Selection of Sustainability Indicators for Wastewater Treatment Technologies

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ABSTRACT

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Wastewater treatment systems must be measured and assessed in terms of its sustainability performance and to enable continuous improvement over the long term. This work involves the selection of indicators and methodologies used for incorporating sustainability consideration into the design of wastewater treatment module. The GoldSET is a decision support tool for development and implementation of sustainability in engineering projects. Following the findings of the indicators for a new wastewater treatment module, this thesis aims to contribute to these activities for the development of sustainable indicators as the tool for assessment improvements. These indicators are developed especially for the industrial wastewater treatment module but may be also suitable for municipal wastewater treatment. It proposes a general framework with a relatively simple, yet comprehensive set of indicators for identification of more sustainable practises for WWTP. The framework consists of a number of qualitative and quantitative indicators comprising the four dimensions of sustainability: environment, society, economy and technology. It then describes the weighing scheme which provides a mechanism to assess the performance of each option with respect to indicator. The largest and most balanced square with respect to the four apexes of environment, social, economic and technical performances gives the most sustainable option. Thus, it serves as a tool which can assist companies in accessing their performance regarding their goals and objectives in the field of sustainable development.

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Chapter 1 Introduction

1.1 Problem statement

Wastewater is composed of over 99% water. Innovative and appropriate technologies can contribute to urban wastewater treatment and reuse. The development of sustainable wastewater management strategies will contribute to the reduction of pathogens; attain high environmental quality, high yields in food and fiber, low consumption, good quality, high efficiency production and full utilization of wastes (Rose, 1999).

The selection of wastewater treatment systems must be based on important aspects such as efficiency, reliability, sludge disposal, land requirements, construction costs, simplicity and operation costs (Walid and Rosenwinkel, 2005). Therefore, each situation must be analysed individually and local conditions must be incorporated from the very beginning of the project cycle.

The design of wastewater treatment systems is a demanding task for the engineers. It consists in determination of the treatment levels to be achieved and sequencing of the methods to be applied in order to meet the ecological requirements. Usually there exist various options to achieve the objectives of the wastewater treatment. They should be always evaluated against many criteria of economic, social and environmental nature (UN, 2007). To help make society more sustainable, we need tools that can both measure and facilitate progress towards a broad range of environment, social economic and technical goals. So, the selection and interpretation of “sustainability indicators” has become an integral part of national and international policy in recent years (Mark et al., 2006).

The wastewater management system is a foundation of modern public health and environment protection. Also, to encourage boarder and more meaningful sustainability, best practices and industrial benchmarking were established within the wastewater management community. The goal of a more sustainable wastewater management system is to use less energy, allow for the elimination or beneficial use of bio-solids, and restore natural nutrient cycles (Diagger and Crawford, 2005). Some drivers that are prompting the industry to incorporate sustainability into their wastewater solutions (WEFTEC, 2006) are:

- Belief or culture that it is the “right thing to do”
- Local and state requirements or policies to incorporate sustainability
- Operational efficiencies
- Cost reduction in operations and maintenance (O&M) (e.g., lower energy cost)
- Lower risk (e.g., less management of toxic chemicals)
- Public acceptance of a more ”green” system
- Improved regulatory relationships.

Golder Associates is actively seeking to promote sustainability principles in the field of wastewater industry through its software GoldSET. The biggest opportunity for reducing the impacts of the wastewater treatment plant (WWTP) module is in the selection of different techniques available, and its design phase, rather than operation or extend phase(GoldSET, 2012). Also, reducing impacts of operation alone is not sufficient to progress towards sustainability. Furthermore, running a more efficient operation of the plant does not in itself lead to sustainable development. While addressing the issue, we need to analyse to what degree impacts can be reduced through selection of better technology suitable for specified location, through better design, through efficient operation and through less maintenance and better possibilities of upgrading. These are all essential things to framing a response to the more fundamental questions of how the wastewater treatment module supports the sustainable development.

For sustainability of urban water systems, Lundin et al., (1999) have described that "… they should not have negative environmental effects even over a long term perspective, while providing required services, protecting human health and environment with a minimum of service resource use. The concept of sustainability has come a long way since the beginning of 90's, and now it is accepted and practiced worldwide. Worldwide problems, especially related to environment, caught public and governmental attention to sustainability and sustainable development themes. As in IISD(2012), the definition of sustainable development requires a world that connects as a system that connects space and time. Sustainable development has been defined in many ways, but the most frequently quoted definition is from *Our Common Future*, also known as the Brundtland Report: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:*

- *the concept of **needs**, in particular the essential needs of the world's poor, to which overriding priority should be given; and*
- *the idea of **limitations** imposed by the state of technology and social organization on the environment's ability to meet present and future needs."*

Sustainability strives for protection of environment and natural resources, maintenance of economic well being, social progress, and the needs of all the individuals, communities and environment. Also, it recognizes the need to design human and industrial system that ensure humankind's use of natural resources and cycles do not lead to diminished quality of life due to either losses in future economic opportunities or adverse impact on social condition, human health and the environment (Mihelcic et al., 2003).

For this study, the use of a balanced set of indicators which provides a holistic assessment was selected for evaluating the sustainability of WWT technologies. The WWT technologies may include a mechanical system, lagoon system or land treatment system etc. Sustainable indicators are usually selected based on the triple bottom line (TBL) approach that comprises environmental, social, and economic dimensions. These three aspects of sustainability are executed as the three apexes of the triangle (Noel-de-Tilly and Lafrancois, 2010). Here in this thesis and in the GoldSET software for the wastewater module the fourth apex is also introduced as a technical aspect of sustainability. A sustainability assessment uses a broad range of criteria that accommodate changing demographics, values, and environmental resources (Bradley et al., 2000). The selection of the criteria is a very important step for the decision analysis, and especially in environmental matters. A consistent family of criteria must include all the important aspects when judging a wastewater treatment system. A framework of sustainability is developed to identify a reasonable set of environmental, social, economic and technical criteria for wastewater treatment. While selecting the indicators, extra care was given to avoid and not double count the indicators as much as possible. These indicators are visually presented in the shape of diamond referencing each apex as environmental, social, economic and technical dimension of indicators. In its simple form the most balanced diamond figure is the most suitable technology for the wastewater treatment module. Each option, indicator and weight is different for each technology, value and place.

1.2 Objectives

1.2.1 Main objectives

The scope of this research was defined to focus mainly on the evaluation and selection of the most appropriate indicators for a WWT system. A literature review was conducted to collect, identify and prioritize the indicators for the wastewater treatment in its operation phase as well as in selection and construction phase. Indicators for sustainable development in its construction phase as well as the operation and upgrading phases is a relatively new phenomena. The specific research objectives are listed in section 1.2.2.

1.2.2 Detailed objectives

The detailed objectives of this project are to develop indicators of sustainable development and indicators of sustainable development for wastewater treatment plants. Detailed objectives are:

- To determine practical applications to use the indicators of sustainable development for wastewater.
- To determine the most appropriate indicators and ranking schemes for wastewater treatment processes.
- To incorporate the sustainable indicators in to the development of the GoldSET wastewater treatment model.

1.3 Thesis Organization

In this section an overview of the contents of various parts of this research are presented. This thesis has been organized into five chapters and the subject matters discussed in each chapter are as follows:

Chapter One: This introductory chapter covers the introduction and objectives of this study.

Chapter Two: A review of the existing relevant literature on the topic is presented. This chapter demonstrates the available information and fundamentals of sustainable development in the field of wastewater management. Furthermore, it reveals the gaps in the knowledge related to the topic under study.

Chapter Three: This chapter details the approaches and methodologies followed throughout this research work.

Chapter Four: This chapter represents and discusses the results obtained from the work performed.

Chapter Five: This chapter includes the case study of a selection procedure of waste water treatment plant

Chapter Six: This chapter includes conclusions of the entire research performed. Moreover, recommendations for future work are presented.

Chapter 2 Literature Review

In this thesis, the literature is reviewed for the identification and analysis of previously published information in the field of wastewater industry and indicators of both sustainable development and sustainable wastewater treatment development.

2.1 Wastewater and Industry

Water is the support of the biosphere, which flows in a great hydrological cycle from the oceans to the atmosphere to the land and back to ocean again. Fresh water is only small percentage of total water resources. But in the past and present society, water is used as if it were unlimited. Most of the natural resources are used only once and then expelled (Niemczynozicz, 1994). However, liquid and solid wastes produced by human settlements and industrial activities pollute most of the watercourses throughout the world. The increasing scarcities of water in the world along with rapid population growth in urban areas increase the need for appropriate water management practices (Corcoran et al., 2010).

Water is an important requirement in many industrial processes, for example, heating, cooling, production, cleaning and rinsing. Overall, some 5–20 per cent of total water usage goes to industry (WWAP, 2009), and industry generates a substantial proportion of total wastewater. Industrial discharge can contain a wide range of contaminants. Industries like mining, pulp and paper, tanneries, food processing, pharmaceutical, sugar refineries are some of the biggest generators of toxic industrial waste (Eckenfelder, 2006). Depending upon the type of industries, industrial waste can also contain heavy metals, organic waste like BOD, pathogens etc. In various industries like coke production, steel production, metal and glass cutting industries water is used as cooling agent. The elevated temperature of wastewater can have an adverse effect on biota. If unregulated, industrial wastewater has the potential to be a highly toxic source of pollution. The complex organic compounds and heavy metals used in modern industrial processes, if released into the environment can cause both human health and environmental disasters, the cost of which is difficult to calculate (Kadlac and Wallace, 2009). Therefore, industry has a primary responsibility to treat the wastewater before releasing it to the environment or to the municipal WWT system (UNEP, 2010). Many industrial facilities pre-treat their wastewater before releasing it into the municipal sewage system.

2.2 Wastewater treatment systems

The degree of wastewater treatment varies countries. In some cases industrial wastewater is discharged directly into bodies of water, while major industrial facilities pre-treat their wastewater before releasing it into the municipal sewage system (UNEP, 2010). Figure 2.1 shows different pathways for wastewater treatment and discharge (IPCC, 2006).

The wastewater treatment methods can be classified as primary, secondary, and tertiary treatment (Table 2.1). In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organisms. These may include aerobic stabilisation ponds, trickling filters, and activated sludge processes, as well as anaerobic reactors and lagoons. Tertiary treatment processes are used to further purify the wastewater of pathogens, contaminants, and remaining nutrients such as nitrogen and phosphorus compounds. This is achieved using one or a combination of processes that can include maturation/polishing ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection.

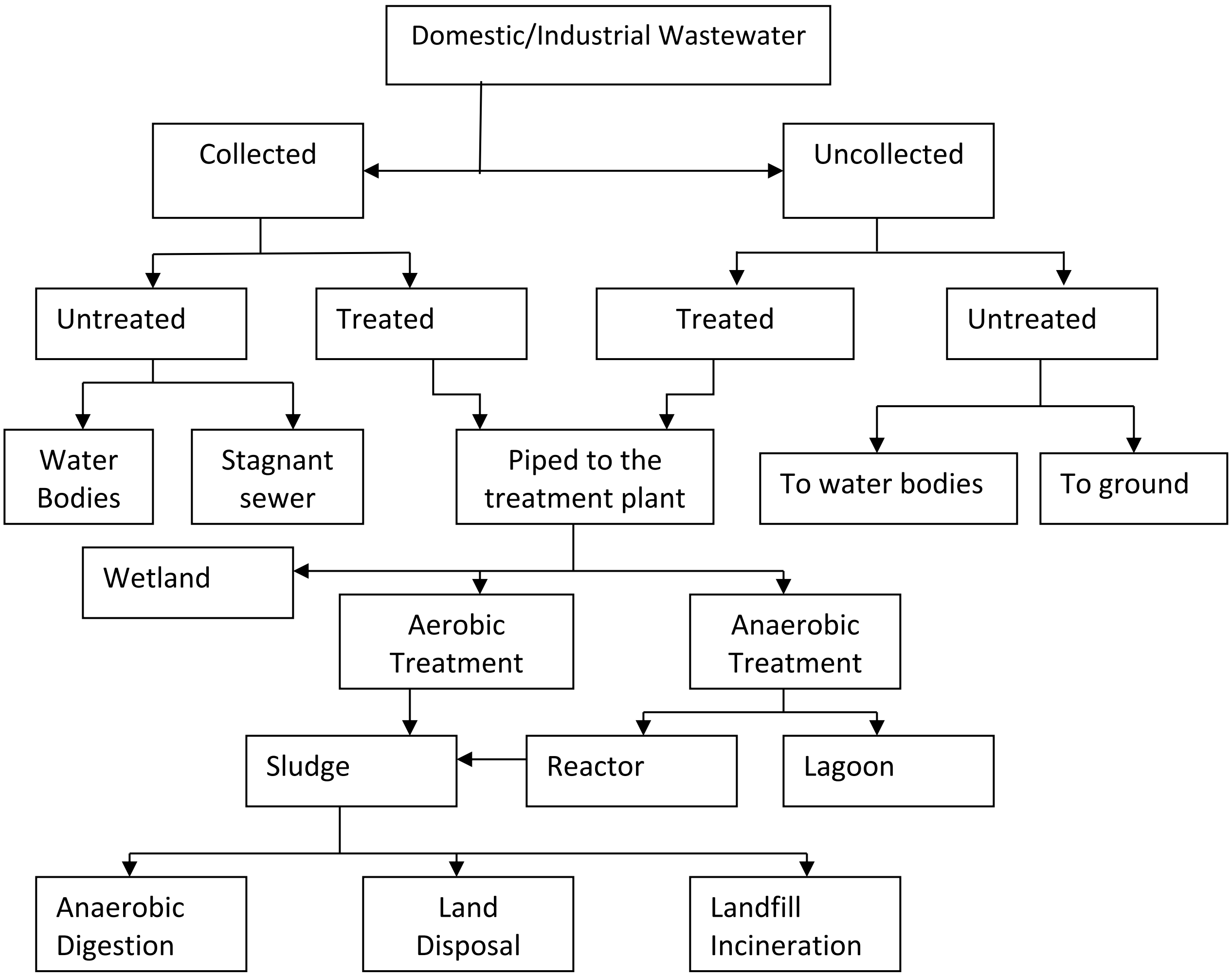


Figure 2.1 Wastewater treatment systems and discharge pathways (IPCC, 2006)

Table 2.1 Levels of wastewater treatment[a]

Treatment Level	Description
Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment options, processes, and ancillary system
Primary	Removal of suspended solids and organic matter
Secondary	Removal of biodegradable organic matter, and SS, nutrients
Tertiary	Removal of residual SS, nutrients
Advanced	Removal dissolved and SS when required for various water use applications

[a]Adapted, in part, from Crites and Tchobanoglous(1998)

2.3 Difficulties and challenges in wastewater treatment system

Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater (IPPC guideline, 2006). The greatest challenge in the water and sanitation sector is the implementation of low cost sewage treatment that permits selective reuse of treated effluents for agricultural and industrial purposes. The selection of technology should be based upon specific site conditions and financial resources of individual communities. Also, there are core parts of sustainable treatment that should be met in each case, such as: No dilution of high strength wastes with clean water; Maximum recovery and re-use of treated water and by-product obtained from the pollution substances (i.e. irrigation, fertilization); Application of efficient, robust and reliable treatment/conversion technologies, which are low cost (in construction, operation, and maintenance), which have a long lifetime and are plain in operation and maintenance; Applicable at any scale from very small to very large; Leading to a high self-sufficiency in all respects; Acceptable for the local population and comply with the regulations and standards (Massoud et al., 2009). The benefits of reusing treated waste waters must also be measured against the cost of not doing so at both the economic and environmental levels (Rose, 1999).

The improved wastewater treatment led to production of large sludge quantities. This sludge can contain a wide range of contaminants like metals, pathogens, and organic and inorganic micro-pollutants. Therefore, sludge disposal became an increasing problem for municipal and industrial wastewater treatment plants (UNEP, 2001).

A change in global climate patterns changes the volume and quality of water availability which influence water usage practices (IPCC, 2006). Also, changes in climate will require adaptation of wastewater management. Anticipation of more droughts and extreme rainfall has a major impact on WWT facilities.

The wastewater and its treatment generate the greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4) and nitrous oxide (N_2O). It is worth noting that methane has an impact 21 times greater than the same mass of carbon dioxide. Nitrous oxide is 310 times more potent (Corcoran et al., 2010). Although, a WWT facility contributes a relatively small quantity of global emissions, wastewater and its management is a growing impact. Methane emissions from wastewater are expected to increase almost 50 per cent between 1990 and

2020, while, estimates of global N_2O emissions from wastewater are incomplete, they suggest an increase of 25 per cent between 1990 and 2020 (IPCC, 2007). So, it is necessary to investigate and implement alternatives to current wastewater treatment, which minimize the production of greenhouse gases and power consumption.

The wastewater treatment facility is an energy-intensive process (Stillwell et al., 2011). To achieve higher quality of outputs, advanced technology must be used, which in turn consume more energy. The sole objective of WWT facility is to improve WWT performance choosing best available practices and technologies for less energy consumption. The WWT facility not only treated the water for reuse purposes but also is considered as a source of nutrient and organic constituents, which is a potential source of energy (Lazarova et al., 2012).

2.4 Sustainable Development

The primary goal of sustainable development is to meet its basic resource needs in ways that can be continued in the future. To do this, we need to figure out what our basic needs are and how to meet those needs most effectively. Sustainable development is part of the mission of countless international organizations, national institutions, sustainable cities and locales, transnational corporations, and nongovernmental organizations (Speth, 2003; Gutman, 2003; Schnoor 2003).

At the Earth Summit held in Rio de Janeiro in 1992, this definition was broadened to the idea that includes the three pillars of sustainable development: environmental protection, social progress and economic development.

Over 150 of the world's major companies in mining, oil and gas, autos, chemicals, logging, banking and finance, cement, electricity generation, drugs and bio-technology are members of the World Business Council for Sustainable Development (WBCSD, 2012).

In the *Sustainable Development Act*, passed in 2006, the Québec government adopted the Brundtland Report's definition with the following elaboration: "Sustainable development is based on a long-term approach which takes into account the inextricable nature of the environmental, social and economic dimensions of development activities."(Hydroquébec, 2012).

There may be as many definitions of sustainability and sustainable development as there are groups trying to define it. All the definitions have to do with:

- Living within the limits
- Understanding the interconnections among economy, society, and environment
- Equitable distribution of resources and opportunities.

1) Webster's New International Dictionary

"Sustain - to cause to continue (as in existence or a certain state, or in force or intensity); to keep up, especially without interruption diminution, flagging, etc.; to prolong."

2) Random House Dictionary of the English Language

"Develop - v.t. - to bring out the capabilities or possibilities of, to bring to a more advanced or effective state"

3) Caring for the Earth

"improving the quality of human life while living within the carrying capacity of supporting eco-systems." (IUCN/UNEP/WWF)

4) Sustainable Seattle

   Sustainability is the "long-term, cultural, economic and environmental health and vitality" with emphasis on long-term, "together with the importance of linking our social, financial, and environmental well-being"

5) Friends of the Earth Scotland

   "Sustainability encompasses the simple principle of taking from the earth only what it can provide indefinitely, thus leaving future generations no less than we have access to ourselves."

6) Thomas Jefferson Sustainability Council

   "Sustainability may be described as our responsibility to proceed in a way that will sustain life that will allow our children, grandchildren and great-grandchildren to live comfortably in a friendly, clean, and healthy world that people:

   - Take responsibility for life in all its forms as well as respect human work and aspirations;
   - Respect individual rights and community responsibilities;
   - Recognize social, environmental, economic, and political systems to be inter-dependent;
   - Weigh costs and benefits of decisions fully, including long-term costs and benefits to future generations;
   - Acknowledge that resources are finite and that there are limits to growth;

- Assume control of their destinies;
- Recognize that our ability to see the needs of the future is limited, and any attempt to define sustainability should remain as open and flexible as possible."

7) Our Common Future

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Page 8, World Commission on Environment and Development. Our Common Future. (Oxford, Great Britain: Oxford University Press, 1987). Frequently referred to as the Brundtland report after Gro Harlem Brundtland, Chairman of the Commission)

8) Hamilton Wentworth Regional Council

"Sustainable Development is positive change which does not undermine the environmental or social systems on which we depend. It requires a coordinated approach to planning and policy making that involves public participation. Its success depends on widespread understanding of the critical relationship between people and their environment and the will to make necessary changes."

9) World Business Council on Sustainable Development

"Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line."

Human and social values changes over time. Concepts that once seemed extraordinary are now taken as well-known. New concepts (e.g. responsible consumerism, environmental justice, intra- and inter-generational equity) are now coming up the curve."

10) Interfaith Center on Corporate Responsibility (ICCR)

"Sustainable development is the process of building equitable, productive and participatory structures to increase the economic empowerment of communities and their surrounding regions(ICCR).

Sustainable development is often presented as being divided into the economy, environment and society. However, when society, economy and environment are viewed as separate and unrelated parts of a community, the community's problems are also viewed as isolated issues as in Figure 2.2 (Hardi and Zdan, 1997; West Midlands Round Table, 2000).

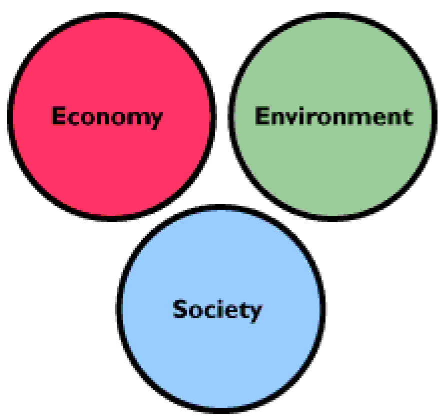


Figure 2.2 View of community as three separated unrelated parts: society, economy and environment (Hardi and Zdan, 1997)

Environmental agencies try to prevent and correct pollution problems. Social needs are addressed by health care services and housing authorities. Economic development councils try to create more jobs, increase work. This type of approach can have a number of bad side-effects:

- Solutions to one problem can make another problem worse. For example creating affordable housing is a good thing as viewed as economic concept and social needs but when that housing is built in areas far from workplaces, the result is increased traffic and the pollution that comes with it.
- Most of the solutions tend to focus on short-term benefits without monitoring long-term results. The pesticide DDT seemed like a good solution to insect pests at the time, but the long-term results were devastating.

So that we need to view the community that takes into account the links between the economy, the environment and the society, rather than separate and unrelated approach, Often sustainable development is presented as aiming to bring the three together in a balanced way, reconciling conflicts. The figure below is frequently used to show the connections: The three sectors are often presented as three interconnected rings as in Figure 2.3 (ICLEI, 1996; du Plessis, 2000; Barton, 2000).

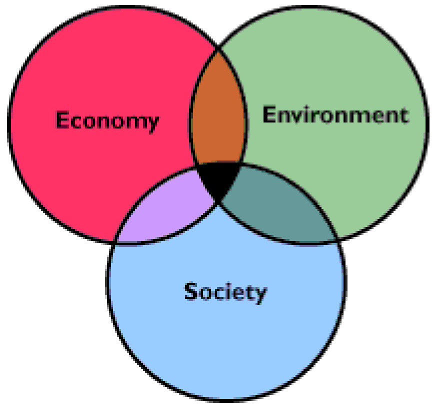


Figure 2.3 Commonly used three ring sectors of sustainability (ICLEI, 1996)

The model usually shows equal sized rings in a symmetrical interconnection. Actions to improve conditions in a sustainable community take these connections into account. Understanding the three parts and their links is a key to understanding sustainability, because sustainability is about more than just only one dimension. It is about understanding the connections achieving balance among the social, economic, and environmental pieces of a community.

A more accurate presentation of the relationship between society, economy and environment than the usual three rings is of the economy nested within society (Figure 2.4), which in turn is nested within the environment (Giddings et al., 2002).

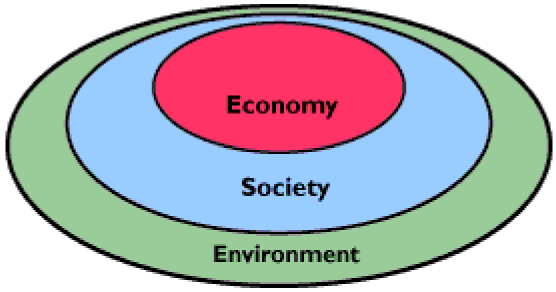


Figure 2.4 A view of community as three concentric circle-economy dependent on society and both economy and society is dependent of environment (Giddings et al., 2002)

As Figure 2.4 illustrates, the economy exists entirely within society, because all parts of the human economy require interaction among people. Economy is placed in the centre. That does not mean that it should be considered as the hub that is surrounded by the other sectors and activities revolve. But it is a subset of the others and it is dependent upon them. Human society depends on environment; the economy depends on society and the environment (Giddings et al., 2002). Sustainability requires managing all households: individual, community, national, and global in such ways that ensure that our economy and society can continue to exist without destroying the natural environment on which we all depend. Sustainability is an issue for all communities, from small rural towns that are losing the natural environment upon which their jobs depend, to large metropolitan areas where crime and poverty are decreasing the quality of life (Ferreira et al., 2003). A key issue for sustainable development is the integration of different actions and sectors, taking a holistic view and overcoming barriers between disciplines.

Sustainable development focuses on improving the quality of life without increasing the use of natural resources. Although sustainable development is not a new idea, what is new is an articulation of these ideas in the context of a global industrial and informational society (SD gateway, 2002).

Sustainability is a complex concept incorporating many different strands: environmental, economical, social, political, cultural factors. Sustainable development has emerged as the dominant development paradigm of the twentieth century, driving forward global policy making and strategy in addition to informing and directing sectorial policies and activities, including those of wastewater industry (CST, 2009).

Since the 1980s, the concept of sustainable development has been progressed rapidly. In 1992 leaders at the Earth Summit built upon the framework of Brundtland Report to create agreements and conventions on critical issues such as climate change, desertification and deforestation. The work-plan for environment and development issues were drafted for the coming decades. Throughout the rest of the 1990s, regional and sectorial sustainability plans have been developed. A wide variety of groups ranging from business to municipal governments to international organizations like World Bank have adopted and given their own particular concepts.

2.5 Sustainable development in wastewater

In the past WW management was characterized by problems that society wanted to solve. The hygienic problems within the cities were the principle reasons for the major efforts in WW management. Eutrophication problems in nearby lakes and coastal seas triggered research and legislation (Pahl-Wostl, 2002). Traditionally, WW management was largely composed of an engineering approach. Improved technologies are proved to be very efficient in solving a number of urgent environmental problems, e.g. wastewater treatment and the increasing sophistication of wastewater treatment plants addressing hygienic and pollution problems. Nowadays involvement of local stakeholders, their opinion and public awareness are equally important.

Better WW management is an important SD goal because it can directly lead to the better living conditions, improved health and productivity of human resources, direct economic benefits. Environmental responsible WW management can reduce GHG emission at an appropriate level (www.ipcc.ch). In many underdeveloped and developing countries uncontrolled open direct disposal, poor sewage practices, results in major public hazards due to vermin, pathogens, safety concerns, air pollution, and contamination of water resources. Some of the strategies to improve WW management system include septic tanks, recycling grey water, improved WWT plant, improved technology, composting etc. (UN Water, n.d.).

To make the sustainability concept more useful for WWM decision making, there is still a challenge. Niemczynowicz (1993) had formulated the action plan for the sustainable development in wastewater. The options below are ranked according to priority as:

1) Preventive actions during all human activities;
2) On-site treatment and reuse close to production
3) Off-site treatment and reuse
4) On-site and off-site concentration and storage

5) Treatment at small-scale treatment plant using low-cost technology

6) High-technological treatment.

Butler and Parkinson (1997) suggest preventive actions such as reuse of sewage sludge, recycling of grey water and rain water, on-site storage of infiltration of storm-water, utilization of natural drainage patterns and local sanitation technologies etc.

2.6 Sustainable development indicators

Hart (1997) simply describes an indicator as 'something that helps you to understand where you are, which way you are going and how far you are from where you want to be, while the Department of Culture Media and Sport (DCMS, 1999) more simply states the aim of indicators is to produce what is measurable and show us something. Indicators today have an increasing resonance in politics, with a seemingly endless desire to measure the previously unmeasured and to compare the performance of different providers of service.

An indicator is something that helps one to understand where you are, which way you are going and how far you are from where you want to be. A good indicator alerts to a problem before it gets too bad and helps you recognize what needs to be done to fix the problem. Indicators of a sustainable community point to areas where the links between the economy, environment and society are weak. They allow seeing where the problem areas are and helping to show the way to fix those problems.

The list of acronymic organizations involved in this development of indicators of sustainable development (ISD) is long and impressive. The European Environment Agency (EEA), United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), The World Bank, World Watch Institute, International Institute of Sustainable Development (IISD), New Economics Foundation(NEF), United Nations Commission for Sustainable Development (UNCSD), WTO (World Tourism Organization) and nationally Department of Culture Media and Sport (DCMS) and Department for Environment Transport and the Regions (DETR) are just the main organizations. The subject is relatively new, the concept that it is trying to measure is difficult.

Sustainability Indicators represent areas of concern which, if improving over time will lead to a more green community. Although these indicators could be categorized under many different topics, these indicators often can be translated into specific targets or goals (www.epa.gov). Sustainability indicators reflect the reality that the three different segments are very tightly interconnected, as shown in the Figure 2.5 (Hart, 2013).

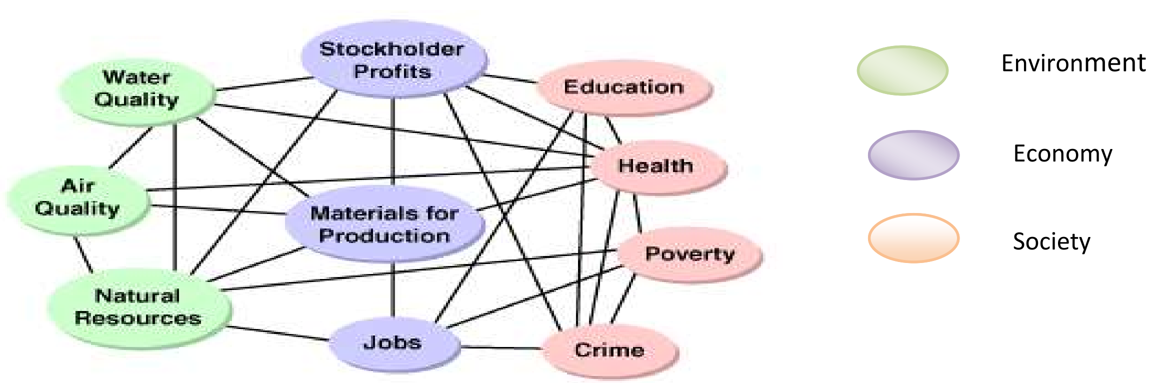


Figure 2.5 Web of interaction of communities among environment, economy and society (Hart, 2013)

As Figure 2.5 illustrates, the natural resources provide the raw materials for production, this creates job facilities and increases stockholder profits. An increase in employment rates decreases the poverty rate and the poverty rate is related to crime. Air quality, water quality and materials used for production have an effect on health. They may also have an effect on stockholder profits: if a process requires clean water as an input, cleaning up poor quality water is an extra expense, which in turn reduces profits. Also, poor air quality or exposure to toxic materials has an adverse effect on worker productivity and health. Sustainability requires the integrated view of multidimensional indicators that shows the links between economy, environment, and society of community.

2.7 Sustainable development indicators in wastewater

The release and conduction of drinking water and treatment of wastewater are necessary in any society. So hence securing water for current and future generations is an important part of sustainable development. This has also been recognized in many of the initiatives to measure different aspects of sustainability and select appropriate sustainable development indicators (SDIs) that were launched following the U.N. conference on Environment and Development in Rio de Janeiro in 1992. Initially, a majority of the SDIs proposed were used at the international, national, regional or other administrative or geographical levels (UNCSD, 1996; OECD, 2001), and included suggestions on indicators such as withdrawal of freshwater (OECD), sewage connection rates (OECD) and releases of nitrogen and phosphorus (UNCSD). In the latter half of the 1990s, the role and responsibility of companies in the implementation of sustainable development attracted increasing attention, leading to a new set of initiatives. They develop new SDIs for use at the company level. The use of SDIs within companies in general is described by Fiksel et al. (1999), Schaltegger and Burritt (2000), and Veleva et al., (2001). SDI projects applying specifically to the water industry are reviewed by for example, Balkema et al., (2002) and Foxon et al., (2002). Good SDIs should be effective, efficient, and democratic and meet the needs of all stakeholders.

Chapter 3 Methodology

Efficient wastewater management with appropriate technology is a concern of all. To select appropriate wastewater treatment technology, frameworks have been developed by several institutions. In order to establish a comprehensive set of indicators, new indicators were developed according to various literature review findings. For each dimension of sustainability, the indicators were developed according to sustainability principles and indicators recognized by internationally renowned and accredited organizations such as GRI-G3 (2000-2011), WHO/UNEP (Helmer and Hespanhol 1997), International Federation of Consulting Engineer (FIDIC, Van der Putte 2007), the World Business Council on sustainable Development (OECD), etc and engineering design references (Metcalf and Eddy, 2003) . This way, in addition to inclusion of all non sustainability aspects covered by the literature finding, the developed indicators are more comprehensive and flexible and can be applied for a variety of applications.

Several sets of sustainability indicators for waste water treatment operations have been suggested that focus on environmental aspects (Lundin et al., 1999; Balkema et al., 2002; Muga and Mihelcic, 2008). In other studies, environmental and/or economic dimensions (Hwang and Hanaki, 2000; Tsagarakis et al., 2002; Palme et al., 2005) and partly societal indicators (Muga and Mihelcic 2008) were considered for wastewater treatment operations; therefore, they do not fully cover the overall sustainability that should be inclusive of a balance of economic, environmental, social and technical considerations.

3.1 Five steps of development of indicators for GoldSET

The analytical framework developed by Golder involves a five-stage process integrating an evolving, adaptable and versatile application called GoldSET. Figure 3.1 describes the five stages of development of software.

3.1.1 Site description

Detailed description of a site is very important for the existing project or/and for a new project. It helps to conceptualize the site conditions and key issues to be addressed. It helps to determine the key stakeholders and their need and interest. The objectives are thus defined before the sustainable development evaluation is done.

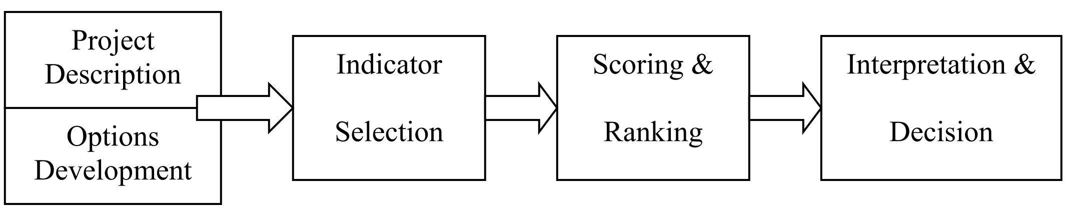


Figure 3.1 A five step evaluation process of GoldSET (www.goldset.com, 2014)

3.1.2 Generating Options

There may be several methods or several technologies available for the treatment of wastewater. Thus, it is important to determine various possible ways for obtaining the objectives for project. Then options are narrowed according to these objectives. The best three options were chosen for the selection of indicators. These options were then studied and analysed in detail.

3.1.3 Selecting indicators

According to the context and specifications of the project, a set of indicators are selected. These selected indicators are chosen based on national and international references, industry-specific references, legal requirement, etc. The selected indicators should reflect the issues that are critical to the overall performance of the project.

3.1.4 Scoring of indicators

Scoring schemes were developed for the indicators, providing impartial mechanisms to assess the relative merits of each option. Both qualitative and quantitative scoring schemes were developed for the indicators. It allows the developed module to be flexible and adaptable for both preliminary investigations where data is not yet known or available, and detailed analyses for projects where quantitative measurements are possible and data are available. To evaluate qualitative indicators like health and safety, impact on landscape (for instance) pre-determined scoring scheme can also be used. All qualitative indicators have scoring schemes consisting of no less than 4 levels. Figure 3.1 shows an example of a scoring scheme for some of the environmental indicators in the application for site remediation.

Quantitative indicators have both relative and absolute scoring schemes. For the specific quantitative indicator like greenhouse gases and Net Present Value (NPV), the framework is adopted to a level of detail calculators. Relative scoring schemes assign a score of zero to the lowest performing option, while assigning 100 to the best performing option. Absolute scoring schemes have a fixed scoring scale independent of the options, and score the options relative to this fixed scale. These fixed values were adopted from accredited organizations (UNEP, WHO, etc.) as benchmarking values for consumption of natural resources or concentration of pollutants in the media.

3.1.5 Interpreting Data

The reliability of the findings can be improved by sensitivity analysis. If new information is available, it can be added. So, it is an iterative process. To improve the reliability of findings, sensitivity analysis is performed.

The result of this process is a more clear understanding of the issues. The best approach from a sustainability aspect is based on the biggest, most balanced triangle with the highest performance in each dimension (Golder, 2012).

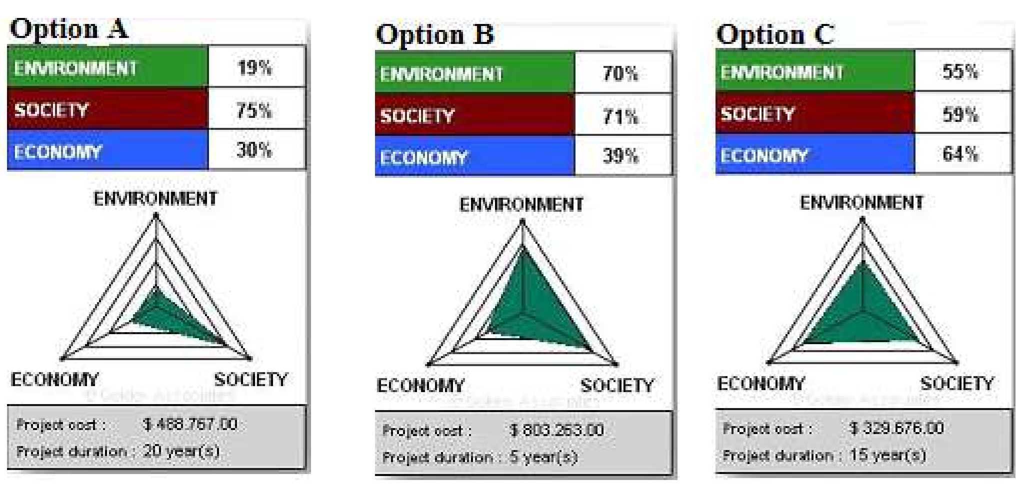


Figure 3.2 Graphical representations of output results(Golder, 2012)

3.2 Selection of indicators

A list of sustainability indicators was selected through several levels of screening through a comprehensive literature review. From the indicators identified in the literature review the most encompassing, robust and relevant, about 60 indicators as in Table 3.1 were collected.

Table 3.1 Core indicators

Environmental	Social	Economical	Technical
• Land • Biodiversity • Water • Ecological Integrity • Pollution (Water/air) • Energy • Nutrient • Raw material • Pathogen removal • BOD/COD • TSS • Heavy metal • Toxic substances • Odor/noise • Nuisance • Use of chemicals • Sludge Production • Ozone depletion • Eutrophication • CO_2,NOx, SOx, Hg, Dioxin, Furan • Optimal resource utilization • Urbanization	• Cultural acceptance • Awareness • Competence requirement • Local development • Responsibility • Public participation • Community size served • International stand of conduct • Creation of employment • Work safety • Training • Public safety • Education • Social values • Cultural heritage • Quality of life	• Cost • Labor • Economic performance • Resources used • Value added • Staff turnover • Expenditure on health and safety • Stakeholders value • Productivity • Waste management • Trade	• Durability • Reliability • Flexibility • Ease of construction • Required technology • Maintenance • Endure shock loads • Complexity

These indicators were in the four dimensions of environmental, social, economic and technical aspects. The indicators were then classified and screened so that the key indicators were identified. Since sustainability is a broad concept, with many components, it is important for the indicators to be applicable over time to measure progress and to assess planning options for the future.

There is no universal set of indicators that is equally applicable in all cases. The selection criteria ensure that the indicators are useful and effective in terms of information to decision makers. Indicators should be designed to be used as part of a process of continuous improvement. There may be many selection criteria listed as indicators, but the following criteria are appropriate to most indicator selection processes and are intended to be (Vos et al., 2005):

- Of direct relevance to objective: The selected indicators must be directly linked to the problem being addressed. The indicators should use the available data in a format that is easy to use and not vague or of overly broad formulation to be of little use.
- Of direct relevance to the target group: Different groups have different needs and different priorities.
- Clear in design: The selected indicators should be designed clearly and any confusion in their design and operation should be avoided.
- As few as necessary: An excessive number of indicators can overburden the selection process and may mean that the system fails to achieve the expected benefits or does not

work at all. A set with a large number of indicators will tend to clutter the overview it is meant to provide.

- Applicable to the options under consideration: In particular, they must reflect the performance of the option regarding the pertinent environmental aspects.
- Comprehensive: The important aspects of sustainability should be covered so that desired performance characteristics or outcomes are not neglected.
- Meaningful and relevant to all stakeholders: The rankings should be clear and convincing for the public (not just to sustainability specialists) that are assessing sustainability. Overly complex or obscure indices might create confusion and distrust. Use of too many indicators should be avoided since the public may consider them not transparent (Asley and Hopkinson, 2002)
- Applicable over time: The indicators should be designed to adapt to the changing technological and environmental conditions. They will also allow for different levels of analysis, from general assessments to detailed information on particular technologies or programs.

The selected indicator must reflect the critical issues of wastewater treatment performance. The indicators are selected based on national and international references along with legal requirements. A sustainability assessment uses a broad range of criteria that accommodate changing demographics, values, and environmental resources (Bradley et al., 2000). The selection of the criteria is a very important step for the decision analysis, and especially in environmental matters. A consistent family of criteria must include all important aspects when judging a wastewater treatment system. A framework of sustainability is developed to identify a reasonable set of environmental, social, economic and technical criteria for wastewater treatment. For each dimension of sustainability, the indicators were developed according to the principles of sustainability and indicators recognised by internationally renowned and accredited organization such as Global Reporting Initiatives (GRI-G3)(2000-2011), International Federation of consulting Engineers(FIDIC)(Van der Putte , 2007), World Health Organization//United Nations Environmental Program (WHO/UNEP), (Helmer and Hespanhol,1998), and engineering design references (Metcalfe and Eddy, 2003).

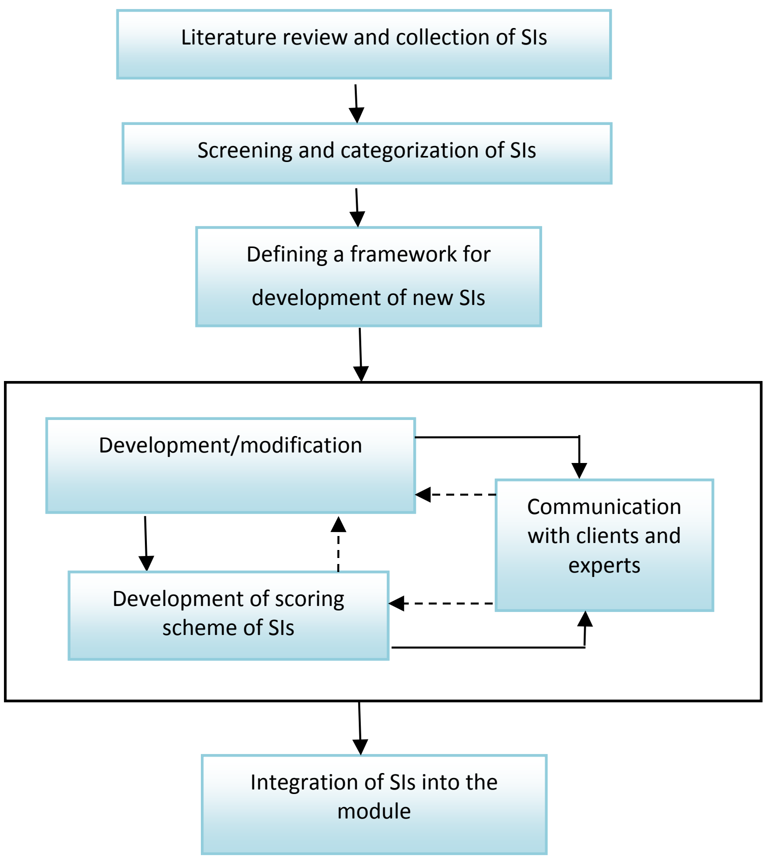


Figure 3.3 Interactive procedures for development of the SIs and their scoring schemes (Mulligan at al., 2012)

These indicators developed are more comprehensive and flexible and can be applied for a variety of applications. Figure 3.3 represents the interactive procedure for development of the sustainability indicators (SIs) and their scoring schemes (Mulligan et al., 2012).

The selection of indicators was based on four dimensions adapted from the literature. The dimensions are:

1. Environmental
2. Social
3. Economic
4. Technical.

3.2.1 Environmental dimension

Environmental indicators are essential tools for tracking environmental progress, supporting policy evaluation and informing the public. Since the early 1990s, such indicators have gained in importance in many countries (OECD, 2008). Environmental indicators seeks to explore the scientific bases and uses of indicators (biological, chemical, physical) and biomarkers as they relate directly to specific measurable effects in ecological and human populations from environmental exposures. Environment indicator gives emphasis on the application from molecular to landscape level indicators. It helps to understand the probability of contaminants or other disturbances in the environment. These contaminants and disturbances in the surrounding environment may produce an adverse impact in exposed receptors or populations.

The degree of harm can be indicated and the data can be integrated to characterize environmental health (ISIE, 2012).

Environmental sustainability refers to the ability of the functions of the environment to sustain the human ways of life which mainly depends upon the ethical basis. The environmental dimension, evaluates the option's performance and effects on the environment regarding its compliance with the regulations and standards for the treated wastewater, intermittent overflow discharges and disposal of solid wastes (hazardous and non-hazardous) to the environment. The long-term viability of the natural environment should be maintained to support long-term development by supplying resources and taking up emissions. This should result in protection and efficient utilization of environmental resources.

Environmental sustainability of wastewater treatment plants is perhaps the most important dimension of their sustainability assessment. There are many benefits for removal of contaminants from wastewaters, but their operation can adversely impact the surrounding environment. Many researchers have tried to focus on key treatment parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), etc. (Emmerson at al., 1995; Hellstrom et al., 2000; Muga and Mihelcic, 2008). However, there is a lack of a widespread set of indicators that cover all potential sources of adverse effects of wastewater treatment operation on the environment. According to the impact on environment these indicators are separated in to three sections: input to system, impact to treatment system and output to the system.

3.2.1.1 Input to the treatment system

The system operation system of the WWT plant should efficiently utilize the environment and also protect the environmental resources. In this category, the use of natural resources such as water, energy and raw materials and chemicals were considered.

Theme: Water Use

Wastewater is composed of over 99% water. It is recommended to minimize the water usage. Water recycling, or reuse by the treatment option is encouraged (Hellstrom et al., 2000), (Lundin et al., 1999; Otterpohl et al., 1997). The water quality constituents associated with wastewater treatment such as BOD, TSS, nutrients and fecal coliforms are evaluated for reuse purposes (Corcoran et al., 2010). The effluent qualities determine whether further treatment is required, along with the discharge options and their potential for reuse (ETC, 1996; Finnson et al.,1996), Removal efficiencies of toxic substances, heavy metals and pathogens have a major impact on water reuse (Otterpohl et al.,1997).

Indicator: Water Use

The utilization of water is an important indicator of sustainability. This indicator measures the intensity of use of water resources. In the case of renewable resources, such as water, sustainable use requires the minimization of fresh water use (York region, 2008; Otterpohl et al., 1997; Butler et al., 1997). The source of water used by the option is determined by its required water quality. The amount of fresh water use should be minimized, or eliminated by the option. In the case of renewable resources, sustainable use would not exceed replacement or regeneration rates of the resources that are being consumed (Lundin et al., 1999; DTO, 1994; Icke et al., 1997; Weaver et al., 2000). Water drawn from the scheme or environmental sources is the total water consumed minus recycled water consumed.

Theme: Energy

In this category, the level of sustainable energy used for each wastewater treatment option is compared. Measurement of net energy consumption by the option is evaluated and the potential for non-polluting and renewable energy sources including solar, wind, geothermal, low-impact hydroelectric, biomass, and cogeneration of energy such as generation of biogas is taken into account (Hellstrom et al., 2000; Otterpohl et al., 1997). There are various opportunities to reduce energy use and its negative impacts (Mels et al., 1999; Emmerson et al., 1995; Corcoran et al., 2010). These include: the type of wastewater treatment technology selected, recycle and reuse of material, correct sizing and rating of equipment (Kamami et al., 2011). Reuse of methane production from the project may reduce the external energy needs.

Indicator: Energy consumption/Generation

A main issue in sustainable development is the use of energy. Energy production, use, and by-products have resulted in major pressures on the environment, both from a resource use and pollution point of view. The use of natural resources especially non-renewable resources such as fossil fuels should be minimized by the option (Butler et al., 1997; Muga et al., 2008; Lundie et al., 2004; Lundin and Morrison, 2002). The industrial systems should adapt to use new, renewable sources without going out of business. Unsustainable energy consumption will lead to the depletion of natural resources and global warming. This indicator reflects the level of sustainable energy use for each wastewater treatment option (Balkema et al., 2002).

Theme: Input materials

Production of raw materials is associated with the consumption of natural resources, energy and waste production (Hellstorm et al., 2000; Emmerson et al., 1995). Reduction of raw material use is essential to environmental protection and resource conservation. The amount of raw materials used by the option should be minimized and the recycling of materials should be encouraged (Otterpohl et al., 1997). Competitive technologies with fewer requirements for raw materials in the processing units, more efficient use of natural resources and more recycled and waste material use are preferred (Emmerson et al., 1995).

Indicator: Recycled material

The waste minimisation is an aim of sustainable development strategies. This can be achieved through, waste prevention, reuse, recycling and recovery. This is the volume of waste which is reused or recycled (DSD, 2001). Recycled materials assess the percent of the input materials that are recycled from other processes. It reduces the quantity of virgin materials used. It reduces the energy consumption by the treatment option (Otterpohl et al., 1997; DTO, 1994; ETC, 1996; Bengtsson et al., 1997). So the use of recycled material is preferred.

Indictor: Environment Toxicity

This indicator assesses the relative environment toxicity of the input material used for different options. Wastewater produces from various industries like metal and glass processing, pulp and paper, various mill and mines, pharmaceutical industry, hospital waste may contain heavy metals and other toxic substances which can pose significant human health and ecological risks (Azapagic, 2004; UNECE, 2012). Classification is made on the UN Globally Harmonised System and Classification and Labelling of Chemicals (GHS) using the information presented on MSDS.

Table 3.2 References of indicators of input to the system

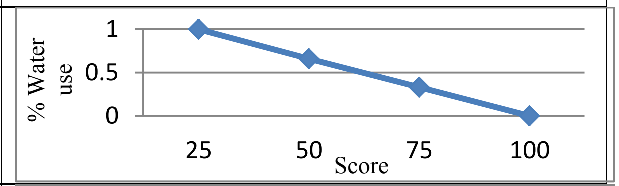
Theme	Indicator	References					
		GRI-G3[1]	FIDIC[2]	EC[3]	US EPA[4]	AWWA[5]	IWA[6]
Environment Dimension							
Input to the system							
Water Use	**Water use**	EN8-Total water withdrawal by source. EN10-Percentage and total volume of water recycled and reused. EN21-Total water discharge by quality and destination.	EN-13: Measurements of water usage on project during all phases EN-14: Measurements of BOD on water bodies affected by project during all phases.	Water Quality- Water quality parameters used for Canadian Environmental Sustainability Indicators (CESI). Water Quality- Water Quality Index (WQI) evaluated by Environment Canada from fresh water.	EMS (Reduce Consumption of Natural Resources - Reduce Potable Water Use)	Reduction of water use through automation and control	
Energy	**Energy Consumption / Generation**	EN3-Direct energy consumption by primary energy source. EN4-Indirect energy consumption by primary source. EN5-Energy saved due to conservation and efficiency improvements. EN6-Initiatives to provide energy-efficient or renewable energy based products and services, and reductions in energy requirements as a result of these initiatives. EN7-Initiatives to reduce indirect energy consumption and reductions achieved.	EC-03 - Extent of energy consumption EC-04 - Extent of the use of renewable energy resources.	Energy (consumption and production)	Electricity consumption generated from non-renewable & renewable sources - EMS (reduction of power consumption)	Optimizatio n of energy usage in design.	wOp18(WWT energy consumption), wOp19 (energy recovery from co-generation processes). wOp20 (Standardised energy consumption)

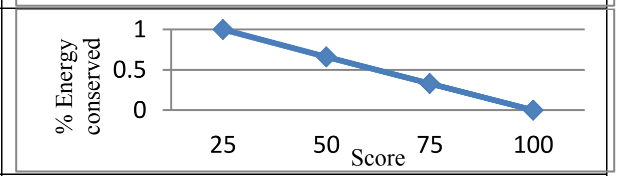
Theme	Indicator	GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Input Materials	**Recycled materials**	EN2 Percentage of materials used that are recycled input materials			According to the regulations - EMS (Optimize Recycling Program)	Use of recycled materials preferred	
	Quantity used	EN21 - Total water discharge by quality and destination.	EN-6: Quantities of fertilizers used compared to norms EN-7: Quantities of pesticides used compared to norms		EMS (Environmental Management System)		
	Environmental toxicity	EN21 - Total water discharge by quality and destination. EN24 - Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III and VIII, and percentage of transported waste shipped internationally.			EMS (Reduce Use of Toxic Chemicals)	Design considerations for safe handling of chemicals.	

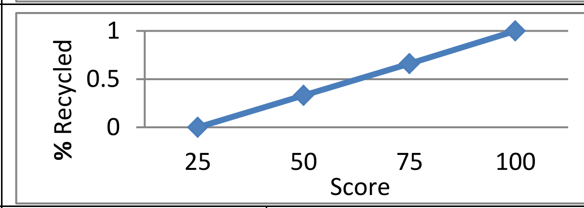
[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

Table 3.3 Indicators of input to the system and their scoring scheme

<table>
<tr><th colspan="7">Environment Dimension</th></tr>
<tr><th colspan="7">Input to the system</th></tr>
<tr><th>Indicator</th><th>Qualitative/ Quantitative</th><th colspan="3">Scoring Scheme</th><th colspan="2">Performance curve</th></tr>
<tr><td>Water Use</td><td>Quantitative</td><td colspan="3">Regressive, linear relationship

Unit of measurement = %</td><td colspan="2">
</td></tr>
<tr><td>Energy conservation/ Generation</td><td>Quantitative</td><td colspan="3">[1]Use energy consumption calculator. Also modify to include co-generation under renewable energy offsets.

Unit of measurement = % Gigajoules</td><td colspan="2">
</td></tr>
<tr><td>Recycled Materials</td><td>Quantitative</td><td colspan="3">Positive, linear relationship

Unit of measurement=%</td><td colspan="2">
</td></tr>
<tr><td rowspan="2">[2]Environmental Toxicity</td><td rowspan="2">Qualitative</td><td>0</td><td>33</td><td>66</td><td>100</td><td></td></tr>
<tr><td>One or more input materials are classified as “chronic aquatic hazard”</td><td>One or more input materials are classified as "acute aquatic hazard category 1 or 2"</td><td>One or more input materials are classified as "acute aquatic hazard category 3"</td><td>No materials are classified as hazardous to the aquatic environment</td><td></td></tr>
</table>

[1] The energy required to run each equipment and operation in each of the option is calculated. If energy is generated from the option, it is also included.

[2] http://live.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev03/English/04e_part4.pdf

Table 3.2 summarizes the references of each indicator. Each indicator is then coded as in GRI-G3, FIDIC, EC, IWA and AWWA. These indicators are then categorized as qualitative or quantitative and their scoring scheme and performance curve are shown in Table 3.3. As in Table 3.3, water use, energy generation and recycled materials are quantitative indicators which can be measured directly through a linear relationship whereas environmental toxicity is a qualitative indicator and scoring is done as shown above by experience of previous projects of GoldSET.

3.2.1.2 Impact of the treatment system

This category is comprised of indicators to account for the impacts of the treatment system itself, including the land use and ecological impacts. The category evaluates the direct and indirect, short-term and long-term impacts of the treatment option on the environment such as impacts on species biodiversity with an emphasis on rare, threatened, endangered, native and beneficial animal and plant species (Azar et al.,1996; Corcoran, 2010). Moreover, each option is evaluated by the existence and evaluation of the records pertinent to the implementation of sustainable projects which indicate the incorporation of the environmental management system to the option's organization.

Theme: Land

Occupied land is an important indicator of sustainability. Land and soil should not become infertile and lose their composition/texture and should conserve their natural properties due to provision of parks and open spaces for residents and habitat that supports the biodiversity (Muga et al., 2008; Bradly et al., 2000). The selected option should allow for urban ecosystem improvements (Moeffaert, 2002).

Indicator: Site Footprint

This indicator assesses the ways in which the footprint of the city relates to its native ecosystems and measure of the size of the option site footprint (Haberl et al., 2004). It also measures the amount of other usable land that the different option requires (Kamami et al., 2011).

Theme: Ecological Integrity

The operation of the plant should not adversely affect the natural habitat and biodiversity (Bauler, 2007). The operation of the treatment system should have no or minimum effects on the natural cycles such as carbon, nitrogen and phosphorus. Any interaction could disturb these cycles and cause non-recoverable impacts (IIPC, 2007). Measures can be taken for conserving biodiversity at ecosystem level and investigations can be made to estimate the need for specific conservation measures to maintain the biological diversity in a country or region (Wiggering et al., 2006; Finnson et al.,1996; Azar et al., 1996). The main challenge is to maintain or restore the diversity and integrity of ecosystems, species and genetic material and to ensure a sustainable use of biodiversity (Calay et al., 2012).

Indicator: Impact upon habitat and /or bio-diversity (consequences of malfunction)

This evaluates the likely impacts like health, growth, interactions, density, composition and distribution etc. caused by malfunction of the system by different option on species diversity. This gives emphasis on rare, threatened, endangered, native and beneficial animals and plant species (Bradley et al., 2000). This indicator also includes the impacts on the site location and solid, liquid or gaseous emissions at discharge point (IIPC, 2007). Loss of this habitat not only decreases biodiversity but also the ability of a coastal ecosystem to soak up pollutants from human activities, such as farming, aquaculture, urban runoff, sewage effluent, and oil spills(Ash and Fazel). Classification of indicators is done on the basis depending on the local fauna and flora condition (IUCN, 2006).

Indicator: Short term impacts upon biodiversity/habitat

Short term impact upon biodiversity evaluates the direct and indirect short-term impacts during the implementation of the option up to 2 years after completion on species diversity (health, growth, interactions, density, composition and distribution), wildlife habitat and land use (including loss, fragmentation, conversion, alteration, disturbance and degradation) particularly with respect to protected, designated or sensitive areas, upon habitat access the with an emphasis on rare, threatened, endangered, native and beneficial animal and plant species (EU, 2004).

Indicator: Long term impacts upon habitat and/or land use

This assesses the long-term impacts (persisting more than 2 years) of the option on wildlife habitats and land use (including loss, fragmentation, conversion, alteration, disturbance and degradation) particularly with respect to protected, designated or sensitive areas. This indicator also includes the impacts on the site location and solid, liquid or gaseous emissions at discharge point. Classification of indicators is done on the basis depending on the local fauna and flora condition.

Theme: Management

It is necessary to integrate environmental considerations into the corporate activities and to meet high conservation standards in fulfilling the responsibilities. All measures should be taken to reduce the burden on the environment such as (EMS, 2004):

- Sharing of environmental information and contributing to regional and international preservation efforts
- Recovering and recycling used products
- Continually improving the environmental management system which covers all corporate activities.

Indicator: Environmental management track record

It measures the track record of the company to implement environmentally sustainable projects. The Environmental Management System (EMS) is a problem identification and problem-solving tool, based on the concept of continual improvement, that can be implemented in an organization in many different ways, depending on the sector of activity and the needs perceived by management (UNEP, 2001; Tinsley and Pillai, 2006; Schmidt et al., 2011).

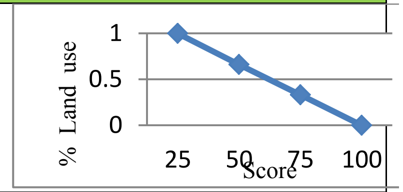
With better management, processing and conservation practices, sustainable management and conservation are possible. The indicators are derived from environmental accounting, to promote both integration of environmental concerns into economic policies and sustainable use and management of natural resources (Van Stolk et al., 2009).

Table 3.4 shows the indicators of environmental dimension of impacts of the system and their references, which includes site footprint, short and long term impact upon habitat, land use and diversity and environmental management track record. Also, these indicators are distinguished as qualitative and quantitative, their scoring schemes and performance curves are shown in Table 3.5.

Table 3.4 References of indicators of input to the system

	Indicator	References				
		GRI-G3	FIDIC	EC	US EPA	AWWA
Environment Dimension (Impact of the system)						
Land	**Site Footprint**	EN11-Location and size of land owned, leased, managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas.	EN-8: Extent to which forests are used or affected in the development, design and delivery of the project	Land use impact on water quality-Protection of ecosystem.	Percentage of land preserved as open space	Locate to minimize impact
Ecological Integrity	**Short/Long term impacts upon biodiversity**	EN12 - Description of significant impacts of activities, products, and services on biodiversity value outside protected areas. EN14 - Strategies, current action and future plans for managing impacts on biodiversity	EN-8: Extent to which forests are used or affected in the development, design and delivery of the project. EN-17: Measurements of affect of project on the abundance of key species	Health of ecosystems and wildlife populations	Assessment of water quality for 4 major groups: Fish, The major groups include: Fish, Invertebrates, Periphyton, Macrophytes	
	Short/ Long term impacts upon habitat and/or land use	EN13 - Habitats protected or restored	EN-8: Extent to which forests are used or affected in the development, design and delivery of the project EN-17: Measurements of affect of project on the abundance of key species	Land Cover (it is related to other indicators such as soil erosion, habitat, etc.) Land Use Impacts on Water Quality	Soil Erosion (bed load, suspended solids, turbidity) Impervious Surface, Farm Acreage	Minimize conduit length to treatment plant
	Environmental management track record			Trends in resource management and protection of habitat	Performance Track Number- Wastewater Management, EMS (Environmental Management System)	

Table 3.5 Scoring scheme of the indicators of input to the system

Indicator	Qualitative/ Quantitative	Scoring Scheme					Performance Curve
Site Footprint	Quantitative	Regressive, Linear Relationship. Unit =square meter					
Short/Long term impact upon biodiversity/habitat and land use	Qualitative	0	25	50	75	100	
		High & Moderate to High Impacts	Moderate	Moderate to High Impacts	Low Impacts	Best Practice	
Impact upon habitat and/or land use (consequences of malfunctions	Qualitative	No system redundancy to stop discharge of "out of spec" effluent. Discharge to a waterbody.	No system redundancy to stop discharge of "out of spec" effluent, but discharged to municipal WWTP	System redundancy to stop discharge of "out of spec" effluent for < 72 hours	System redundancy to stop discharge of "out of spec" effluent for > 72 hours	Best practice	
Environment Management Track Record	Qualitative	Company has no EMS but track record of meeting regulatory requirements.	Company has basic EMS and track record of meeting regulatory requirements	Company has basic EMS and track record of implementing sustainable environmental practices above regulatory requirements.	Company has detailed EMS and track record of implementing sustainable environmental practices above regulatory requirements.	Compliance with ISO14001-2004 and ISO14004-2004 standards, and to industry best-practice guidelines	

[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

3.2.1.3 Output from the treatment system

The generation of hazardous wastes has a direct impact on health and the environment through exposure to this kind of wastes. The total amount of waste (particularly hazardous waste) generated by the option is disadvantageous since it requires additional steps such as waste processing units and transportation of wastes in addition to potential risk of waste disposal. Special care must be taken when dealing with hazardous wastes. Also, a sustainable level of hygiene has to be reached in the treatment system so that the potential exposure to pathogens has to be minimized for the environment and onsite workers. The qualities and quantities of any output from the treatment system in the form of liquid, solid and gas are evaluated. Environmental pollution generated by the treatment systems is an important indicator of sustainability. This category, evaluates the option's performance and effects on the environment regarding its compliance with the regulations and standards for the treated wastewater, intermittent overflow discharges and disposal of solid wastes (hazardous and non-hazardous) to the environment. The quality parameters of treated and discharged wastewater such as BOD, COD, TSS, pH, nitrogen (N), phosphorus (P), toxicity, metals, etc. are compared with the acceptable levels according to the local regulations/guidelines and in case of any incompliance, post treatment steps should be considered by the option. The under-treated liquid discharge from a treatment system can have detrimental impacts upon flora and fauna at the point(s) of discharge, such as its impact upon marine ecosystem. Moreover, the benchmarking values for natural fresh water bodies are considered as the best management practices of natural resources.

The emissions of greenhouse gases (GHGs), ozone depletion substances (ODS) as well as other emissions such as sulfur and nitrogen oxides and volatile organic carbon (VOCs) are of particular concern. Accumulation of global climate forcing gases in the stratosphere threatens the global climate change. The depletion of ozone layer has the consequence of harmful UV (ultraviolet) rays to penetrate the atmosphere to have adverse effects on human health, animals, plants, micro-organisms, marine life, materials, biogeochemical cycles, and air quality. The emission of greenhouse gases is measured in CO_2 equivalent, using global warming potential (GWP) including energy and equipment emissions (footprint) and fugitive emissions (e.g. methane).

Theme: Liquid output/ Discharge

Most of the water used by the industries is discharged in degraded quality (DSD, 2001). The quality and quantity of the watery outputs from the treatment systems impacts the environment in different ways. The BOD (Biochemical Oxygen Demand) represents the biodegradable organic material and COD (Chemical Oxygen Demand) represents the total organic materials both of which indicate the amount of organic substances that are discharged to the environment through the treatment effluents. Treated water quality standards have been established to protect the environment and prevent adverse consequences of discharging the poor-quality treated water to water bodies. The presence of high BOD may indicate increases in particulate and dissolved organic carbon from non-human and animal sources that can pose a threat to ecosystem health. Metals (especially heavy metals) are a group of substances that can disturb the chemical composition of the water bodies and threaten the aquatic life

(Emmerson et al.,1995). Suspended solids are potential sources of pollution for the environment and they can also carry other hazardous organic and inorganic substances (Mels et al., 1999; Emmerson et al, 1995; Lundin et al., 1999). The flows of nitrogen and phosphorus to receiving waters that are responsible for eutrophication and depletion of oxygen in water bodies should be evaluated (Hellstorm et al, 2000). Also, the possibility of recycling nutrients from wastewater in agriculture is naturally an area of interest (Mels et al., 1999; Muga and Michelcic, 2008; Kamami et al., 2011). This indicator has the potential to illustrate the effectiveness of measurements of high nutrient inputs that can generate large concentrations of algae that restrict the available light and reduce dissolved oxygen levels for other organisms. Increasing concentrations of algae can be designed to reduce nutrient inputs in accordance with the goals of the Regional Seas Conventions and Action Plans (WCMC/NEP). It also indicates threats to human and animal health by toxic algal blooms.

Indicator: Quality of discharge watery waste

This is a measure of the quality of the liquids being discharged by the option (all output liquids discharged from the system including wastes including by-products and others). Local regulations / guidelines are applicable for including: BOD, COD, pH, TSS, N, P, heavy metals, toxicity (Muga and Michelcic, 2008; Kamami et al., 2011). Any post-treatment steps that may be required in order to meet the regulations can be included here (Emmerson et al., 1995).

Indicator: Quantity of discharge watery waste

This measures the amount of liquid output generated by the option including waste and by-products (DTO, 1994; ETC, 1996; Lundin and Morrison, 2002; Ødegaard, 1995).

Indicator: Re-use (can / will it be re-used reducing use of other sources)

This indicator measures the amount of liquid output that can be used for purposes other than disposal (Lundin et al., 1999; Butler and Parkinson, 1997). This is the percentage of liquid output that will be used for useful purposes rather than disposal. Recycling and reusing the liquids such as water saves a significant amount of energy (McMahon et al., 2006).

Theme: Solid outputs

The quality and quantity of the solid outputs from the treatment systems impacts the environment in different ways. Solids generated from the WWTP are now a big challenge for sustainability. Further treatment for solid waste thus produced is necessary before disposing to landfill or solid obligatory to manage waste management, which in turn requires more energy and cost (Lundin et al., 1999; Jacobs et al., 1996; Mels et al., 1999).

Indicator: Quality of solid waste

This is a measure of the quality of the solid being discharged by the option (all output solids discharged from the system including wastes including by-products and others). Local regulations / guidelines are applicable for including: BOD, COD, pH, TSS, N, P, heavy metals, toxicity (EPA, Ireland, 1997). Any post-treatment steps that may be required in order to meet the regulations can be included here.

Indicator: Quantity of solid waste

This measures the amount of solid output generated by the option including waste and by-products. The generation of industrial and municipal solid waste is derived from the production of waste on a weight basis at the point of production. Waste quantity produced varies from degree of treatment and treatment process used (Harrington, 1997).

Indicator: Re-use (can / will it be re-used reducing use of other sources)

This indicator measures the amount of solid output that can be used for purposes other than disposal. When sludge offers the potential for beneficial reuse, several methods of direct land application are in use, all of which require continual policing to enforce the necessary rules for application (Lundin and Morrison, 2002; Harrington, 1997).

Theme: Gaseous Outputs

The gaseous emissions of the option and their environmental effects should be evaluated. The emissions of greenhouse gases (GHGs), ozone depletion substance (ODS) as well as other emissions such as sulfur and nitrogen oxides and volatile organic carbon (VOCs) are of particular importance. The emission of greenhouse gases is one of the major environmental concerns. Accumulation of global climate forcing gases in the stratosphere, threatens to change climates on a global scale. The depletion of ozone layer has the consequence of harmful UV (ultraviolet) rays to penetrate the atmosphere to have adverse effects on human health, animals, plants, micro-organisms, marine life, materials, biogeochemical cycles, and air quality (Bradley et al., 2000; Lundin and Morris, 2002).

Indicator: GHG emissions

It consists of anthropogenic emissions of the greenhouse gases, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), together with the indirect greenhouse gases nitrogen oxides (NOx), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs). Local regulations / guidelines should be considered for evaluation of this indicator.

Indicator: Air quality

Environmental pollution generated by the system is an important indicator of sustainability. The indicator provides a measure of the state of the environment in terms of air quality and is an indirect measure of population exposure to air pollution of health concern in urban areas. Ambient air pollution concentrations of ozone, carbon monoxide, particulate matter (defined as PM10, PM2,5, SPM, black smoke), sulfur dioxide, nitrogen dioxide, nitrogen monoxide, volatile organic compounds including benzene (VOCs) and lead. Use of ozone-depleting substances (ODS) such as CFCs should be prohibited. Local regulations / guidelines should be considered for evaluation of this indicator. Table 3.6 shows the references of indicators of output of the system of WWTP, which includes quality and quantity of liquid discharge, solid discharge and gaseous output of the WWTP. Table 3.7 shows the scoring scheme of environmental indicators of output to the system and their scoring scheme along with whether qualitative or quantitative indicators.

Table 3.6 References of indicators of output to the system

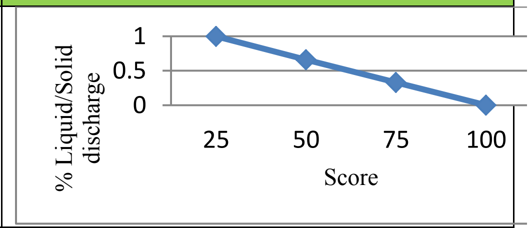
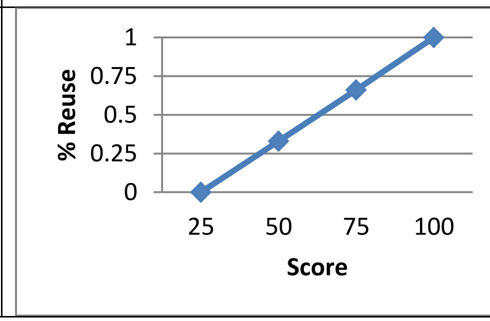
Theme	Indicator	References					
		GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Environment Dimension (Output to the system)							
Liquid outputs / discharge	**Quality of liquid waste discharge**	EN21 Total water discharge by quality and destination	EN-14: Measurements of BOD on water bodies affected by project during all phases EN-11: Measurements of changes in algae concentrations		Treatment Standards - EMS (Improve Quality of Treated WW)	Wastewater Treatment Effectiveness Rate (quantifies a utility's compliance with the effluent quality standards in effect at each of its wastewater treatment facilities)	wEn1 (WW TP compliance with discharge consents)- wOp44 (WW quality tests carried) wOp45 (BOD tests), wOp46(COD tests), wOp47 (TSS tests), wOp48(total phosphorus tests), wOp49 (nitrogen tests), wOp 50 (fecal E.coli tests), wOp51 (other tests)
	Quantity of liquid waste discharge	EN21 Total water discharge by quality, destination			EMS (Waste Reduction)	Total volume processes (millions of gallons) in the period of study	
	Re-use	EN10 Percentage and total volume of water recycled and reused.	EN 13 Measurements of water usage on project during all phases EN 14 Effects of project on BOD in water bodies		Water recycled and reused according to the guidelines		wEn2 (WW reuse)

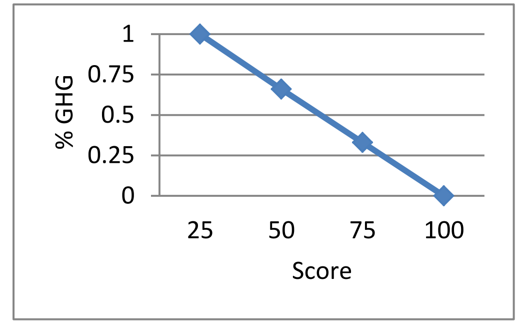
Theme	Indicator	References					
		GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Environment Dimension (Output to the system)							
Solid outputs	**Quality of discharge solid waste**	EN2 Percentage of material used by weight or volume. EN21 Total water discharge by quality and destination EN22 - Total weight of waste by type and disposal method.	EN14 Measurements of BOD on water bodies affected by project during all phases EN-11:Measurements of changes in algae concentrations	Managing and reducing wastes.	According to the biosolids guidelines - EMS (reduction of solid waste)	Wastewater Treatment Effectiveness Rate (quantifies a utility's compliance with the effluent quality standards in effect at each of its wastewater treatment facilities)	wOp52 (sludge tests carried out), wOp53 (industrial discharges tests carried out)
	Quantity of discharge solid waste	EN22 Total weight of waste by type and disposal method.		Managing and reducing wastes.	According to the biosolids guidelines		wEn6(sludge production), wEn14 (solid waste from screens and grit), wEn 12 (sediments from sewers), wEn13 (sediments from ancillaries) wEn15 (sediments from on-site systems)
	Re-use	EN2 Percentage of materials used that are recycled input materials.		Managing and reducing wastes.	Tons of solid waste generated and solid waste recycled per capita (according to the biosolids guidelines)		wEn6(sludge utilization)

Theme	Indicator	References					
		GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Environment Dimension (Output to the system)							
Gaseous outputs	**GHG emissions**	EN16 Total direct and indirect greenhouse gas emissions by weight. EN17 Other relevant indirect greenhouse gas emissions by weight. EN18 Initiatives to reduce greenhouse gas emissions and reductions achieved.	EN-1: Quantities of GHGs emitted in all phases of project.	GHG Emissions	EMS (Reduce Air Pollution)		
	Air quality and quantity	EN19 Emissions of ozone-depleting substances by weight. EN20 NO, SO, and other significant air emissions by type and weight.	EN-1: Quantities of GHGs emitted in all phases of project. EN-2: Quantities of ozone-depleting substances used in all phases of project. EN-3: Quantities of key air pollutants emitted in all phases of project.	Air Quality	Days in the past year with Air Quality Index (AQI) in the good range - EMS (Reduce Air Pollution)		

[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

Table 3.7 Scoring scheme of the environmental indicators of output to the system

<table>
<tr><th>Indicator</th><th>Qualitative Quantitative</th><th colspan="4">Scoring Scheme</th><th>Performance Curve</th></tr>
<tr><td>Quantity of liquid/ solid waste discharge</td><td>Quantitative</td><td colspan="4">Regressive, Linear Relationship</td><td>
</td></tr>
<tr><td rowspan="2">Quality of liquid/ solid waste discharge</td><td rowspan="2">Qualitative</td><td>0</td><td>33</td><td>66</td><td>100</td><td rowspan="2"></td></tr>
<tr><td>Option meets regulatory requirements only.</td><td>Discharge quality surpasses regulatory requirements</td><td>Discharge quality significantly surpasses regulatory requirements</td><td>Discharge meets industry best-practice standards and guidelines</td></tr>
<tr><td>Re-Use</td><td>Quantitative</td><td colspan="4">Positive, Linear Relationship</td><td>
</td></tr>
</table>

Indicator	Qualitative Quantitative	Scoring Scheme					Performance Curve
GHG	Quantitative	GHG Calculator developed by GoldSET.					
Environment Management Track Record	Qualitative	0	25	50	75	100	
		Company has no EMS but track record of meeting regulatory requirements.	Company has basic EMS and track record of meeting regulatory requirements	Company has basic EMS and track record of implementing sustainable environmental practices above regulatory requirement	Company has detailed EMS and track record of implementing sustainable environmental practices above regulatory requirements	Compliance with ISO14001-2004 and ISO14004-2004 standards, and to industry best-practice guidelines	

3.2.2 Social Dimension

The social dimension represents the people's social-cultural and spiritual needs which have to be secured in an equitable way with stability in human relationships and institutions. This dimension builds upon human relations and the need for people to interact and to organize their society with respect to the option's activities and its organizational interactions with the society. The social issues relating to sustainable development comprise the knowledge and conduct of the population, their health and integrated sustainable development management.

A system can function in a socially sustainable approach if its presence contributes to the welfare of society and if the affected population has some control over its actions. Facilities and procedures that are not fairly managed will not be sustainable because they will lack community support. Furthermore, potential impacts should be transparent and communicated to the stakeholders. Decisions must be made with public input and be given serious consideration.

Theme: Health and Safety

Health and safety of the community especially workers related to the option's treatment activities are very important. The operation should be safe with minimum hazard potentials for the public and workers (Fiksel, 2002).

Indicator: Public Health & Safety

It evaluates the potential impacts of the project on public. Any negative impacts on public (residents, transients) safety should be avoided (Augudelo et al., 2007). Evaluation is to be based upon the track records of the option on similar circumstances.

Indicator: Workers Health & Safety

It evaluates the potential impacts of the option for the health and safety of the corporation and contractor staffs. Any negative impacts for the health and safety of the corporation and contractor staff (accidents, time off, illness, etc.) include indoor air quality should be avoided. Evaluation is to be based upon the track records of the option on similar circumstances (Agudelo et al., 2007).

Indicator: Hazardous materials

This accesses the extent the hazardous material used and/or generated by the option. Use of any hazardous materials (to human health) on site should be avoided. Classification is made based on the UN Globally Harmonised System and Classification and Labelling of Chemicals (GHS) using the information presented on MSDS (GRI-G3, 2011).

Theme: Impact on Local Community

This category represents the relationship of the residents to the wastewater system. In particular, it examines whether the burdens and benefits of the system are equitably distributed, as well as the extent of stakeholder involvement in the process and other wastewater system activities. It also measures how the wastewater system contributes to the economy of the city. Job creation and contribution to the community's economy and provision of valuable services are examples of options social benefits (Bradley et al., 2000). The option should be acceptable regarding the local culture and historic buildings. Also, it should not introduce an unpleasant image to the community.

Indicator: Economic Advantages for the Local Community

Direct economic values generated include revenues, operating costs, employee compensation, donations and other community investments, retained earnings, and payments to capital providers and governments (York region, 2008; Diagger, 2004).

Indicator: Existing local business (excluding contractors and suppliers)

Local employment opportunities and the degree to which the system generates employment is an important aspect of option's evaluation. This may include direct and indirect economic effects the implementation of specific options including positive opportunities for local business generation and negative effects on existing business (Ulrika et al., 2005; ETC, 1996). This indicator may need to be split if there are important local business sectors that may be individually affected (e.g. tourism) (Hellstorm et al., 2007).

Indicator: Local job creation and diversity

This category measured how the wastewater system contributes to the economy of the city. One important measure was the degree to which the system generates employment (Diagger et al., 2004). Another important measure was the contribution the system makes to the city's economy through its own economic efficiency and provision of valuable services (Von Stalk et al., 2006). This assesses the intensity of local job creation and encourages the participation of individuals.

Indicator: Community support for the option/project

The knowledge of the public from the options and degree of acceptance is important for the selection of the option. The more the public is aware of the treatment systems, the more confidence they have about the option's related activities and the higher level of positive attitude towards a system. This is especially important when the public is sensitive about the health and safety issues.

Theme: Management

It is important that the option employs the management programs in its organization. It describes the status of the implementation of good management practices, especially organizations with advanced knowledge and experience with applying these tools. Correlations with other indicators could indicate the relationship between the organization's performances with investments in improved management practices. Ranking of company's track record in delivering socially acceptable projects, development of CSR (Corporate Social Responsibility) plan involves the local community and the level of community consultation/participation in the development of the project.

Indicator: Management practices

The degree of integration of best management practices regarding environmental and social performance (minimal use of natural resources and water, renewable energy and energy efficiency, treatment surpassing the applicable criteria, promotion of the 3Rs, transparency, etc.). The option with certified management practices is preferred. A structured and organized ability to divide and manage responsibilities, discussions, conflicts, etc. and make decisions, involve stakeholders is essential for the integrity of the organization. The organizational hierarchy should be clearly documented for the stakeholders. Institutional capacity also can be related to any kind of legislative hindrance to implement the system. A self-scoring scheme might be employed based on the seven aspects of best management practices. These seven aspects are:

1- Strategic Planning
2- Long-Term Financial Planning
3- Risk Management Planning
4- Performance Measurement System
5- Optimized Asset Management Program
6- Customer Involvement Program

7- Continuous Improvement Program

Table 3.8 demonstrates the summary of the theme, indicators of social dimension and their references as coded as in GRI-G3, FIDIC, EC, US EPA, AWWA and IWA. Similarly indicators are distinguished as qualitative and quantitative and their scoring is shown in Table 3.9.

Table 3.8 Summary of indicators for social dimension

Theme	Indicator	Reference					
		GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Health and Safety	**Public Health & Safety**		SO8 - Record of safety performance during construction SO11 - Change in prop. & no. of populations in formal & informal settlement.	Public Health	Overall protection of human health and the environment	Risk Management (minimizing risks to public health and safety)	
	Workers Health & Safety	LA7 - Rates of injury, occupational diseases, lost days, absenteeism, & no. of work-related fatalities by region LA8 - Education, training, counseling, prevention, & risk control programs in place to assist workforce members, their families, or community members regarding serious diseases. LA9 - Health and safety topics covered in formal agreements with trade unions. PR2 - Number of incidents of non-compliance with regulation and voluntary codes concerning h&s impacts of products and services	SO-8 - Record of safety performance during construction.		Overall protection of human health and the environment	Employee Health and Safety Severity Rate (measures lost workdays per employee per year. It is identical to that contained in OSHA Form 300A and already recorded by utilities in the United States)	wPe18 (vaccination), wPe20 (working accidents), wPe21 (personnel working fatalities), wPe23 (absenteeism due to accidents or illness at work), wOp55 (gas detectors), wOp56(permanently installed gas detectors)
	Hazardous materials	LA9 - Health and safety topics covered in formal agreements with trade unions.			Manage Hazardous Materials		wPe18 (vaccination)
Impacts on local community	**Local Job Creation & Diversity**	EC7 - Procedures for local hiring and proportion of senior management hired from the local community at locations of significant operation. LA1 - Total workforce by employment type, employment contract, and region.	SO1: Proportion of local workers, companies employed on the project, as compared to other workers, company	Employment	EMS (Positive Impacts on Community)		wPe1 (personnel in WWT per population equivalent)

Theme	Indicator	GRI-G3	FIDIC	EC	US EPA	AWWA	IWA
Impacts on local community	**Community support for the option/ project**		SO-12: Assessment of impacts on local culture, historic buildings		EMS Community Contribution and Input)		
Nuisance	**Impact of construction work on the community**	SO1 Percentage of operations with implemented local community engagement, impact assessments, and development programs.			Reduced Impacts on Community		
	Impact of operations on the community	SO1 Percentage of operations with implemented local community engagement, impact assessments, and development programs.	SO-13: Degree to which the project displaces the local population		Reduced Impacts on Community		wQS19 (total complaints) wQS22 (pollution incidents complaints), wQS23 (odor complaints) wQS24 (rodents-related complaints), wQS25 (customer account related complaints), wQS26 (other complaints)
Manageme nt	**Management Practices**	EC8 - Development and impact of infrastructure investment and services provided primarily for public benefit through commercial, in kind, or pro bono engagement.			EMS Community Contribution and Input)	Organizational Best Practices Index[1]	wQS27 (response to complaints)

[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

Table 3.9 Scoring scheme of the social indicators

Indicator	Qualitative/ Quantitative	Scoring Scheme					Performance Curve
Public/Worker Health and Safety	Qualitative	0	33	66	100		
		Option meets all applicable public health and safety laws and regulations, and involves technologies or methods for which no health and safety regulations exist.	Option meets all applicable public health and safety laws and regulations and involves no unregulated health and safety concerns.	Option surpasses regulatory requirements	Meets industry best-practice standards and guidelines.		
Hazardous Material	Qualitative	0	33	100			
		Use of materials assigned the signal word "danger"	Use of materials assigned the signal word "warning"	No use of materials with an assigned signal word			
Economic Advantages for the Local Community	Qualitative	0	25	50	75	100	
		No portion of goods and/or services will be provided by local businesses.	0-25% of goods and/or services will be provided by local businesses.	25 - 50% of goods and/or services will be provided by local businesses.	50 - 75% of goods and/or services will be provided by local businesses.	>75% of goods and/or services will be provided by local businesses.	

Indicator	Qualitative/ Quantitative	Scoring Scheme					Performance Curve
Local Job Creation & Diversity	Qualitative	0	25	50	75	100	
		Negligible impact on employment opportunities for locals	Significant (>25% or more of the labour component of the total budget) temporary or seasonal employment opportunities for locals.	Significant, temporary or seasonal employment opportunities for locals, including deliberate efforts to hire minority and/or low-income groups.	Significant, permanent employment opportunities for locals.	Significant, permanent employment opportunities for locals, including deliberate efforts to hire minority and/or low-income groups.	
Community support for the option/project	Qualitative	0	25	50	75	100	
		Large negative public sentiment against the option. e.g. group complaints, local media reports / campaign	Small negative public sentiment against the option. e.g. Individual complaints	No identifiable public sentiment	Small positive public sentiment in favour of the option. e.g. individual submissions of support.	Large positive public sentiment in favour of the option. e.g. group submissions of support, campaigns.	
Nuisance	Qualitative	0	25	50	75	100	
		High nuisance level	Med nuisance level, long duration (ave. >1 week/month)	Med nuisance level, med duration (ave. 1 day - 1 week/month)	Med nuisance, short duration (ave. <1 day/month)	Low nuisance level	
Management	Qualitative	'Company has no CSR policy	Company has basic CSR policy	Company has basic CSR policy and track record of implementing social practices above regulatory requirements.	Company has detailed CSR policy and track record of implementing social practices above regulatory requirements.	Compliance with ISO standards, and to industry best-practice guidelines	

3.2.3 Economic Dimension

Economic sustainability is a very important element of sustainable development. It allows making sustainable changes and economic growth at reduced environmental impact. In other words, economic growth and environmental impact must be decoupled through improved eco-efficiency. Economic policy and market mechanisms must be applied in support of sustainable development. Regarding the importance of tools such as legislation, public awareness etc., the economy is a very powerful tool for sustainable development. It provides efficient incentives for making choices for sustainable development.

Traditional economic indicators focus on the economy apart from other areas of people's daily lives. Such indicators often measure all economic activities regardless of their possible (positive or negative) effects on the quality of life, or the quality of the local environment. This category of indicators considers a broad range of parameters related to the quality of life and the environment. The analysis sought to connect options of the wastewater treatment systems to local economic development. The indicators focus on economic impacts on the community while evaluating the financial performance of the options.

Economic sustainability implies that all costs for any activity must be taken into account when economic and business decisions are made. This includes in particular long term environmental costs as well as social costs. With regards to the economic dimension, it is important to identify the sustainable economic drivers that influence the project and to determine whether or not the project in itself makes any kind of contribution for the establishment of economic tools for sustainable development

Theme: Economic Performance

All costs associated with the option from the project stage to the service stage are considered, since they are important for the total cost evaluation. These costs are associated with Net Present Value (NPV), project cost, capital cost, operation and maintenance costs, decommissioning cost, the user cost, discharge cost, energy costs, chemical cost, cost of replacement of equipment and potential financial burdens associated with the option. All costs associated with the option from the project stage to the service stage are important for the cost evaluation. The option may have the potential for receiving public or private grants or subsidies (tax credits for R&D, government grants or subsidies) or potential third party recovery.

Indicator: NPV (Total project cost)

It measures the present value of total costs associated with the project implementation. It includes capital cost, operation and Maintenance (O&M) Costs, User Cost, decommissioning cost over the life of the project. It is quantitative indicator and it is calculated using NPV Calculator. The per capita monthly cost of overall treatment should be minimized. However, it should not compromise the efficiency of the treatment option.

Indicator: Financial Recoveries

This evaluates whether a project has a potential for receiving public or private grants or subsidies (tax credits for R&D, government grants or subsidies) or potential third party recovery (Fiskel, 2002).

Theme: Land Use

The cost associated with the use of the land by the option that could otherwise be used for other purposes (past or present) is considered. The economic value of the land covered by the footprint of the option (e.g. lagoon vs activated sludge system) is a determining factor (Morford, 2007). The economic value of the land used by the implementing the option as opposed to be used for other developments (Wiggering et al., 2006).

Indicator: Land use

This is the cost associated with the use of the land by the option that could otherwise be used for other purposes (Haberl and Schandl, 1998;, Kroll et al., 2009).

Theme: Construction

The option should be easy to build with easily available resources and legal requirements, such as the ease of obtaining necessary permits, construction machinery, transportation, etc.

Indicator: Ease of obtaining necessary permits

This indicator assesses the costs associated with obtaining the necessary permits and associated potential delays (to the project and production) and how difficult it will be to obtain the necessary approvals and permits required for the discharge for the option (Niemczynowicz, 1994).

Indicator: Interference with activities on site

This assesses the economic cost of disruption of routine site activities during the implementation of the option.

Theme: Logistics

The extent of logistics associated with the implementation of the option should be determined and available. Logistics involves the integration of information, transportation, inventory, warehousing, material handling, and packaging, and security. Today the complexity of production logistics can be modeled, analyzed, visualized and optimized by plant simulation software.

Indicator: Logistics

The required logistics and associated costs for the option should be available (Fiksel, 1994).

Table 3.10 Summary of references of economical indicators

Theme	Indicator	Reference				
		GRI-G3	**FIDIC**	**US EPA**	**AWWA**	**IWA**
Economic Performance	**NPV (Total Project Cost)**	EC1 Direct economic value generated and distributed, including revenues, operating costs, employee compensation, donations and other community investments, retained earnings, and payments to capital providers and governments.	EC-1: Extent to which the project provides economic benefit to the local economy EC-14: Extent to which the facility requires care and maintenance, compared to norms	EMS (Reduction of Costs)	Operations and Maintenance Cost Ratios (tally the cost of operations and maintenance and relate them on per account and per millions of gallons of wastewater processed bases)	wFi5 [Unit total costs (running plus capital)per population equivalent], wFi7 (Unit running costs per population equivalent), wFi15 (other running costs)
	Financial Recoveries	EC2 - Financial implications and other risks and opportunities for the organization's activities due to climate change. EC4 Significant financial assistance received from government. EC9 - Understanding and describing significant indirect economic impacts, including the extent of impacts.		EMS (Cost Savings)	Return on Assets	
Land use	**Land footprint**	EC1 Direct economic value generated and distributed, including revenues, operating costs, employee compensation, donations and other community investments, retained earnings, and payments to capital providers and governments.				

Theme	Indicator	GRI-G3	FIDIC	US EPA	AWWA	IWA
Construction	**Ease of obtaining necessary permits**		EC-6: Disposition of industrial and municipal wastes compared to norms, other practices	Reduce Permitting Costs and Uncertainty		
	Interference with activities on site	EC9 Understanding and describing significant indirect economic impacts, including the extent of impacts.				
Logistics	**Logistics**			Vehicle Miles Traveled		wQS29 (traffic disturbances)

[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

Table 3.11 Scoring scheme of the Economical Indicators

Indicator	Qualitative/ Quantitative	Scoring Scheme					Performance Curve
NPV	Quantitative	NPV Calculator					
Financial Recoveries	Qualitative	0	25	50	75	100	
		No potential for financial recovery	Potential recovery of 0 -10% of total cost	Potential recovery of 10 -20% of total cost	Potential recovery of 20 -30% of total cost	Potential recovery of over 30% of total cost	
Land footprint	Quantitative	Regressive, linear relationship					
Ease of obtaining necessary permits	Qualitative	0	25	50	75	100	
		Difficulties expected in obtaining many permits	Difficulties expected in obtaining a small number of permits	Permit approval expected to be conditional for a small number of permits	Approval process expected to be straightforward		
Interference with activities on site	Qualitative	0	25	50	75	100	
		Major delays (>1day)	Moderate (1h - 1 day) > 1 / week	Moderate (1h - 1 day) < 1 / week	Minor (<1 h) > 1 / week	No anticipated impact	
Logistics		0	33	66	100		
		More complicated logistical requirements. Many previously unused suppliers	More complicated logistical requirements. Some previously unused suppliers	Simple logistical requirements. Some previously unused suppliers	Simple logistical requirements. Option uses previous logistic supply chain		

3.2.4 Technical Dimension

This dimension provides tools to compare the technical aspects of the various options and provides a decision-making tool to investigate which option can provide the best durable service for the community while being simple to apply with minimum complexity and technical difficulties. Selection of a sustainable technology is associated with using technologies that have low cost, are appropriate to the local financial and geographical conditions and within the technical capacity of the benefiting community. The required technology should be easily available and there should be proven cases of successful application of the technology for similar treatment objectives with regional and environmental similarities. It should be able to meet the relevance regulations and treatment requirements. Technical systems can fail due to technical problems such as mechanical failures; however, such events should be minimized and the systems must be capable of recovering without excessive cost or effort. The scoring can be done based on the past performance of the technology and provisions of the option to cope with any service interruptions, such as an emergency.

Theme: Performance

This category measures the flexibility and adaptability of the treatment system to the changing environmental and seasonal effects, shock loadings, etc. It is an important measure of sustainability because it encourages continuous improvement and promotes innovation, while taking into account changes in future environmental and technological conditions. A more complex technology is likely to require more complex equipment and higher degree of maintenance, which, in turn, requires a highly skilled workforce. This can increase the maintenance cost and unavailability of the technical personnel. Moreover, more complex designs can lead to unforeseen issues arising in later project stages. A technology with lower design complexity and compatible with the social and educational capacity of the community is preferred.

The performance evaluation of the option should be done in an effective way. This evaluation will be:

1- Multi-dimensional, utilizing appropriate measures for internal and external stakeholders, supporting both routine work and special projects, and offering integrated measurement systems responsive to the needs of line employees, management, and executives.
2- Have a process for establishing targets, usually in conjunction with the budgeting process, reflect broad internal, external, financial, and improvement goals in strategic and operating plans,
3- Provide measures focused on quality, efficiency, and effectiveness, and
4- Include a routine monitoring and reporting process

Tools such as Utility Business Process Framework, the Kaplan and Norton Balanced Scorecard, and the Government Accounting Standards Board (GASB) performance measurement framework offer useful outlines for organizing a measurement system (AWWA guidelines).

Indicator: Technical performance

The required technology should be easily available and there should be proven cases of successfully applied technology for the similar treatment objectives with the regional and environmental similarities. This indicator accesses the reliability of technology to meet the project goal.

Indicator: Durability

Durable systems are those that can provide their service even when unexpected events occur such as disruption in the electricity service or a sudden temperature drop. Technical systems can fail due to technical problems such as mechanical failures but such events should be minimized and the systems must be capable of recovering without excess cost or effort (Balkema et al., 2002; ETC, 1996). This indicator access the durability of option. It also evaluates the long-term durability of the project option. The assessment is to be based upon proven or tested performance in similar environments.

Indicator: Flexibility/Robustness

This indicator measures the flexibility and adaptability of systems to changing environmental and seasonal effects, shock loadings, etc. It is an important measure of sustainability because it encourages continuous improvement and promotes innovation, while taking into account changes in future environmental and technological conditions (Agudelo et al., 2007; Balkema et al., 2002; Butler and Parkinson, 1997). This is qualitative indicator and scoring is done as small, medium and large that are to be defined in the context of individual systems. Suggested values are: small=<1 h@15% additional load/flow; medium =<1 h to 1 day @ 15% additional load/flow; large=<1 h to 1 day @ 25% additional load/flow. These definitions should be refined during testing phase.

Indicator: Technical Uncertainty

The level of technological uncertainty associated with the success of the option in achieving the overall objectives based on the previous experience with the technique (Niemczynowicz, 1994). Appropriate measures can be recommended to reduce technical uncertainty related to performance (Diagger, 2004). It measures the confidence associated with the option through previous proven implementation and measurement. Appropriate measures can be recommended to reduce technical uncertainty such as small scale trials.

Theme: Operation and Maintenance

The treatment option should be working with minimum requirements for maintenance as any interruption in the process would have adverse impacts on the environment. The option should have secure measures to minimize the impacts due to system maintenance (Metcalfe and Eddy, 2003).

An appropriate technology to the local financial and geographical conditions is preferred. A technology suitable to the technical capacity of the benefiting community that can provide training to local communities so that they can carry out operation and maintenance work themselves. This ensures that communities can sustain their projects after the installation and start-up of the system with possibilities to extend or replicate their projects in the future

(Kamal et al., 2008). Technologies should use locally sourced materials and spare parts which can be easily purchased and transported. A good and reliable technology with the minimum frequency and level of required maintenance is preferred.

Indicator: Maintenance - level required (frequency and complexity)

The treatment option should be working with minimum requirements for maintenance as any interruption in the process would have adverse impacts on the environment. The option should have secure measures to minimize the impacts due to system maintenance. A more complex technology is likely to require more complex equipment and higher degree of maintenance which in turn, requires highly skilled workforce. This can increase the maintenance cost and unavailability of the technical personnel (Metcalfe and Eddy, 2003).

Indicator: Operation - level required (frequency and complexity)

The treatment option should be working with minimum requirements for operation as any interruption in the process would have adverse impacts on the environment. The option should have secure measures to minimize the impacts due to system operations (Ødegaard, 1995). A more complex technology is likely to require more complex equipment and higher degree of operation which in turn, requires highly skilled workforce. This can increase the operation cost and unavailability of the technical personnel (Main, 2011).

Theme: Complexity

The option should be constructed with minimal complexity and in a minimum time period to minimize the possible adverse environmental impacts during the construction stage as well as those due to absence of the properly-treated wastewater (Bracken et al., 2005). The option should be capable of being upgraded in the future along with the development of the community. This should be clearly predictable with foreseeable management plans for a given period of time (Niemczynowicz, 1994). The level of complexity of the design is an important factor to select the technology. More complex designs may lead to unforeseen issues arising in later project stages.

Indicator: Design complexity

A technology with less design complexity and compatible with the social and educational capacity of the community is preferred. This defines the level of complexity of the design (Bracken et al., 2005; Murray et al., 2009).

Indicator: Construction Complexity

The option should be constructed with the minimum complexity and in a minimum time period to minimize the possible adverse environmental impacts during the construction stage (Niemczynowicz, 1994). Technologies are preferred to include locally sourced materials and spare parts which can be easily purchased and transported (Braken, 2005).

Theme: Upgradability

An appropriate technology to the local financial and geographical conditions is preferred. A technology suitable to the technical capacity of the benefiting community that can provide training to local communities so that they can carry out operation and maintenance work themselves (Butler et al., 1997). This ensures that communities can sustain their projects after the installation and start-up of the system with possibilities to extend or replicate their projects in the future. The option should be able to be upgraded in the future along with the development of the community (Balkema et al., 2002). This should be clearly predictable with foreseeable management plans for a given period of time.

Indicator: Upgradability

Appropriate measures can be recommended to measure the upgradability of the option. The level of technological uncertainty associated with the success of the option in achieving the overall objectives based on the previous experience with the technique. The project should be able to upgraded (Bengtsson et al., 1997).

Table 3.12 References for the Technical Indicators

Theme	Indicator	Reference			
		FIDIC	EC	AWWA	IWA
Performance	**Technical performance (reliability)**			Wastewater Treatment Effectiveness Rate (MGD WW processes per employee) - Improved labor efficiency.	wQS2 (resident population served by WWTP wQS5 (treated WW in WWTP), wQ56 (preliminary treatment), wQS7 (primary treatment), wQS8 (secondary treatment), wQS9 (tertiary treatment)
	Durability	EC-13: extent to which durable materials were specified. Design for extended service life.			
	Flexibility/Robustness		Flexible approach in environmental measurement		
	Technical Uncertainty			Sewer Overflow Rate (measures the condition of the sewerage collection system and the effectiveness of maintenance activities. It is expressed as the ratio of the number of overflows per 100 miles of collection piping)	wEn3, 4, 5 (Intermittent overflow discharge)
Upgradability	**Upgradability**				wPh1 (preliminary treatment utilization), wPh2 (primary treatment utilization), wPh3(secondary treatment utilization), wPh4(tertiary treatment utilization), wPh9 (pump power utilization in WWTP), wPh11 (automation degree), wPh12 (remote control degree)

Table 3.13 Scoring scheme of the Technical indicators

Indicator	**Qualitative/ Quantitative**	**Scoring Scheme**			
Technical Performance Reliability	Qualitative	0	33	66	100
		Unproven reliability to achieve design criteria - pilot testing required / underway.	Proven reliability to achieve design criteria for other applications. For previous unproven durability reliability - pilot testing completed.	Proven reliability to achieve design criteria in similar applications / environment	Direct past experience proving reliability at a satisfactory level for similar applications
Flexibility/Robustness	Qualitative	0	33	66	100
		System cannot process elevated loadings and flows above design criteria	System can process small elevated loadings and flows above design criteria	System can process medium elevated loadings and flows above design criteria	System can process large elevated loadings and flows above design criteria
Technical Uncertainty	Qualitative	0	33	66	100
		New technology. No track record. No experience with pilot testing.	New technology, pilot testing in site conditions completed. Existing technology without previous application to these project conditions	Technology in broad industrial use. No previous experience (directly) using.	Previous experience with use / implementation of the technologies
Design complexity	Qualitative	0	33	66	100
		Consultant, new or bespoke design.	Consultant, standard design (greater than 240 hours)	Standard design, consultant. (under 240 hours)	Package plant - minor design required (under 40 hours).

Indicator	Qualitative/ Quantitative	Scoring Scheme				
Operation/Maintenance - level required (frequency and complexity)	Qualitative	0	25	50	75	100
		Project operations do not have the required skills and availability at the site to undertake required maintenance activities. External contractors required at high frequency to perform maintenance activities.	Project operations have the required skills and availability at the site to undertake some required maintenance activities. External contractors required at moderate frequency.	Project operations have the required skills and availability at the site to undertake most required maintenance activities. External contractors required at low frequency	Project operations have the required skills and availability at the site to undertake all required maintenance activities. External contractors not required.	Project operations have the required skills and availability at the site to undertake all required maintenance activities with specific maintenance staff dedicated to the site. External contractors not required
Construction complexity	Qualitative	0	33	66	100	
		Novel or advanced construction methods required.	Standard construction (greater than 240 hours)	Standard construction. (under 240 hours)	Package plant - minor on-site construction required (under 40 hours)	
Upgradability	Qualitative	0	33	66	100	
		Future expansion not feasible	Future expansion < 20% feasible	Future expansion > 20% feasible	Future expansion > 20% feasible	

[1]GRI (Global Reporting Initiatives). (2011). Sustainability Reporting Guidelines.
[2]Project sustainability management, International Federation of Consulting Engineers, (FIDIC, 2004).
[3]Environment Canada, (EC, 2012) Complete list of environment Indicators.
[4] USEPA
[5]American Water Works Association. (AWWA, 2012). Benchmarking Performance Indicators.
[6]IWA Publishing, 2010. Quardos et al.

Chapter 4 Results

The assessment of sustainability for the options involved the following steps:

- Review of the literature to find which indicators have been used in the past to assess the sustainability of wastewater treatment plants.
- Selection of appropriate indicators for the options to be considered and regarding the local conditions.
- Preparation of a summarized list of themes and indicators.
- Interviews with the stakeholders to gather data to support indicator selection and scoring.
- Data evaluation and calculation of indicators.
- Evaluation of the likely performance of the alternatives and scoring.

Since the sustainability analysis intended to assess the impacts of wastewater treatment plants' activities over a wide range of criteria, the indicator framework comprised of both qualitative and quantitative indicators.

Both qualitative and quantitative scoring schemes were developed for the indicators to assess the relative merits of each option. It allows the module to be flexible and adaptable for both the preliminary investigations where data is not yet known or available, and the detailed analyses for projects where quantitative measurements are possible and the relevant data are available.

Quantitative indicators have both relative and absolute scoring schemes. Relative scoring schemes assign a score of zero to the lowest performing option, while assigning 100 to the best performing option. Absolute scoring schemes have a fixed scoring scale independent of the options, and score the options relative to this fixed scale. These fixed values were adopted from accredited organizations (UNEP, WHO, etc.) as benchmarking values for consumption of natural resources or concentration of pollutants in the media.

Table 4.1 General categories of developed sustainability indicators selected for the wastewater module

Environmental	Economic	Social	Technical
• Water use • Energyconsumption • Environmental toxicity • Impacts on biodiversity • Hazardous output • Liquid waste discharge • Re-use, recycle • GHG emissions • Air quality	• NPV (total project cost) • Capital costs • Operation and maintenance costs • Decommissioning costs • User costs • Financial uncertainty • Financial recoveries • Land footprint • Ease of obtaining necessary permits • Logistics	• Public health & safety • Worker health & safety • Hazardous materials • Local job creation and diversity • Management practices	• Durability • Reliability • Flexibility • Complexity • Upgradability

Some indicators could be empirically measured based on current information and some others could not be easily quantify. In particular, the flexibility and institutional capacity indicators historically demonstrated themselves to be difficult to quantify. However, qualitative analysis can lead to subjective quantification, and it is important to provide values for these indicators so that they are not disadvantaged in providing the overall assessment of sustainability. The four categories of sustainability along with their key indicators are summarized in Table 4.1.

Results and output module

The scoring scheme provides an effective mechanism to assess the performance of each option in all four dimensions of sustainability, generating a comparative graphical representation of each option's sustainability performance. The most sustainable option is portrayed by the largest, most balanced square with respect to the four axes of environmental, social, economic and technical performance as shown in Figure 4.1.

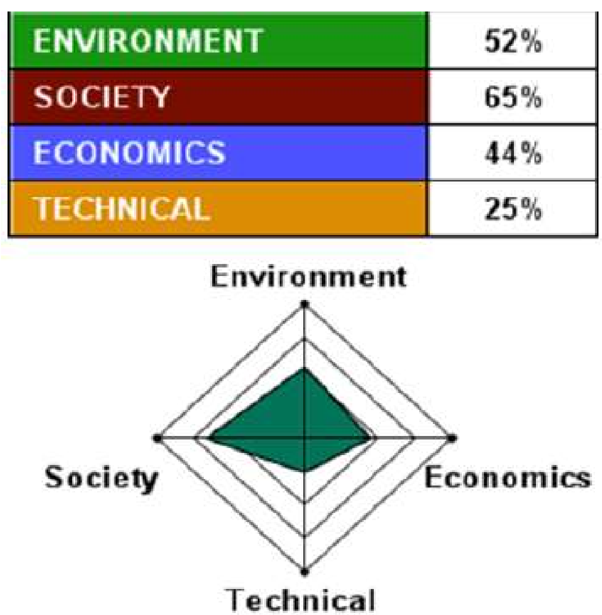


Figure 4.1 Graphical representation of the output results

The module can be customized for a specific or new application to optimize design decisions. Through this multi-criteria analysis framework, alternatives can be compared regarding environmental, economic, societal and technical aspects that are relevant to wastewater treatment decisions. It provides evaluations for different issues such as the lifecycle costs, regulatory risks, energy and greenhouse gas emissions, reuse opportunities, and social acceptability.

Chapter 5 Case Study

Golder Associates has developed a sustainability decision support tool “GoldSET” which helps to access sustainability benefits and trade-offs, improving the overall performance and productivity of projects. GoldSET is a reliable, customizable engineering tool that helps to ensure planning, designing and engineering leads of projects to sustainable practices. GoldSET provides a sustainability assessment framework that can be used to perform option analysis evaluating project- specific solutions. In order to facilitate the process, module or customised tool is developed in wastewater treatment process to evaluate project alternatives.

The “Project General Information” page of software module contains the name and location of the project, type of module, users, project summary, date and use of fourth dimension. There is a five stage systematic approach to transparent decision making.

Various options were evaluated for the domestic and industrial wastewater and storm water at an industrial yard in Minnesota, United States using wastewater module v1.0. Average inflow rate of the wastewater treatment plant is 230,000 liters per day. It is also a hub for other industries including petroleum pipelines and oil refining, rail and trucking also contributed to the contamination of the area of concern.

Industrial wastewater discharges through Outfall 102. Domestic wastewater discharges through Outfall 101.Water from these two outfalls mixes in a combining tank and discharge to unnamed drainage course via Outfall 003.The unnamed drainage course leads to an unnamed tributary to the Pokegama River. The Pokegama River discharges to St. Louis River Estuary approximately 1 1/2 miles northwest of Pokegama Yard.

Step 1- Project Description: Conceptualization of the site conditions

This contains the detailed description of project objectives and constraints, general site description, site geology and hydrogeology, receptors, risk and opportunities.

The goal of this evaluation is to determine whether wastewater management changes are warranted given the current low rates of wastewater generation and current costs to maintain and operate on-site treatment facilities in compliance with the Wisconsin Pollutant Discharge Elimination System (WPDES) permit. To attain this goal the following objectives were set:

- Evaluate the wastewater characteristics and current operations at the Pokegama Yards,
- Investigate feasibility of segregating various wastewater sources,
- Consider various treatment and disposal alternatives for wastewater,
- Prepare a cost estimate for the most promising alternate, and
- Compare the cost against current operating costs.

Step 2-Option Development

After knowing the detailed objectives of the project, water characteristics at input and discharge points, timing and duration of project, zoning and surroundings, above and below ground infrastructures, access to site, type of soil, surface and groundwater characteristics, sensitive concerns at receptors and distance, standards, laws and regulations, a number of options for treatment systems of wastewater is developed as in Table 5.1 and fatal flaw analysis was done according to various criteria:

- Industrial Wastewater Current System
- Industrial Wastewater Flow reduction System
- Industrial Wastewater Batch Operation
- Industrial Wastewater Replacement System
- Industrial Wastewater Holding Tank

Table 5.1 Fatal Flaw Analysis

Options	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System	Industrial Wastewater Holding Tank
Objective(s) met?	Yes	Yes	Yes	Yes	Yes
Technically feasible?	Yes	Yes	Yes	Yes	Yes
Timing & Duration constraints met?	Yes	Yes	Yes	Yes	Yes
Financially feasible?	Yes	Yes	Yes	Yes	Yes
Risks are acceptable?	Yes	Yes	Yes	Yes	Yes
Option is qualified?	Yes	Yes	Yes	Yes	Yes
Qualify anyway?	No	No	No		No
Justification	Yes	Yes	Yes	Yes	Yes
Status	Selected	Selected	Selected	Selected	Not Selected

A pre-feasibility assessment was performed to identify potential options. The options under consideration are listed in the table below. A selected option means that it has been qualified for further evaluation. Options are detailed next.

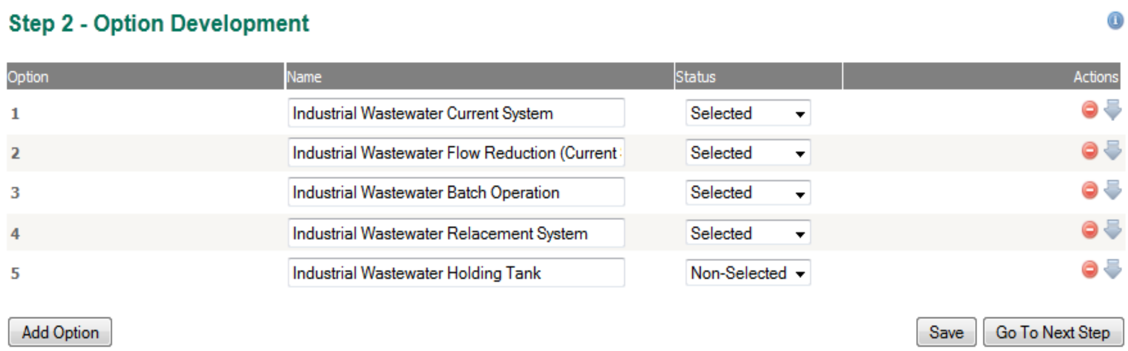


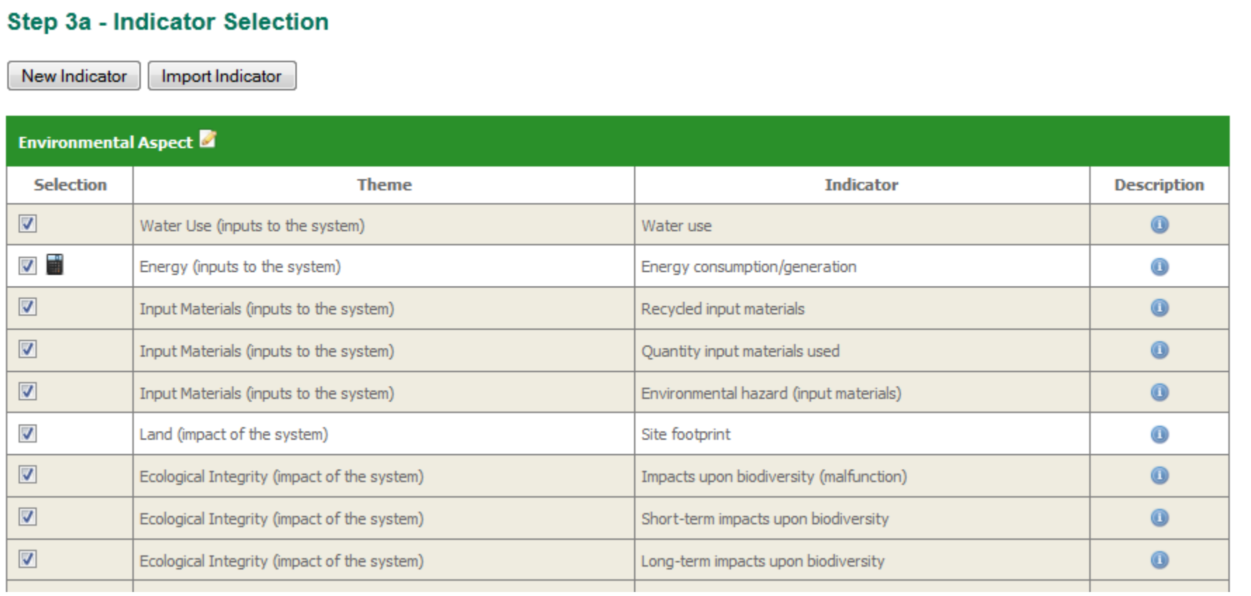
Figure 5.1 Option development (www.goldset.com, 2014)

More options can be added by "Add Option" tab. The most effective four options are selected as in "Status" tab. The detailed indicators are only analysed for the selected option of wastewater module.

Step 3a-Indicator Selection

A set of environmental, societal, economical and technical indicators was selected for each and every selected option described in this thesis. New indicators can be added and imported from the indicator bank in the GoldSET. Brief descriptions, references, goal of each indicator are also provided.

A set of indicators can be selected in this stage. If the specified indicator is not selected we can specify it by unchecking it in the selection column (Figure 5.2). A brief description of each indicator and its theme is also provided in the software system.



Step 3a - Indicator Selection

New Indicator | Import Indicator

Environmental Aspect

Selection	Theme	Indicator	Description
☑	Water Use (inputs to the system)	Water use	
☑	Energy (inputs to the system)	Energy consumption/generation	
☑	Input Materials (inputs to the system)	Recycled input materials	
☑	Input Materials (inputs to the system)	Quantity input materials used	
☑	Input Materials (inputs to the system)	Environmental hazard (input materials)	
☑	Land (impact of the system)	Site footprint	
☑	Ecological Integrity (impact of the system)	Impacts upon biodiversity (malfunction)	
☑	Ecological Integrity (impact of the system)	Short-term impacts upon biodiversity	
☑	Ecological Integrity (impact of the system)	Long-term impacts upon biodiversity	

Figure 5.2 Selection of Indicators (www.goldset.com, 2014)

Step 3b-Indicator Weighting

Indicators are weighted according to the importance for the client and level of concern to stakeholders. It is categorized as 1, 2 or 3 as in Figure 5.3 according to importance of the client and level of concern of stakeholders. For example if the level of concern to stakeholder is very high but importance for the client is low to moderate, then the indicator is weighted as 2. Then the software page looks as in Figure 5.4.

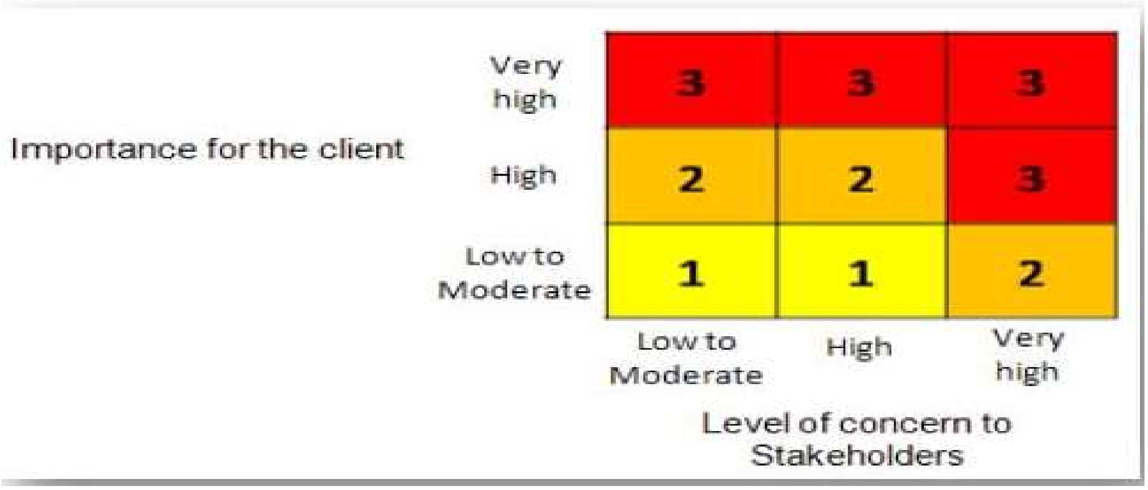


Figure 5.3 Weighting of Indicators in accordance with importance for the client and concern to stakeholders (www.goldset.com, 2014)

Step 3b - Weighting

Environmental Aspect		
Theme	Indicator	Indicator Weighting
Water Use (inputs to the system)	Water use	2
Energy (inputs to the system)	Energy consumption/generation	1
Input Materials (inputs to the system)	Recycled input materials	3
	Quantity input materials used	1
	Environmental hazard (input materials)	3
Land (impact of the system)	Site footprint	1
Ecological Integrity (impact of the system)	Impacts upon biodiversity (malfunction)	3
	Short-term impacts upon biodiversity	3
	Long-term impacts upon biodiversity	3
	Impacts upon habitat and/or land use (malfunction)	1
	Short-term impacts upon habitat and/or land use	1

Figure 5.4 Indicator weighting in GoldSET (www.goldset.com, 2014)

Step 4a-Quantitative Evaluation

Quantitative indicators evaluated by the actual quantity used by the system. For example to evaluate the energy consumption indicator, the actual amount of energy produced by certain system is calculated and computed. It has specific units of measurement and can be evaluated by a performance curve.

Step 4a - Quantitative Evaluation

Environmental Aspect

Code	Indicator	Units	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Relacement System
ENV-1	Water use	m3	12500	10000	4600	12500
ENV-2	Energy consumption/generation	GJ	1576.8	1354.55	1341.24	1290.16
ENV-3	Recycled input materials	%	0	50	0	0
ENV-4	Quantity input materials used	m3 or kg	0	2000	25	4000
ENV-6	Site footprint	m2	464	742	464	300
ENV-15	Quantity of solid ouput	m3 or kg	9000	7000	5000	7000
ENV-16	Solid output re-use	%	100	100	100	100
ENV-17	GHG emissions	t CO2 e.	311.42	265.7	264.77	251.13
ENV-20	Quantity of liquid waste discharge	m3	0	0	0	0
ENV-21	Liquid output re-use	%	0	0	0	0
ENV-22	Fuel / Oil recovered	kL	8	8	8	8

Figure 5.5 Evaluation of quantitative indicators (www.goldset.com, 2014)

As shown in Figure 5.5 the exact amount of each quantitative indicator is calculated for each selected options of WWTP. The GoldSET software has developed its own green house gas calculator (Table 5.2) and energy generation calculator (Table 5.3) to calculate the exact amount of GHG produced and energy generated (Table 5.4) by each option selected (Table 5.5,5.6,5.7,5.8). Also, for specific amount of cash flow calculation there is NPV calculator developed (Table 5.9) so we calculate and determine the quantitative economical issues easily from the software.

Table 5.2 Estimated GHG Emissions.

	Industrial WW Current System	Industrial WW Flow Reduction	Industrial WW Batch Operation	Industrial WW Replacement System
	t CO2 e.	**t CO2 e.**	**t CO2 e.**	**t CO2 e.**
Construction	0	0.992	0.0665	1.997
O & M	0	0	0	0
Decommissioning	0	0	0	0
Total	0	0.992	0.0665	1.997

Table 5.3 Estimated Energy Consumption.

	Industrial WW Current System	Industrial WW Flow Reduction	Industrial WW Batch Operation	Industrial WW Replacement System
	GJ	**GJ**	**GJ**	**GJ**
Construction	0	14.271	0.957	28.725
O &M	0	0	0	0
Decommissioning	0	0	0	0
Total	0	14.271	0.957	28.725

Table 5.4 Industrial Wastewater Current System - GHG Emissions & Energy Consumption.

Equipment	Qty	Data	Size	Energy Type	Power/Fuel Consumption	Energy Consumption (GJ PFE)	GHG Emission (t CO2 eq.)
Backhoe	0	0 h	580 K Backhoe	Diesel	9.3 L/h	0	0
Hauling	0	0 km	10 yard dump	Diesel	0.5 L/km	0	0
Base rate of current plant	1	100 %	Average Annual KW/yr	kW	5 kW	0	0
Bar Screen	0	0 %	Small	hp	0.5 hp	0	0
Comminutor	0	0 %	Small	hp	0.75 hp	0	0
Grit Removal	0	0 %	Small	hp	0.5 hp	0	0
Sludge Scraper	0	0 %	Small	hp	0.5 hp	0	0
Mechanical mixer (submersible)	0	0 %	Small	kW	1.2 kW	0	0

Table 5.5 Industrial Wastewater Flow Reduction (Current Sys) - GHG Emissions & Energy Consumption.

Equipment	Qty	Data	Size	Energy Type	Power/Fuel Consumption	Energy Consumption (GJ PFE)	GHG Emission (t CO2 eq.)
Backhoe	1	32 hr	580 K Backhoe	Diesel	9.3 L/hr	11.398	0.792
Hauling	3	50 km	10 yard dump	Diesel	0.5 L/km	2.872	0.199
Base rate of current plant	1	85 %	Average Annual kW/yr	kW	5 kW	0	0
Bar Screen	0	0 %	Small	hp	0.5 hp	0	0
Comminutor	0	0 %	Small	hp	0.75 hp	0	0
Grit Removal	0	0 %	Small	hp	0.5 hp	0	0
Sludge Scraper	0	0 %	Small	hp	0.5 hp	0	0
Mecahnical mixer (submersible)	0	0 %	Small	kW	1.2 kW	0	0

Table 5.6 Industrial Wastewater Batch Operation - GHG Emissions & Energy Consumption

Equipment	**Qty**	**Data**	**Size**	**Energy Type**	**Power/Fuel Consumption**	**Energy Consumption (GJ PFE)**	**GHG Emission (t CO2 eq.)**
Backhoe	0	0 hr	580 K Backhoe	Diesel	9.3 L/hr	0	0
Hauling	1	50 km	10 yard dump	Diesel	0.5 L/km	0.957	0.0665
Base rate of current plant	1	85 %	Average Annual kW/yr	kW	5 kW	0	0
Bar Screen	0	0 %	Small	hp	0.5 hp	0	0
Comminutor	0	0 %	Small	hp	0.75 hp	0	0
Grit Removal	0	0 %	Small	hp	0.5 hp	0	0
Sludge Scraper	0	0 %	Small	hp	0.5 hp	0	0
Mecahnical mixer (submersible)	0	0 %	Small	kW	1.2 kW	0	0

Table 5.7 Industrial Wastewater Relacement System - GHG Emissions & Energy Consumption.

Equipment	**Qty**	**Data**	**Size**	**Energy Type**	**Power/Fuel Consumption**	**Energy Consumption (GJ PFE)**	**GHG Emission (t CO2 eq.)**
Backhoe	0	0 hr	580 K Backhoe	Diesel	9.3 L/h	0	0
Hauling	15	100 km	10 yard dump	Diesel	0.5 L/km	28.725	1.997
Base rate of current plant	1	80 %	Average Annual kW/yr	kW	5 kW	0	0
Bar Screen	0	0 %	Small	hp	0.5 hp	0	0
Comminutor	0	0 %	Small	hp	0.75 hp	0	0
Grit Removal	0	0 %	Small	hp	0.5 hp	0	0
Sludge Scraper	0	0 %	Small	hp	0.5 hp	0	0
Mechanical mixer (submersible)	0	0 %	Small	kW	1.2 kW	0	0

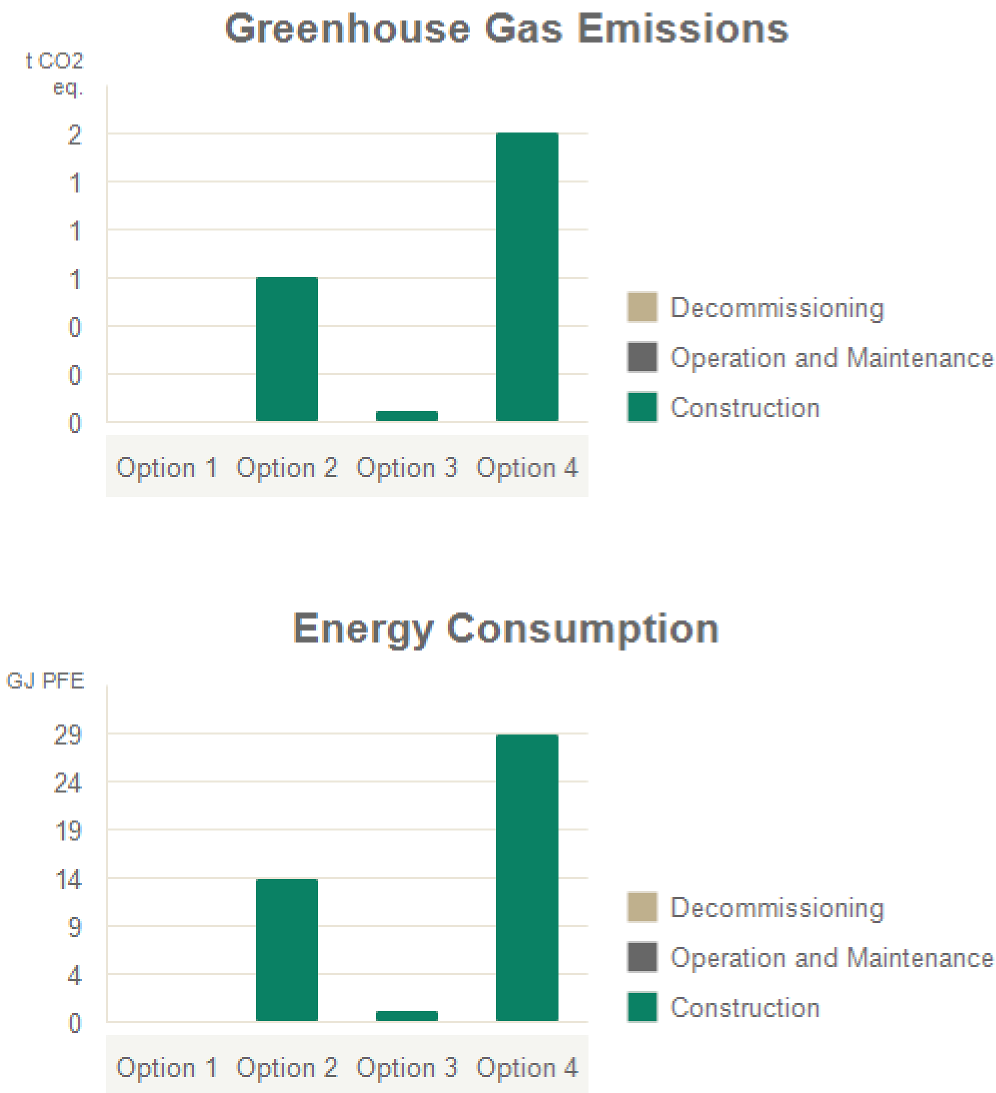


Figure 5.6 Greenhouse Gas (GHG) Emissions and Energy Consumption (www.goldset.com, 2014)

Table 5.8 Net Present Value Calculations.

	Industrial Wastewater Current System	**Industrial Wastewater Flow Reduction (Current Sys)**	**Industrial Wastewater Batch Operation**	**Industrial Wastewater Replacement System**
(%)	**0**	**0**	**0**	**0**
NPV (total project costs) ($)	**-240,000**	**-2,445,040**	**-177,600**	**-320,000**

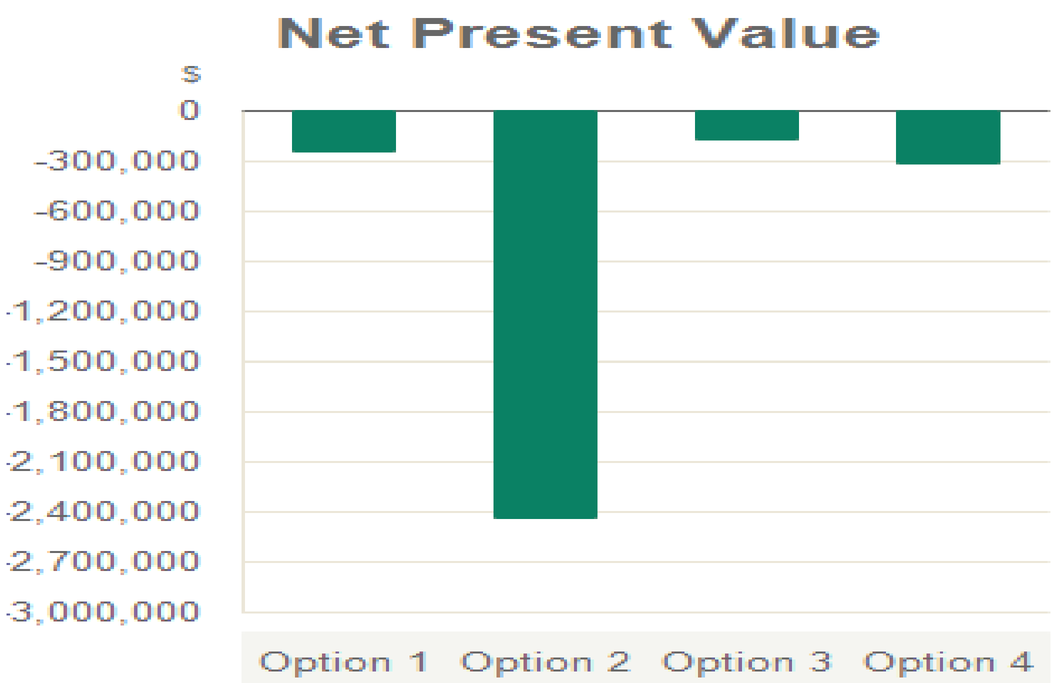


Figure 5.7 Net Present Value Calculations – Results (www.goldset.com, 2014)

Step 4b-Qualitative Evaluation

Most of the qualitative indicators are evaluated on the basis of previous experience of the experts, best practices and from the outcome of pilot testing and projects, as shown in Table 5.9. Scores have been assigned for each applicable indicator.

Table 5.9 Qualitative evaluation of indicators

INDICATOR	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System
ENV-1 Water use	0	32	100	0
ENV-2 Energy consumption/generation	0	78	82	100
ENV-3 Recycled input materials	0	100	0	0
ENV-4 Quantity input materials used	100	50	99	0
ENV-5 Environmental hazard (input materials)	100	100	100	100
ENV-6 Site footprint	63	0	63	100
ENV-7 Impacts upon biodiversity	0	0	50	100
ENV-8 Short-term impacts upon biodiversity	75	75	75	100

ENV-9 Long-term impacts upon biodiversity	75	75	75	100
ENV-10 Impacts upon habitat and/or land use	0	0	50	100
ENV-11 Short-term impacts upon habitat and/or land use	75	75	75	100
ENV-12 Long-term impacts upon habitat and/or land use	75	75	75	100
ENV-14 Quality of solid waste	100	100	100	100
ENV-15 Quantity of solid ouput	0	50	100	50
ENV-16 Solid output re-use	50	50	50	50
ENV-17 GHG emissions	0	76	77	100
ENV-18 Air quality	100	100	100	100
ENV-19 Quality of liquid waste discharge	0	0	0	100
ENV-20 Quantity of liquid waste discharge	50	50	50	50
ENV-21 Liquid output re-use	50	50	50	50
ENV-22 Fuel / Oil recovered	50	50	50	50

Table 5.10 Dimension Social - Evaluation of Indicators.

INDICATOR	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System
SOC-1 Public health & safety	100	100	100	100
SOC-2 Workers health & safety	66	66	100	100
SOC-3 Hazardous materials	100	100	100	100
SOC-4 Local sourcing (contractors and suppliers)	75	75	75	75
SOC-5 Existing local businesses	50	75	25	25
SOC-6 Local job creation & diversity	0	0	0	0
SOC-7 Community attitudes	50	50	50	50
SOC-8 Disruption of construction work on the community	80	80	80	80
SOC-9 Disruption of operations on the community	100	100	100	100
SOC-10 Management Practices	0	0	0	0

Table 5.11 Dimension Economic - Evaluation of Indicators

INDICATOR	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System
ECO-1 NPV (total project costs)	3	100	0	6
ECO-2 Financial recoveries	0	0	0	0
ECO-3 Logistics	100	100	100	66
ECO-4 Ease of obtaining necessary permits	100	66	100	33
ECO-5 Interference with activities on site	80	60	60	40
ECO-6 Potential for fines, penalties and surcharges	0	0	66	100
ECO-7 Land footprint	50	50	50	50

Table 5.12 Dimension Technical - Evaluation of Indicators

INDICATOR	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current System)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System
TEC-1 Reliability	33	33	66	100
TEC-2 Durability	33	33	66	100
TEC-3 Peak energy consumption	0	75	75	100
TEC-4 Flexibility / robustness	33	66	33	100
TEC-5 Technical uncertainty	100	100	66	100
TEC-6 Technical support	0	0	0	0
TEC-7 Maintenance - level required (frequency and complexity	25	25	50	75
TEC-8 Operation - level required (frequency and complexity	25	25	75	100
TEC-9 Design complexity	100	66	33	100
TEC-10 Construction complexity	100	66	33	100
TEC-11 Upgradability	33	66	66	100

Whenever applicable, details are provided to justify the evaluation of each option with respect to the selected indicators. The details are presented in the tables below.

Table 5.13 Dimension Environmental - Evaluation of Indicators : Comments

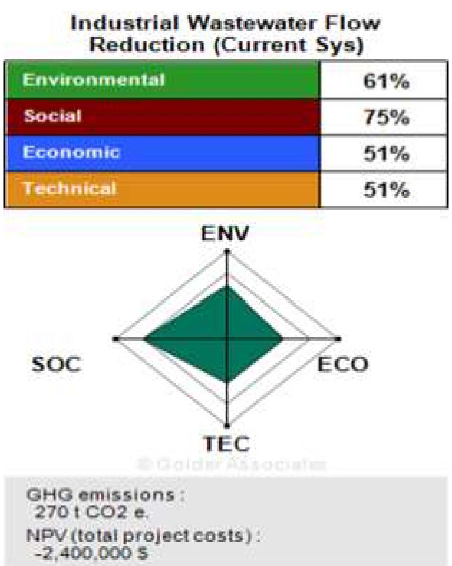
INDICATOR	**Industrial Wastewater Current System**	**Industrial Wastewater Flow Reduction (Current Sys)**	**Industrial Wastewater Batch Operation**	**Industrial Wastewater Replacement System**
ENV-8 Short-term impacts upon biodiversity	Current system has low flow and is assumed to have low short-term impacts upon biodiversity.	assumed to be the same as the current system.	assumed to be the same as the current system.	New system would be designed to best practice
ENV-9 Long-term impacts upon biodiversity	Current system has low flow and is assumed to have low short-term impacts upon biodiversity.	assumed to be the same as the current system.	assumed to be the same as the current system.	New system would be designed to best practice
ENV-10 Impacts upon habitat and/or land use (malfunction)			Holding tank would have system alarm and would allow for three days discharge to be held to allow for repairs to system.	New system would be designed to current industry best practice.
ENV-11 Short-term impacts upon habitat and/or land use				New system would be designed to current industry best practice.
ENV-12 Long-term impacts upon habitat and/or land use				New system would be designed to current industry best practice.

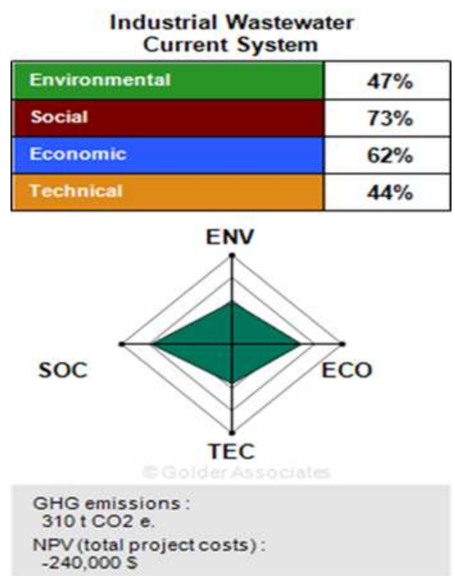
Table 5.14 Dimension Social - Evaluation of Indicators : Comments

INDICATOR	Industrial Wastewater Current System	Industrial Wastewater Flow Reduction (Current Sys)	Industrial Wastewater Batch Operation	Industrial Wastewater Replacement System
SOC-1 Public health & safety				
SOC-2 Workers health & safety			would lower contractor involvement, so would lower worker health and safety risk.	would lower contractor involvement, so would lower worker health and safety risk.
SOC-3 Hazardous materials				
SOC-4 Local sourcing (contractors and suppliers)				
SOC-5 Existing local businesses		construction of flow diversion system would result in short term use of local contractors.	This option would result in loss of seasonal business to contractor providing support services.	This option would result in loss of seasonal business to contractor providing support services.

Step 5- Interpretation and decision making

After all indicators are weighted for each options, the data is interpreted to asses the performance in all dimensions of sustainability, it then generates a comparative graphical representation of each option's sustainability performance. The four apexes of the quadrilateral represent the environmental, societal, economical and technical sustainable indicators. The most balanced triangular figure is selected as the best project as shown in Figure 5.9 below:





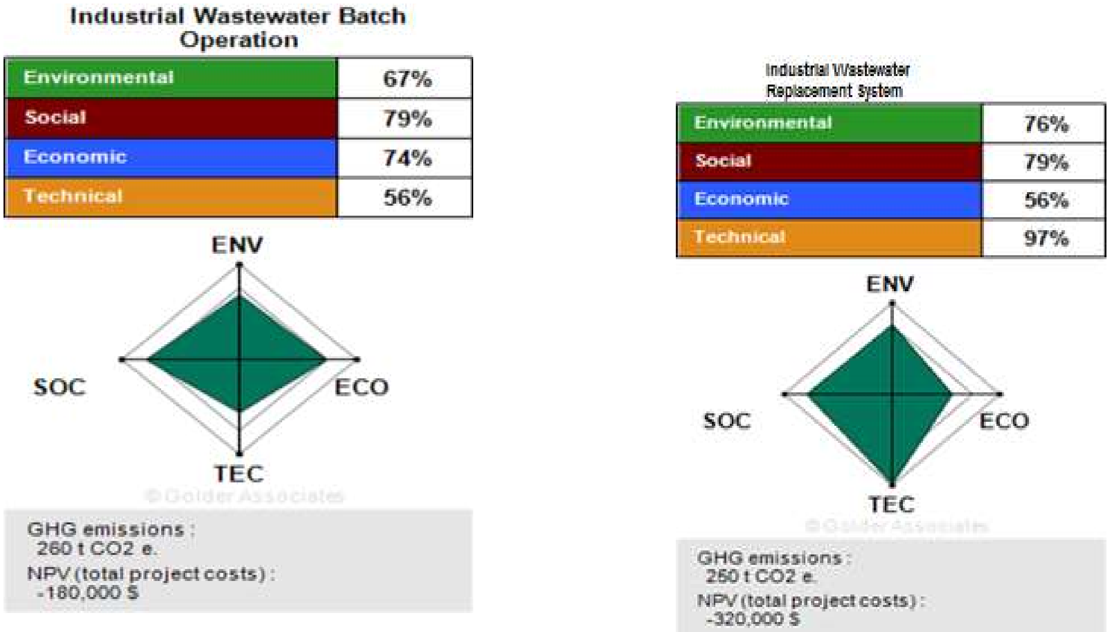


Figure 5.9 The output representation of the software

Chapter 6 Conclusions and Recommendations

The current status and practices of sustainable development indicators are selected. Assessment of the sustainability of wastewater system should include environmental, social, economic, and technical aspects of the option. A sustainability module was developed to evaluate the different options for technology selection and/or assessment of existing wastewater treatment plants. The module can be applied by selection and adjusting the weighting of the evaluation criteria through a scoring mechanism to fit the specific local conditions. The best practices can be a big step towards identifying and selecting these indicators.

The sustainability of the various wastewater treatment options can be compared when criteria are identified and weighted and performance measures selected to fit the specific conditions. As new and improved wastewater treatment technologies are developed, more wastewater management options will be available to offer greater sustainability along with increased reliability and flexibility. Thus, wastewater treatment systems can offer a higher level of sustainability to users, the community, and the environment.

The developed module is applicable for assessment of sustainability of existing plants as well as for detailed assessments of different designs and technology selections. Its outcome also helps the decision makers for general project planning decisions, process revamping, or the future upgrades and prioritization. Through the development of industry- specific indicators, the module may be applied to other sectors such as oil and gas, mining, industrial, municipal and manufacturing (sustainable cities) wastewater contexts.

Sustainability means change. Sustainability challenges many of those approaches, attitudes and practices. Sustainable practices can be incorporated at any stages. Many WWTP have been operating for many years, even decades. Such plants are prime candidates for process optimization, re-evaluation and upgrading not only for performance but also for sustainability.

Recommendations

Various kinds of equipments, pumps and motors, all consumes resources and energy, have workers safety concerns, and lead to environment impacts. Those impacts need to be considered as a part of WWTP evaluation, design and implementation.

The WWT industry needs to develop a standard set of evaluation criteria and matrices that can be used in decision making and operation.

The sustainability indicators in WWTP will require the evaluation of off-site effects at the local, regional and global scales.

The technical aspect is relatively new in waste water treatment modules. Several technology options should be analysed using selected indicators.

This procedure of selection of indicators focus on industrial wastewater treatment system. For municipal or specialized wastewater treatment system, detailed selection and weighing of indicators are necessary.

The weighing of indicators was done by consultation and proven records and data according to GoldSET, Golder Associates. It needs further data analysis and results from wastewater treatment system.

Thesis Contribution

The primary focus of this is on the idea of developing a framework for selecting the indicators and methodologies used for incorporating sustainability consideration into design of wastewater treatment module. This approach allows us to study the different indicators used in wastewater treatment plant their evaluating, their weighted value and selection of most appropriate indicators for a WWT system. The thesis makes the following contributions:

- A set of different indictors are collected, identified, are prioritize for wastewater treatment system. More than 100 indicators are identified. These are screened and categorized as sustainable indicators. These are selected for new plant planning, for evaluating the existing plant, for future upgrade and for replacing the existing one. The selected indicators reflect the issues that are critical to the overall performance of the project.
- The core indicators are categorized as qualitative or quantitative according to their characteristics, and these are ranked and weighted accordingly.
- These indicators are incorporated in the development of GoldSET software wastewater module v1.1 (https://golder.goldset.com/portal/module.aspx?id=4)
- The technical dimension is introduced in WWT system.

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