium)
- Positive impact on human health due to reduced noise (body's acute stress response to noise raises blood pressure and heart rate among other consequences)
- Added cost of temporary materials for staged construction and detour; of accelerated construction (prefabrication, cost of acquisition of temporary yard, preparation and potential restoration cost; transport cost of heavier components, skilled labor); schedule efficiency cost of staged construction due to inefficient work sequencing
- Added cost of noise control at source (cost increases in accordance to strategy hierarchy: from avoidance to abatement)
- Cost savings due to schedule efficiency through construction logistics; accelerated construction; full closure (efficient work sequencing as compared to staged construction)
- Avoided cost of accidents for public (vehicle repair or medical cost) and for workers
- Avoided cost of delay of project delivery in the case of construction season constraints
- Avoided cost of environmental incident and restoration cost through works off-site (e.g. avoided incident of debris into water course)
- Avoided agency cost of penalty for exceedance of noise regulations; and avoided potential liability claim cost (e.g. result of noise complaints)
- Avoided cost of delay due to construction carry-over; jobsite accidents; complaints.
- Avoided cost of lost productivity, vehicle operating costs and fuel cost due to optimized construction logistics, not full disruption of access
- Added cost of lost productivity, vehicle operating costs and fuel cost due to full-closure; detouring; construction site-related traffic congestion
- Increased community satisfaction due to notification and timely response to complaints

PERFORMANCE INDICATORS	METRICS
No. of addressed construction impacts (and to what extend)	Address one, two, three or all types of the following construction impacts: • Noise • safety/wayfinding for public • disruption of access/mobility • distracting or intrusive lighting in workzone
Level of exceedance of existing or adopted target noise levels (continuous or non-continuous) for construction period	Noise level at any residential premises not to exceed background noise by: • 10 dB(A) or more for up to 18 months after project commencement • 5 dB(A) or more after 18 months during daytime hours (and beyond normal working hours) Noise not above background levels inside any adjacent residence during nighttime
	No. of days with works undertaken outside of normal working hours
	No. of days that required noise exemption for nighttime construction works
Reduced construction noise through noise control strategies, such as: • minimum distance from sensitive receptors, (e.g. site access roads and noisy plant as far as possible from residential areas) • new engine technology (low-noise emitting equipment) • properly sized equipment and plant on-site • avoided prolonged idling of equipment and • noise transmission reduction (screening, enclosure or silencing of noise sources)	
Increased safety for vulnerable road users through management of worksite access and egress routes for delivery trucks	
Minimized disruption from construction traffic (delivery trucks for hauling of materials and waste) upon the transport network through improved construction logistics	
Reduced interruption of service (full-closure)	• No. of days with planned full-closures (short and/ or long duration) • Total hours of full closures
Provision of alternative access during construction works through the minimum possible detour	Additional miles of detour
Implementation of partial closure of service- staged construction	Number of lanes open in each direction during work zone
	Added working days as compared to full-closure due to inefficiency of work sequencing
	Avoided days of full disruption due to staged construction
Reduced construction duration through performance of selected works off-site	Any reduction of no. of working days as compared to a base case (Base case can be a similar scope and scale construction project)
Reduced construction duration through accelerated construction	
Control of distracting or intrusive lighting in workzone	No. exceedance of minimum lighting requirements for nighttime workzone based on activities performed
Level of exceedance of vibration goals for high risk activities (such as rolling for compaction) for structural damage of structures	No. exceedance of vibration goals for structural damage to buildings and structures.

110 As already explained notes link impacts with specific indicators

The resulting indicators are 26:

		DIRECT IMPACT	INDIRECT IMPACT
QL1.3	Reduction of workers exposure to street traffic through the performance of selected works off-site • use of temporary construction yard (preferably in close proximity to the site) • use of prefabricated materials		(+)
QL1.6	No. of addressed construction impacts (and to what extend)	(+)	
	Level of exceedance of existing or adopted target noise levels (continuous or non-continuous) for the construction period	(+)	
	Reduced construction noise through noise control strategies, such as: - minimum distance from sensitive receptors, (e.g., site access roads and noisy plant as far as possible from residential areas) - new engine technology (low-noise emitting equipment) - properly sized equipment and plant on-site - avoided prolonged idling of equipment and - noise transmission reduction (screening, enclosure or silencing of noise sources)	(+)	
	Minimized disruption from construction traffic (delivery trucks for hauling of materials and waste) upon the transport network through improved construction logistics	(+)	
	Provision of alternative access during construction works through the minimum possible detour		(+)
	Reduced construction duration through the performance of selected works off-site	(+)	
	Reduced construction duration through accelerated construction	(+)	
	Level of exceedance of vibration goals for high-risk activities (such as rolling for compaction) for structural damage of structures	(+)	
	Reduced dust production through the performance of selecting works off-site (e.g., saw-cutting into segments for removal of existing structures, transfer and demolishment off-site)	(+-)	
LD1.4	Assessment of the availability and viability of beneficial reuse of excess resources (e.g., waste materials, land area/space, or management/personnel capacity)		(+)
	Increased collaboration with external groups to find beneficial use of project byproducts (project's waste streams or excess resources) off-site or incorporating off-site waste or excess resources into the project		(+)
	Short-term or long-term incorporation of at least one byproduct synergy or reuse into the project		(+)
RA1.2	% of project materials that are reused or recycled		(+)
	% of reuse of existing pavement materials by weight or cost (such as hot mix asphalt (HMA), Portland cement concrete (PCC), unbound granular base material, stabilized base material, reinforced concrete, structural steel, and timber) during rehabilitation works		(+)
	On-site use of demolition arisings		(+)
RA1.4	% (by volume) of total construction waste diverted from disposal		(+)
	Reduced (by volume) surplus materials (ordered and not used) over the total volume of materials ordered		(+)
	% (by volume) of surplus materials beneficially reused		(+)
RA1.5	% of excavated material reused/retained on-site		(+)
	% of excavated material moved off-site / reused to other nearby projects		(+)

	Use of locally sourced fill materials and a close proximity of destination of excavated materials to the site		**(+)**
	% of reduced fuel consumption by avoided workforce vehicle/transportation movements to and from the site with public transport Other relevant indicators: - Reduced miles traveled by the workforce by using public transport - % of number of total recorded local public transportation mode uses over the total number of workforce transportation movements - total distance traveled by the workforce to and from the site (total distance of each individual round trip) - total number of recorded workforce vehicle/transportation movements to and from site - Average distance traveled per person to and from site		**(+)**
RA2.2	% of reduction of overall fuel consumption through improved planning and logistics. Specific strategies may include: i. Reduce number of deliveries; ii. Reduce idle times; iii. On-site reuse of soils or other materials to decrease truck traffic to and from site iv. Reduce on-site trucking – proper logistics planning such as staging material in close proximity to installation location; v. Schedule acceleration without additional resource consumption; vi. Waterborne/rail transportation of materials versus trucking (third-party distribution or logistics); vii. On-site plants (concrete plant/asphalt plant) in lieu of trucking material to the site; and viii. Prefabrication of design elements.		**(+)**
	Increased volume of components constructed off-site		**(+)**
NW2.4	Minimization of potential impacts on surface water and groundwater quality through the performance of selected works off-site (e.g., demolition of existing structures)		**(+)**

Through the filtered indicators, the user can consult on strategies, targets, and numeric data to understand how to enhance the project's performance in relation to 'IMPACT' during construction works.

The final step of this process is to consult the datasheet' TYPE OF IMPACT ASSESSED' section and the associated notes for an overall view of the rest of impacts related, in order to proceed with an informed decision on specific strategies to adopt based on his priorities (e.g., capital cost savings, O&M cost savings or reduced embodied carbon, etc.)

In the case of MTO, for example, indicators referring to credits LD1.4, RA1.2, RA1.4, and RA1.5, which were not identified through their core strategies, could be a reference for enhancement of future projects in terms of 'NOISE' during construction.

STEP 6: USE OF THE ENVISION MANUAL FOR GUIDANCE ON REQUIRED DOCUMENTATION, BEST PRACTICES AND HIGHER LEVELS OF ACHIEVEMENT

The final step of using the Sustainability Lifecycle tool is the use of the Envision Manual. The manual provides detailed examples of best practices for each credit, connects strategies with levels of achievement (levels of sustainable performance of projects), and lists the required documentation that has to be produced to support each level of achievement. Consultation of the Envision Manual is, therefore, a necessary step for a more detailed assessment of project performance.

USEFULNESS OF THE TOOL

The present research proposes **an additional tool within the Envision® framework:** the "Sustainability Lifecycle tool." It is an Envision-based tool currently customized for transportation projects that aim to achieve sustainable performance across all the stages of their lifecycle. Project teams of transportation infrastructure need to make core decisions, for which, by definition, the impacts related to all lifecycle stages have to be addressed. Typical examples of such decisions are:

1. choose between the option to rehabilitate or the option to replace an existing infrastructure project (for existing deteriorating structures),
2. materials selection
3. selection of construction methods that will be applied
4. provision to accommodate the future potential increase in demand or not

Thus, decision-makers need to have a tool based on which they can form and adapt the project's core decisions towards an enhanced sustainable performance throughout its lifecycle.

The lifecycle sustainability tool highlights sustainability indicators already included in Envision, which can be used as guidelines for decision-makers and project teams, ideally in the early stages of inception and initial planning. They can also be used during design development and construction planning. Apart from the triple-bottom-line sustainability dimensions, the guidelines also consider impacts throughout all life cycle stages of the project, including the operations, maintenance, and end-of-life, allowing its users to optimize project resilience for both short-term and long-term impacts. Therefore, it provides a holistic framework that considers environmental, social, and economic impacts for the whole lifecycle of projects to enable informed decisions on sustainable transportation infrastructure.

Being an extension of the Envision framework, the tool invites owners, communities, designers, contractors, and other stakeholders to collaborate for higher sustainable transportation infrastructure development. As such, it is suggested that project teams using the Sustainability Life cycle tool should be familiar with the Envision rating system and framework to make the most of the process towards more informed sustainable choices in infrastructure development.

The lifecycle sustainability tool's framework has several uses:

- Lifecycle assessment tool:

Combined with the Envision rating system methodology, **it can be used as a lifecycle self-assessment tool** helping the users to better identify and understand their project's impacts to each of the triple bottom line categories (environmental, social, economic benefits and disadvantages) as well as evaluate its performance in each lifecycle stage.

- Multiple criteria, decision-making tool:

It can also be used as a **multiple-criteria decision-making tool** by providing an informed framework for comparative analysis between different alternatives whose impacts and benefits can be directly assessed and addressed.

- Guidelines to enhance sustainable performance:

Furthermore, after the self-assessment, the users **can address shortcomings or low-performance areas** (i.e., Envision credits not sufficiently addressed) by pursuing the corresponding sustainability indicators and following the respective guidelines to **enhance the project's sustainable performance**. In the early stages of planning and design development, the indicators could function as targets to pursue.

- Educational manual for lifecycle sustainability:

Simultaneously, the tool's framework is presented in the form of a manual to be used as an educational tool by individuals interested in enriching their knowledge concerning life cycle sustainability. Each Envision credit appears together with the respective sustainability indicators that function as a guide of specific strategies towards fulfilling each credit's intent. Providing information regarding the impacts of each sustainability strategy (impact category, type of impact, lifecycle stage, etc.) describes the relationship of sustainable strategies with impacts per lifecycle stage and the triple bottom line pillars of sustainability.

- Evidence-based documentation of project decisions:

Finally, the tool can be used to solidify infrastructure owners and prove their sustainable strategies. By connecting strategies with specific social, environmental, and economic impacts both immediate and long-term, the tool provides a basis for users to support their arguments or efficiently document experience-based strategies.

In any of the ways mentioned, successful use of the tool necessitates collaboration, teamwork, and learning.

NEXT STEPS

TOOL AUTOMATION

The current state of the lifecycle & TBL model lists all data that can be linked to sustainability indicators and Envision credits. It highlights data implied and indirectly addressed in Envision by introducing details on sustainability impacts (direct or indirect, positive or negative, and impact category). These features give the opportunity to assess and improve each project's performance in various impact categories selected by addressing the respective credits manually.

Although the use of the manual as presented is currently feasible as a guide for the assessment and quantification of impacts across all life cycles, it presents the tool in a linear fashion, which does not fully reveal the tool's potential.

To maximize the potential of the tool and, at the same time, make it user-friendly and efficient, procedures could be automated, such as credit groupings according to selected impacts, multiple-criteria selection of credits, and prioritization. This is a feasible upgrade of the tool given that the manual is based on an extensive excel-based framework that contains all the relevant information.

For example, in the Excel table of the tool, each indicator is independently linked to TBL impacts, while the manual presents impacts only at the credit level; as a compact, printable version of the Excel table. Impact links to specific indicators are provided through the form of notes at each credit. The ability to filter automatically not only credits but also indicators (strategies) in terms of impacts would optimize results for the user.

DEVELOPMENT OF CUSTOMIZED SIMILAR TOOLS FOR OTHER INFRASTRUCTURE SYSTEMS

At the request of the sponsor, the present tool is a customized pilot application for transportation infrastructure projects and more specifically for roadways, bridges, and transit projects. By using the structure of Envision that is built to assess all types of infrastructure, the tool methodology is scalable and can be applied to other infrastructure types as well.

OPEN-ENDED METHOD

Like most research in the field of broadening the scope of LCA practice, the present research is an open-ended methodology to adapt to new input and be updated. New numeric indicators can be incorporated, and new impacts can be included for assessment based on specific project needs.

APPENDIX

ENVISION ANALYSIS TABLES

Table 23. Envision credits in relation to lifecycle stages

CATEGORY	SUBCATEGORY	CREDITS	MATERIAL PRODUCTION	CONSTRUCTION	OPERATION	MAINTENANCE	END OF LIFE
QUALITY OF LIFE	WELLBEING	QL1.1 Improve Community Quality of Life			X		
		QL1.2 Enhance Public Health & Safety			X		
		QL1.3 Improve Construction Safety		X		X	
		QL1.4 Minimize Noise & Vibration			X		
		QL1.5 Minimize Light Pollution			X		
		QL1.6 Minimize Construction Impacts		X		X	
	MOBILITY	QL2.1 Improve Community Mobility & Access			X		
		QL2.2 Encourage Sustainable Transportation			X		
		QL2.3 Improve Access & Wayfinding			X		
	COMMUNITY	QL3.1 Advance Equity and Social Justice			X		
		QL3.2 Preserve Historic & Cultural Resources			X		
		QL3.3 Enhance Views & Local Character		X	X	X	
		QL3.4 Enhance Public Space & Amenities		X	X	X	
LEADERSHIP	COLLABORATION	LD1.1 Provide Effective Leadership & Commitment		X	X	X	
		LD1.2 Foster Collaboration & Teamwork		X	X	X	
		LD1.3 Provide for Stakeholder Involvement		X	X	X	
		LD1.4 Pursue Byproduct Synergies		X	X	X	
	PLANNING	LD2.1 Establish a Sustainability Management Plan		X	X	X	
		LD2.2 Plan for Sustainable Communities			X		
		LD2.3 Plan for Long-Term Monitoring & Maintenance		X	X	X	
		LD2.4 Plan for End of Life	X			X	X
	ECONOMY	LD3.1 Stimulate Economic Prosperity & Development		X	X	X	
		LD3.2 Develop Local Skills & Capabilities		X	X	X	
		LD3.3 Conduct a Life-Cycle Economic Evaluation		X	X	X	X
RESOURCE ALLOCATION	MATERIALS	RA1.1 Support Sustainable Procurement Practices	X				
		RA1.2 Use Recycled Materials	X	X		X	
		RA1.3 Reduce Operational Waste			X		
		RA1.4 Reduce Construction Waste		X		X	
		RA1.5 Balance Earthwork On Site		X		X	
	ENERGY	RA2.1 Reduce Operational Energy Consumption			X		
		RA2.2 Reduce Construction Energy Consumption		X		X	
		RA2.3 Use Renewable Energy			X		
		RA2.4 Commission & Monitor Energy Systems			X		
	WATER	RA3.1 Preserve Water Resources			X		
		RA3.2 Reduce Operational Water Consumption			X		
		RA3.3 Reduce Construction Water Consumption		X		X	
		RA3.4 Monitor Water Systems			X		
NATURAL WORLD	SITING	NW1.1 Preserve Sites of High Ecological Value		X	X	X	
		NW1.2 Provide Wetland & Surface Water Buffers		X	X	X	
		NW1.3 Preserve Prime Farmland		X	X	X	
		NW1.4 Preserve Undeveloped Land		X	X	X	
	CONSERVATION	NW2.1 Reclaim Brownfields		X	X	X	
		NW2.2 Manage Stormwater		X	X	X	
		NW2.3 Reduce Pesticide & Fertilizer Impacts		X	X	X	

		NW2.4 Protect Surface & Groundwater Quality		X	X	X
	ECOLOGY	NW3.1 Enhance Functional Habitats			X	
		NW3.2 Enhance Wetland & Surface Water Functions		X	X	X
		NW3.3 Maintain Floodplain Functions			X	
		NW3.4 Control Invasive Species		X	X	X
		NW3.5 Protect Soil Health		X	X	X
CLIMATE & RESILIENCE	EMISSIONS	CR1.1 Reduce Net Embodied Carbon	X	X	X	X
		CR1.2 Reduce Greenhouse Gas Emissions			X	
		CR1.3 Reduce Air Pollutant Emissions			X	
	RESILIENCE	CR2.1 Avoid Unsuitable Development			X	
		CR2.2 Assess Climate Change Vulnerability			X	
		CR2.3 Evaluate Risk and Resilience			X	
		CR2.4 Establish Resilience Goals and Strategies			X	
		CR2.5 Maximize Resilience	X	X	X	X
		CR2.6 Improve Infrastructure Integration			X	

Table 24. Envision credits in relation to TBL impact assessment

CATEGORY	SUBCATEGORY	CREDITS	ENVIRONMENTAL	SOCIAL IMPACT	ECONOMIC
QUALITY OF LIFE	WELLBEING	QL1.1 Improve Community Quality of Life	X	X	X
		QL1.2 Enhance Public Health & Safety			
		QL1.3 Improve Construction Safety			
		QL1.4 Minimize Noise & Vibration	X	X	
		QL1.5 Minimize Light Pollution	X	X	
		QL1.6 Minimize Construction Impacts			
	MOBILITY	QL2.1 Improve Community Mobility & Access		X	
		QL2.2 Encourage Sustainable Transportation			
		QL2.3 Improve Access & Wayfinding			
	COMMUNITY	QL3.1 Advance Equity and Social Justice		X	
		QL3.2 Preserve Historic & Cultural Resources			
		QL3.3 Enhance Views & Local Character	X		
		QL3.4 Enhance Public Space & Amenities		X	
LEADERSHIP	COLLABORATION	LD1.1 Provide Effective Leadership & Commitment			
		LD1.2 Foster Collaboration & Teamwork			
		LD1.3 Provide for Stakeholder Involvement			
		LD1.4 Pursue Byproduct Synergies	X		X
	PLANNING	LD2.1 Establish a Sustainability Management Plan	X	X	X
		LD2.2 Plan for Sustainable Communities		X	
		LD2.3 Plan for Long-Term Monitoring & Maintenance			
		LD2.4 Plan for End of Life	X	X	X
	ECONOMY	LD3.1 Stimulate Economic Prosperity & Development			X
		LD3.2 Develop Local Skills & Capabilities			X
		LD3.3 Conduct a Life-Cycle Economic Evaluation	X	X	X
RESOURCE ALLOCATION	MATERIALS	RA1.1 Support Sustainable Procurement Practices			
		RA1.2 Use Recycled Materials			
		RA1.3 Reduce Operational Waste			
		RA1.4 Reduce Construction Waste			
		RA1.5 Balance Earthwork On Site			
	ENERGY	RA2.1 Reduce Operational Energy Consumption			

		RA2.2 Reduce Construction Energy Consumption			
		RA2.3 Use Renewable Energy			
		RA2.4 Commission & Monitor Energy Systems			
	WATER	RA3.1 Preserve Water Resources	X		
		RA3.2 Reduce Operational Water Consumption			
		RA3.3 Reduce Construction Water Consumption			
		RA3.4 Monitor Water Systems			
NATURAL WORLD	SITING	NW1.1 Preserve Sites of High Ecological Value	X		
		NW1.2 Provide Wetland & Surface Water Buffers	X		
		NW1.3 Preserve Prime Farmland			
		NW1.4 Preserve Undeveloped Land			
	CONSERVATION	NW2.1 Reclaim Brownfields			
		NW2.2 Manage Stormwater			
		NW2.3 Reduce Pesticide & Fertilizer Impacts			
		NW2.4 Protect Surface & Groundwater Quality	X		
	ECOLOGY	NW3.1 Enhance Functional Habitats	X		
		NW3.2 Enhance Wetland & Surface Water Functions	X		
		NW3.3 Maintain Floodplain Functions	X		
		NW3.4 Control Invasive Species	X		
		NW3.5 Protect Soil Health	X		
CLIMATE & RESILIENCE	EMISSIONS	CR1.1 Reduce Net Embodied Carbon			
		CR1.2 Reduce Greenhouse Gas Emissions			
		CR1.3 Reduce Air Pollutant Emissions			
	RESILIENCE	CR2.1 Avoid Unsuitable Development	X		
		CR2.2 Assess Climate Change Vulnerability	X	X	X
		CR2.3 Evaluate Risk and Resilience	X	X	X
		CR2.4 Establish Resilience Goals and Strategies			
		CR2.5 Maximize Resilience			
		CR2.6 Improve Infrastructure Integration	X	X	X

Table 25. Envision credits in relation to LCA impacts

CATEGORY	SUBCATEGORY	CREDIT	GHG EMISSIONS	ENERGY	WATER	SOIL	BIODIVERSITY	RESILIENCE VALUE	PUBLIC HEALTH
QUALITY OF LIFE	WELLBEING	QL1.1 Improve Community Quality of Life							
		QL1.2 Enhance Public Health & Safety							X
		QL1.3 Improve Construction Safety							X
		QL1.4 Minimize Noise & Vibration					X		X
		QL1.5 Minimize Light Pollution					X		
		QL1.6 Minimize Construction Impacts							X
	MOBILITY	QL2.1 Improve Community Mobility & Access	X	X					
		QL2.2 Encourage Sustainable Transportation	X	X					
		QL2.3 Improve Access & Wayfinding							
	COMMUNITY	QL3.1 Advance Equity and Social Justice							
		QL3.2 Preserve Historic & Cultural Resources							
		QL3.3 Enhance Views & Local Character				X	X		
		QL3.4 Enhance Public Space & Amenities							
AD ER SH	COLLABORATION	LD1.1 Provide Effective Leadership & Commitment	X	X	X	X	X		
		LD1.2 Foster Collaboration & Teamwork							

		LD1.3 Provide for Stakeholder Involvement							
		LD1.4 Pursue Byproduct Synergies	X	X	X				
	PLANNING	LD2.1 Establish a Sustainability Management Plan	X	X	X				
		LD2.2 Plan for Sustainable Communities	X	X	X				
		LD2.3 Plan for Long-Term Monitoring & Maintenance	X	X	X				
		LD2.4 Plan for End of Life							
	ECONOMY	LD3.1 Stimulate Economic Prosperity & Development							
		LD3.2 Develop Local Skills & Capabilities							
		LD3.3 Conduct a Life-Cycle Economic Evaluation	X	X	X			X	
RESOURCE ALLOCATION	MATERIALS	RA1.1 Support Sustainable Procurement Practices	X	X	X				
		RA1.2 Use Recycled Materials							
		RA1.3 Reduce Operational Waste	X	X					
		RA1.4 Reduce Construction Waste	X	X					
		RA1.5 Balance Earthwork On Site	X	X					
	ENERGY	RA2.1 Reduce Operational Energy Consumption	X	X					
		RA2.2 Reduce Construction Energy Consumption	X	X					
		RA2.3 Use Renewable Energy	X	X					
		RA2.4 Commission & Monitor Energy Systems		X					
	WATER	RA3.1 Preserve Water Resources			X		X	X	
		RA3.2 Reduce Operational Water Consumption			X				
		RA3.3 Reduce Construction Water Consumption			X				
		RA3.4 Monitor Water Systems			X				
NATURAL WORLD	SITING	NW1.1 Preserve Sites of High Ecological Value				X	X		
		NW1.2 Provide Wetland & Surface Water Buffers			X				
		NW1.3 Preserve Prime Farmland				X	X		
		NW1.4 Preserve Undeveloped Land				X	X		
	CONSERVATION	NW2.1 Reclaim Brownfields				X	X		
		NW2.2 Manage Stormwater			X			X	
		NW2.3 Reduce Pesticide & Fertilizer Impacts			X	X			
		NW2.4 Protect Surface & Groundwater Quality			X				
	ECOLOGY	NW3.1 Enhance Functional Habitats			X				
		NW3.2 Enhance Wetland & Surface Water Functions			X				
		NW3.3 Maintain Floodplain Functions			X				
		NW3.4 Control Invasive Species					X		
		NW3.5 Protect Soil Health				X			
CLIMATE & RESILIENCE	EMISSIONS	CR1.1 Reduce Net Embodied Carbon	X	X					
		CR1.2 Reduce Greenhouse Gas Emissions	X	X					X
		CR1.3 Reduce Air Pollutant Emissions	X	X					X
	RESILIENCE	CR2.1 Avoid Unsuitable Development	X	X	X	X			
		CR2.2 Assess Climate Change Vulnerability	X	X	X	X	X	X	
		CR2.3 Evaluate Risk and Resilience	X	X	X	X	X	X	X
		CR2.4 Establish Resilience Goals and Strategies	X	X	X	X	X	X	
		CR2.5 Maximize Resilience	X	X	X	X	X	X	X
		CR2.6 Improve Infrastructure Integration						X	

Table 26. Envision credits with quantitative indicators

CATEGORY	SUBCATEGORY	CREDITS	Metrics
QUALITY OF LIFE	WELLBEING	QL1.4 Minimize Noise & Vibration	
		QL1.5 Minimize Light Pollution	
		QL1.6 Minimize Construction Impacts	
	MOBILITY	QL2.1 Improve Community Mobility & Access	
		QL2.2 Encourage Sustainable Transportation	
		QL2.3 Improve Access & Wayfinding	

LEADERSHIP	COLLABORATION	LD1.2 Foster Collaboration & Teamwork
	ECONOMY	LD3.1 Stimulate Economic Prosperity & Development
RESOURCE ALLOCATION	MATERIALS	RA1.1 Support Sustainable Procurement Practices
		RA1.2 Use Recycled Materials
		RA1.3 Reduce Operational Waste
		RA1.4 Reduce Construction Waste
		RA1.5 Balance Earthwork On Site
	ENERGY	RA2.1 Reduce Operational Energy Consumption
		RA2.2 Reduce Construction Energy Consumption
		RA2.3 Use Renewable Energy
		RA2.4 Commission & Monitor Energy Systems
	WATER	RA3.2 Reduce Operational Water Consumption
		RA3.3 Reduce Construction Water Consumption
		RA3.4 Monitor Water Systems
NATURAL WORLD	SITING	NW1.2 Provide Wetland & Surface Water Buffers
		NW1.3 Preserve Prime Farmland
		NW1.4 Preserve Undeveloped Land
	CONSERVATION	NW2.2 Manage Stormwater
	ECOLOGY	NW3.3 Maintain Floodplain Functions
		NW3.5 Protect Soil Health
CLIMATE & RESILIENCE	EMISSIONS	CR1.1 Reduce Net Embodied Carbon
		CR1.2 Reduce Greenhouse Gas Emissions
		CR1.3 Reduce Air Pollutant Emissions

CEEQUAL ANALYSIS TABLES

Table 27. CEEQUAL credits in relation to lifecycle stages

CATEGORY	ASSESSMENT ISSUE	ASSESSMENT CRITERIA	PRODUCTION MATERIAL	CONSTRUCTION	O & M	END OF LIFE
1. MANAGEMENT	1.1 Sustainability leadership	1.1.1 Principles of sustainable development	X	X	X	X
		1.1.2 Construction management strategy	X	X		
		1.1.3 Selection process for designers and contractors	X	X		
		1.1.4 Environmental and social performance in contracts	X	X		
		1.1.5 Sustainability targets for construction	X	X		
		1.1.6 Environmental targets for key sub-contractors	X	X		
		1.1.7 Sustainability targets for operation			X	X
		1.1.8 Workforce consultation on sustainability performance		X		
		1.1.9 Communicating best practice		X		
	1.2 Environmental management	1.2.1 Environmental impacts and benefits assessment	X	X	X	X
		1.2.2 Implementing environmental enhancements		X	X	
		1.2.3 Supporting environmental benefits in contracts	X	X	X	X
		1.2.4 Environmental impacts during construction	X	X		
		1.2.5 Environmental and social aspects assessment		X	X	
		1.2.6 Co-ordination of environmental and social aspects		X		
		1.2.7 Identification and prioritization of impacts		X		
		1.2.8 Sustainability management mechanisms	X	X		
		1.2.9 Implementation of mechanisms	X	X	X	
		1.2.10 Success of mechanisms	X	X	X	

		1.2.11 Sustainability training		X		
		1.2.12 Project team communications	X	X		
	1.3 Responsible construction management	1.3.1 Considerate behavior		X		
		1.3.2 Independent assessment of considerate behavior		X		
		1.3.3 Visual impact during construction		X		
	1.4 Staff and supply chain governance	1.4.1 Organizational plans and policies for ethical labor practices		X		
		1.4.2 Application of ethical labor plans and policies to the project	X	X		
		1.4.3 Monitoring ethical labor practices during construction		X		
		1.4.4 Independent verification or certification of ethical labor plans and policies	X	X		
	1.5 Whole life costing	1.5.1 Whole life costing	X	X	X	X
2. RESILIENCE	2.1 Risk assessment & mitigation	2.1.1 Identifying resilience requirements		X	X	
		2.1.2 Identifying dependencies			X	
		2.1.3 Communicating dependencies		X	X	
		2.1.4 Identifying and assessing risks	X	X	X	X
		2.1.5 Communicating risks		X	X	
		2.1.6 Resilience plan	X	X	X	X
	2.2 Flooding and surface water run-off	2.2.1 Flood risk assessment			X	
		2.2.2 Flood-risk-based enhancements			X	
		2.2.3 Sustainable drainage systems (SuDS)			X	
		2.2.4 Long-term flood resilience and adaption		X		
		2.2.5 Implementation of flood-risk-based enhancements		X		
		2.2.6 Implementation of sustainable drainage systems		X		
		2.2.7 Managing run-off at source			X	
	2.3 Future needs	2.3.1 Identifying future needs			X	X
		2.3.2 Opportunities to address future needs			X	
		2.3.3 Designing for future needs		X	X	
3. COMMUNITIES & STAKEHOLDERS	3.1 Consultation & engagement	3.1.1 Initial community consultation		X		
		3.1.2 Further community consultation		X	X	
		3.1.3 Stakeholder consultation on effects during construction and operation		X	X	
		3.1.4 Assessing community demographics		X	X	X
		3.1.5 Responsibility for ongoing community consultation		X		
		3.1.6 Community engagement	X	X		
		3.1.7 Recording community comments		X		
		3.1.8 Assessing community comments during design		X		
		3.1.9 Assessing community comments during construction		X		
	3.2 Wider social benefits	3.2.1 Social impacts and benefits assessment	X	X	X	X
		3.2.2 Significant social benefits		X	X	
		3.2.3 Supporting social benefits in contracts	X	X	X	
		3.2.4 Wider social benefits		X	X	
		3.2.5 Health and wellbeing of future users or neighbors		X	X	
		3.2.6 Community diversity		X	X	
		3.2.7 Enhancement beyond functional requirements		X	X	
		3.2.8 Partnership links		X		
		3.2.9 Social impacts and benefits during construction	X	X		
		3.2.10 Implementing partnership links during construction	X	X		
	3.3 Wider economic benefits	3.3.1 Economic impacts and benefits assessment	X	X	X	X
		3.3.2 Significant economic benefits		X	X	
		3.3.3 Supporting economic benefits in contracts	X	X	X	
		3.3.4 Involvement of local firms	X	X		
USE & ECOLOGY	4.1 Land use and value	4.1.1 Land use strategy		X	X	
		4.1.2 Project location alternatives		X		
		4.1.3 Consideration of project location alternatives		X		

		4.1.4 Site suitability		X	X	
		4.1.5 Justification of site suitability		X	X	
		4.1.6 Land use efficiency		X	X	
		4.1.7 Selecting temporary land		X		
		4.1.8 Temporary land use	X	X		
		4.1.9 Previous use of the site ('Greenfield' / 'Brownfield')		X		
		4.1.10 Conservation of soils and other on-site resources		X	X	
	4.2 Land contamination & remediation	4.2.1 Contamination risk assessment	X	X	X	
		4.2.2 Further assessment of contamination		X	X	
		4.2.3 Land contamination specialists		X		
		4.2.4 Land contamination management procedures		X		
		4.2.5 Evaluation of remediation options		X		
		4.2.6 Ground generated gases			X	
		4.2.7 Implementation of remedial solution		X		
		4.2.8 Long-term effectiveness of remedial solution	X	X	X	X
		4.2.9 Prevention of future contamination			X	X
	4.3 Protection of biodiversity	4.3.1 Surveys for protected species		X	X	X
		4.3.2 Injurious or invasive species		X	X	
		4.3.3 Survey and evaluation of ecological value		X		
		4.3.4 Initial consultation with nature conservation organizations	X	X		
		4.3.5 Further consultation with nature conservation organizations	X	X		
		4.3.6 Land of high ecological value		X	X	
		4.3.7 Ecological works plan	X	X		
		4.3.8 Managing negative impacts on e1isting ecological value		X		
		4.3.9 Monitoring protection, mitigation, and compensation measures	X	X		
		4.3.10 Success of protection, mitigation, & compensation measures		X		
	4.4 Change& enhancement of biodiversity	4.4.1 Change in ecological value		X	X	
		4.4.2 Enhancing existing ecological features		X	X	
		4.4.3 New wildlife habitats		X		
		4.4.4 Special structures or facilities for wildlife		X		
		4.4.5 Improving the water environment	X	X	X	X
		4.4.6 Improving the water environment – implementation		X	X	
		4.4.7 Incorporating existing water features		X		
	4.5 Long-term management of biodiversity	4.5.1 Ongoing ecological management			X	
		4.5.2 Program for monitoring			X	
5. LANDSCAPE & **HISTORIC ENVIRONMENT**	5.1 Landscape & visual impact	5.1.1 Landscape and visual factors		X	X	
		5.1.2 Impact on landscape character			X	
		5.1.3 Landscape development policies		X		
		5.1.4 Local landscape character		X	X	
		5.1.5 Advance landscape works		X		
		5.1.6 Appropriateness of species selected		X	X	
		5.1.7 Assessment of existing vegetation		X		
		5.1.8 Retention of existing vegetation		X		
		5.1.9 Non-vegetation features		X		
		5.1.10 Landscape design proposals		X		
		5.1.11 Protection of existing vegetation during construction		X		
		5.1.12 Long-term management plan		X	X	X
		5.1.13 Responsibility for long-term management			X	
	5.2 Heritage assets	5.2.1 Baseline studies and surveys		X		
		5.2.2 Use of suitable professionals and standards		X		
		5.2.3 Consultation		X		
		5.2.4 Reporting baseline studies and surveys		X		
		5.2.5 Integration of listed or registered heritage assets		X		

		5.2.6 Integration of non-registered heritage assets		X		
		5.2.7 Setting for listed or registered heritage assets		X		
		5.2.8 Surveys for archaeological remains		X		
		5.2.9 Mitigation strategy for archaeological investigation		X	X	
		5.2.10 Mitigation design for loss of heritage assets		X	X	
		5.2.11 Mitigation of impacts on archaeological remains		X		
		5.2.12 In-situ protection of heritage assets		X		
		5.2.13 Monitoring mitigation works		X		
		5.2.14 Use of appropriate materials	X	X		
		5.2.15 Use of specialist skills	X	X		
		5.2.16 Reporting mitigation works		X		
		5.2.17 Public learning		X		
6. POLLUTION	6.1 Water pollution	6.1.1 Consultation with regulatory authorities		X		
		6.1.2 Preventing pollution in operation			X	
		6.1.3 Control of impacts on the water environment from the completed project			X	
		6.1.4 Long term monitoring of impacts on the water environment	X	X	X	X
		6.1.5 Control of impacts on the water environment during construction	X	X		
		6.1.6 Preventing pollution during construction	X	X		
		6.1.7 Protecting e1isting water features during construction	X	X		
		6.1.8 Monitoring water quality during construction		X		
	6.2 Air, noise and light pollution	6.2.1 Identification of potential effects on neighbors during construction		X		
		6.2.2 Identification of potential effects on neighbors in operation			X	
		6.2.3 Mitigating effects on neighbors in operation			X	
		6.2.4 Innovative solutions for nuisance mitigation in operation			X	
		6.2.5 Mitigating effects on neighbors during construction		X		
		6.2.6 Construction effects on neighbors		X		
		6.2.7 Implementation of mitigation measures during construction		X		
		6.2.8 Innovative solutions to minimize nuisance during construction		X		
		6.2.9 Monitoring of effects on neighbors		X		
		6.2.10 Achievement of effective mitigation during construction		X		
		6.2.11 Physical damage by vibration		X		
		6.2.12 Mitigation of operation effects		X	X	
7. RESOURCES	7.1 Strategy for resource efficiency	7.1.1 Project resources strategy	X	X	X	X
		7.1.2 Supporting resource efficiency objectives in contracts	X			
		7.1.3 Policies and targets for resource efficiency in operation			X	
		7.1.4 Policies and targets for resource efficiency during construction	X	X		
		7.1.5 Implementing policies and targets for resource efficiency	X	X		
		7.1.6 Implementing the project resource strategy	X			
		7.1.7 Material resource efficiency plan	X	X	X	X
		7.1.8 Construction resource strategy	X	X		
		7.1.9 Implementing the construction resource strategy	X	X		
		7.1.10 Implementing the material resource efficiency plan	X	X		
	7.2 Reducing whole life carbon emissions	7.2.1 Carbon management	X	X	X	X
		7.2.2 Independent third-party certification of carbon management	X	X	X	
		7.2.3 Achieving carbon reduction targets				
		7.2.4 Exemplary level: Net zero carbon	X	X	X	X

7.3 Environmental impact of construction products	7.3.1 Life cycle assessment (LCA)	X	X	X	X
	7.3.2 Environmental Product Declarations (EPDs)	X			
	7.3.3 Hazardous materials	X			
	7.3.4 Low-VOC and/or biodegradable coatings		X		
	7.3.5 Application of coatings		X		
7.4 Circular use of construction products	7.4.1 Business models for a circular economy – considered	X	X	X	X
	7.4.2 Business models for a circular economy – implemented	X	X	X	
	7.4.3 Durability and low maintenance			X	
	7.4.4 Long term planned maintenance			X	
	7.4.5 Future disassembly / de-construction				X
	7.4.6 Materials register		X	X	X
	7.4.7 Retention of existing structures and materials		X		
	7.4.8 On-site use of demolition arisings		X		
	7.4.9 Cut and fill optimization		X		
	7.4.10 Soil management		X	X	
	7.4.11 Beneficial re-use of topsoil		X		
	7.4.12 Reclaimed or recycled materials	X	X		
	7.4.13 Reclaimed or recycled bulk fill and sub-base		X		
	7.4.14 Beneficial re-use of e1cavated material		X		
	7.4.15 Surplus materials				
	7.4.16 Materials storage		X		
	7.4.17 Beneficial use of surplus materials		X		
7.5 Responsible sourcing of construction products	7.5.1 Legal & sustainable timber	X			
	7.5.2 Responsible sourcing of construction products – consideration	X			
	7.5.3 Responsible sourcing of construction products – implementation	X	X		
	7.5.4 Locally sourced and recycled materials – early consideration	X	X		
	7.5.5 Locally sourced and recycled materials – further consideration	X	X		
	7.5.6 Locally sourced and recycled materials – use	X	X		
7.6 Construction waste management	7.6.1 Duty of Care		X		
	7.6.2 Permitting for waste treated or used on site		X		
	7.6.3 Hazardous waste		X		
	7.6.4 Site waste management planning – preparation				
	7.6.5 Site waste management planning – implementation		X		
	7.6.6 Clearance and disposal of existing vegetation – consideration		X		
	7.6.7 Clearance and disposal of e1isting vegetation – implementation		X		
	7.6.8 Hazardous material assessments	X			
	7.6.9 Transfer station/ recycling center performance		X		
	7.6.10 Inert waste diverted from landfill		X		
	7.6.11 Non-hazardous waste diverted from landfill		X		
7.7 Energy use	7.7.1 Energy & carbon emissions reduction for operation			X	
	7.7.2 Implementation of energy & carbon reductions for operations			X	
	7.7.3 Opportunities for renewable/low-carbon/0-carbon energy within the operational scheme			X	
	7.7.4 Incorporating renewable / low-carbon / 0-carbon energy within the operational scheme			X	
	7.7.5 Energy consumption during construction – consideration during design		X		
	7.7.6 Energy consumption during construction – incorporation in design		X		
	7.7.7 Energy consumption during construction – consideration by contractor		X		

		7.7.8 Energy consumption during construction – implementation by contractor		X		
		7.7.9 Construction plant - selection and maintenance		X		
		7.7.10 Renewable / low-carbon / 0-carbon energy during construction- consideration		X		
		7.7.11 Renewable / low-carbon / 0-carbon energy during construction- implementation		X		
	7.8 Water use	7.8.1 Embodied water – consideration	X	X		
		7.8.2 Embodied water – implementation	X	X		
		7.8.3 Capturing run-off for beneficial use		X	X	
		7.8.4 Water consumption during operation – consideration during design			X	
		7.8.5 Water consumption during operation – reduction measures included in design			X	
		7.8.6 Water consumption during operation – reduction measures incorporated in works			X	
		7.8.7 Water consumption during construction – client requirements	X	X		
		7.8.8 Water consumption during construction – policies, plans and targets	X	X		
		7.8.9 Water consumption during construction		X		
8. TRANSPORT	8.1 Transport networks	8.1.1 Relationship to the transport network		X		
		8.1.2 Transport effects of the completed project			X	
		8.1.3 Access for pedestrians and cyclists			X	
		8.1.4 Need for additional transport infrastructure			X	
		8.1.5 Enhanced operational transport outcomes			X	
		8.1.6 Community consultation on the design objectives		X		
		8.1.7 Resilience of the transport network	X	X	X	X
		8.1.8 Adaptability of the transport network			X	
		8.1.9 Performance for non-motorized users			X	
	8.2 Construction logistics	8.2.1 Planning construction traffic movements	X	X		
		8.2.2 Transport effects of construction activities	X	X		
		8.2.3 Reducing risks for vulnerable road users		X		
		8.2.4 Responsible fleet operations	X	X		
		8.2.5 Minimizing disruption from construction traffic	X	X		
		8.2.6 Success in minimizing construction traffic impacts		X		
		8.2.7 Movement of construction materials	X	X		
		8.2.8 Movement of construction materials – implementation	X	X		
		8.2.9 Workforce travel planning		X		
		8.2.10 Workforce travel planning – implementation		X		

Table 28. CEEQUAL credits in relation to TBL impacts assessment

CATEGORY	ASSESSMENT ISSUE	ASSESSMENT CRITERIA	ENVIRONMENTAL	SOCIAL	ECONOMIC
1. MANAGEMENT	1.1 Sustainability leadership	1.1.1 Principles of sustainable development	X	X	X
		1.1.2 Construction management strategy	X	X	X
		1.1.3 Selection process for designers and contractors	X	X	
		1.1.4 Environmental and social performance in contracts	X	X	
		1.1.5 Sustainability targets for construction			
		1.1.6 Environmental targets for key sub-contractors			

		1.1.7 Sustainability targets for operation			
		1.1.8 Workforce consultation on sustainability performance			
		1.1.9 Communicating best practice			
	1.2 Environmental management	1.2.1 Environmental impacts and benefits assessment	X		
		1.2.2 Implementing environmental enhancements	X		
		1.2.3 Supporting environmental benefits in contracts	X		
		1.2.4 Environmental impacts during construction	X		
		1.2.5 Environmental and social aspects assessment	X	X	
		1.2.6 Co-ordination of environmental and social aspects			
		1.2.7 Identification and prioritization of impacts	X	X	
		1.2.8 Sustainability management mechanisms	X		
		1.2.9 Implementation of mechanisms			
		1.2.10 Success of mechanisms			
		1.2.11 Sustainability training			
		1.2.12 Project team communications	X	X	
	1.3 Responsible construction management	1.3.1 Considerate behavior		X	
		1.3.2 Independent assessment of considerate behavior		X	
		1.3.3 Visual impact during construction			
	1.4 Staff and supply chain governance	1.4.1 Organizational plans and policies for ethical labor practices		X	
		1.4.2 Application of ethical labor plans and policies to the project			
		1.4.3 Monitoring ethical labor practices during construction			
		1.4.4 Independent verification or certification of ethical labor plans and policies			
	1.5 Whole life costing	1.5.1 Whole life costing			X
2. RESILIENCE	2.1 Risk assessment & mitigation	2.1.1 Identifying resilience requirements			
		2.1.2 Identifying dependencies	X	X	X
		2.1.3 Communicating dependencies			
		2.1.4 Identifying and assessing risks	X	X	X
		2.1.5 Communicating risks	X	X	X
		2.1.6 Resilience plan			
	2.2 Flooding and surface water run-off	2.2.1 Flood risk assessment	X	X	
		2.2.2 Flood-risk-based enhancements			
		2.2.3 Sustainable drainage systems (SuDS)			
		2.2.4 Long-term flood resilience and adaption			
		2.2.5 Implementation of flood-risk-based enhancements			
		2.2.6 Implementation of sustainable drainage systems			
		2.2.7 Managing run-off at source			
	2.3 Future needs	2.3.1 Identifying future needs	X	X	X
		2.3.2 Opportunities to address future needs	X	X	X
		2.3.3 Designing for future needs			
3. COMMUNITIES & STAKEHOLDERS	3.1 Consultation & engagement	3.1.1 Initial community consultation			
		3.1.2 Further community consultation			
		3.1.3 Stakeholder consultation on effects during construction and operation			
		3.1.4 Assessing community demographics			
		3.1.5 Responsibility for ongoing community consultation			
		3.1.6 Community engagement	X	X	
		3.1.7 Recording community comments			
		3.1.8 Assessing community comments during design			
		3.1.9 Assessing community comments during construction			
	3.2 Wider social benefits	3.2.1 Social impacts and benefits assessment		X	
		3.2.2 Significant social benefits		X	
		3.2.3 Supporting social benefits in contracts		X	
		3.2.4 Wider social benefits			
		3.2.5 Health and wellbeing of future users or neighbors		X	
		3.2.6 Community diversity			

		3.2.7 Enhancement beyond functional requirements			
		3.2.8 Partnership links			
		3.2.9 Social impacts and benefits during construction		X	
		3.2.10 Implementing partnership links during construction			
	3.3 Wider economic benefits	3.3.1 Economic impacts and benefits assessment			X
		3.3.2 Significant economic benefits		X	X
		3.3.3 Supporting economic benefits in contracts			X
		3.3.4 Involvement of local firms			
4. LAND USE & ECOLOGY	4.1 Land use and value	4.1.1 Land use strategy			
		4.1.2 Project location alternatives			
		4.1.3 Consideration of project location alternatives			
		4.1.4 Site suitability	X		
		4.1.5 Justification of site suitability	X		
		4.1.6 Land use efficiency			
		4.1.7 Selecting temporary land			
		4.1.8 Temporary land use			
		4.1.9 Previous use of the site ('Greenfield' / 'Brownfield')			
		4.1.10 Conservation of soils and other on-site resources			
	4.2 Land contamination & remediation	4.2.1 Contamination risk assessment	X		
		4.2.2 Further assessment of contamination	X		
		4.2.3 Land contamination specialists			
		4.2.4 Land contamination management procedures			
		4.2.5 Evaluation of remediation options			
		4.2.6 Ground generated gases			
		4.2.7 Implementation of remedial solution			
		4.2.8 Long-term effectiveness of remedial solution			
		4.2.9 Prevention of future contamination			
	4.3 Protection of biodiversity	4.3.1 Surveys for protected species			
		4.3.2 Injurious or invasive species			
		4.3.3 Survey and evaluation of ecological value	X		
		4.3.4 Initial consultation with nature conservation organizations			
		4.3.5 Further consultation with nature conservation organizations			
		4.3.6 Land of high ecological value	X		
		4.3.7 Ecological works plan			
		4.3.8 Managing negative impacts on e1isting ecological value			
		4.3.9 Monitoring protection, mitigation, and compensation measures			
		4.3.10 Success of protection, mitigation, & compensation measures			
	4.4 Change& enhancement of biodiversity	4.4.1 Change in ecological value			
		4.4.2 Enhancing e1isting ecological features			
		4.4.3 New wildlife habitats	X		
		4.4.4 Special structures or facilities for wildlife	X		
		4.4.5 Improving the water environment			
		4.4.6 Improving the water environment – implementation			
		4.4.7 Incorporating e1isting water features			
	4.5 Long-term management of biodiversity	4.5.1 Ongoing ecological management			
		4.5.2 Program for monitoring			
5. LANDSCAPE & HISTORIC ENVIRONMENT	5.1 Landscape & visual impact	5.1.1 Landscape and visual factors	X	X	
		5.1.2 Impact on landscape character	X	X	
		5.1.3 Landscape development policies			
		5.1.4 Local landscape character			
		5.1.5 Advance landscape works			
		5.1.6 Appropriateness of species selected	X		
		5.1.7 Assessment of existing vegetation	X		
		5.1.8 Retention of existing vegetation	X		

		5.1.9 Non-vegetation features		
		5.1.10 Landscape design proposals		
		5.1.11 Protection of existing vegetation during construction		
		5.1.12 Long-term management plan		
		5.1.13 Responsibility for long-term management		
	5.2 Heritage assets	5.2.1 Baseline studies and surveys		X
		5.2.2 Use of suitable professionals and standards		X
		5.2.3 Consultation		
		5.2.4 Reporting baseline studies and surveys		X
		5.2.5 Integration of listed or registered heritage assets		X
		5.2.6 Integration of non-registered heritage assets		
		5.2.7 Setting for listed or registered heritage assets		
		5.2.8 Surveys for archaeological remains		
		5.2.9 Mitigation strategy for archaeological investigation		
		5.2.10 Mitigation design for loss of heritage assets		
		5.2.11 Mitigation of impacts on archaeological remains		
		5.2.12 In-situ protection of heritage assets		
		5.2.13 Monitoring mitigation works		
		5.2.14 Use of appropriate materials	X	X
		5.2.15 Use of specialist skills		X
		5.2.16 Reporting mitigation works	X	
		5.2.17 Public learning		
6. POLLUTION	6.1 Water pollution	6.1.1 Consultation with regulatory authorities		
		6.1.2 Preventing pollution in operation		
		6.1.3 Control of impacts on the water environment from the completed project	X	
		6.1.4 Long term monitoring of impacts on the water environment		
		6.1.5 Control of impacts on the water environment during construction	X	
		6.1.6 Preventing pollution during construction		
		6.1.7 Protecting e1isting water features during construction		
		6.1.8 Monitoring water quality during construction	X	
	6.2 Air, noise and light pollution	6.2.1 Identification of potential effects on neighbors during construction	X	X
		6.2.2 Identification of potential effects on neighbors in operation	X	X
		6.2.3 Mitigating effects on neighbors in operation		
		6.2.4 Innovative solutions for nuisance mitigation in operation		
		6.2.5 Mitigating effects on neighbors during construction		
		6.2.6 Construction effects on neighbors		
		6.2.7 Implementation of mitigation measures during construction		
		6.2.8 Innovative solutions to minimize nuisance during construction		
		6.2.9 Monitoring of effects on neighbors		
		6.2.10 Achievement of effective mitigation during construction		
		6.2.11 Physical damage by vibration		
		6.2.12 Mitigation of operation effects		
7. RESOURCES	7.1 Strategy for resource efficiency	7.1.1 Project resources strategy		
		7.1.2 Supporting resource efficiency objectives in contracts		
		7.1.3 Policies and targets for resource efficiency in operation		
		7.1.4 Policies and targets for resource efficiency during construction		
		7.1.5 Implementing policies and targets for resource efficiency		
		7.1.6 Implementing the project resource strategy		
		7.1.7 Material resource efficiency plan		

	7.1.8 Construction resource strategy	X		
	7.1.9 Implementing the construction resource strategy	X		
	7.1.10 Implementing the material resource efficiency plan			
7.2 Reducing whole life carbon emissions	7.2.1 Carbon management	X		
	7.2.2 Independent third-party certification of carbon management			
	7.2.3 Achieving carbon reduction targets			
	7.2.4 Exemplary level: Net zero carbon			
7.3 Environmental impact of construction products	7.3.1 Life cycle assessment (LCA)	X		
	7.3.2 Environmental Product Declarations (EPDs)	X		
	7.3.3 Hazardous materials	X	X	
	7.3.4 Low-VOC and/or biodegradable coatings			
	7.3.5 Application of coatings			
7.4 Circular use of construction products	7.4.1 Business models for a circular economy – considered			
	7.4.2 Business models for a circular economy – implemented			
	7.4.3 Durability and low maintenance			
	7.4.4 Long term planned maintenance	X	X	X
	7.4.5 Future disassembly / de-construction			
	7.4.6 Materials register			
	7.4.7 Retention of existing structures and materials	X		X
	7.4.8 On-site use of demolition arisings			
	7.4.9 Cut and fill optimization	X		X
	7.4.10 Soil management			
	7.4.11 Beneficial re-use of topsoil			
	7.4.12 Reclaimed or recycled materials			
	7.4.13 Reclaimed or recycled bulk fill and sub-base			
	7.4.14 Beneficial re-use of e1cavated material			
	7.4.15 Surplus materials	X		X
	7.4.16 Materials storage			
	7.4.17 Beneficial use of surplus materials			
7.5 Responsible sourcing of construction products	7.5.1 Legal & sustainable timber			
	7.5.2 Responsible sourcing of construction products – consideration			
	7.5.3 Responsible sourcing of construction products – implementation	X	X	X
	7.5.4 Locally sourced and recycled materials – early consideration	X	X	X
	7.5.5 Locally sourced and recycled materials – further consideration			
	7.5.6 Locally sourced and recycled materials – use			
7.6 Construction waste management	7.6.1 Duty of Care			
	7.6.2 Permitting for waste treated or used on site			
	7.6.3 Hazardous waste			
	7.6.4 Site waste management planning – preparation			
	7.6.5 Site waste management planning – implementation			
	7.6.6 Clearance and disposal of e1isting vegetation – consideration			
	7.6.7 Clearance and disposal of e1isting vegetation – implementation			
	7.6.8 Hazardous material assessments	X	X	
	7.6.9 Transfer station/ recycling center performance			
	7.6.10 Inert waste diverted from landfill			
	7.6.11 Non-hazardous waste diverted from landfill			
7.7 Energy use	7.7.1 Energy & carbon emissions reduction for operation			
	7.7.2 Implementation of energy & carbon reductions for operations			
	7.7.3 Opportunities for renewable/low-carbon/0-carbon energy within the operational scheme	X		

		7.7.4 Incorporating renewable / low-carbon / 0-carbon energy within the operational scheme		
		7.7.5 Energy consumption during construction – consideration during design		
		7.7.6 Energy consumption during construction – incorporation in design		
		7.7.7 Energy consumption during construction – consideration by contractor		
		7.7.8 Energy consumption during construction – implementation by contractor		
		7.7.9 Construction plant - selection and maintenance		
		7.7.10 Renewable / low-carbon / 0-carbon energy during construction- consideration		
		7.7.11 Renewable / low-carbon / 0-carbon energy during construction- implementation		
	7.8 Water use	7.8.1 Embodied water – consideration	X	
		7.8.2 Embodied water – implementation	X	
		7.8.3 Capturing run-off for beneficial use		
		7.8.4 Water consumption during operation – consideration during design	X	
		7.8.5 Water consumption during operation – reduction measures included in design	X	
		7.8.6 Water consumption during operation – reduction measures incorporated in works	X	
		7.8.7 Water consumption during construction – client requirements		
		7.8.8 Water consumption during construction – policies, plans and targets		
		7.8.9 Water consumption during construction		
8. TRANSPORT	8.1 Transport networks	8.1.1 Relationship to the transport network	X	X
		8.1.2 Transport effects of the completed project	X	X
		8.1.3 Access for pedestrians and cyclists		X
		8.1.4 Need for additional transport infrastructure		
		8.1.5 Enhanced operational transport outcomes		
		8.1.6 Community consultation on the design objectives		
		8.1.7 Resilience of the transport network		
		8.1.8 Adaptability of the transport network		
		8.1.9 Performance for non-motorized users		
	8.2 Construction logistics	8.2.1 Planning construction traffic movements	X	X
		8.2.2 Transport effects of construction activities		
		8.2.3 Reducing risks for vulnerable road users		
		8.2.4 Responsible fleet operations	X	X
		8.2.5 Minimizing disruption from construction traffic		
		8.2.6 Success in minimizing construction traffic impacts		
		8.2.7 Movement of construction materials	X	X
		8.2.8 Movement of construction materials – implementation		
		8.2.9 Workforce travel planning		
		8.2.10 Workforce travel planning – implementation		

Table 29. CEEQUAL credits in relation to LCA impacts

CATEGORY	ASSESSMENT ISSUE	ASSESSMENT CRITERIA	GHG EMISSIONS	ENERGY	WATER	SOIL	BIODIVERSITY	RESILIENCE VALUE	PUBLIC HEALTH
1. MANAGEMENT	1.1 Sustainability leadership	1.1.1 Principles of sustainable development	X	X	X	X	X	X	X
		1.1.2 Construction management strategy	X	X	X	X	X	X	X
		1.1.3 Selection process for designers and contractors	X	X	X	X	X	X	X
		1.1.4 Environmental and social performance in contracts	X	X	X	X	X	X	X
		1.1.5 Sustainability targets for construction	X	X	X	X	X	X	X
		1.1.6 Environmental targets for key sub-contractors	X	X	X	X	X	X	X
		1.1.7 Sustainability targets for operation	X	X	X	X	X	X	X
		1.1.8 Workforce consultation on sustainability performance							
		1.1.9 Communicating best practice							
	1.2 Environmental management	1.2.1 Environmental impacts and benefits assessment	X	X	X	X	X	X	X
		1.2.2 Implementing environmental enhancements							
		1.2.3 Supporting environmental benefits in contracts	X	X	X	X	X		
		1.2.4 Environmental impacts during construction	X	X	X	X	X		
		1.2.5 Environmental and social aspects assessment	X	X	X	X	X	X	X
		1.2.6 Co-ordination of environmental and social aspects							
		1.2.7 Identification and prioritization of impacts							
		1.2.8 Sustainability management mechanisms	X	X	X	X	X	X	X
		1.2.9 Implementation of mechanisms							
		1.2.10 Success of mechanisms							
		1.2.11 Sustainability training	X	X	X	X	X	X	X
		1.2.12 Project team communications							
	1.3 Responsible construction management	1.3.1 Considerate behavior							
		1.3.2 Independent assessment of considerate behavior							
		1.3.3 Visual impact during construction							
	1.4 Staff and supply chain governance	1.4.1 Organizational plans and policies for ethical labor practices							X
		1.4.2 Application of ethical labor plans and policies to the project							X
		1.4.3 Monitoring ethical labor practices during construction							X
		1.4.4 Independent verification or certification of ethical labor plans and policies							X
	1.5 Whole life costing	1.5.1 Whole life costing						X	
2. RESILIENCE	2.1 Risk assessment & mitigation	2.1.1 Identifying resilience requirements						X	
		2.1.2 Identifying dependencies	X	X	X			X	X
		2.1.3 Communicating dependencies						X	
		2.1.4 Identifying and assessing risks	X	X	X	X	X	X	X
		2.1.5 Communicating risks	X	X	X	X	X	X	X
		2.1.6 Resilience plan	X	X	X	X	X	X	X
	2.2 Flooding and surface water run-off	2.2.1 Flood risk assessment			X			X	
		2.2.2 Flood-risk-based enhancements			X			X	
		2.2.3 Sustainable drainage systems (SuDS)			X			X	
		2.2.4 Long-term flood resilience and adaption			X			X	
		2.2.5 Implementation of flood-risk-based enhancements			X			X	
		2.2.6 Implementation of sustainable drainage systems			X			X	
		2.2.7 Managing run-off at source			X	X	X		
	2.3 Future needs	2.3.1 Identifying future needs							

		2.3.2 Opportunities to address future needs							
		2.3.3 Designing for future needs							
3. COMMUNITIES & STAKEHOLDERS	3.1 Consultation & engagement	3.1.1 Initial community consultation							X
		3.1.2 Further community consultation							X
		3.1.3 Stakeholder consultation on effects during construction and operation							X
		3.1.4 Assessing community demographics						X	
		3.1.5 Responsibility for ongoing community consultation							
		3.1.6 Community engagement	X						X
		3.1.7 Recording community comments							X
		3.1.8 Assessing community comments during design							X
		3.1.9 Assessing community comments during construction							X
	3.2 Wider social benefits	3.2.1 Social impacts and benefits assessment						X	X
		3.2.2 Significant social benefits						X	X
		3.2.3 Supporting social benefits in contracts							
		3.2.4 Wider social benefits							
		3.2.5 Health and wellbeing of future users or neighbors	X	X	X	X	X		X
		3.2.6 Community diversity							
		3.2.7 Enhancement beyond functional requirements							
		3.2.8 Partnership links							
		3.2.9 Social impacts and benefits during construction	X	X					X
		3.2.10 Implementing partnership links during construction							
	3.3 Wider economic benefits	3.3.1 Economic impacts and benefits assessment	X					X	
		3.3.2 Significant economic benefits							
		3.3.3 Supporting economic benefits in contracts							
		3.3.4 Involvement of local firms							
4. LAND USE & ECOLOGY	4.1 Land use and value	4.1.1 Land use strategy			X	X	X	X	
		4.1.2 Project location alternatives						X	
		4.1.3 Consideration of project location alternatives							
		4.1.4 Site suitability			X	X	X	X	
		4.1.5 Justification of site suitability							
		4.1.6 Land use efficiency			X	X	X		
		4.1.7 Selecting temporary land							
		4.1.8 Temporary land use							
		4.1.9 Previous use of the site			X	X	X		
		4.1.10 Conservation of soils and other on-site resources				X			
	4.2 Land contamination & remediation	4.2.1 Contamination risk assessment	X		X	X	X		X
		4.2.2 Further assessment of contamination	X		X	X	X		X
		4.2.3 Land contamination specialists							
		4.2.4 Land contamination management procedures				X	X		X
		4.2.5 Evaluation of remediation options			X	X	X		
		4.2.6 Ground generated gases	X						
		4.2.7 Implementation of remedial solution			X	X	X		X
		4.2.8 Long-term effectiveness of remedial solution							
		4.2.9 Prevention of future contamination			X	X	X		X
	4.3 Protection of biodiversity	4.3.1 Surveys for protected species					X		
		4.3.2 Injurious or invasive species					X		
		4.3.3 Survey and evaluation of ecological value					X		
		4.3.4 Initial consultation with nature conservation organizations					X		
		4.3.5 Further consultation with nature conservation organizations					X		
		4.3.6 Land of high ecological value					X		
		4.3.7 Ecological works plan					X		X
		4.3.8 Managing negative impacts on existing ecological value					X	X	X
		4.3.9 Monitoring protection, mitigation, and compensation measures					X		X

		4.3.10 Success of protection, mitigation, & compensation measures					X		
	4.4 Change& enhancement of biodiversity	4.4.1 Change in ecological value			X	X	X		
		4.4.2 Enhancing existing ecological features							
		4.4.3 New wildlife habitats					X		
		4.4.4 Special structures or facilities for wildlife					X		
		4.4.5 Improving the water environment			X				
		4.4.6 Improving the water environment – implementation			X				
		4.4.7 Incorporating existing water features			X				
	4.5 Long-term management of biodiversity	4.5.1 Ongoing ecological management			X	X	X		
		4.5.2 Program for monitoring			X	X	X		
5. LANDSCAPE & HISTORIC ENVIRONMENT	5.1 Landscape & visual impact	5.1.1 Landscape and visual factors		X	X	X	X		
		5.1.2 Impact on landscape character				X	X		
		5.1.3 Landscape development policies							
		5.1.4 Local landscape character			X	X	X		
		5.1.5 Advance landscape works				X			
		5.1.6 Appropriateness of species selected			X	X	X		
		5.1.7 Assessment of existing vegetation			X	X	X		
		5.1.8 Retention of existing vegetation							
		5.1.9 Non-vegetation features			X	X	X		
		5.1.10 Landscape design proposals			X	X	X		
		5.1.11 Protection of existing vegetation during construction					X		
		5.1.12 Long-term management plan			X	X	X		
		5.1.13 Responsibility for long-term management			X	X	X		
	5.2 Heritage assets	5.2.1 Baseline studies and surveys							
		5.2.2 Use of suitable professionals and standards							
		5.2.3 Consultation							
		5.2.4 Reporting baseline studies and surveys							
		5.2.5 Integration of listed or registered heritage assets							
		5.2.6 Integration of non-registered heritage assets							
		5.2.7 Setting for listed or registered heritage assets							
		5.2.8 Surveys for archaeological remains							
		5.2.9 Mitigation strategy for archaeological investigation							
		5.2.10 Mitigation design for loss of heritage assets							
		5.2.11 Mitigation of impacts on archaeological remains							
		5.2.12 In-situ protection of heritage assets							
		5.2.13 Monitoring mitigation works							
		5.2.14 Use of appropriate materials	X	X	X				
		5.2.15 Use of specialist skills							
		5.2.16 Reporting mitigation works							
		5.2.17 Public learning							
6. POLLUTION	6.1 Water pollution	6.1.1 Consultation with regulatory authorities			X				
		6.1.2 Preventing pollution in operation			X			X	
		6.1.3 Control of impacts on the water environment from the completed project			X			X	
		6.1.4 Long term monitoring of impacts on the water environment			X				
		6.1.5 Control of impacts on the water environment during construction			X				
		6.1.6 Preventing pollution during construction			X				
		6.1.7 Protecting existing water features during construction							
		6.1.8 Monitoring water quality during construction							
	6.2 Air, noise and light pollution	6.2.1 Identification of potential effects on neighbors during construction	X	X				X	X
		6.2.2 Identification of potential effects on neighbors in operation	X	X	X			X	X

		6.2.3 Mitigating effects on neighbors in operation	X	X	X			X	X
		6.2.4 Innovative solutions for nuisance mitigation in operation							X
		6.2.5 Mitigating effects on neighbors during construction	X	X	X			X	X
		6.2.6 Construction effects on neighbors	X	X	X				X
		6.2.7 Implementation of mitigation measures during construction	X	X	X				X
		6.2.8 Innovative solutions to minimize nuisance during construction							X
		6.2.9 Monitoring of effects on neighbors	X	X	X			X	X
		6.2.10 Achievement of effective mitigation during construction	X						X
		6.2.11 Physical damage by vibration	X						X
		6.2.12 Mitigation of operation effects	X						X
7. RESOURCES	7.1 Strategy for resource efficiency	7.1.1 Project resources strategy	X	X	X	X		X	
		7.1.2 Supporting resource efficiency objectives in contracts	X	X	X	X			
		7.1.3 Policies and targets for resource efficiency in operation	X	X	X	X			
		7.1.4 Policies and targets for resource efficiency during construction	X	X	X	X			
		7.1.5 Implementing policies and targets for resource efficiency	X	X	X	X			
		7.1.6 Implementing the project resource strategy	X	X	X	X			
		7.1.7 Material resource efficiency plan	X	X	X	X	X	X	X
		7.1.8 Construction resource strategy	X	X	X	X			
		7.1.9 Implementing the construction resource strategy	X	X	X	X			
		7.1.10 Implementing the material resource efficiency plan	X	X	X	X			
	7.2 Reducing whole life carbon emissions	7.2.1 Carbon management	X					X	X
		7.2.2 Independent third-party certification of carbon management	X						X
		7.2.3 Achieving carbon reduction targets	X						X
		7.2.4 Exemplary level: Net zero carbon	X					X	X
	7.3 Environmental impact of construction products	7.3.1 Life cycle assessment (LCA)	X	X	X	X	X	X	X
		7.3.2 Environmental Product Declarations (EPDs)	X	X	X	X	X	X	X
		7.3.3 Hazardous materials	X	X	X	X	X	X	X
		7.3.4 Low-VOC and/or biodegradable coatings							X
		7.3.5 Application of coatings							X
	7.4 Circular use of construction products	7.4.1 Business models for a circular economy – considered	X	X	X	X	X	X	X
		7.4.2 Business models for a circular economy – implemented							
		7.4.3 Durability and low maintenance							
		7.4.4 Long term planned maintenance							
		7.4.5 Future disassembly / de-construction							
		7.4.6 Materials register	X	X	X	X	X	X	X
		7.4.7 Retention of existing structures and materials			X	X		X	X
		7.4.8 On-site use of demolition arisings				X			
		7.4.9 Cut and fill optimization				X			
		7.4.10 Soil management			X	X	X	X	
		7.4.11 Beneficial re-use of topsoil			X	X	X	X	
		7.4.12 Reclaimed or recycled materials	X	X					
		7.4.13 Reclaimed or recycled bulk fill and sub-base	X	X					
		7.4.14 Beneficial re-use of excavated material				X			
		7.4.15 Surplus materials							
		7.4.16 Materials storage	X		X	X	X	X	X
		7.4.17 Beneficial use of surplus materials							
	7.5 Responsible	7.5.1 Legal & sustainable timber							

	sourcing of construction products	7.5.2 Responsible sourcing of construction products – consideration	X						
		7.5.3 Responsible sourcing of construction products – implementation	X	X					
		7.5.4 Locally sourced and recycled materials – early consideration							
		7.5.5 Locally sourced and recycled materials – further consideration							
		7.5.6 Locally sourced and recycled materials – use	X	X					
	7.6 Construction waste management	7.6.1 Duty of Care	X	X					
		7.6.2 Permitting for waste treated or used on site	X	X	X	X			
		7.6.3 Hazardous waste	X	X					
		7.6.4 Site waste management planning – preparation	X	X	X	X	X	X	X
		7.6.5 Site waste management planning – implementation	X	X	X	X	X	X	X
		7.6.6 Clearance and disposal of existing vegetation – consideration	X	X		X	X		
		7.6.7 Clearance and disposal of existing vegetation – implementation	X	X		X	X		
		7.6.8 Hazardous material assessments	X	X	X	X	X		X
		7.6.9 Transfer station/ recycling center performance	X	X	X				
		7.6.10 Inert waste diverted from landfill	X	X					
		7.6.11 Non-hazardous waste diverted from landfill	X	X					
	7.7 Energy use	7.7.1 Energy & carbon emissions reduction for operation	X	X					
		7.7.2 Implementation of energy & carbon reductions for operations	X	X					
		7.7.3 Opportunities for renewable/low-carbon/0-carbon energy within the operational scheme	X	X				X	
		7.7.4 Incorporating renewable / low-carbon / 0-carbon energy within the operational scheme	X	X					
		7.7.5 Energy consumption during construction – consideration during design	X	X		X			
		7.7.6 Energy consumption during construction – incorporation in design	X	X		X			
		7.7.7 Energy consumption during construction – consideration by contractor	X	X					
		7.7.8 Energy consumption during construction – implementation by contractor	X	X					
		7.7.9 Construction plant - selection and maintenance	X	X	X				
		7.7.10 Renewable / low-carbon / 0-carbon energy during construction- consideration	X	X					
		7.7.11 Renewable / low-carbon / 0-carbon energy during construction- implementation	X	X					
	7.8 Water use	7.8.1 Embodied water – consideration			X			X	
		7.8.2 Embodied water – implementation			X			X	
		7.8.3 Capturing run-off for beneficial use			X			X	
		7.8.4 Water consumption during operation – consideration during design			X				
		7.8.5 Water consumption during operation – reduction measures included in design			X				
		7.8.6 Water consumption during operation – reduction measures incorporated in works			X				
		7.8.7 Water consumption during construction – client requirements			X				
		7.8.8 Water consumption during construction – policies, plans and targets			X				
		7.8.9 Water consumption during construction			X				
8. TRANSPORT	8.1 Transport networks	8.1.1 Relationship to the transport network							
		8.1.2 Transport effects of the completed project	X	X			X		X
		8.1.3 Access for pedestrians and cyclists							X
		8.1.4 Need for additional transport infrastructure							

		8.1.5 Enhanced operational transport outcomes					
		8.1.6 Community consultation on the design objectives					
		8.1.7 Resilience of the transport network				X	X
		8.1.8 Adaptability of the transport network				X	
		8.1.9 Performance for non-motorized users					X
	8.2 Construction logistics	8.2.1 Planning construction traffic movements	X				X
		8.2.2 Transport effects of construction activities	X				X
		8.2.3 Reducing risks for vulnerable road users					X
		8.2.4 Responsible fleet operations	X				X
		8.2.5 Minimizing disruption from construction traffic	X				X
		8.2.6 Success in minimizing construction traffic impacts	X				X
		8.2.7 Movement of construction materials	X	X	X		
		8.2.8 Movement of construction materials – implementation	X	X	X		
		8.2.9 Workforce travel planning	X	X			X
		8.2.10 Workforce travel planning – implementation	X				X

Table 30. CEEQUAL Assessment Issues with quantitative indicators (17 issues & 47 criteria)

CATEGORY	ASSESSMENT ISSUE	ASSESSMENT CRITERIA
1. LEADERSHIP	1.1 Sustainability leadership	1.1.5 Sustainability targets for construction 1.1.6 Environmental targets for key sub-contractors 1.1.7 Sustainability targets for operation
	1.2 Environmental management	1.2.2 Implementing environmental enhancements 1.2.9 Implementation of mechanisms
2. RESILIENCE	2.2 Flooding and surface water run-off	2.2.7 Managing run-off at source
3. COMMUNITIES & STAKEHOLDERS	3.1 Consultation & engagement	3.1.6 Community engagement
	3.2 Wider social benefits	3.2.10 Implementing partnership links during construction
	3.3 Wider economic benefits	3.3.4 Involvement of local firms
4. LAND USE & ECOLOGY	4.1 Land use and value	4.1.7 Selecting temporary land 4.1.8 Temporary land use 4.1.9 Previous use of the site ('Greenfield' / 'Brownfield')
	4.4 Change & enhancement of biodiversity	4.4.1 Change in ecological value
5. LANDSCAPE & HISTORIC ENVIRONMENT	5.1 Landscape & visual impact	5.1.8 Retention of existing vegetation
7. RESOURCES	7.1 Strategy for resource efficiency	7.1.7 Material resource efficiency plan 7.1.9 Implementing the construction resource strategy 7.1.10 Implementing the material resource efficiency plan
	7.3 Environmental impact of construction products	7.3.1 Life cycle assessment (LCA) 7.3.4 Low-VOC and/or biodegradable coatings
	7.4 Circular use of construction products	7.4.5 Future disassembly / de-construction 7.4.7 Retention of existing structures and materials 7.4.8 On-site use of demolition arisings 7.4.12 Reclaimed or recycled materials 7.4.13 Reclaimed or recycled bulk fill and sub-base 7.4.14 Beneficial re-use of excavated material 7.4.15 Surplus materials 7.4.17 Beneficial use of surplus materials
	7.5 Responsible sourcing of construction products	7.5.3 Responsible sourcing of construction products – implementation
	7.6 Construction waste management	7.6.4 Site waste management planning – preparation 7.6.5 Site waste management planning – implementation

	7.7 Energy use	7.6.7 Clearance and disposal of existing vegetation – implementation 7.6.10 Invert waste diverted from landfill 7.6.11 Non-hazardous waste diverted from landfill 7.7.1 Energy & carbon emissions reduction for Operation 7.7.2 Implementation of energy & carbon reductions for operations 7.7.4 Incorporating renewable / low-carbon / 0-carbon energy within the operational scheme 7.7.7 Energy consumption during construction – consideration by contractor 7.7.8 Energy consumption during construction – implementation by contractor 7.7.11 Renewable / low-carbon / 0-carbon energy during construction- implementation
	7.8 Water use	7.8.1 Embodied water – consideration 7.8.2 Embodied water – implementation 7.8.4 Water consumption **during operation** – consideration during design 7.8.5 Water consumption **during operation** – reduction measures included in design 7.8.6 Water consumption **during operation** – reduction measures incorporated in works
8. TRANSPORT	8.2 Construction logistics	8.2.6 Success in minimizing construction traffic impacts 8.2.9 Workforce travel planning 8.2.10 Workforce travel planning – implementation

Table 31. CEEQUAL Assessment Issues that require global or national standards (23 issues & 57 criteria)

CATEGORY	ASSESSMENT ISSUE	ASSESSMENT CRITERIA
1. Management	1.1 Sustainability leadership	1.1.1 Principles of sustainable development 1.1.2 Construction management strategy 1.1.5 Sustainability targets for construction
	1.2 Environmental management	1.2.11 Sustainability training
	1.4 Staff and supply chain governance	1.4.1 Organizational plans and policies for ethical labor practices 1.4.4 Independent verification or certification of ethical labor plans and policies
	1.5 Whole life costing	1.5.1 Whole life costing
2. Resilience	2.1 Risk assessment & mitigation	2.1.2 Identifying dependencies 2.1.3 Communicating dependencies 2.1.4 Identifying and assessing risks 2.1.5 Communicating risks
	2.2 Flooding and surface water run-off	2.2.1 Flood risk assessment 2.2.3 Sustainable drainage systems (SuDS)
3. Communities & Stakeholders	3.3 Wider economic benefits	3.3.4 Involvement of local firms
4. Land use & Ecology	4.3 Protection of biodiversity	4.3.1 Surveys for protected species 4.3.4 Initial consultation with nature conservation organizations 4.3.5 Further consultation with nature conservation organizations
	4.4 Change & enhancement of biodiversity	4.4.1 Change in ecological value 4.4.5 Improving the water environment 4.4.6 Improving the water environment – implementation

	4.5 Long-term management of biodiversity	4.5.1 Ongoing ecological management
5. Landscape & Historic environment	5.1 Landscape & visual impact	5.1.10 Landscape design proposals 5.1.11 Protection of existing vegetation during construction
	5.2 Heritage assets	5.2.2 Use of suitable professionals and standards 5.2.8 Surveys for archaeological remains
6. Pollution	6.1 Water pollution	6.1.1 Consultation with regulatory authorities 6.1.5 Control of impacts on the water environment during construction
	6.2 Air, noise and light pollution	6.2.4 Innovative solutions for nuisance mitigation in operation 6.2.6 Construction effects on neighbors
7. Resources	7.1 Strategy for resource efficiency	7.1.1 Project resources strategy 7.1.7 Material resource efficiency plan 7.1.8 Construction resource strategy 7.1.9 Implementing the construction resource strategy
	7.2 Reducing whole life carbon emissions	7.2.1 Carbon management 7.2.2 Independent third-party certification of carbon management 7.2.4 Exemplary level: Net zero carbon
	7.3 Environmental impact of construction products	7.3.1 Life cycle assessment (LCA) 7.3.2 Environmental Product Declarations (EPDs) 7.3.4 Low-VOC and/or biodegradable coatings
	7.4 Circular use of construction products	7.4.1 Business models for a circular economy – considered 7.4.2 Business models for a circular economy – implemented 7.4.7 Retention of existing structures and materials 7.4.16 Materials storage
	7.5 Responsible sourcing of construction products	7.5.1 Legal & sustainable timber 7.5.2 Responsible sourcing of construction products – consideration 7.5.3 Responsible sourcing of construction products – implementation
	7.6 Construction waste management	7.6.1 Duty of Care 7.6.10 Inert waste diverted from landfill
	7.7 Energy use	7.7.10 Renewable / low-carbon / 0-carbon energy during construction- consideration 7.7.11 Renewable / low-carbon / 0-carbon energy during construction- implementation
	7.8 Water use	7.8.1 Embodied water – consideration 7.8.2 Embodied water – implementation 7.8.7 Water consumption during construction – client requirements 7.8.8 Water consumption during construction – policies, plans and targets 7.8.9 Water consumption during construction
8. Transport	8.2 Construction logistics	8.2.3 Reducing risks for vulnerable road users 8.2.4 Responsible fleet operations

IS RATING SCHEME ANALYSIS TABLES

Table 32. IS credits in relation to lifecycle stages

THEMES	CREDIT		MATERIAL PRODUCTION	CONSTRUCTION	O&M	END OF LIFE
Management & Governance	**Management Systems**					
	Man-1	Sustainability leadership and commitment	X	X	X	X
	Man-2	Risk and opportunity management				
	Man-3	Organizational structure, roles and responsibilities	X	X	X	X
	Man-4	Inspection and auditing	X	X	X	X
	Man-5	Reporting and review	X	X	X	X
	Man-6	Knowledge sharing	X	X	X	X
	Man-7	Decision-making	X	X	X	X
	Procurement And Processing					
	Pro-1	Commitment to sustainable procurement				
	Pro-2	Identification of suppliers	X	X	X	X
	Pro-3	Supplier evaluation and contract award	X	X	X	X
	Pro-4	Managing supplier performance	X	X	X	X
	Climate Change And Adaptation					
	Cli-1	Climate change risk assessment	X	X	X	X
	Cli-2	Adaptation options	X	X	X	X
Using Resources	**Energy And Carbon**					
	Ene-1	Energy and carbon monitoring and reduction		X	X	X
	Ene-2	Renewable energy		X	X	
	Water					
	Wat-1	Water use monitoring and reduction			X	
	Wat-2	Replace potable water	X	X	X	X
	Materials					
	Mat-1	Materials footprint measurement and reduction	X	X	X	X
	Mat-2	Environmentally labeled products and supply chains	X	X	X	X
Emissions Pollution & Waste	**Discharges To Air Land And Water**					
	Dis-1	Receiving water quality		X	X	
	Dis-2	Noise		X	X	
	Dis-3	Vibration		X	X	
	Dis-4	Air quality		X	X	
	Dis-5	Light pollution		X	X	
	Land					
	Lan-1	Previous land use		X	X	
	Lan-2	Conservation of onsite resources		X	X	
	Lan-3	Contamination and remediation	X	X	X	X
	Lan-4	Flooding design			X	
	Waste					
	Was-1	Waste management		X	X	X
	Was-2	Diversion from landfill		X	X	X
	Was-3	Deconstruction/ Disassembly/ Adaptability			X	X
Ecology	**Ecology**					
	Eco-1	Ecological value		X	X	X

	Eco-2	Habitat connectivity	X	X	
People & Place	**Community Health Well Being And Safety**				
	Hea-1	Community health and well-being	X	X	
	Hea-2	Crime prevention		X	X
	Heritage				
	Her-1	Heritage assessment and management	X	X	
	Her-2	Monitoring and management of heritage	X	X	
	Stakeholder Participation				
	Sta-1	Stakeholder engagement strategy	X	X	X
	Sta-2	Level of engagement	X	X	
	Sta-3	Effective communication	X	X	
	Sta-4	Addressing community concerns	X	X	
	Urban And Landscape Design				
	Urb-1	Urban design	X	X	
	Urb-2	Implementation		X	

Table 33. IS Credits in relation to TBL impact assessment

THEMES	CREDITS		ENVIRONMENTAL	SOCIAL	ECONOMIC
Management & Governance	**Management Systems**				
	Man-1	Sustainability leadership and commitment			
	Man-2	Risk and opportunity management	**X**	**X**	**X**
	Man-3	Organizational structure, roles and responsibilities			
	Man-4	Inspection and auditing			
	Man-5	Reporting and review			
	Man-6	Knowledge sharing			
	Man-7	Decision-making	**X**	**X**	**X**
	Procurement And Processing				
	Pro-1	Commitment to sustainable procurement	**X**		
	Pro-2	Identification of suppliers			
	Pro-3	Supplier evaluation and contract award	**X**	**X**	**X**
	Pro-4	Managing supplier performance			
	Climate Change And Adaptation				
	Cli-1	Climate change risk assessment			
	Cli-2	Adaptation options			
Using Resources	**Energy And Carbon**				
	Ene-1	Energy and carbon monitoring and reduction			**X**
	Ene-2	Renewable energy	**X**		**X**
	Water				
	Wat-1	Water use monitoring and reduction			
	Wat-2	Replace potable water			
	Materials				
	Mat-1	Materials footprint measurement and reduction	**X**		
	Mat-2	Environmentally labeled products and supply chains	**X**		
Emissions Pollution & Waste	**Discharges To Air Land And Water**				
	Dis-1	Receiving water quality	**X**		
	Dis-2	Noise	**X**		
	Dis-3	Vibration	**X**		**X**

	Dis-4	Air quality	X		
	Dis-5	Light pollution	X		
	Land				
	Lan-1	Previous land use			
	Lan-2	Conservation of onsite resources	X		
	Lan-3	Contamination and remediation	X		
	Lan-4	Flooding design	X	X	X
	Waste				
	Was-1	Waste management	X		X
	Was-2	Diversion from landfill			
	Was-3	Deconstruction/ Disassembly/ Adaptability	X		
Ecology	**Ecology**				
	Eco-1	Ecological value	X		
	Eco-2	Habitat connectivity	X		
People & Place	**Community Health Well Being And Safety**				
	Hea-1	Community health and well-being			
	Hea-2	Crime prevention	X	X	X
	Heritage				
	Her-1	Heritage assessment and management			
	Her-2	Monitoring and management of heritage			
	Stakeholder Participation				
	Sta-1	Stakeholder engagement strategy			
	Sta-2	Level of engagement		X	
	Sta-3	Effective communication			
	Sta-4	Addressing community concerns			
	Urban And Landscape Design				
	Urb-1	Urban design	X	X	X
	Urb-2	Implementation			

Table 34. IS credits in relation to LCA impacts

THEME	CREDITS		GHG Emissions	Energy	Water	Soil	Biodiversity	Resilience Value	Public Health
MANAGEMENT & GOVERNANCE	Man-1	Sustainability leadership and commitment							
	Man-2	Risk and opportunity management	X	X	X	X	X	X	X
	Man-3	Organizational structure, roles and responsibilities	X	X	X	X	X	X	X
	Man-4	Inspection and auditing	X	X	X	X	X	X	X
	Man-5	Reporting and review	X	X	X	X	X	X	X
	Man-6	Knowledge sharing	X	X	X	X	X	X	X
	Man-7	Decision-making							
	Pro-1	Commitment to sustainable procurement							
	Pro-2	Identification of suppliers	X	X	X	X	X	X	X
	Pro-3	Supplier evaluation and contract award	X	X	X	X	X	X	X
	Pro-4	Managing supplier performance							
	Cli-1	Climate change risk assessment							
	Cli-2	Adaptation options							
USING RESOURCES	Ene-1	Energy and carbon monitoring and reduction	X	X	X	X			
	Ene-2	Renewable energy	X	X	X	X			
	Wat-1	Water use monitoring and reduction			X	X		X	X

	Wat-2	Replace potable water	X	X	X	X	X		X
	Mat-1	Materials footprint measurement and reduction	X	X	X	X			X
	Mat-2	Environmentally labeled products and supply chains	X	X	X	X			X
EMISSIONS POLLUTION & WASTE	Dis-1	Receiving water quality			X	X	X	X	X
	Dis-2	Noise							X
	Dis-3	Vibration							X
	Dis-4	Air quality							
	Dis-5	Light pollution					X		X
	Lan-1	Previous land use			X	X	X	X	X
	Lan-2	Conservation of onsite resources				X		X	
	Lan-3	Contamination and remediation							
	Lan-4	Flooding design			X		X	X	X
	Was-1	Waste management	X	X	X	X			X
	Was-2	Diversion from landfill	X	X	X	X			X
	Was-3	Deconstruction/ Disassembly/ Adaptability	X	X	X	X			X
ECOLOGY	Eco-1	Ecological value	X	X	X	X	X		X
	Eco-2	Habitat connectivity	X	X	X	X	X		X
PEOPLE & PLACE	Hea-1	Community health and well-being							X
	Hea-2	Crime prevention							X
	Her-1	Heritage assessment and management							X
	Her-2	Monitoring and management of heritage							X
	Sta-1	Stakeholder engagement strategy	X	X	X	X	X	X	X
	Sta-2	Level of engagement	X	X	X	X	X	X	X
	Sta-3	Effective communication	X	X	X	X	X	X	X
	Sta-4	Addressing community concerns	X	X	X	X	X	X	X
	Urb-1	Urban design	X	X	X	X	X		X
	Urb-2	Implementation	X	X	X	X	X		X

Table 35. IS credits with quantitative indicators

Management & Governance	Man-7	Decision-making
	Pro-3	Supplier evaluation and contract award
	Cli-1	Climate change risk assessment
	Cli-2	Adaptation options
Using Resources	Ene-1	Energy and carbon monitoring and reduction
	Ene-2	Renewable energy
	Wat-1	Water use monitoring and reduction
	Wat-2	Replace potable water
	Mat-1	Materials footprint measurement and reduction
	Mat-2	Environmentally labeled products and supply chains
Emissions Pollution & Waste	Dis-1	Receiving water quality
	Dis-2	Noise
	Dis-3	Vibration
	Dis-4	Air quality
	Dis-5	Light pollution
	Lan-1	Previous land use
	Lan-2	Conservation of onsite resources
	Lan-4	Flooding design
	Was-2	Diversion from landfill
	Was-3	Deconstruction/ Disassembly/ Adaptability
Ecology	Eco-1	Ecological value
	Eco-2	Habitat connectivity
People & Place	Sta-2	Level of engagement

	Sta-3	Effective communication
	Sta-4	Addressing community concerns
Innovation	Inn-1	Innovation

Table 36. Core strategies contribution to Checklist scores per credit

CORE STRATEGIES	RELATED ENVISION CREDITS & SCORES									
Bridge replacement vs. rehabilitation	QL1.2	QL1.4	QL2.1	**LD2.3**	**LD2.4**	**LD3.1**	LD3.3	CR1.1	CR1.2	**CR2.5**
Score	12 of 20	10 of 12	**14 of 14**	**12 of12**	8 of 14	**20 of 20**	10 of 14	0 of 20	0 of 26	**20 of 26**
Single-span vs. original two-span	NW1.2	NW3.1	**NW3.2**	NW3.3	LD3.3	CR1.1	CR2.2	CR2.3	CR2.5	
Score	16 of 20	2 of 18	**20 of 20**	11 of 14	10 of 14	0 of 20	14 of 20	18 of 26	20 of 26	
Use of Integral abutment	**QL1.6**	**LD2.3**	LD2.4	LD3.3	CR1.1	CR1.2	CR2.2	CR2.3	CR2.4	CR2.5
Score	**8 of 8**	**12 of 12**	8 of 14	10 of 14	0 of 20	0 of 26	14 of 20	18 of 26	8 of 20	**20 of 26**
Redundant corrosion protection system (use of premium materials)	**LD2.3**	LD2.4	LD3.3	CR1.1	CR2.3	**CR2.5**				
Score	**12 of 12**	8 of 14	10 of 14	0 of 20	18 of 26	**20 f 26**				
Construction quality	**LD2.3**	LD2.4	LD3.3	CR1.1	CR1.2	**CR2.5**				
Score	**12 of 12**	8 of 14	10 of 14	0 of 20	18 of 26	**20 f 26**				
Correction of horizontal alignment	QL1.2	CR2.6								
Score	12 of 20	13 of 18								
Correction of vertical alignment & embankment widening	QL1.2	NW3.3	CR2.2	CR2.3	CR2.4	CR2.5	CR2.6			
score	12 of 20	11 of 14	14 of 20	18 of 26	8 of 20	**20 of 26**	13 of 18			
Widening of the highway section	QL1.2	**QL2.1**	**LD2.3**	**LD3.1**						
Score	12 of 20	**14 of 14**	**12 of 12**	**20 of 20**						
Increased sidewalk width	QL1.2	**QL2.1**	**QL2.3**	LD1.3						
Score	12 of 20	**14 of 14**	**14 of 14**	3 of 18						
Extension of the sidewalk beyond project limit	QL1.2	**QL2.3**	**LD3.1**							
score	12 of 20	**14 of 14**	**20 of 20**							
Provision for a future bicycle lane	QL2.1	**QL2.2**	**QL2.3**	CR2.6						
Score	14 of 14	**16 of 16**	**14 of 14**	13 of 18						
Salvage of old structure parts	RA1.2	RA1.4	CR1.1							
Score	4 of 16	0 of 16	0 of 0							
ABC construction	QL1.2	**QL1.6**	**LD3.1**	LD3.2	LD3.3	RA2.2				
Score	12 of 20	**8 of 8**	**20 of 20**	4 of 16	10 of 14	4 of 12				
Use of prefabricated components	QL1.3	**QL1.6**	LD3.2	RA2.2						
Score	5 of 14	**8 of 8**	4 of 16	4 of 12						
Performance of selected works off-site during a seasonal shutdown	QL1.3	**QL1.6**	LD3.3							
Score	5 of 14	**8 of 8**	10 of 14							

Staged construction	QL1.3	**QL1.6**	**LD3.1**	LD3.3
Score	5 of 14	**8 of 8**	**20 of 20**	10 of 14
Use of ready-mix plant near worksite (15 min)	RA2.2	CR1.1		
Score	4 of 12	0 of 0		

Table 37. Detailed Results of the Envision Pre-assessment Checklist for the Bayfield River Bridge replacement project (credits marked with grey were considered not applicable for the project)

Impact Category	Impact Subcategory	Credits	Points	Max. Points
Quality of Life	Wellbeing	QL1.1 Improve Community Quality of Life	2	26
		QL1.2 Enhance Public Health & Safety	12	20
		QL1.3 Improve Construction Safety	5	14
		QL1.4 Minimize Noise & Vibration	10	12
		QL1.5 Minimize Light Pollution	0	12
		QL1.6 Minimize Construction Impacts	8	8
	Mobility	QL2.1 Improve Community Mobility Access	14	14
		QL2.2 Encourage Sustainable Transportation	16	16
		QL2.3 Improve Access & Wayfinding	14	14
	Community	QL3.1 Advance Equity & Social Justice	-	-
		QL3.2 Preserve Historic & Cultural Resources	2	18
		QL3.3 Enhance Views & Local Character	14	14
		QL3.4 Enhance Public Space & Amenities	-	-
Leadership	Collaboration	LD1.1 Provide Effective Leadership & Commitment	12	18
		LD1.2 Foster Collaboration & Teamwork	0	18
		LD1.3 Provide for Stakeholder Involvement	3	18
		LD1.4 Pursue Byproduct Synergies	12	18
	Planning	LD2.1 Establish a Sustainability Management Plan	0	18
		LD2.2 Plan for Sustainable Communities	9	16
		LD2.3 Plan for Long-Term Monitoring & Maintenance	12	12
		LD2.4 Plan for End-of-Life	8	14
	Economy	LD3.1 Stimulate Economic Prosperity & Development	20	20
		LD3.2 Develop Local Skills & Capabilities	4	16
		LD3.3 Conduct a Life-Cycle Economic Evaluation	10	14
Resource Allocation	Materials	RA1.1 Support Sustainable Procurement Practices	0	12
		RA1.2 Use Recycled Materials	4	16
		RA1.3 Reduce Operational Waste	0	14
		RA1.4 Reduce Construction Waste	0	16
		RA1.5 Balance Earthwork On Site	0	8
	Energy	RA2.1 Reduce Operational Energy Consumption	-	-

		RA2.2 Reduce Construction Energy Consumption	4	12
		RA2.3 Use Renewable Energy	-	-
		RA2.4 Commission & Monitor Energy Systems	-	-
	Water	RA3.1 Preserve Water Resources	7	12
		RA3.2 Reduce Operational Water Consumption	-	-
		RA3.3 Reduce Construction Water Consumption	0	8
		RA3.4 Monitor Water Systems	-	-
Natural World	Siting	NW1.1 Preserve Sites of High Ecological Value	22	22
		NW1.2 Provide Wetland & Surface Water Buffers	16	20
		NW1.3 Preserve Prime Farmland	-	-
		NW1.4 Preserve Undeveloped Land	24	24
	Conservation	NW2.1 Reclaim Brownfields	-	-
		NW2.2 Manage Stormwater	0	24
		NW2.3 Reduce Pesticide & Fertilizer Impacts	0	12
		NW2.4 Protect Surface & Groundwater Quality	5	20
	Ecology	NW3.1 Enhance Functional Habitats	2	18
		NW3.2 Enhance Wetland & Surface Water Functions	20	20
		NW3.3 Maintain Floodplain Functions	11	14
		NW3.4 Control Invasive Species	-	-
		NW3.5 Protect Soil Health	4	8
Climate & Resilience	Emissions	CR1.1 Reduce Net Embodied Carbon	0	20
		CR1.2 Reduce Greenhouse Gas Emissions	0	26
		CR1.3 Reduce Air Pollutant Emissions	2	18
	Resilience	CR2.1 Avoid Unsuitable Development	-	-
		CR2.2 Assess Climate Change Vulnerability	14	20
		CR2.3 Evaluate Risk and Resilience	18	26
		CR2.4 Establish Resilience Goals and Strategies	8	20
		CR2.5 Maximize Resilience	20	26
		CR2.6 Improve Infrastructure Integration	13	18
		Total score	**381**	**804**
			47.4%	

Fig.21: Diaphragms (cross-bracing) between the super-module sections; bolted connections

Fig.22: Use of Duplex 2205 grade stainless steel in the entire deck and approach slabs

Fig.23: Supermodule and deck section

Fig.24: Precast abutments

Fig.25: Uplift of the supermodule with heavy lift crane (each component weighed approximately 90-95 tonnes and was 40.6 m long)

Fig.26: Transport of the supermodule from the temporary yard to the site with multi-axle hydraulic trailers with spacers

Fig.27: Erection of supermodule to its final position

Fig.28: Open steel railings for better integration to the surroundings

Fig.29: Dedicated protected pedestrian path during construction works

Fig.30: Metalized coating on the exterior and bottom face of the exterior girders

BIBLIOGRAPHY

CHAPTER 1.

Barandica, J. M., Fernández-Sánchez, G., Berzosa, Á., Delgado, J. A., and Acosta, F. J. (2013). Applying life cycle thinking to reduce greenhouse gas emissions from road projects.

Chester, M., Matute, J., Bunje, P., Eisenstein, W., Pincetl, S., Elizabeth, Z., and Cepeda, C. (n.d.). Life cycle assessment for transportation decision-making. Publication for UCLA Center for Sustainable Urban Systems.

European Environment Agency (1999). Environmental indicators: Typology and overview. Technical report No. 25/1999.

Gorige, K., and Mr. Uday. (2017). Life cycle analysis of transport modes. Anveshana's International Journal of Research in Engineering and Applied Science 2 (2).

Gowdy, J. M., and Howarth, R. B. (2007). Sustainability and benefit–cost analysis: Theoretical assessments and policy options. Ecological Economics 63(4), 637-638.

Guinee, J., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., and Rydberg, T. (2010). Life cycle assessment: Past, present, and future.

Harvey, J. T., Kendall, A., Saboori, A., Ostovar, M., Butt, A. A., Hernandez, J., and Haynes, B. (2018). Framework for life cycle assessment of Complete Streets projects: A research report from the National Center for Sustainable Transportation.

International Organization for Standardization (ISO) (2006). Environmental management— Life cycle assessment— Principles and framework. ISO Standard 14040. Geneva, Switzerland.

Kluts, I., and Miliutenko, S. (2012). Overview of road infrastructure planning process and the use of environmental assessments in the Netherlands and Sweden. Stockholm, Sweden: KTH Urban Planning and Environment.

Leblanc, R. (2019). Comparing carbon footprint and life cycle analyses.

Li, H., Deng, Q., Zhang, J., Olanipekun, A. O., and Lyu, S. (2019). Environmental impact assessment of transportation infrastructure in the life cycle: Case study of a fast track transportation project in China.

Liljenström, C. (2013). Life cycle assessment in early planning of road infrastructure: Application of the LICCER-model. Master of Science thesis.

Manzo, S., and Salling, K. B. (2016). Integrating life-cycle assessment into transport cost- benefit analysis.

Miliutenko, S. (2016). Consideration of life cycle energy use and greenhouse gas emissions for improved road infrastructure planning. Doctoral thesis in Planning and Decision Analysis with specialization in Environmental Strategic Analysis.

Muench, S.T., Anderson, J.L., Hatfield, J.P., Koester, J.R., & Söderlund, M. et al. (2011). Greenroads Manual v1.5.(J.L. Anderson, C.D. Weiland, and S.T. Muench, Eds.). Seattle, WA: University of Washington.

Noland, R. B., and Hanson, C. S. (2015). Life-cycle greenhouse gas emissions associated with a highway reconstruction: A New Jersey case study.

Potting, J., Brattebø, H., Birgisdottir, H., and Lundberg, K. (2013). LICCER model case study report: Application of the LICCER-model to a Norwegian road section crossing the Oslo fjord.

PRé. (2016). Introduction to LCA with Sima Pro.

Stapledon, T. (2012). Why infrastructure sustainability is good for your business.

Cooperative Research Centre for Infrastructure and Engineering Asset Management (CIEAM). Endorsed by the Australian Green Infrastructure Council (AGIC).

Stripple, H. (2001) Life cycle assessment of road: A pilot study for inventory analysis.

Report of the IVL Swedish Environmental Research Institute for the Swedish National Road Administration.

Stripple, H., and Erlandsson, M. (2004). Methods and possibilities for application of life cycle assessment in strategic environmental assessment of transport infrastructures.

Thoft-Christensen, P. (2012). Infrastructures and life-cycle cost-benefit analysis. Structure and Infrastructure Engineering.

Trunzo, G., Moretti, L. and D'Andrea, A. (2019) Life cycle analysis of road construction and use. Sustainability 11, 377.
Tudela, A., Akiki, N., and Cisternas, R. (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investments. Transportation Research Part A, 40(5), 414-423.
UNEP (2003). Evaluation of environmental impacts in life cycle assessment.
UNEP/SETAC (2011). Towards a Life Cycle Sustainability Assessment: Making informed choices on products.
UNEP/SETAC (2013). The methodological sheets for sub-categories in Social Life Cycle Assessment (S-LCA).
Van Haaster, B., Ciroth, A., Fontes, J. et al. (2017). Development of a methodological framework for social life-cycle assessment of novel technologies. International Journal of Life Cycle Assessment 22, 423–440.
Vickerman, R. (2007). Cost-benefit analysis and large-scale infrastructure projects: state of the art and challenges. Environment and Planning B: Planning and Design 34, 598-610.

CHAPTER 2.
Assa Amiril, Abdul Hadi Nawawi, Roshana Takim, Siti Nur Farhana Ab. Latif. "Transportation Infrastructure Project Sustainability Factors and Performance". Conference paper. January 2014.
CEEQUAL Version 6, Technical Manual for International Projects. ©2019 by BRE Global Ltd.
Envision® Manual v3. ©2018 by Institute for Sustainable Infrastructure (ISI).
Envision® Manual v2. ©2015 by Institute for Sustainable Infrastructure (ISI).
Greenroads Manual v1.5. ©2011 by University of Washington and CH2MHILL.
Greenroads Rating System Broshure v2. Greenworads.org
IS Rating Scheme technical manual Version 1.2 ©Infrastructure Sustainability Council of Australia (ISCA) 2018.
J.M. Diaz-Sarachaga, D. Jato- Espino, B. Alsulami, D. Castro-Fresno. "Evaluation of existing sustainable Infrastructure Rating Systems for their application in developing countries". GITECO Research Group, Universidad de Cantabria & Civil Engineering Department. Taif University.
J.M. Diaz-Sarachaga. "The role of sustainable infrastructure rating systems in urban development". GITECO Research Group of Cantabria University. Conference Paper. March 2016.
K. Griffiths, C. Boyle, T.F.P Henning. "Infrastructure sustainability rating tools – how they have developed and what we might expect to see in the future". Conference Paper. June 2015.
K. Griffiths, C. Boyle, T.F.P Henning. "Comparative assessment of infrastructure sustainability rating tools". Conference Paper. January 2017.
Oluwatobi Oluwalaiye, Mehmet E. Ozbek. "Consistency between Infrastructure Rating Systems in Measuring Sustainability". Infrastructures Journal. MDPI. February 2019.
P.C. Bueno, J.M. Vassallo, K. Cheung. "Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods". Transport Reviews. Taylor & Francis Journals. vol. 35(5). Pages 622-649. September 2015.
Ranjiv Gupta, Jeremy W. F. Morris, R. David Espinoza. "Financial Sustainability as a Metric for Infrastructure Projects". Conference Paper. August 2016.
The Port Authority of NY and NJ, Sustainable Infrastructure Guidelines, March 2011.

CHAPTER 3.
Au, J., Mermigas, K., Brossard, J., Kroely, B., Schorn, S., and Akhtar, N. "Ministry of Transportation Ontario Bridge Management System 2018," paper for the 10th International Conference on Short and Medium Span Bridges, held in Quebec City, Canada in July 31 – August 3, 2018
McIntosh Perry Consulting Engineers Ltd., "Structural Design Report for Highway 4, Bayfield River Bridge," prepared for Ministry of Transportation, West Region, October 2017
McIntosh Perry Consulting Engineers Ltd., "Design Synopsis," prepared for Ministry of Transportation, West Region, June 2018

Mermigas, K. “Evolution of Bridge Practices in Ontario, Canada,” Paper prepared for presentation at the Structures Session of the 2018 Conference of the Transportation Association of Canada, Saskatoon, SK

Ministry of Transportation, Provincial Highways Management Division, Highway Standards Branch, Bridge Office, “Structural Manual,” September, 2016

Ministry of Transportation, Structural Office, “Structural Financial Analysis Manual (SFAM),” last updated in 1993

Ministry of Transportation, Materials Engineering and Research Office, “Pavement Design and Rehabilitation Manual – Second Edition,” March 2013.

Ministry of Transportation, “Sustainability Insight: An innovative strategy for Ontario’s Ministry of Transportation”

MMM Group Limited, “Highway 6 Rocky Saugeen River Bridge Rehabilitation Site No. 8-159 Structural Design Report,” prepared for Ministry of Transportation, West Region, November 2014

Ontario Ministry of Transportation, “Tender for grading, drainage, granular base, hot mix asphalt, electrical and structural replacement at Hwy. 4 Bayfield River Bridge,” 2018

ABBREVIATIONS

ABC	Accelerating bridge construction
BCI	Bridge Condition Index
CBA	Cost-Benefit Analysis
CEEQUAL	Civil Engineering Environmental Quality Assessment & Award Scheme
CR	Climate and Resilience
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EPD	Environmental Product Declaration
FU	Functional Unit
GHG	Greenhouse Gas
IA	Impact Assessment
ISO	International Organization for Standardization
LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life cycle Impact Assessment
LD	Leadership
IISD	International Institute for Sustainable Development
IRR	Internal Rate of Return
ISCA	Infrastructure Sustainability Council of Australia
ISI	Institute of Sustainable Infrastructure
ISO	International Organization for Standardization
MCA	Multi-criteria Analysis
MERO	Materials Engineering and Research Office
MODA	Multiple Objective Determination Analysis
MTO	Ontario's Ministry of Transportation
N/A	Not Available
NPV	Net Present Value
NW	Natural World
O&M	Operation and Maintenance
PAS	Publicly Available Specification
p.e.	Person-Equivalent
PP	Payback Period
PI	Profitability Index
QL	Quality of Life
RA	Resource Allocation
SAVi	Sustainable Asset Valuation
SEA	Strategic Environmental Assessment
SETAC	Society of Environmental Toxicology and Chemistry
SFAM	Structural Financial Analysis Manual
SLCA	Social Life Cycle Assessment
SROI	Sustainable Return on Investment
TBL	Triple Bottom Line
TBL-CBA	Triple bottom line cost benefit analysis
TEA	Techno-Economic Analysis
UNEP	United Nations Environmental Program