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Life cycle greenhouse gas emissions estimation for small hydropower schemes in India

Varun [a,*], Ravi Prakash [b], I.K. Bhat [c]

[a] Department of Mechanical Engineering, National Institute of Technology, Hamirpur 177005 (HP), India
[b] Department of Mechanical Engineering, Motilal Nehru National Institute of Technology, Allahabad 211004 (UP), India
[c] Malaviya National Institute of Technology, Jaipur 302017 (Rajasthan), India

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ABSTRACT

This paper presents for the first time correlations for greenhouse gas (GHG) emissions from small hydropower schemes in India. In this paper an attempt has been made to develop life cycle GHG emissions correlations for three different types of small hydropower schemes (run-of river, canal based and dam-toe) in India. It has been found out that GHG emissions depend on the head and capacity of the small hydropower project. The results obtained from correlations show good agreement with the estimated results using EIO-LCA (Economic Input–Output-Life Cycle Assessment) technique. These correlations may be useful for the development of new small hydropower (SHP) schemes, as they can be used to predict life cycle GHG emissions based on capacity, head and type of SHP schemes.

1. Introduction

The increased generation and consumption of electricity from conventional sources are likely to result in adverse consequences for the environment and human health. The potential of renewable energy sources is enormous; hence they can meet the world's energy demand substantially. Renewable energy is perennial, locally available, environment friendly, well suited for decentralized applications and can be used in remote areas. Especially after the oil crisis of 1973, interest in small hydropower (SHP) has been revived. The development of hydroelectric power generation throughout the world is receiving renewed attention as the economic, political and environmental costs of conventional power production are rising [1,2].

A general tendency, observed globally, is to define SHP schemes by power output. Different countries are following different norms keeping the upper limit ranging from 5 to 50 MW. In India, Central Electricity Authority (CEA) in its own publication defines SHP up to 15,000 kW station capacities [3] and further this range was increased up to 25,000 kW by Ministry of New and Renewable Energy (MNRE), Government of India. Small hydro can also be defined as those hydro projects which cost less than or equal to Rs. 1000 million, equivalent to an installed capacity of approximately 25 MW. In India, it has been estimated that a potential of 15,000 MW exists in small hydro out of which only 801 plants having 2954 MW capacity are operational and 271 plants with another 915 MW are under various stages of construction [4].

All energy systems emit greenhouse gases (GHGs) and contribute to anthropogenic climate change. It is now widely recognized that GHG emissions resulting from the use of a particular energy technology need to be quantified. These GHG emissions are quantified over its full life-cycle. Life Cycle Assessment (LCA) is widely recognized as a systematic approach that considers not only the resource usage but also environmental discharges associated with each project stage. LCA is a technique for assessing various aspects associated with development of a product and its potential impact throughout a product's life (cradle to grave) from raw material acquisition to its final disposal [5]. LCA study should systematically and adequately address the environmental aspects of systems. The details and time frame of the study depend upon the goal and scope definition.

Lombardi [6] performed an exergetic life cycle assessment and a classical environmental life cycle assessment (LCA) for three low carbon dioxide emission power cycles. The configurations of the power cycles are: semi closed gas turbine combined cycle, integrated gasification combined cycle and O_2/CO_2 innovative cycle. The CO_2 reduction is effective during the life cycle. Gagnon et al. [7] studied the environmental impacts of electricity generation

* Corresponding author. Tel.: +91 1972 254742; fax: +91 1972 223834.
E-mail addresses: varun7go@gmail.com, varun7go@rediffmail.com (Varun).

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Nomenclature

A_0, B_0	Constant
C	Capacity, kW
CO_2	Carbon dioxide
EIO	Economic Input–Output
g	gram
GHG	Greenhouse Gas
GJ	Giga Joule
H	Head, m
LCA	Life Cycle Assessment
PVC	Poly-vinyl Chloride
PPP	Purchase Power Parity
SHP	Small Hydropower
US	United States of America
USD	United States Dollar

Subscripts

e	electricity
eq	equivalent

systems based on life cycle assessments (LCAs). The LCAs show that the following options have excellent performance: hydropower (run-of-river and with reservoir), nuclear energy and wind power. Gagnon and Vate [8] reported the findings of the assessment of greenhouse gas (GHG) emissions from the full life cycle of hydropower and deduced that for hydropower plants in cold climate, a typical GHG emission factor is 15 g-CO_{2eq}/kWh_e, which is 30–60 times less than the factors of usual fossil fuel generation. Goralczyk [9] stated the importance of life cycle assessment (LCA) in renewable energy sector. Hondo [10] carried out an LCA study on nine different types of power generation systems: coal fired, oil-fired, LNG- fired, LNG-combined cycle, nuclear, hydropower, geothermal, wind power and solar photovoltaic (PV). Life cycle greenhouse gas (GHG) emission per kWh of electricity generated was estimated for the systems using a combined method of process analysis and input–output analysis. Wagner et al. [11] carried out life cycle assessment of the offshore wind farm alpha ventus and compared its environmental influence to that of Germany's electricity mix and deduced that 1 kWh of electricity generated by the wind farm was burdened with 0.137 kWh primary energy equivalent and 32 g-CO_{2eq}. Raadal et al. [12] presented a comprehensive overview of the life cycle GHG emissions from wind and hydropower generation, based on these published studies it was found that GHG emissions from wind and hydropower ranges from 0.2 to 152 g-CO_{2eq} per kWh_e. Castelazo et al. [13] conducted for the first time a life cycle assessment (LCA) study of electricity generation in Mexico. The LCA results show that 225 TWh of electricity generate about 129 million tonnes of CO_2 equivalent per year, of which the majority (87%) is due to the combustion of fossil fuels. The Renewables and nuclear contribute only 1.1% to the total CO_{2eq}. Sebastian et al. [14] carried out LCA study to determine the reduction of GHG emissions when the co-firing of different biomass resources is compared to coal-fired electricity production in Spain. The results show that by using biomass resource in an existing coal power plant to replace 10% coal on an energy basis, 6–7% decrease in GHG emissions have been reported. Soimakallio et al. [15] reviewed the complexity and challenges of determining GHG emissions from grid electricity consumption and conservation in LCA. GHG emissions of a specific power plant depend significantly on the technology and primary energy used. Furthermore, the system boundaries set for determining individual parameters, consideration of various GHG emission components and choices for other methodological issues, such as allocation, are crucial. Weisser [16] reviews and compares the recent life cycle GHG emissions from fossil energy technologies, nuclear and renewable energy technologies, as well as carbon capture and storage (CCS) and energy storage systems. The results presented here indicate that introduction of advanced fossil fuel technologies can also lead to improvements in life cycle GHG emissions. Overall, hydro, nuclear and wind energy technologies can produce electricity with the least life cycle global warming impact.

In the present study, estimation of GHG emissions from different small hydropower (SHP) schemes (with varying capacity and head) has been carried out in the Indian scenario.

2. Methodology

LCA is a tool for evaluating the environmental impacts of a product or project through its entire life span, usually from raw material extraction to its final disposal (cradle to grave). Economic input–output LCA has been used by the authors for assessing life cycle GHG emissions for SHP schemes. The EIO-LCA approach consists of a matrix of economic data and a matrix of sector level environmental coefficients. An EIO based model of US economy is maintained by the Green Design Institute at Carnegie Mellon University (CMU) [17]. The process model approach is used to account for GHG emissions associated with the manufacturing of major construction materials and electro-mechanical equipment used in various projects. Since no EIO-LCA model has been developed for India hence the Carnegie Mellon EIO-LCA model (US Dept. of Commerce 1997 Industry Benchmark) is used in the present study [17]. The cost estimates of these projects pertain to different years. These costs are inflation adjusted and expressed in Indian Rupees (₹) for the year 2004–05. In India we observe the period April 1–March 31 as the fiscal year. Further the costs are converted into equivalent US dollars by using the purchase power parity (PPP) in that year (2004). Further US dollar has been adjusted for the year 1997 by using the inflation index of US and this model has been used in conducting LCA studies [18–20].

$$\text{Equivalent Cost in US \$} = \frac{\text{Cost in INR}}{\text{PPP}} \times \frac{\text{Inflation index for year 1997}}{\text{Inflation index for year 2004}} \quad (1)$$

In this study, functional unit is considered to be 1 kWh of net electricity produced (kWh_e). GHG emissions are normalised to an equivalent of CO_2 (g) emissions per kWh of net electricity production based on IPCC (International Panel on Climate Change) 100 year Global Warming Potential (GWP) [21].

$$\text{GHG emissions } (\text{g} - CO_2/kWh_e) = \frac{\text{Total } CO_2 \text{ emissions throughout its life} - \text{cycle}(\text{g} - CO_2)}{\text{Annual power generation}(kWh_e/\text{year}) \times \text{lifetime (year)}} \quad (2)$$

Life cycle of SHP project can be divided into four stages: (i) civil works (ii) electro-mechanical (E&M) equipment (iii) operation and maintenance (O&M) and (iv) decommissioning.

The first hydropower plant in India was established in 1897 at Sidrapong near Darjeeling (West Bengal) which is having an installed capacity of 130 kW. This hydropower is still in working condition and now having an installed capacity of 600 kW after renovation, modernization and uprating of the existing plant. Few other power houses belonging to that period such as Shivasundaram in Mysore (2 MW, 1902), Galogi in Mussoorie (3 MW, 1907) and Jubbal (50 kW, 1930) near Shimla are still working