Chapter 13
Life-Cycle Assessment (LCA) as a Management Tool: An Emphasis on Electricity Generation, Global Climate Change, and Sustainability

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Introduction

The International Organization for Standardization (ISO) recommends the use of life-cycle assessment (LCA) to better comprehend and reduce environmental impacts related to manufactured products and services offered to our society. The principles of LCA are presented in the international standard ISO 14040; however, the implementation of the standard is not simple, and a couple of studies have addressed the existing limitations (Khan et al. 2002; Ross and Evans 2002).

One fundamental question is how to characterize a given environmental insult and how to select an appropriate metric to evaluate and minimize their impacts. This problem stem from the multiplicity of environmental insults caused by human activities, which are difficult to compare using a single approach. Moreover, most environmental problems have an intrinsic temporal dimension since environmental impacts persist in the environment for years and in some cases for generations. This yields sustainability concerns, which demand frameworks that allow the comparison of outcomes over time.

One problem that is still unresolved is the sustainability of our global climate, which requires the stabilization of the carbon dioxide (CO_2) concentration at an acceptable level. Climate change mitigation is challenging, and at the same time fascinating because it involves compromises between different nations and evokes a global decision making perspective, which at the same time affects local decisions and actions.

This chapter presents a decision-making framework for climate change based on the yardstick of the global carbon cycle. The cycle governs the accumulation of

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CO_2, which is the most abundant greenhouse gas (GHG) in the atmosphere .after water vapor, and a product of anthropogenic activities such as the burning of fossil fuels and deforestation. The buildup of CO_2 and other GHGs in the atmosphere increases the odds of extreme climate events, and justify GHG emission reductions now!

Environmental Decision Making Frameworks

Traditionally environmental decision-making has been focused on three classes of approaches (Portney and Stavins 2000):

1. Zero risk approach
2. Balancing approach
3. Technology based approach

The goal of the zero risk approach is to avoid the occurrence of any adverse health/environmental effect. While such an approach is the most desirable one, science and economics defy its practical application. Say we want to apply this principle to global climate change impacts of electricity generation. First, it is difficult to specify GHG emission thresholds, and second, comprehensive environmental assessments show that no electricity generation option is free of greenhouse gas (GHG) emissions (Pacca and Horvath 2002; Gagnon et al. 2002; ORNL/RFF 1995).

The balancing approach weighs competing outcomes and recommends regulatory action based on particular results. Usually this approach involves the use of cost benefit analysis (CBA), which requires the translation of all environmental values into economic values. The problem is that economics is ill-prepared to convert a wide range of non-market values into dollars, and in the case of climate change long time horizons intrinsic to the problem and disputes related to the valuation of local/regional costs complicate the task (Tol 2003; O'Neill 1993).

Finally, the technology-based approach characterizes the maximum attainable pollution level based on the adoption of the best available technology (BAT). A problem with this approach is that it is difficult to define the "best technology" because emissions can often be further reduced at higher costs, and technologies are constantly changing.

This chapter presents a LCA that moves the valuation of environmental sustainable technologies away from economic values and incorporates physical units and simple scientific models. The approach seeks the continuous improvement of technologies and encourages industry to perfect its current practices (Nash and Ehrenfeld 1996). The global warming effect (GWE) framework proposed herein is an objective method to guide industry towards sustainability based on the perils of climate change.

Method

The GWE method combines two well established methods: LCA and global warming potential (GWP).

Life-cycle assessment (LCA) is a method that captures resource consumption, pollution and solid waste production during every life cycle phase of a product or process leading to the production of a service.

Analytical steps in a LCA involve:

1. Compilation of material and energy inputs and outputs in a product/system
2. Evaluation of impacts associated with inputs and outputs
3. Interpretation of results

One of the challenges of LCA is the selection of the indicators used to evaluate the performance of a product or process. This is sometimes classified as a boundary problem, which means that the analyst selects a set of relevant indicators, while others are left aside. In any case, normative choices related to the selection of indicators are value laden and need to be explicit in the LCA (Hertwich et al. 2000). Usually, the choice of indicators to characterize the performance of a product or service is dynamic and its selection is shaped throughout the LCA by means of learning by doing type feedbacks. In the case of electricity generation technologies each technology class presents specific impacts. Nevertheless, the contribution of electricity generation to the emission of GHGs is notable, and justifies the use of a method to compare the performance of alternatives based on their impact on global climate change.

The GWE method seeks the stabilization of the GHG concentration in the atmosphere and the minimization of the potential climate change impacts. The use of the method reflects a concern with sustainability under a broader global standpoint, and its LCA facet adds comprehensiveness.

Accordingly, the LCA of greenhouse gas (GHG) emissions of a power plant takes into account emissions during the extraction of the resources, the manufacturing of the components, the construction of the power plant, its installation, its operation, its maintenance, and finally its decommissioning. In addition, the transport of materials, components, and fuels, which is part of almost all phases, is also considered an emission source (see Fig. 13.1).

LCA can be used in the assessment of various environmental problems; however, depending on the ultimate environmental/health implications the results of the

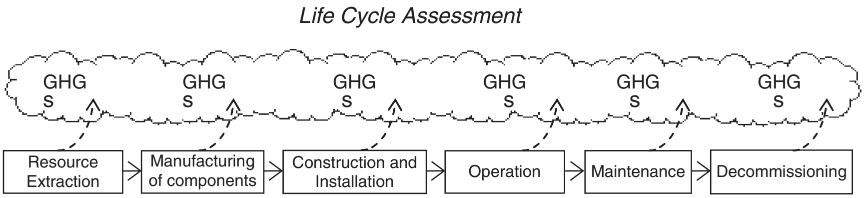

Fig. 13.1 Life Cycle Phases of a Power Plant

assessment are meaningless. For example, emissions of carbon monoxide kill people inside a garage but are harmless in the outdoor environment.[1] That is, most of the time, the location of air releases affects their environmental/health impacts. However, in the case of GHG emissions and their consequences, the spatial distribution is less critical, and the use of LCA renders a robust analytical outcome due to the inclusion of all emissions associated with the various products and services that are consumed to generate electricity.

The use of input output based LCA (IOLCA) is especially desirable since IOLCA tends to be more inclusive than process based LCA in capturing inputs to sustain a given process. An analysis based on a published literature review done by Lenzen and Munksgaard (2002) shows that the average of all IOLCA energy input to output ratio of wind farms is 2.7 times greater than the average of all process based LCA energy input to output ratios. That indicates that IOLCA usually account for more energy inputs than process based LCA.

The effect of GHG emissions is global and the timing of the releases or the way the analysis aggregates emissions that occur at different periods is more important than the spatial distribution of the emissions. The spatial distribution of emissions is not an issue because CO_2 and other GHGs are well mixed in the atmosphere, and the effects of climate change impact the whole world. In contrast, the temporal component of emissions impacts their potential effects. For example, the same amount of GHG released during the construction of a hydroelectric dam 50 years ago poses less potential effects when compared to the potential effects of GHG released from the construction and operation of a new natural gas power plant. That happens because each GHG has a characteristic residence time and eventually leaves the atmosphere and migrates to other pools.

Thus, in order to compare the potential effect of GHG releases at different moments, it is necessary to know their characteristic residence time to estimate how much of the gas is still in the atmosphere in the future. The problem is that the concentration of CO_2, which is a major GHG, is controlled by a myriad of processes and the representation of its persistency in the atmosphere through a single residence time is not accurate. At the same time, because of the importance of CO_2 due to its abundance in the atmosphere it is convenient to compare the effects of other GHGs to the effect of CO_2, by means of global warming potentials (GWP).

The persistence of CO_2 in the atmosphere is controlled by the carbon cycle, which may be represented by a parameterized pulse response function (PRF), as a function of time. One example of PRF is the one used in the GWP calculations by de IPCC, which is derived from a simple global carbon model known as the Bern model. The GWPs are used to normalize the effect of 1 kg of a specific GHG to the effect of 1 kg of CO_2. That is, both the chemical characteristics of different GHGs and the time they are released affect their impacts (Houghton et al. 2001).

The PRF function allows one to calculate the contribution of a stream of carbon emissions over time to the future atmospheric concentration. The idea parallels the present worth (PW) calculation of an income stream ($S_{(t)}$) (Formula 13.1). However,

[1] Eventually, CO is oxidized into CO_2 and contributes to climate change.

in the case of GHGs the monetary discount rate (r) is replaced by the inverse of the residence time (τ) of the greenhouse gas,[2] whereas in the case of carbon dioxide, the exponential decay function is replaced by a parameterized function that represents the fraction of carbon in the atmosphere as a function of time.

$$PW = \int_0^t S_{(t)} e^{-rt} \tag{13.1}$$

The parameterized function is the output of the Bern model cycle assuming a given pulse emission into the atmosphere (10 Gt of carbon in 1995) and a constant background concentration (353.57 ppm) (Enting et al. 1994). Therefore, to determine the amount of CO_2 emitted that remains in the atmosphere after a certain time it is necessary to replace e^{-rt} by $F[CO_2(t)]$ (Formula 13.2) and integrate the function over the desired time interval (t). If the stream of CO_2 emissions are constant over time they can be taken out of the integral and multiplied by the integral of Formula 13.2 to determine the CO_2 remaining in the atmosphere.

$$\begin{aligned} F[CO_2\,(t)] = {} & 0.175602 + 0.137467e^{-t/421.093} + 0.185762e^{-t/70.5965} \\ & + 0.242302e^{-t/21.42165} + 0.258868e^{-t/3.41537} \end{aligned} \tag{13.2}$$

One advantage of using the function derived from the carbon cycle is that it offers a better evaluation of the cumulative effect of carbon emissions than an economic assessment based on market discount rates or discount rates usually applied to public investments. Figure 13.2 compares $F[CO_2(t)]$ versus a 3.2% annual discount rate, which is suggested by the Office of Management and Budget of the White House to evaluate the feasibility of public projects in the US (OMB 2003). It shows that the future concentration of CO_2 after 50 years is twice as much the economic value ascribed to CO_2 over the same period discounted at a 3.2% discount rate. The use of

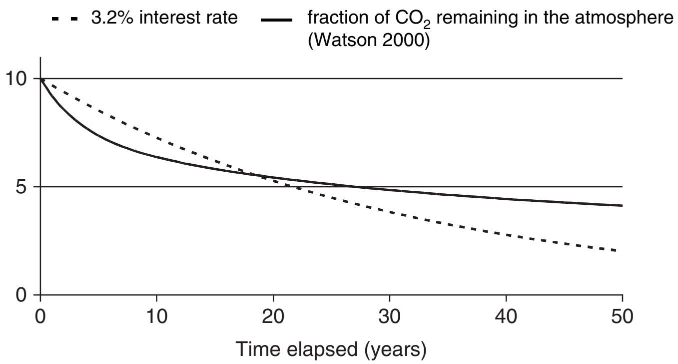

Fig. 13.2 Comparison of $F[CO_2(t)]$ Versus a 3.2% Annual Discount Rate

[2] Residence time for various GHG can be obtained from Chapter 6 of the Working Group 1, Science volume, of the Third Assessment Report of the IPCC, 2001 (Houghton, 2001).

economic assessments in less developed countries is even of bigger concern because higher changes in the consumer price index compared to more developed countries reflect a more abrupt loss of monetary value (UNDP 2004).

The point is not only to be more precise about the future relevance of a given GHG release but also to draw attention to the factors that affect the global carbon cycle and the human impacts related to such factors. That is, anthropogenic disruptions of the carbon cycle are relevant in the assessment of technologies and their global climate change impacts.

Actually, the PRF implicitly embeds a set of assumptions that affects the shape of the function. The PRF it is the output of a box model that represents the global carbon cycle, which is affected by various anthropogenic activities. One contentious issue in the model is the treatment of flows of carbon between the atmosphere and the terrestrial ecosystem. The science in this area is progressing rapidly, and new knowledge may be incorporated in the models in the future. Another important assumption is the background CO_2 concentration in the atmosphere over the period of analysis, which usually demands the construction of scenarios based on various assumptions about the future. Scenarios are affected by many other parameters such as economic growth, technology change, population, land use change, and energy policy (Fig. 13.3).

The PRF plotted on Fig. 13.3 assumes a fixed CO_2 background concentration of 353.57 ppm of CO_2 from 1990 onwards; however, the current concentration is 376 ppm (Keeling and Whorf 2003). If the model runs with the current concentration instead of the 353.57 ppm concentration the future concentration of CO_2 is going

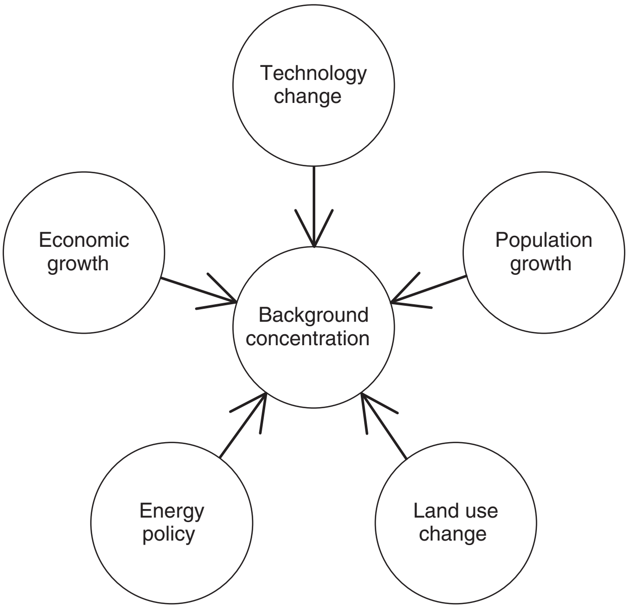

Fig. 13.3 Parameters Affecting CO_2 Background Concentration

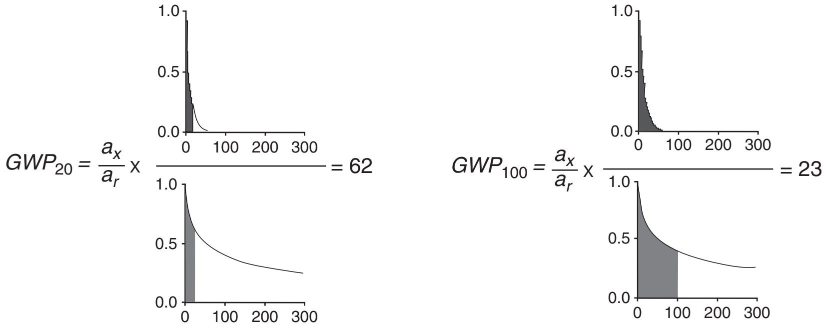

Fig. 13.4 Graphical Representation of GWPs Calculation over 20 and 100 Years

to be even higher. The assumption that the background concentration is fixed is not realistic, and a more realistic figure would incorporate to the calculations an increasing CO_2 profile as the background concentration and would result in even higher future concentrations given the parameterized model.

Nonetheless, the PRF described in Formula 13.2 is used by the latest IPCC report to calculate the GWPs. The GWPs were proposed to compare the potency of 1 kg of any GHGs to the potency of 1 kg of CO_2 over discrete time periods (20, 100, and 500 years). The GWP was not proposed as a proxy for impacts because it only compares the potency of a GHG to the potency of CO_2. For example, the GWP calculated by the IPCC for methane is a function of the analytical period, the ratio between the radiative efficiencies of methane and CO_2 and the residence time of methane and CO_2 in the atmosphere (Fig. 13.4). In contrast, this paper proposes the GWE as a proxy for global climate change impacts. The GWE inherits from the GWP the ability to aggregate and compare effects arising from emissions of different GHGs, and uses LCA to captured emissions associated with a given technology.

In summary, the GWE is a novel method that combines a life-cycle assessment (LCA) approach with a method inspired in the global warming potentials (GWP) method. The GWE compares and aggregates life-cycle emissions of power plants over flexible analytical periods, and intends to reconcile local decisions with global climate decision-making. The GWE can be applied to various technologies. As an example, the use of GWE to compare electricity generation options is presented.

Example: Application to Electricity Generation Sources

The use of GWE to select amongst different electricity generation sources results in significant GHG emission reduction (Pacca and Horvath 2002). Currently Anthropogenic releases of greenhouse gases (GHGs) in the biosphere are the major cause for climate change, and electricity generation accounts for 2.1 Gt year^{-1} (Giga Mg of carbon per year) or 37.5% of total global carbon emissions (Metz et al. 2001).

No electricity generation system is free of greenhouse gas (GHG) emissions through their entire life cycle, despite some being GHG-free in the operation phase. A comparative assessment of different sources available to power industrial activities contributes to the sustainability of a sector that relies on electricity as part of the inputs of its manufacturing chain.

The effects of different electricity generation options on climate change are determined using the GWE, which is the sum of the product of instantaneous GHG emissions (M) and their specific time-dependent GWP. The GWE is the sum of all GHG emissions of a power plant over a given analytical period. Therefore, the global warming effect in mega grams of CO_2 equivalent ($MgCO_2Eq$) is:

$$GWE = \sum M_j \,.\, GWP_{j,TH} \tag{13.3}$$

where:

M_j is the mass (in Mg) of the instantaneous emission of each GHG "j", and
$GWP_{j,TH}$ is the global warming potential for each GHG "j" calculated over the time horizon "*TH*" using Equation (13.2).

Instantaneous emission values *Mj* could be obtained from different LCA libraries, which compile emission factors for various materials and processes; however, this analysis is based on information from the economic input-output matrix (www.eiolca.net).

For example, the GWE of CH_4 emissions over 20 years corresponds to the quantities emitted in years 1, 2, 3, ... 20 multiplied by methane's GWPs when the *TH* is 20, 19, 18, ... 1 years, and then added. In the case of an emission that is constant every year there is no need for the calculation of periodical GWPs. In this case, the calculation of GWP involves multiplying the GWP calculated for the total time period by the constant annual emission rate to give the radiative forcing produced by the annual release of the GHG. If emissions vary from year to year then the calculation of specific GWPs is necessary.

The GWP for a GHG and a given time horizon is (Houghton et al. 2001):

$$\mathrm{GWP} = \frac{\int_0^{\mathrm{TH}} \mathrm{a_x} \cdot \left[\mathrm{x}_{(t)}\right] \mathrm{dt}}{\int_0^{\mathrm{TH}} \mathrm{a_r} \cdot \left[\mathrm{r}_{(t)}\right] \mathrm{dt}} \tag{13.4}$$

where:

a_x is the radiative efficiency of a given GHG. The radiative efficiency represents the radiative forcing divided by the change in its atmospheric concentration prior to the industrial revolution up to 1998 (the base year of the EIO-LCA data is 1997). The Radiative forcing measures the magnitude of a potential climate change mechanism. It represents the perturbation to the energy balance of the atmosphere following a change in the concentration of GHGs.

a_r is the radiative efficiency of CO_2, which is assumed to be equal to 1 because all other GHGs are compared to CO_2.

$x_{(t)}$ in the numerator is the predicted airborne fraction of GHG, which is represented by an exponential decay function using a GHG-specific atmospheric lifetime.

$r_{(t)}$ in the denominator represents the CO_2 response function used in the latest IPCC reports to calculate GWPs, which appears in a footnote of IPCC Special Report on Land Use, Land-Use Change and Forestry (Watson 2000).

$_{TH}$ is the time horizon between the instantaneous release of the GHG and the end of the analysis period.

Therefore, the impact of each technology on global climate change is a function of the future fraction of GHG in the atmosphere compared to the effect of CO_2 over the same period. In addition, in the case of CH_4, it is assumed that all CH_4 oxidizes into CO_2, which is not captured by the GWP calculations for CH_4, and therefore is added to the mass of CO_2 left in the atmosphere (Houghton et al. 2001).

The CO_2 PRF is used to determine the future concentration of carbon in the atmosphere. Thus, the period of analysis affects the results of the analysis, and the lifetime of a facility, which does not necessarily matches the period of analysis, is solely a function of the obsolescence of its structures and technology. Consequently, the analysis may capture effects of upgrades, changes in technology, human values, resource availability, etc. If the period of analysis is extended beyond the need for upgrades of renewable power plants, the tendency is that the GWE normalized by kilowatt hour (gCO_2eq/kWh) stabilizes at a level dictated by emissions from recurring retrofits. In contrast, the GWE for fossil fueled power plants stabilizes much sooner since it is dictated by GHG emissions during fuel combustion (Fig. 13.5).

Emission of GHGs during the decommissioning of power plants are usually neglected but depending on the technology that value may be considerable and needs to be factored in the calculation of normalized emissions. In the case of hydroelectric plants a source of concern is the potential carbon emissions from sediments accumulated in the reservoir. The mineralization of carbon in sediments releases both CH_4 and CO_2 and because of the timing of these releases their impact could be relevant when normalized over the life time of the facility (Pacca 2004).

A recent estimation of sediment organic carbon (SOC) stored in large reservoirs in the US and large lakes in Canada show that the amount of carbon in the reservoirs is considerable. The question remaining is what is the fate of that carbon during the decommissioning of the dam and the removal of the sediments from the reservoir's

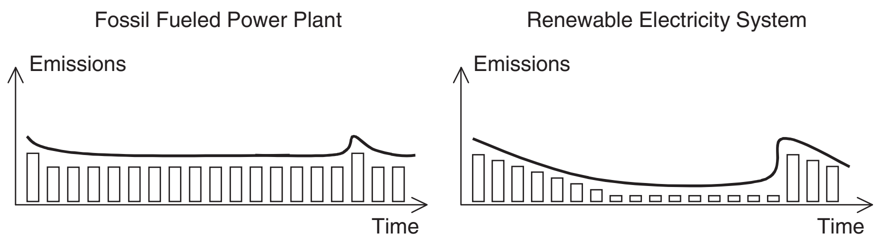

Fig. 13.5 Fossil Fuel and Renewable Energy Cycles

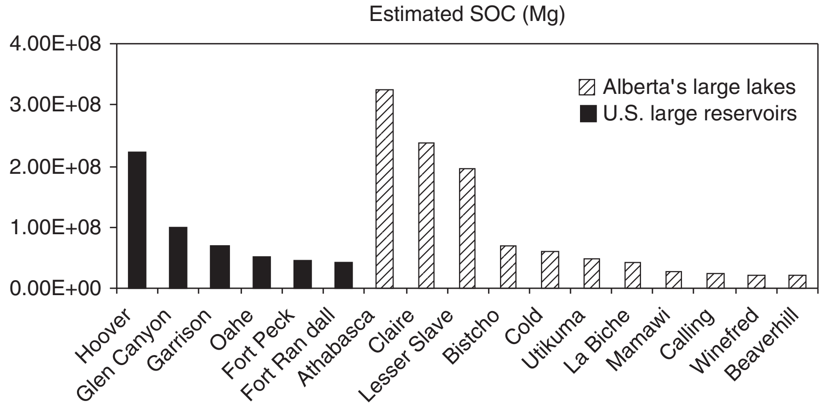

Fig. 13.6 Sediment Organic Carbon (SOC) Stored in Reservoirs and Lakes in North America

bed (Fig. 13.6)? If SOC is emitted to the atmosphere in the form of CH_4 or CO_2, the contribution of this source to the GWE of hydroelectric plants could be highly significant.

According to the GWE, the temporal distribution of emissions is more important than their spatial distribution, and the method captures this component very well. This characteristic is noteworthy because the GWE intends to be an alternative to economic analysis to make time dependent choices and extend the analysis to longer periods than those contemplated by market based discount rates. Another advantage of the method is that it works with relative comparisons instead of the ultimate/absolute impacts because it is based on GWP computations that compare the effect of GHG emissions to the emission of a similar amount of CO_2 over a chosen time horizon (Houghton et al. 2001).

The GWE method was applied to a comparative assessment of the Glen Canyon dam (GCD) hydroelectric plant and other imaginary electricity generation options that were conceived based on local resources availability as a replacement for GCD. The dam, which is located on the Colorado River close to the border of Utah and Arizona, forms the second largest reservoir in the U.S. The installed capacity of the power plant is 1.3 GW and in 1999 it produced 5.5 TWh. The LCA of a hydroelectric power plant involves the quantification of the materials and energy used in the construction of the facility. The major inputs are quantified and data from the economic input-output matrix (www.eiolca.net) is used to find out the emissions corresponding to the consumption of the inputs (Table 13.1). A similar strategy is used to evaluate impacts from the construction of the other electricity generation alternatives.

Results from the case study show that a wind farm appears to have lower GWE than the other alternatives considered, and the performance of hydroelectric plants depends on the ecosystem type displaced by the reservoir. All power plants are subject to retrofits after 20 years. Effects of retrofit appear in the 20th year of the evaluation of the wind farm (Fig. 13.7). For the Glen Canyon power plant, the upgrade 20 years after the beginning of operation increased power capacity by 39%,

Table 13.1 Major Construction Inputs and GWE (after 20 years) for Glen Canyon Hydroelectric Plant (Pacca 2002)

Inputs	Total MT	Unit cost (1992 $/MT)	Total cost (1992 $)	CO_2	$+CH_4$	$+N_2O$	=GWE
Concrete	9,906,809	30	297,652,257	400,792	751	7,898	409,441
Excavation (m^3)	4,711,405	na	114,839,000	3,812			3,812
Turbines and turbine generator sets	na	na	65,193,084	41,725	45	249	42,019
Power distribution and transformers	na	na	13,754,764	12,358	16	79	12,453
Steel	32,183	385	12,402,138	43,710	29	244	47,583
Copper	90	2,368	214,167	186	na	2	188
Aluminum	67	1,268	84,804	157	na	2	159
Total			**503,240,216**	**500,000**	**1,000**	**9,000**	**500,000**

Total emissions are rounded to one significant digit. MT, metric ton; GWE, global warming effect; na, not available.

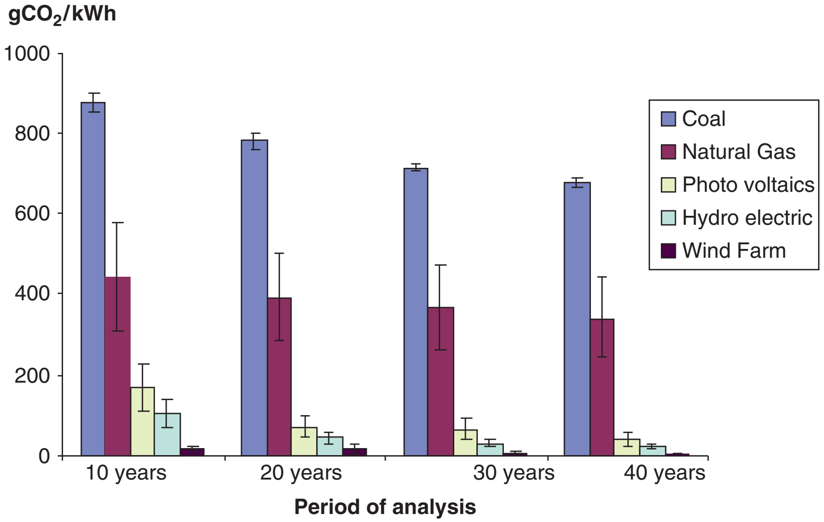

Fig. 13.7 Results from GWE Applied to the Glen Canyon Hydroelectric Plant Case Study

but resulted in about a mere 1% of the CO_2 emissions from the initial construction, and came with no additional emissions from the reservoir which accounts for the majority of the GWE (Pacca and Horvath 2002).

Long analytical periods allow the assessment of alternatives such as retrofits and upgrades that may pose a smaller environmental burden in the global environment than the construction of new structures. This logic should be considered as part of design for the environment initiatives that seek the minimization of the GWE.

However, emissions during the decommissioning of power plants should also be considered as part of the estimation of emissions normalized per energy output.

Hydropower is not an electricity source free of GHG emissions. Emissions from hydroelectric power plants may be produced by construction of the power plant, biomass decay of the vegetation flooded by the reservoir, lost net ecosystem production (NEP), and decomposition of carbon trapped in the reservoir's ecosystems during the decommissioning of the reservoir. A LCA of hydroelectric plants should include a hybrid analysis that translates land use change impacts in terms of their equivalent carbon emissions. The same approach holds for other electricity generation systems that also impact land such as large-scale massive PV installations or even road construction for maintenance of large wind farms.

Since the establishment of the Intergovernmental Panel on Climate Change in 1988, climate change science has attempted to investigate different areas of anthropogenic activities such as the ones represented in the set of IPCC special reports (Metz et al. 2000; Nakicenovic and Swart 2000; Watson 2000; Penner et al. 1999; Watson et al. 1997). The IPCC published a special report on land use change and the scientific knowledge on the issue is rapidly progressing. More recently a report with methods to Good Practice Guidance for Land Use, Land-Use Change and Forestry includes a set of models, carbon intensity, and carbon emission factors to calculate the impacts of land use change. As a concept the GWE method attempts to bridge in new scientific understanding between GHGs in the atmosphere and terrestrial ecosystems that are impacted by the footprint of large power plants such as a hydroelectric plant that rely on a large reservoir. In addition to the traditional assessment due to the combustion of fossil fuels, the GWE incorporates land use change information in the assessment of global climate change that is caused by the footprint of electricity generation technologies.

Policy Implications

The GWE method as a LCA tool has two management implications that foster sustainability in the industry. The first is the use of the GWE as a tool to compare different sources of electricity and to elect the option with the least impact on global climate change. The second is the minimization of global climate change impacts of a given activity/technology by identifying the life cycle phase/process that produces the greatest contribution to the GWE given a chosen analytical period. Results of the method are time dependent and may include an array of different greenhouse gases, which have their potential effect normalized to the potential effect of CO_2in the atmosphere. The method is conclusive when the concern is GHG emissions and sustainability.

Temporal flexibility is fundamental to support decision-makers that usually demand answers in the short run (decades). Moreover, due to unexpected outcomes shorter analytical periods than the 100-year time horizon associated with GWPs, which are usually applied to energy analyses, may be necessary to avoid an even greater problem arising from global climate change. Nevertheless, it is crucial to keep in mind that infrastructure is not perpetual and the end of life of any structure should be also part of LCA.

The GWE framework assumes a dynamic definition of technology since it intends to transform current practices into less polluting options. The continuous utilization of the framework as a management tool could feed a perpetual quest for sustainable energy technologies, which are always evolving and becoming more environmentally sound. Transparency is also important in the characterization of technologies. That is, when a technology is characterized as part of the assessment it is important to explicitly represent the chosen parameters. For example, energy conversion efficiencies of different power systems should be apparent in the analysis and reflect choices done by the analyst. That is the work should report if the analysis is based on a combined cycle or single cycle natural gas fueled turbines or on a crystalline or thin film photovoltaic modules, and the respective efficiencies should be explicitly stated.

Among the actions that could result from the application of the GWE is the use of renewable energy in the manufacturing of PV modules and the life extension of hydroelectric plants, provided that net impacts from their decommissioning are not highly cumulative over time. Impacts from decommissioning are heavily weighted by the GWE method because they are likely to occur at the end of the analytical period and they might be responsible for the release of CH_4, which has a high GWP value on the short run when compared to CO_2. The retrofit of hydroelectric power plants has been justified as a way to produce electricity at a minimal environmental cost; however, if the accumulation of sediments creates a potential emission source of GHG, the extension of the lifetime of hydroelectric plants may not be as beneficial as was expected.

The framework intends to be flexible in order to accommodate and transparently represent variability. The inclusion of a simple global carbon cycle model in the method provides a connection to socio-economic factors in the assessment and links population growth, development, technological changes, land-use change, and energy policy to the future CO_2 background concentration and the behavior of GHGs in the atmosphere over time.

Another use of the GWE method is to normalize results from previous published LCAs. There is a considerable number of energy LCAs in the literature dealing with impacts on climate change. They draw on different methods and assumptions to assess carbon dioxide emissions from electricity generation projects. Some of these studies present the primary information used to characterize a given power plant but rely on different assumptions and methods to finally calculate the contribution of the power plants. Most studies that run assessment of various GHGs use a fixed GWP to convert other GHGs to carbon dioxide equivalents; and therefore, are locked to fixed time horizons. Such strategy may constrain the use of the results and the comparison of different case studies. The use of the GWE framework to process data available from other published sources is useful to normalize and compare results without having to collect basic information about each project. This could be useful in setting up a database with various projects with different characteristics for a given power generation technology class, and establish benchmarks for various alternatives.

The use of the framework presented can be extended to other services and goods. The use of GWE decoupled from ultimate damages associated with climate change enhances the method's applicability since fewer assumptions and uncertainties are incorporated in the technology assessment. Consequently, the framework allows for a more clear presentation of its conclusions to a broad audience and instigates discussion about the conclusions. Even if the GWE method is not directly used to establish global emissions targets, its grand purpose is aligned with climate change mitigation, and its adoption gradually reduces the burden on the global environment.

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