

Unveiling Solar: A Thorough Examination of its Environmental Dimensions in Advancing Renewable Solutions and Mitigating Pollution

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ABSTRACT

Solar energy has emerged as a viable and sustainable alternative as the world grapples with climate change and fossil fuel depletion. Nevertheless, it is essential to recognize the disadvantages of solar energy to ensure that its development does not come at the expense of the environment and society. This paper investigates the impacts of solar energy, including its effects on land resources, wildlife habitats, water consumption, and environmental pollution. In addition to environmental impacts, solar energy's negative effects also include social and economic difficulties. Furthermore, there necessitates a concerted emphasis on the maturation of photovoltaic technologies with minimal aqueous dependencies, thereby diminishing competition with agricultural and other water-related imperatives. The paper also discusses potential solutions for mitigating these problems, such as implementing land-use policies that priorities conservation, encouraging rooftop solar panel installations, developing solar panel technologies that require less water, and promoting the use of environmentally friendly materials. In addition, the paper urges policymakers, industry leaders, and individuals to take action to resolve these issues and promote a more sustainable and equitable solar energy industry. While solar energy has the potential to revolutionize the way we generate and use energy, it is essential to resolve its negative aspects to ensure that everyone can enjoy its benefits.

Keywords— Solar Energy, Renewable Energy, Environmental Pollution, Social and Economic Impacts, Sustainability.

I. INTRODUCTION

Solar power is an enduring source of energy harnessed from the sun's radiance, channeled through photovoltaic cells [1]. The paramount advantages intrinsic to solar energy encompass its perpetual and sustainable essence, its progressively augmenting cost-efficiency, minimal upkeep prerequisites, the potential for self-sufficiency in power generation, and the catalytic effect it has on employment opportunities. In its character as a renewable energy source, solar power remains untarnished by depletion over time and, in comparison to conventional fossil fuels, emerges as a markedly eco-friendly substitute [2]. The financial outlay linked to solar energy has been witnessing a steady decline over the years, rendering it a more economically accessible resource for individuals and enterprises. Solar panels, renowned for their low-maintenance disposition and prolonged life expectancy, signify a source of energy with minimal care obligations. Furthermore, solar energy carries the potential to bestow energy autonomy, diminishing dependence on foreign reserves of oil and natural gas [3]. The burgeoning solar sector has ushered in a wave of job creation, spanning manufacturing, installation, and maintenance [4].

The resurgence of solar power has witnessed a remarkable surge in recent times, predominantly attributable to its well-established advantages. As per the International Energy Agency's findings, solar energy emerges as the globe's most rapidly burgeoning electricity source, poised to amass a substantial 580 gigawatts of electrical prowess by 2025. This extraordinary progression can be ascribed to myriad catalysts [5]. The diminishing cost of solar energy has made it progressively more economical and within reach. This reduction in expense emanates from breakthroughs in technology, heightened competition within the solar sector, and governmental incentives that stimulate its embrace. Consequently, individuals and corporate entities alike are discovering it increasingly pragmatic to harness solar vitality. Moreover, solar energy plays a pivotal role in ameliorating

dependency on fossil fuels and alleviating the adverse repercussions of climate fluctuations. Numerous nations globally have acknowledged the exigency of transitioning to eco-friendly energy sources such as solar power to counteract environmental vicissitudes [6].

Solar power harbors certain restrictions and deficiencies that warrant thoughtful consideration. Primarily, solar energy's availability hinges upon the radiant presence of the sun, rendering it incapable of furnishing a perpetual and dependable source of electrical power. This limitation is particularly conspicuous in regions plagued by frequent overcast or inclement weather, as solar panels exhibit diminished efficacy under such meteorological circumstances. Additionally, the generation of solar power necessitates an extensive expanse of land, a demand that can exert deleterious ramifications upon wildlife habitats and ecosystems [7]. Another consequential concern pertains to the fabrication of solar panels, which necessitates the utilization of fossil fuels and noxious chemicals, thereby engendering detrimental ecological repercussions. Furthermore, the viability of solar panels is contingent on the specific architectural configuration of one's roof, rendering them less efficacious for certain roof types. For individuals contemplating relocation shortly, investing in solar panels may prove to be an imprudent choice. The spectre of hazardous materials, akin to those encountered in electronic devices, looms over solar panels, posing a latent threat to the environment and human well-being. Lastly, the fiscal outlay associated with harnessing solar energy can be substantial, although this concern may progressively wane in significance as technological advancements bolster efficiency and augment storage capacity. Notwithstanding these impediments, solar energy endures as a propitious and sustainable energy reservoir. Vehement efforts are being marshalled to confront these challenges through the prism of innovation and dedicated research [8].

Solar energy has some limitations and drawbacks that need to be considered. Firstly, solar energy can only be produced when the sun is shining, which means that it cannot provide a constant and reliable source of electricity. This is particularly true in areas with frequent cloudy or rainy weather, as solar panels are less effective under such conditions. Additionally, solar panels require a significant amount of land to generate electricity, which can have negative impacts on wildlife habitats and ecosystems. Another concern is the manufacturing of solar panels, which requires the use of fossil fuels and toxic chemicals that can have negative environmental impacts. Furthermore, solar panels may not work for every roof type, and they may not be a good investment if you are planning to move soon. This review paper is mainly focused on the impacts of solar energy production and ways in which it can be made sustainable.

II. CURRENT SOLAR ENERGY PRODUCTION STATUS

As per the Data compiled by Data based on three main sources: - BP Statistical Review of World Energy., Ember Yearly Electricity Data (2023), Ember European Electricity Review (2022) [9]–[11] a world map is being plotted showing the variation of solar energy production is last decade i.e. from 2011 to 2022. This highlights the quick global adoption of solar energy for energy needs.

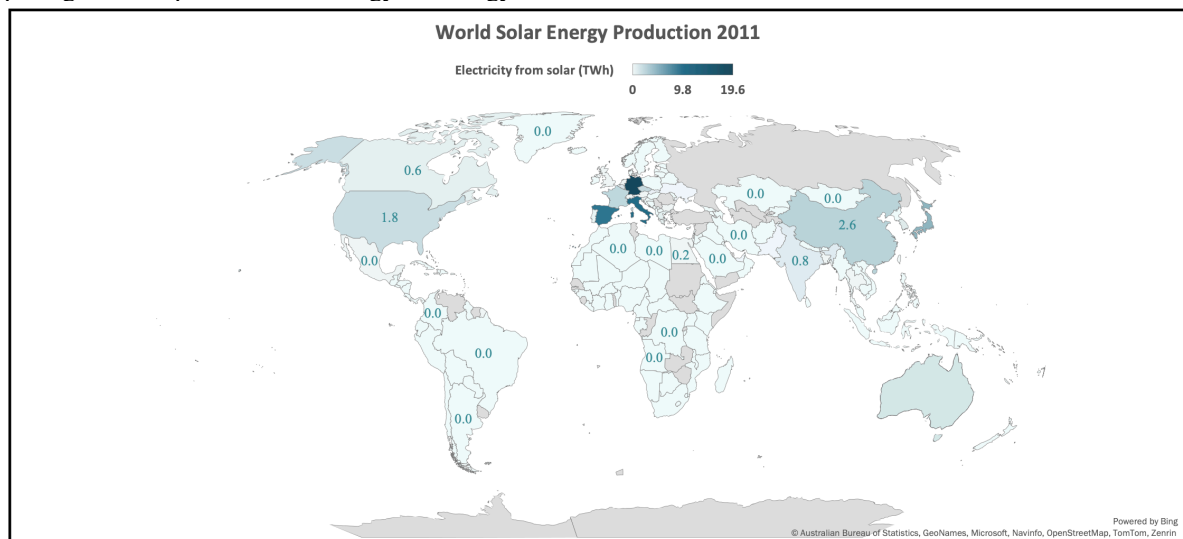


Fig. 1 a): World Solar Energy Production, 2011 [9]–[11]

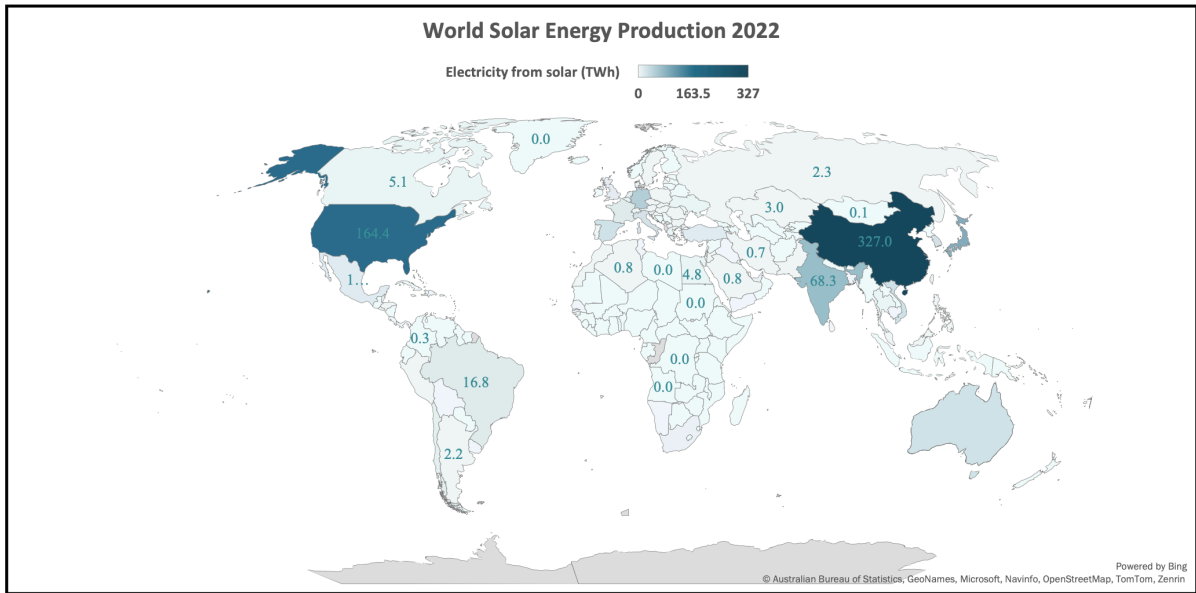


Fig. 1 b): World Solar Energy Production, 2022 [9]–[11]

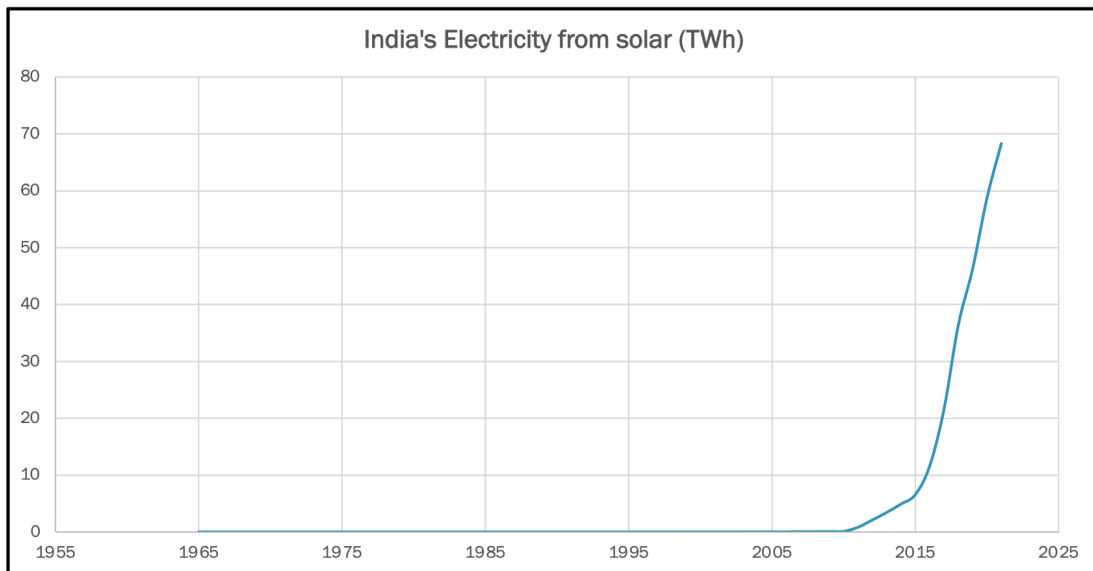


Fig. 2: India's Solar Energy Production [9]–[11]

III. THE DARK SIDE OF SOLAR ENERGY

A. Environmental Impacts

- **Impact of land resources**

Land utilization emerges as a pivotal facet within the realm of solar energy's ecological ramifications, especially in the context of expansive solar farms. These formidable solar installations necessitate substantial land allocation to accommodate the extensive arrays of photovoltaic panels, imperative for the generation of electricity on an industrial scale. This endeavor, however, carries the potential for deleterious repercussions on the surrounding ecosystems, manifesting as the forfeiture of wildlife habitat and the perturbation of pristine natural panoramas [12].

In certain instances, solar farms have incurred censure for their development on fertile agricultural terrain or within regions renowned for their biodiversity. Such siting decisions wield profound implications for indigenous ecosystems and agricultural output alike [13]. Nevertheless, it merits acknowledgment that a plethora of solar installations, exemplified by rooftop photovoltaic arrays, obviate the requirement for additional land and can be seamlessly integrated into preexisting developed areas [14]. Moreover, an array of concerted initiatives

exists to ameliorate the ecological imprint of solar farms. These include the localization of projects on degraded or marginal land, the implementation of safeguards for wildlife preservation, and the adoption of low-impact techniques for solar panel installation. Such endeavors collectively endeavor to strike a harmonious balance between harnessing solar energy's bounteous potential and preserving the delicate equilibrium of our natural surroundings [15].

The establishment of solar panels and their consequent intrusion into natural habitats has emerged as a formidable environmental concern associated with solar energy deployment. In the grand scheme of solar energy generation, expansive solar farms may necessitate the clearance of indigenous flora and the transformation of pristine landscapes into platforms for solar panel placement and its correlated infrastructure. Such actions can precipitate the disintegration and forfeiture of living spaces for fauna, thus culminating in far-reaching ecological repercussions. To elucidate, the eradication of native vegetation can incite detrimental consequences such as soil erosion, the depletion of biological diversity, and alterations in the indigenous climate patterns. Furthermore, the installation of solar panels often necessitates the employment of substantial machinery and ancillary equipment, thereby escalating the perturbation of ecosystems and provoking the compaction of soil [16].

- **Impact of water resources**

Solar panels necessitate a measure of water for cleansing and cooling, yet the quantum of water required is typically markedly inferior when juxtaposed with alternative power generation methodologies such as coal or nuclear power facilities. Water finds its primary utility in the cleansing of panels, ridding them of dust and detritus to ensure the utmost efficiency and optimal energy yield. Furthermore, water occasionally serves to temper the panels, averting the specter of overheating and safeguarding the equipment from potential harm. The magnitude of water consumption for the dual objectives of purification and temperature regulation may exhibit variance contingent upon the specific solar technology in use and the geographical locale, given that certain regions boast a more copious supply of water resources than others. In a concerted effort to ameliorate the water footprint associated with solar energy production, numerous enterprises are engaged in the development of innovative technologies and methodologies that either curtail or eliminate water utilization. For instance, select entities have embraced dry cleaning methodologies that obviate the need for water altogether, while others have adopted a sustainable approach by repurposing recycled water or wastewater for cleansing and thermal regulation. Moreover, certain solar power installations are strategically situated in regions replete with ample sunlight yet devoid of abundant water sources, rendering the adoption of water-intensive cooling systems unfeasible [17].

Harnessing the potency of solar energy necessitates substantial tracts of land, a resource often engaged in a relentless tussle with agriculture and other essential water requirements. This stems from the fact that solar energy generation frequently unfolds in regions with meagre water reservoirs, thereby engendering a clash between energy production and the multifaceted demands of the land. Furthermore, certain solar technologies, most notably the likes of concentrating solar power (CSP), entail the extravagant utilization of water for cooling, a facet that can only serve to exacerbate the pervasive issue of water scarcity in arid terrains. To grapple with these disconcerting conundrums, a plethora of strategies beckon, poised to mitigate the precarious juggling act between solar energy and agriculture or ancillary water necessities. One stratagem of notable mention advocates for the localization of solar energy production in topographies unsuitable for cultivation, such as arid deserts or barren wastelands. Another avenue of approach advocates for the deployment of solar technologies that exhibit parsimony about water usage, typified by the photovoltaic (PV) solar panels, which remain immune to the necessity of water for cooling. In tandem with these, the prudent adoption of water-conservation methodologies can prove instrumental. These include the judicious utilization of recycled or treated wastewater for cooling purposes or the incorporation of dry cooling systems that circumvent any dependence on water [18].

In the grand tapestry of this discourse, it becomes resoundingly clear that while there may indeed exist a vying competition between solar energy and the exigencies of water, a panoply of strategic measures is at our disposal to temper these conflicts. What remains paramount is the judicious contemplation of the water dynamics inherent to a specific region, coupled with the imperious need to cultivate solar energy production in a manner that not only stands as a bulwark of sustainability but also assiduously curbs deleterious ramifications upon agriculture and the myriad of land applications therein [17].

B. Pollution

Solar panels, hailing from a diverse array of constituents like silicon, aluminum, glass, and plastics, among a myriad of other components, are the prodigious offspring of a labour-intensive genesis. This birthright, fuelled by substantial energy consumption, gives rise to the lamentable emanation of greenhouse gases and sundry noxious airborne byproducts. Moreover, within the crucible of their production, one encounters the utilization of certain chemicals, such as cadmium and lead, whose toxic proclivities pose a pernicious peril to both human well-being and the ambient environment [17].

At the culmination of their productive life, these solar sentinels find themselves confronting the inexorable destinies of disposal or reincarnation, each bearing its distinct ecological footprints. Solar panels, being replete with materials of enigmatic recalcitrance, present formidable challenges in the realm of recycling. The

improper interment of these artifacts can instigate the inadvertent dissemination of pernicious chemical agents into the pristine environs. To contend with these daunting quandaries, a cornucopia of strategic initiatives beckons, promising mitigation of the ecological repercussions that shadow the production and ultimate disposition of these solar behemoths.

One cogent strategy calls for the utilization of materials endowed with diminished toxicity and an innate proclivity for facile reclamation. An alternate avenue for redress lies in the augmentation of the production process's efficiency, thereby curtailing the quantum of energy prerequisites and the concomitant emission emanations. Furthermore, the establishment of conscientious policies that invent proper solar sepulcher and recycling stands as a beacon to guide us through this environmentally treacherous terrain [19].

The fabrication of solar panels encompasses a multifarious amalgamation of substances, some of which harbor the potential for toxicity and peril to both human well-being and the ecosystem. For example, certain variants of solar panels incorporate cadmium telluride (CdTe) or copper indium gallium selenide (CIGS) as their semiconductor substrates, entities prone to expelling deleterious compounds if mishandled or ineffectively disposed of. Furthermore, the production procedure necessitates the utilization of solvents, acids, and assorted chemicals, all of which hold the potential to impose jeopardy upon laborer's and environmental stability when not subjected to meticulous management.

C. Social Impacts

Although the cost of harnessing solar energy is decreasing, the initial investment needed to purchase solar panels and set up the necessary infrastructure is still very high. This financial obstacle is especially challenging for impoverished communities, preventing them from accessing the many benefits of solar power. These benefits include lower electricity costs and decreased reliance on fossil fuels, which are crucial considering growing environmental concerns[20]. In tandem with the substantial installation costs, the upkeep and restoration of solar panels may entail ongoing expenses. Neglecting the proper maintenance regimen can precipitate a decline in efficiency, or worse still, render these panels entirely non-operational. Such setbacks cast a pall over both the economic and ecological merits of this sustainable energy source.

To redress these quandaries, concerted endeavors have been undertaken to democratize and render solar energy more financially viable for underprivileged communities. These initiatives encompass an array of strategies, including the provision of financial mechanisms, the establishment of community-based solar programs, and the promulgation of government incentives. Yet, despite these commendable strides, the journey toward universal access to renewable energy beckons for a sustained commitment to investment and innovation.

IV. MITIGATION METHODS

A. Land Impacts

In order to solve these problems, substantial efforts have been made to democratize solar energy and make it more affordable for impoverished areas. These projects cover a wide range of tactics, such as the construction of community-based solar programmes, the provision of funding channels, and the issuance of government incentives. Nevertheless, the road to achieving widespread access to renewable energy still calls for a persistent commitment to investment and innovation [21], [22].

In order to address the challenge of needing a lot of land for solar farms, a potential solution is to incentivize the installation of rooftop solar panels on both residential and commercial buildings. This strategic utilization of extant rooftop expanses holds the promise of a substantial diminishment in the demand for terrestrial tracts earmarked for the generation of solar energy. Governmental instruments, such as the judicious implementation of tax incentives and the establishment of net metering initiatives, stand poised to serve as potent catalysts in promoting the widespread integration of rooftop solar panels. Furthermore, the fostering of community-driven initiatives and forging strategic alliances with solar installation enterprises can synergistically facilitate the provisioning of cost-effective and easily accessible avenues for the installation of rooftop solar panels. It is important to underscore that a multiplicity of convergent forces coalesce to render this proposition viable and consequential. By harnessing the untapped potential of elevated rooftop domains, a paradigm shift in energy generation paradigms becomes palpable. The strategic alignment of government-backed economic incentives and the collaborative engagement of the private sector augur well for the democratization of solar energy [23].

As solar panels reach the end of their lifespan, there is a growing concern about how to dispose of them properly. Solar panels can contain hazardous materials such as lead, cadmium, and gallium arsenide that can pose risks to human health and the environment if not handled properly. Therefore, implementing regulations on the disposal of solar panels is crucial to minimize their environmental impacts. Several countries have already implemented regulations on the disposal of solar panels. In the European Union, for example, solar panel manufacturers are required to take back and recycle solar panels at the end of their lifespan under the Waste Electrical and Electronic Equipment (WEEE) Directive. In the United States, several states have passed laws that require solar panel manufacturers to establish recycling programs and report on the disposal of their products [24].

In addition to regulations, there are also efforts to develop more sustainable ways of manufacturing and disposing of solar panels. For example, some companies are exploring the use of non-toxic materials in the production of solar panels, and others are developing processes to recycle and reuse solar panel components. By implementing regulations on the disposal of solar panels and promoting sustainable manufacturing practices, it is possible to minimize the environmental impacts of solar energy and ensure its long-term sustainability.

B. Water Impacts

The production of solar panels poses a notable quandary in the realm of sustainability due to its voracious appetite for water, both in the manufacturing phase and the subsequent cleansing and cooling processes. The demand for water can create conflicts in areas where it is scarce and valuable. However, experts are working hard to develop new technologies that can reduce the amount of water used in processes like solar panel production. Their efforts aim to solve this problem and make better use of our limited resources. One such pioneering technology resides in the realm of dry silicon etching, which stands in stark contradistinction to its aqueous counterpart [25]

In the traditional wet etching procedure, silicon undergoes dissolution via the amalgamation of chemicals and copious amounts of water. This modus operandi not only begets copious hazardous byproducts but also exacts a toll in the form of substantial water consumption. The dry etching paradigm, in stark contrast, harnesses the power of plasma to etch the silicon, obviating the need for copious water and concomitantly curbing the generation of perilous waste materials [26]. By implementing such groundbreaking technologies, the ecological footprint of solar panel production can be appreciably diminished. Simultaneously, it offers a judicious resolution to concerns entailing water utilization and the contentious competition that ensues in the context of other vital water needs [27].

V. CONCLUSION

In retrospect, the shadowed facets of solar energy encompass an array of ecological and societal repercussions. These encompass the dislodgment of habitats vital to wildlife, the contestation for access to precious water resources and the utilization of noxious substances in the manufacturing process. Furthermore, the sporadic nature inherent in solar energy generation, coupled with the formidable expenses linked to its installation and upkeep, along with potential incompatibilities with particular roofing configurations and relocation complexities, can be appraised as disadvantages. Nevertheless, concerted endeavors are presently underway to redress these concerns. These initiatives encompass the institution of land-use regulations that accord precedence to preservation, the promotion of rooftop photovoltaic systems, the innovation of solar panel technologies characterized by reduced water requirements, the enforcement of stringent regulations governing the disposal of solar panels to curtail environmental repercussions, and the endorsement of ecologically benign materials in the manufacturing process. While indisputably presenting a set of challenges, solar energy stands as an incontrovertible boon as a renewable and sustainable wellspring of power. In tandem with the burgeoning appetite for solar energy, it becomes paramount to accord primacy to the implementation of sustainable principles and policies, thus guaranteeing the enduring constructive influence of solar energy in the realm of global energy transformation.

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