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Environmental impacts of solar energy systems

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Abstract

The yearly growth in worldwide energy usage, coupled with the associated environmental problems and worries, are major factors driving the widespread adoption of sustainable and renewable energy on a global scale. Solar energy systems have garnered significant attention in the past decade, surpassing other forms of renewable energy systems. Nevertheless, renewable energies might still cause negative environmental impacts. Therefore, it is crucial to prioritise careful consideration and implement appropriate precautionary measures. This report delivers a detailed assessment of the environmental impacts of both established and innovative solar energy solutions, shedding light on their effects on the ecosystem, considering their impact on the environment at both small and large sizes. The study examines both the associated advancements and the crucial components in their systems. The strategy encompasses all steps, commencing with the designs, and progressing through the manufacture, materials, construction or installation phases, as well as the operation lifetime and decommissioning. This article explores targeted strategies for various systems, including waste reduction and recycling, as well as providing technically and ecologically beneficial suggestions for minimising their effects.

Keywords: Impact, Solar, Energy, Environment.

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1. Introduction

The creation of energy is seen as a significant obstacle during the process of industrial advancement, particularly due to the exponential growth of the global population. Communities are growing and moving into previously unoccupied areas and adopting new technology, resulting in a general increase in energy demand, especially for electrical energy.[1] Therefore, there is an increasing demand for a reliable, eco-friendly, and effective energy source to ensure the long-term sustainability and well-being of society.[2] In 2018, coal, crude oil, and natural gas, collectively known as fossil fuels, accounted for over 80% of the primary energy supply, according to the International Energy Agency.[3] Unbeknownst to us, the widespread utilisation of fossil resources has proven to be a two-sided weapon, tragically causing significant harm to the ecosystem. The excessive reliance on fossil fuels and their widespread misuse across various sectors of life have resulted in a range of hazardous environmental issues. These issues encompass a range of severe climate-related phenomena, including drought-stricken land, intense heatwaves, devastating wildfires, increasing sea levels, destructive floods, and other catastrophic weather events.[4]

A study was undertaken to explore environmentally acceptable and efficient alternative energy sources, as the current energy market depends on limited resources and has adverse environmental impacts.[5] Significant endeavours have been undertaken to improve the effectiveness of current conversion systems of energy leading to the creation of efficient energy conversion systems. These breakthroughs have been driven by harnessing a diverse range of renewable energy technologies, encompassing wind, solar thermal, solar photovoltaic, geothermal, hydroelectric, and biomass energy solutions.[6]

A significant portion of these endeavours has successfully advanced renewable energy systems, prompting industrialised nations to transition their current energy balance towards more reliance on renewable sources. This has also led to a global push for reducing carbon emissions. The Paris Agreement, a significant geopolitical decision, has mandated a global decrease in carbon emissions.[7] However, the IRENA's 2017 Climate-Safe Energy Solutions report states that in order to successfully accomplish these ambitious objectives and adequately mitigate the adverse impacts of climate change, complete elimination of carbon emissions from energy consumption must be achieved within a span of less than 50 years. To achieve a fourfold expansion of the global economy by 2060, a crucial requirement is that the growth rate of renewable energy sources accelerates to a minimum of seven times its present pace.[8]

According to the 2019 statistics report published by IRENA, the capacity of renewable energies expanded by 7.4%, leading to a substantial net gain of 176 gigawatts (GW) in overall capacity. Asia accounted for 54% of this increase, with solar and wind energies contributing to 90% of the new capacities. In 2019, renewable energies accounted for around 70% of new power installations.[9] Upon examining the current growth statistics of renewable technologies, it becomes evident that there is a significant global interest in solar-powered systems. In 2019, solar power accounted for about 60% of the overall capacity increase of renewables, which amounted to 98 GW.[10]

Given the significant enthusiasm for renewable energy systems, especially solar technology, it is imperative to prioritise environmental measures. Ensuring the eco-friendliness of newly introduced energy supply systems requires a thorough assessment of renewable technologies' sustainability, a detailed examination of their environmental consequences, and the implementation of corrective measures to alleviate potential environmental harm.[11]

Solar power is more cost-effective in comparison to alternative energy producing methods. Additionally, they are plentiful and well-suited for numerous uses. The maintenance expenses associated with solar power installations are very minimal. An important drawback is the susceptibility to weather intermittency, which necessitates the use of an energy storage system, hence increasing the overall cost of the device.[12] The expansion of solar electricity has experienced exponential growth from 1992 to 2020. It has transitioned from being used in small-scale applications to becoming a widely adopted source of electricity. Following the introduction of solar cells in the 1950s, solar energy generation has emerged as a popular method for tapping into renewable energy sources, with many countries around the world embracing this technology to harness the power of the sun.[13] China currently holds the top position as the largest producer of solar electricity, surpassing the United States, Japan, and Germany. Solar energy can be utilised in two main ways: as a source of heat in solar thermal applications, or indirectly as a source of electricity in concentrated solar power plants. It can also be directly used to generate electricity in solar PV systems, concentrated solar PV systems, and photo-assisted fuel cells. Additionally, solar energy can be used to produce fuels such as hydrogen or hydrocarbons through CO_2 reduction.[14]

Several research organisations have conducted comparable literature reviews on various solar systems and distinct environmental impacts. Although researchers have explored the environmental implications of OPVs through assessments of CED, EPBT, and GHG emissions, their work has been restricted to OPVs alone, neglecting comparisons with other technologies, and has failed to drive significant improvements in environmental sustainability.[15] Subsequently, Saïcha et al. focused their research primarily on evaluating the energy payback time (EPBT) and carbon dioxide (CO_2) emissions associated with photovoltaic (PV) technology. Nevertheless, the study failed to evaluate the technical characteristics of the panel and the components of the balance of system (BOS). It solely focused on the PV panel and disregarded other components of the system. Furthermore, it did not take into account the emerging PV technologies. Additionally, the study only considered CO_2 emissions and neglected other environmental factors. In a recent study, examined various solar energy systems and determined that CdTe PVs and solar pond CSP have the lowest greenhouse gas emissions during their lifespan. However, the study failed to take into account the impact of other components of the system and neglected to examine developing photovoltaic technologies. Additionally, the study was confined to examining only greenhouse gas emissions.[16]

Research has been conducted on various aspects of solar technologies, including their economic feasibility, efficiency, and applications, as well as the impact of individual components, such as PV panels or specific PV technologies, on system performance. Additionally, studies have explored electrical and thermal storage technologies, solar thermal collectors, and country-specific Life Cycle Assessments (LCAs) to evaluate the environmental impacts of different solar technologies and compare the effects of installation and manufacturing locations. Nevertheless, the research carried out by Liliana Marcela et al. failed to consider a comprehensive worldwide database while comparing different technologies.[17] Ensuring consistent global practices in life cycle assessments (LCA) and the establishment of global regulations are essential. In addition, the research conducted by Grant and Hicks and Mousa and Taylor did not take into account the varied solar technologies when comparing different installation and manufacturing locations. This research focused on evaluating the environmental footprint of solar energy technologies, specifically commercial and emerging solar photovoltaic (PV) and concentrated solar power (CSP) systems, utilizing cutting-edge Life Cycle Assessment (LCA) methodologies and environmental impact analyses to conduct a comprehensive examination of these technologies.[18]

Solar photovoltaic (PV) systems

The Earth's surface receives a direct solar radiation of 1366 W/m2 from the sun. As the energy traverses the atmosphere, it gradually decreases and attains a peak standard surface irradiance of around 1000 W/m^2 at sea level in clear weather conditions. The sun is a reliable and sizable energy source that provides major environmental benefits compared to traditional sources and certain technological advantages over other renewable energy sources, depending on the exact location. A solar photovoltaic (PV) system typically consists of arrays.[19]

Solar thermal systems

Concentrated Solar Power (CSP) systems, also referred to as solar thermal systems, possess the same appealing attribute that has garnered global attention for solar PV technology: the abundance of usable energy derived from the sun. Over the past decade, CSP systems have experienced a consistent surge in adoption across various regions worldwide, mirroring the growth trajectory of their solar PV counterparts.[20] The building of solar power plants requires a higher level of technological investment compared to other types of power plants. This is because any unforeseen or overlooked soil or land factors can have a significant impact on the system's long-term consistency, efficiency, and performance. Hence, substantial alterations to the landscape are typically necessary, including the elimination of vegetation, levelling of land, compaction of soil, removal of unnecessary roads, and the creation of primary access roads. This can result in heightened outcomes.[21]

Conclusion

This review has provided a comprehensive analysis of the environmental effects of solar energy systems. It has examined many commercial and emerging solar photovoltaic (PV) and concentrated solar power (CSP) systems, highlighting their novel technology and installations, as well as the key components of these systems.

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