Renewable Energy 101 (2017) 537–549

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Life cycle impact assessment of photovoltaic power generation from crystalline silicon-based solar modules in Nigeria

D.O. Akinyele [a, *], R.K. Rayudu [a], N.K.C. Nair [b]

[a] Smart Power and Renewable Energy Systems Group, Victoria University of Wellington, PO Box 6140, Wellington, New Zealand
[b] Power Systems Group, Department of Electrical and Computer Engineering, University of Auckland, New Zealand

ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form
25 August 2016
Accepted 10 September 2016

Keywords:
Energy payback time
Net energy ratio
Life cycle carbon emission rate
Normalised solar irradiation
Primary energy

ABSTRACT

This paper evaluates the life cycle impact (LCI) of a 1.5 kW solar photovoltaic (PV) system. The LCI is examined in terms of the life cycle emission rate (LCER), global warming potential (GWP), cumulative energy demand (CED), energy payback time (EPT) and net energy ratio (NER), using six different locations - one from each of Nigeria's six geo-political zones as case studies. With a performance ratio of 80%, lifetime of 20–30 years, module efficiency of 15.4%, solar irradiation of 1493–2223 kWh/m^2/yr, LCER of 37.3–72.2 g CO_2/kWh and CED of 3800–8700 MJ eq., the GWP, EPT and NER values of 1907–5819 kg CO_2-eq., 0.83–2.3 years and 7.08–36.17, respectively, are obtained. The significance of these results is that the lowest GWP and EPT, i.e. 1907 kg CO_2-eq. and 0.83 years, are obtained for the location with the highest solar irradiation, while the highest values, i.e. 5819 kg CO_2-eq. and 2.3 years, are obtained for the location with the lowest irradiation. Furthermore, the highest NER is obtained for the location with the highest irradiation while the lowest value has been obtained for the location having the lowest irradiation. The study provides an insight into the significance and impact of a location's solar energy potential on the environmental performance of a PV system, which can be useful for energy analysis, planning and decision-making purposes.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Electric energy generation technologies such as solar photovoltaic modules continue to be popular around the globe, not only because of the possibility of utilizing them for achieving future energy security, but also due to the increasing awareness and concerns about carbon dioxide emissions, global warming and climate change [1–4]. Such technologies are generally considered to be eco-friendly because of their potential to generate energy from a resource (i.e. solar energy) that has comparatively less environmental impact [2]. Therefore, the environmental performance evaluation of generation technologies is usually required to provide insights into the energy requirements and emissions generated over their lifetimes [3].

The life cycle impact analyses focus on two major aspects viz. the energy and the emissions parts. The question of the quantity of energy needed to manufacture a solar power generation system and how long the system is required to operate so as to recover the primary energy requirement is of interest in analysing the environmental performance of PV systems [5]. Basically, this has to do with the energy-related aspect of the LCI analysis and is associated with the cumulative energy demand, the energy payback time and the net energy ratio metrics. The cumulative energy demand is therefore defined as the total primary energy required for manufacturing, transporting, installing, operating and decommissioning a product [5,6]. For most renewable energy technologies, including solar photovoltaic modules, the largest proportion of cumulative energy demand is the energy requirement for manufacturing.

However, the life cycle emission rate (LCER) and the global warming potential (GWP) are emissions related aspect of the LCI analyses, and they are generally part of the indicators that are associated with the most critical environmental problems [5]. Similarly, the manufacturing of solar PV modules accounts for >90% of the life cycle carbon footprints. The CO_2 emission rate and the GWP are usually measured in gCO_2-eq./kWh and kgCO_2-eq., respectively [3,7].

Several articles have been published on solar electric power

* Corresponding author.
E-mail addresses: daniel.akinyele@ecs.vuw.ac.nz, akin_dan@yahoo.com (D.O. Akinyele).

http://dx.doi.org/10.1016/j.renene.2016.09.017
0960-1481/© 2016 Elsevier Ltd. All rights reserved.

Nomenclature

A_{sa}	active surface area of PV (m^2)
C_e	life cycle emissions of PV ((gCO_2/kWh)
BOS	balance of system
CE_k	cumulative emissions of groups k
CED	cumulative energy demand
CFC	chlorofluorocarbons
CO_2	carbon dioxide
CH_4	methane
D_{sf}	design safety factor
EPT	energy payback time (yr)
EROI	energy return on investment
E_{AEG}	annual energy generation (kWh)
E_m	primary energy demand for manufacturing PV (MJ)
E_t	primary energy demand for transporting PV (MJ)
E_i	primary energy demand for installing PV (MJ)
E_o	primary energy demand for operating PV (MJ)
E_d	primary energy demand for decommissioning PV (MJ)
F_c	fuel consumption rate (l)
GHG	greenhouse gas
GWP	global warming potential ($kgCO_2$-eq.)
HIT	heterojunction technologies
IEA	international energy agency
IEC	international electrotechnical commission
IPCC	intergovernmental panel on climate change
k	index representing the groups or species of emissions that belong to the GHG family
mono c-Si	monocrystalline silicon
poly c-Si	polycrystalline silicon
YEO	yearly energy output of solar PV (kWh)
M_1	generator fuel curve intercept coefficient (l/hr/kW)
M_2	generator fuel curve slope (l/hr/kW)
NER	net energy ratio
LCER	life cycle emission rate (gCO_2/kWh)
LCI	life cycle impact
PR	performance ratio (%)
PSH	peak sun hour
PV_{lt}	lifetime of PV (yr)
PV_r	rated PV capacity (kW)
S_{irr}	location solar irradiation
$^{*}S_{irr}$	location solar irradiation normalised by 1700 kWh/m^2/yr
$^{**}S_{irr}$	location solar irradiation normalised by 1800 kWh/m^2/yr
U_{ld}	users' load demand (kWh)
μ_k	global warming potential factor
η_G	average primary energy-to-electrical energy conversion factor

generation systems both for on-grid and off-grid applications. Some of these papers are referred to in this study for analysis purposes [8–30]. The social, cultural and political dimensions of off-grid renewable energy programs have been presented, focusing on developing countries [8]. Off-grid electricity generation with renewable energy technologies has been discussed [9]. The design and costing of a stand-alone solar photovoltaic system are presented considering a Tanzanian rural household [10]. The development of photovoltaic power plant for remote residential applications has been discussed, focusing on the socio-technical and economic perspectives [11]. These authors [8–11] present the technical and economic analysis of energy systems.

A technical and economic viability assessment of PV power plants has been discussed for rural electrification in the Gambia [12]. Also, a techno-economic analysis has been conducted for solar photovoltaic power plant focusing on the garment zone of Jaipur city [13], while the viability analysis of PV power plants is presented using Egypt as a case study [14]. Distributed power generation is also presented considering a small scale PV plant in Greece [15]. Techno-economic sizing of the off-grid hybrid renewable energy-based electrification system has been presented for Sri Lanka [16]. The global progress in PV technologies and the scenario of the development of solar panel plant and module's electrical performance estimation has been discussed [17]. A study on the economic and technical assessment of a hybrid electrification system (wind-photovoltaic-diesel) has been presented, using Algeria as a test case [18].

Furthermore, distributed photovoltaic power generation for energy-poor households has been analysed using the techno-economic approach [19]. Research on off-grid community electrification projects has been published, focusing on the wind and solar energies in Nicaragua [20]. Also, a study has been conducted on the viability of grid-connected solar PV electricity system in Jos, Nigeria [21]. Decentralised PV energy generation system has been presented, with a focus on the social, economic and the environmental benefits analyses [22]. A new approach for optimal sizing of standalone photovoltaic systems has also been proposed, using Malaysia as a case study [23]. The viability of grid-connected solar PV system has been discussed examining a location in Ethiopia [24], while the analysis of hybrid energy systems has been presented for application in southern Ghana [25]. A study on the optimal green energy management has been reported considering both the on-grid and off-grid electrification systems [26].

A study on optimal planning and design of a renewable energy based supply system has been discussed for microgrids [27], while the assessment of hybrid renewable power sources has been presented using Malaysia as a case study [28]. A review of the factors affecting operation and efficiency of photovoltaic based electricity generations systems has been published [29]. A paper has also been published, which focuses on solar energy potentials in strategically located cities in Nigeria in terms of PV design [30].

The commonality of these studies is the technical and economical evaluation of the energy generation systems, which provides a relevant and acceptable background for off-grid electrification systems planning and design purposes. Some of the studies have also discussed the institutional barriers to widespread application of PV systems, while a few others presented solar PV power generation performance analysis. However, we found that the environmental impact analysis was not discussed in some of these studies [8,10–13,15–18,20,21,23,25–28,30], while in the other studies it is estimated that the amount of carbon emissions saved by the renewable energy systems is equal to the amount of carbon emissions produced by the fossil fuel systems [9,14,19,22,24,29]. Such an assumption means that the emissions from the solar PV systems are not considered from the lifecycle point of view, but estimated in terms of the annual emissions avoided. The literature provides that certain amounts of emissions are produced when the renewable energy system is being manufactured, installed, operated and decommissioned [3,5].

In addition, the authors in Refs. [9–16,21,24,25,28] have

Download English Version:

https://daneshyari.com/en/article/4926906

Download Persian Version:

https://daneshyari.com/article/4926906

Daneshyari.com