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Review

Review of life cycle assessment of nanomaterials in photovoltaics

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Abstract

Photovoltaic (PV) technologies are gaining a share in the renewable energy production market. Recently nanomaterials have been used by researchers to improve the performance and efficiency of PVs. Consideration to the environmental aspects of nanomaterials infused PVs is a growing area of interest. Therefore, the objective of this paper is to investigate the application of LCA to PV technology. Particularly, the authors are interested in scrutinizing the application of LCA to PV systems infused with nanomaterials. In this paper, a literature review was performed to describe and assess the limitations of current research on the usage of life cycle assessment (LCA) methodologies to predict the environmental impact of nanomaterials usage on PVs. The approach to this review focuses on two sub-categories: production and/or use of PVs, and end-of-life of PVs. Following this approach the context and progress of LCA is described. Research gaps and opportunities for improved environmental performance throughout the life cycle of nano-infused PVs are identified and discussed. This work provides a basis for the continue analysis of emerging nanomaterials and PV technologies.

Keywords: Nanomaterials; Photovoltaics (PVs); Life cycle assessment (LCA); End-of-life; Critical review

Contents

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1. Introduction

Since the modern form of solar cells were developed at the Bell Telephone Laboratories in 1954 (TIME Magazine, 1954), the solar energy sector has been in continuous expansion. Recent progress in solar energy has provided a myriad of opportunities and the sector is slowly gaining a greater share in the energy market (IRENA, 2012). Photovoltaic solar panels (PV) are one of the solar technologies leading the growth of solar energy sector. There are three well known generations of PV technologies. The first generation corresponds to the most commercially available crystalline silicon PVs. The second generation corresponds to thin film technology PVs. Lastly, the third generation corresponds to the still-in-research phase PVs comprising of mainly concentrated PVs, quantum dots PVs and hybrid PVs (Kazmerski, 2006; Conibeer, 2007; Singh, 2013).

PV technology as a whole – the technology behind the harvesting of solar energy – has several benefits that make it stand out from all other energy sources, especially fossil fuels and natural gas. These benefits include the unlimited supply of the energy source which is the sun, as such renewability, and also the modular feature of the technology which allows great flexibility for installations and applications. Low operation and maintenance cost is yet another attractive feature that has propelled the technology. The global installed PV capacity was 67.4 GW at the end of 2011 and is projected to grow to a capacity between 131 GW and 196 GW in the year 2015 (EPIA, 2012). From an economic perspective, taking the example of crystalline silicon PVs, just within two years the cost dropped from USD 4.05/W to 2.21/W from 2008 to 2010 (IRENA, 2012; Solarbuzz, 2011). In these reports (IRENA, 2012; Solarbuzz, 2011), for the thin film PV technologies, specifically single-junction amorphous PV modules, the cost is projected to decrease from 0.99/W in 2010 to USD 0.55/W in 2015. Across the range of PV technologies, a decline in cost has been waited for several decades. The level of maturity has allowed the technology to gain a larger share of the renewable energy market.

Advances in material technology as well as lower production costs, have been two important factors for the recent growth of PV (Tyagi et al., 2013). However to date the technical options for improving the energy conversion efficiency is facing challenges due to the limitations of the materials used in the manufacturing of PVs. Materials with higher energy efficiencies are needed if PV technology is to continue its expansion on the market (Wadia et al., 2009; Peter, 2011). Recent development in the field of nanomaterials has provided new opportunities to meet such requirements (Macaira et al., 2013; Abdin et al., 2013; Chen et al., 2013).

PVs are labeled as a source of renewable energy due to the unlimited availability of solar energy. However, the manufacturing of PV requires the input of materials that are not renewable. Manufacturing of PV requires significant amount of water, metals, and energy, etc. The addition of nanomaterials may allow PV to overcome the efficiency barrier of traditional bulk materials used today. On a less positive side, the manufacturing of nanomaterials is energy intensive, requiring more energy than material manufacturing at a bulk scale (Gutowski et al., 2010). For the sustainability of PV systems, it is imperative that systematic approaches are implemented to ensure that future developments are optimized for environmental performance throughout the life cycle. The objective of this paper is to investigate the application of LCA to PV technology. The authors are particularly interested in scrutinizing the application of LCA to PV systems infused with nanomaterials. The manuscript is organized as follows: first the methodology is explained. Subsequently the results for two selected categories are presented and discussed. Lastly, recommendations are given along with conclusions.

2. Methodology

The methodology consisted of searching scientific databases for two categories. The first category is “LCA studies conducted on the production and use of PVs”. A literature search was conducted on various databases and journal sources aiming at the production and use stages of PVs. Seventy-two scholarly articles were selected for further reviews. The articles were furthered categorized as follows, 44 covering LCA on production and use of PV technologies only while 19 articles cover “nanomaterials relating to the production and use of PV technologies”. Only 9 articles fall under “LCA on nanomaterials in PV technologies”, which have substantial content covering both LCA and nanomaterials pertaining to PV technologies.

The first category is “studies conducted on end-of-life of PV technologies”. The end of life of products is an important stage in the whole life cycle. At this stage, proper recover of materials is critical as the same may end up contaminating the environment. For certain products the recycling and material recovery industry is well established, as is the case of the automobile. With regard with energy technologies like PV panels the industry has not yet been established since many of the PV in the market have not reach the end of life stage. Therefore PV manufacturers and researchers already identified the need for research on further treatment options of used PV modules and to develop