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LCA of renewable energy for electricity generation systems—A review

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ABSTRACT

Sustainable development requires methods and tools to measure and compare the environmental impacts of human activities for various products (goods and services). Providing society with goods and services contributes to a wide range of environmental impacts. Environmental impacts include emissions into the environment and the consumption of resources as well as other interventions such as land use, etc. Life cycle assessment (LCA) is a technique for assessing environmental loads of a product or a system. The aim of this paper is to review existing energy and CO_2 life cycle analyses of renewable sources based electricity generation systems.

The paper points out that carbon emission from renewable energy (RE) systems are not nil, as is generally assumed while evaluating carbon credits. Further the range of carbon emissions from RE systems have been found out from existing literature and compared with those from fossil fuel based systems, so as to assist in a rational choice of energy supply systems.

Contents

1. Introduction: LCA methodology

Life cycle assessment (LCA) is a technique for assessing various aspects associated with development of a product and its potential impact throughout a product's life (i.e. cradle to grave) from raw material acquisition, processing, manufacturing, use and finally its disposal [1]. LCA studies should systematically and adequately address the environmental aspects of products/systems. The depth of the details and time frame of an LCA study may vary to a large extent, depending on the definition of goal and scope. The scope, assumptions, description of data quality, methodologies and output of LCA studies should be transparent. LCA methodology should be amenable to inclusion of new scientific findings and improvements in the state-of-the-art of the technology. The strength of LCA is in its approach to study in a holistic manner the whole product/system and enables us to avoid the sub-optimization that may be the result of only a few processes being focused on. The results are also related for the use of a product, which allows comparisons between alternatives. Life cycle assessment (LCA) includes definition of goal and scope, inventory analysis, impact assessment and interpretation of results as shown in Fig. 1 [2–4].

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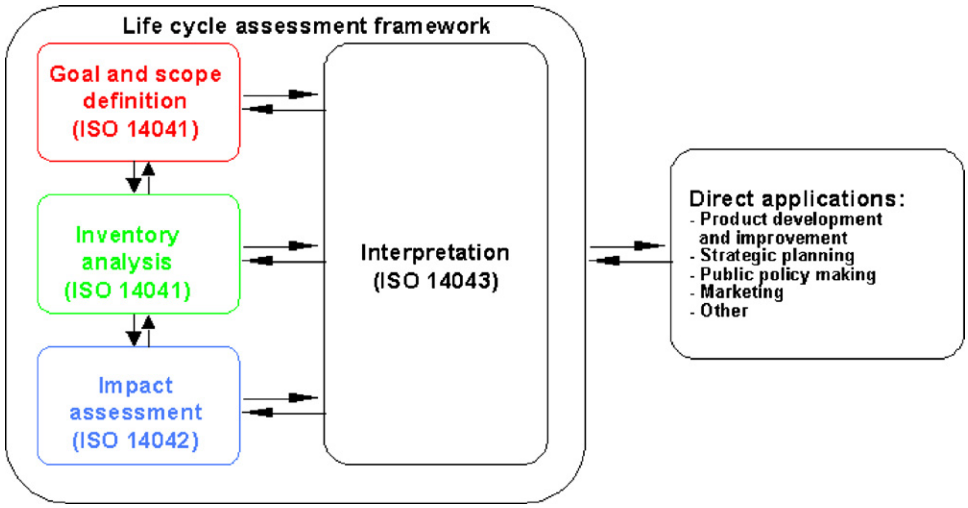

Fig. 1. Life cycle assessment framework [5].

The increased awareness of the importance of energy in our society and the growing concern over future sources of energy have led to inquiries as to how much energy is used in producing goods and services. An important application of LCA is net energy analysis. Net energy has been defined as the amount of energy that remains for consumer use after the energy costs of finding, producing, upgrading and delivering the energy have been paid [6]. If a new technology consumed more energy than it produced so that it had a net energy output negative, it could not provide any useful contribution to energy supplies and should be dismissed as a net energy sink. Conversely, if a new energy technology could achieve a positive net energy output when energy is in short supply, then it should be adopted for use even if the economic evaluation of its prospects is found to be unfavourable [7].

LCA is an instrument to quantify all impacts of the entire energy supply chain, e.g. to obtain the cumulative energy demand (CED) for production of a power plant, its life cycle carbon emissions, etc. The whole facility is split up into components and subcomponents and all energy and material flows through these are examined [8]. The life cycle impact of typical renewable energy systems is important when comparing them to conventional fuel-based systems for rational choice of energy sources. In addition to the well-known differences between conventional fuel based and renewable energy systems in economic impact, a number of stark differences in all other impact areas strongly favour the renewable energy solutions [9].

2. LCA of renewable energy systems

The LCA can be applied to assess the impact on the environment of electricity generation and will allow producers to make better decisions pertaining to environmental protection [10]. Tahara et al. [11] studied CO_2 payback time for future renewable energy electric power plants compared with commercial fossil fuel-fired electric power plants (coal, oil and LNG) in order to estimate CO_2 reduction potential of renewable energy. Kreith et al. [12] estimates the lifetime CO_2 emissions from coal-fired, PV and solar thermal power plants in the US. These CO_2 estimates are based on a net energy analysis derived from both operational systems and detailed design studies. The system wise detailed study is as follows.

2.1. Wind energy system

Haack [13] calculates the energy cost of energy from a small wind electric system using the methodology employed by Pilati and Richard [14] in examining electricity generating systems. This methodology requires the calculation of the energy to construct and operate electricity generating systems but does not consider the energy required to dispose of a generating plant or its waste products. Input energy values include direct energy as well as indirect energy. Direct energy is like coal for fueling a coal fired power plant where as indirect energy is the energy embodied in manufacturing the components in an electricity generating system. Indirect energy costs are quantified by the use of energy values assigned to 357 sectors of the United States economy. These energy values are calculated from economic input–output tables. These tables are expressed as British Thermal Units (BTU) per dollar value of final product.

The small wind electric conversion system examined in this study consists of a 3 kW rated wind generator on a 20 m tower with a 400 Ah battery storage system and an electrical current inverter. The energy cost of power from the small wind electric system in this study is 1.92 BTU of primary energy input for every BTU of electrical output. This value is the ratio of small wind electric system input energy, 5.96×10^8 BTU of primary energy, to output energy of 3.1×10^8 BTU of electricity.

Schleisner [15] studied the assessment of energy and emissions related to the production and manufacturing of materials for an offshore wind farm as well as wind farm on land. The energy production over the lifetime of the wind farms has been estimated in order to calculate the energy pay back time of the wind farms. The wind farms analysed are an off-shore wind farm consisting of 10, 500 kW turbines with a total capacity of 5 MW, and a land based wind farm consisting of 18, 500 kW units with a total capacity of 9 MW. The turbines are three-bladed off-shore pitch regulated machines, each with a capacity of 500 kW at a nominal wind speed of 16 m/s. The tower height is 40.5 m and the rotor diameter is 39 m. The primary energy used in the production and disposal of materials comprising off-shore wind farm is 43,873 GJ. The yearly electricity production of 12,500 MWh of the wind farm is converted to primary energy that would be consumed at a conventional power plant in order to estimate the energy pay back time. Based on an estimated efficiency of 40%, the energy use is paid back in 0.39 year or less than 2% of a 20-year life time for off-shore wind farm, emissions are 16.5 g-CO_2/kWh, 0.03 g-SO_2/kWh and 0.05 g-NOx/kWh and for the land based wind farm the corresponding figures are 9.7 g-CO_2/kWh, 0.02 g-SO_2/kWh and 0.03 g-NOx/kWh, respectively.

Jungbluth et al. [16] modeled wind turbines of 600 kW, 800 kW and 2 MW as for European onshore conditions. The full life cycle