Feasibility of Emerging Technologies in Solar Panel

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ABSTRACT
The Photovoltaic industry has seen significant growth in recent decades as the energy demand has increased, where the current diverse technologies are being commercialised or still in research phase. Hence, to evaluate the energy/environmental effects of such devices, more life cycle assessment (LCA) studies are being conducted on these systems. This research seeks to critically evaluate the findings relating to energy and environmental implications produced throughout the third generation (non-silicon rooted) PV technology's life cycle. Moreover, the review effort enables highlighting and comparing essential factors such as (PV system, geographic location, efficiency), energy/environmental aspects, and Life Cycle Assessment studies related to various Photovoltaic systems to emphasize the significance of such aspects, and to give information as a basis of comparison for future analyses.

Keywords: *PV generations; environmental impacts; energy impacts; life cycle assessment (LCA): Energy Payback Time (EPBT): Positive Energy Demand (PED)*

INTRODUCTION
Energy is crucial to development and economic expansion. Utilizing renewable energy sources is necessary given the rising need for energy as their alternatives may be detrimental to the environment. Solar energy offers an optimal solution for this current situation. Photovoltaic (PV) modules that concentrate solar radiations, are used in solar technology to generate electric power from solar energy.

This energy is utilized to produce electricity or it can be stored thermally or in batteries. Hence, Solar technology is now being developed with a lot more effort. As stated by [1], some of the serious problems that arise throughout this procedure includes reduced silicon cell efficiency, greater processing costs, lack of appropriate infrastructure, and a lack of competent labour. Photovoltaic systems are widely available, emission-free and good for the environment. The limitations of this energy source are its high energy conversion efficiency and the SPV system's initial expense.

In the past, several semiconductor materials and technologies were employed to create PV cells that were both affordable and highly efficient. Researchers developed a wide range of unique materials and devices in quest of greater efficiencies, performances, and sustainability starting with the earliest photovoltaic (PV) technologies based on silicon [2].

In light of this supposition, it is crucial to consider the following factors when evaluating a new PV technology: (i) the energy used in its manufacture; (ii) the kinds of resources and materials produced; (iii) the waste generated throughout the manufacturing and use processes; (iv) the ratio of energy created to energy used; and (v) the product's end of life.

RESEARCH GAP

In-depth research is being done on cutting-edge technologies like third generation solar cells considering solar photovoltaics are the technology of the future. According to these studies, such advanced technologies could reduce PVs' negative environmental effects. However, a lot of these research works lacks one or more of the following: -

- A lot of these studies modelled substances and processes that might be challenging to transfer from laboratory to commercial manufacturing.
- Due to a lack of data for comparable types of solar cells, these studies did not consider end-of-life management and recycling options.

So, we must simulate device layouts and manufacturing processes that we think accurately reflect the conditions of the anticipated low-cost production in order to assess PV technologies.

Research Questions

a. Classify the generations of PV Cells (from first generation to third).
b. What are the different types of emerging technologies in solar photovoltaic?
c. Does the life cycle of emerging advanced PV technologies impact energy and environment?

AIM AND OBJECTIVE

The aim of this paper is to explore the life cycle of emerging solar PV technologies and their impact on energy and environment.
The objectives to achieve the aim are:

a. To identify the classifications of PV cells generations and various types of emerging technologies in solar photovoltaic.
b. To assess emerging PV technologies on the basis of key parameters and their life cycle analysis.
c. To suggest improvements and measures for better efficiencies and lower environmental impacts.

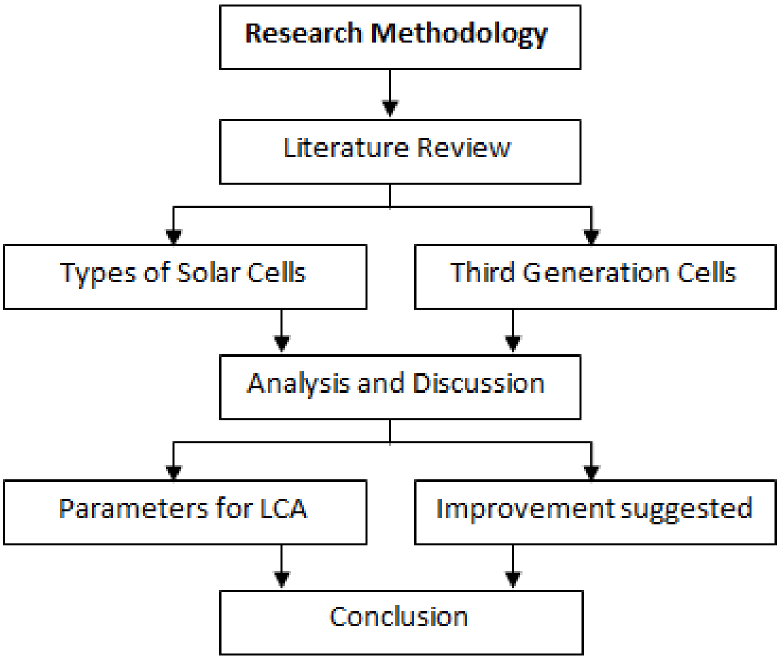
METHODOLOGY

First, there are three distinct generations of solar cells: first, second, and third. The third generation of solar cells has not yet entered the commercial market.

Each of these types have their own advantages and disadvantages and hence, it’s important to understand their differences for analysing their environmental impacts and efficiencies for a sustainable future.

Secondly, various literature works on third generation cells (DSSC’s, PSC’s and OPV) have been discussed. These studies analysed cells on the basis of energy reductions, efficiencies and environmental impacts as compared to other Silicon based technologies.

At last, a deep discussion has been done on these third-generation solar cells, including key parameters for conducting such LCA works, the research gaps of above stated literature works and other shortcomings, and suggestions to improve the performance of these latest technologies on the basis of economic and environmental factors and better efficiencies.



TYPES OF SOLAR CELLS

One or more layers of materials with light-absorbing qualities can be used to make solar cells. Single junction cells are easy to make but less effective (first case). On the other hand, multi-junction cells are more complex since they feature a variety of charge separation and absorption techniques [3] [4]. The performance of the cells must be improved, the efficiency and price of production methods must be optimized and the market price of the modules must be lowered through continuous development of PV technology.

Photovoltaic systems are distinguished on the basis of the solar cell technology and materials used. These technologies are classified into three generations:

- First-generation cells - also known as traditional solar cells, are developed of crystalline silicon, the PV technology which is most widely used in industry and comprises materials like polysilicon and mono-c silicon.
- Second generation solar cells - Amorphous silicon, CIGS and CdT cells are some of the thin-film solar cells from second generation that are used in small stand-alone power systems, integrated photovoltaic buildings, and utility-scale photovoltaic power plants [5].
- Third generation solar cells - Perovskite Solar Cells (PSCs), Organic (OPVs) and Dye-Sensitized Solar Cells (DSSCs), Photovoltaics make up the 3rd generation of solar cells.

CLASSIFICATION OF THIRD GENERATION SOLAR CELLS

A) Perovskite solar cells

Methylammonium lead halide perovskites, which have advanced quickly in recent years, are the basis for perovskite solar cells, which are organic-inorganic hybrid materials.

A cradle-to-gate environmental LCA was conducted in [6] for two distinct low-cost perovskite device structures. It found that the manufacturing of perovskite solar cells had lower environmental impacts than that of m-Si (First generation Cells), but that the environmental impacts from each unit of electricity generated were greater than those of any commercial PV technology, primarily due to their shorter lifetimes. [7] . It was discovered that the organic materials used to make the precursors for perovskite deposition had a significant negative impact on marine eutrophication. EPBT was predicted to last one to one and a half years.

Perovskite solar cells had a primary energy demand (PED) higher than the thin film cells but lower than that of mono-Si solar cells. Perovskite solar cells required more electricity for production than any other currently available commercial technology. [6] concluded that, if perovskite cells were to enter the market, their environmental impacts would be higher than those of all commercial PV technologies mainly because of their shorter lifetimes.

B) Dye-Sensitized Solar Cells

Due to its forthright preparation process, low cost, minimal toxicity and ease of manufacture, dye-sensitized solar cells (DSSCs) are among the thin film solar cells that have been the subject of in-depth research recently.

The study in [8] analysed the laboratory process preliminary data for the manufacturing of a DSSC and then evaluated the PV panel manufacturing process on the basis of pre-industrialization data extracted from literature and web resources. They investigated the case analysis of an installation connected to the virtual roof grid (BOS) [9].

The authors came to the conclusion that the biggest environmental impact came from material manufacture. The most energy-consuming process is the one used to produce conductive solar glass (due to the huge amount of energy required for covering glass with a conductive oxide layer). For glass-glass DSSC devices, the EPBT dropped as efficiency increases. According to sensitivity analysis, sustainability is achieved under every circumstance, with short-term performance being at its best [10]. In spite of a far from ideal laboratory production process, calculations conducted in [8]compare DSSC favourably with other crystalline silicon PV technologies in terms of the embedded energy of the PV module.

C) Organic Solar Cells

According to [11] building-integrated photovoltaics (BIPV), which uses conductive organic polymers or tiny organic molecules for light absorption, is where organic solar cells have the biggest impact. The low absorption of organic film aids in light reduction and supplies the building with electricity during the day, when demand is highest. Organic molecules may be tailored to the desired colours by slightly altering their chemical properties, unlike conventional semiconductors, and can therefore be a crucial component of the design.

The authors in [11] used particular data from the life cycles of fullerene synthesis, semiconductor polymer, small molecules, and interfacial material-processing to evaluate the life-cycle impact of OPV. They concluded that the fullerenes utilised as acceptors are the most energy-consuming subsystems of organic photovoltaics. Energy payback time (EPBT), cumulative energy demand (CED), and greenhouse gas (GHG) emission factor measurements of the environmental implications of OPVs revealed a declining trend [12]. Also, it was discovered that nuclear power plants had lower GHG emission factors than coal power plants, natural gas combined cycle plants, or even coal power plants [10] [13]. As a result, these power plants may help the energy sector develop in a sustainable way.

ANALYSIS AND DISCUSSION

Key Parameters

The choice of various characteristics, including environmental costs or gains and energy indices, affects the analysis's conclusions. The following have been identified as the critical factors in PV LCA studies:

The efficiency of cell

To determine if this metric is measured or approximated, researchers employed various efficiencies to assess the analysis' findings. They estimated the implications to the environment and the energy supply associated with an improvement in solar panel performance. Improvements in a PV system's conversion efficiency typically had a positive impact on the environment (reduction of CO_2 emission factor, GWP and EPBT etc).

The geographical location

The reference geographical location (a PV panel in various environments) has an impact on both the irradiation - which affects the PV system's performance, and the nation's energy production mix - which affects how the environment is perceived. Variations in irradiation have a direct impact on the total amount of energy generated over the course of the life cycle, which is important for the payback time indices and the energy and environmental implications. The installation of PV systems was found to be most suitable for regions that receive significant solar radiation.

The PV system (BOS)

Switches, cables, inverters, batteries, control and measurement systems and panel-mounting frameworks are a few of the essential parts that make up the BOS. The environmental impacts may be understated if the BOS impacts are ignored, depending on the installation type and technology (ground-based/rooftop installation). For instance, if the BOS includes components like batteries and power conditioning electronics, the PV system's carbon footprint might be reduced by over 30%. BOS 'contribution states that the impact is greater if the device's efficiency declines.

In [14], the authors thoroughly examined every stage of fabrication as well as the life cycle of every material used in OPV modules. They investigated the effects on the environment of two distinct OPV solar modules under various manufacturing integrations, usage spans, and disposal methods. The results were shown for module efficiency of 5% (laboratory cells) and 10% (expected industrial). For this reason, they took into account two system scenarios—a portable solar charger and a solar rooftop array—as well as two various end-of-life situations, namely incineration and landfill. OPV versions surpassed mc-Si and a-Si in terms of performance. Fire and life safety aspects should also be considered while considering the new emerging materials in the building including their installation processes [15,16,17]. The panels should also be integrated with the building management systems. [18] suggested that the exterior apparatus should be resilient and robust during the use-phase and recyclable at its end of life in order to improve the recyclability and biodegradability of OPV modules.

PSC technology has a limited lifespan, significant issues, a lack of scale-up techniques and waste disposal methods [19] evaluated potential lead emissions during the use phase and two distinct end-of-life scenarios and came to the conclusion that the lead emissions are primarily caused by the production of the panel and BoS. They proposed replacing lead with less hazardous alternatives.

The device lifespan in DSSCs is mostly influenced by the iodide/triiodide redox pair. Among the alternative redox shuttles, the cobalt complexes have exhibited the greatest performances. [20] states, DSSCs can achieve further improvements in terms of sustainability through the implementation of nature-based dyes, the use of alternative substrates.

CONCLUSION

Photovoltaic systems are distinguished on the basis of the solar cell technology and materials used. These technologies are classified into three generations - First Generation, Second Generation and Third Generation Solar cells. The analysis of the literature reveals a considerable amount of third generation PV LCA studies. The efficiency, location, BOS, manufacturing technique, EoL phase, etc., which are determined by the LCA analysts, are significant variables that influence the outcomes of various studies. One of the most important parameters, according to sensitivity analysis, is an increase in efficiency. The environmental effects of OPV technology appear to be solely related to fullerenes and their derivatives. The most detrimental effects on the environment were caused by electrolyte deposition, back contact deposition and glass substrate preparation during the manufacturing of perovskite solar cells.

Electricity use has had a significant impact on all generations, thus it's necessary to strive for less energy-intensive manufacturing processes or to lessen environmental responsibilities by employing an energy mix that isn't based mostly on fossil fuels. In comparison to the first generation, third generation manufacturing methods use less energy and have less environmental impacts. Nonetheless, there is still room for improvement in terms of production procedures, such as layer deposition temperatures and timings, encapsulation steps, etc.

A crucial aspect to consider is the usage of precious materials like gold, silver, copper, and platinum or other possibly hazardous components [21]. Although the findings of LCA analyses for third generations are typically better at the environmental level compared to other PVs (for instance, Si based), it is crucial to take into account the true sustainability of a scenario of large-scale dissemination of these devices using such materials. A recurring indicator in the LCA of PV called EPBT indicates how energy-efficient the system is. As technology advances, the EPBT parameter decreases, hence, first generation displays considerably larger EPBT (more than two years), whereas third generation EPBT is lower. Also, the recycling phase has a significant impact on the life cycle assessment of PV systems. For the sake of the environment, it is necessary to recover PV's heavy and largely used components. Recycling toxic substances and rare metals is essential to decrease the environmental impacts.

To conclude, even though third generation solar cells may be a revolution in PV technology since they are more efficient and have lower negative effects on the environment than previous generations, much more research is still required to address these issues and start their commercialization.

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