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Infrastructure-Integrated Photovoltaic (IIPV): a boost to solar energy's green credentials?

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Abstract

Infrastructure-integrated photovoltaic (IIPV) has potential to improve the green credentials of solar energy at a time when environmental impacts of energy systems are under increasing scrutiny. However, little attention has been given to the environmental sustainability of IIPV in comparison with standalone PV systems and other energy technologies. Research is urgently needed to address this apparent gap in our understanding of IIPV's impact on existing infrastructure, the environment and wider society before its large-scale deployment.

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Keywords: infrastructure; integrated; photovoltaic; environmental sustainability

1. Introduction

Solar photovoltaic (PV) is one of the fastest growing renewable energy sources in recent years. Thanks to the versatility of PV technologies, their integration into infrastructure systems is also on the rise. Infrastructure-integrated PV (IIPV) has been applied in many sectors including transport (e.g., on top of parking lots for electric vehicle charging [1] and as highway sound barriers [2] and pavements [3]), water (e.g., on reservoirs [4], dams and canals [5]), agriculture (e.g., on top of farmland [6], greenhouses and aquaculture farms [7]) and the built

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environment (e.g., integrated with street lighting [8] and buildings [9]). Figs. 1 and 2 show two examples of IIPV. These innovative IIPV applications could potentially give solar energy's green credentials a welcoming boost, at a time when environmental impacts of energy systems are under increasing scrutiny. Given the enormous demand for new infrastructure globally [10], there is great potential for IIPV development. It's main application could be in urban environments which already house more than 50% of the global population and account for 70% of global energy use and CO_2 emissions [11,12]. However, the apparent lack of research on the environmental, architectural, and behavioral implications of IIPV could hamper its development in the long term.

Fig. 1. A solar PV farm on top of a car park

Fig. 2. A solar PV farm on top of cropland

2. Environmental impacts of solar energy

Renewable energy technologies in general are considered to be more environmentally friendly than their fossil fuel counterparts. However, they can and do have significant environmental impacts, particularly from a life cycle perspective [13]. Standalone solar PV systems could suffer from high impacts in categories including toxicity, biodiversity, air pollution, metal depletion and land use (and food security as a consequence) in comparison with other renewables or even fossil fuels [13–16]. These impacts may soon limit further large-scale deployment of PV systems considering the looming Water-Energy-Food-Environment (WEFE) nexus [17,18].

IIPV, an idea that is not new [19], could potentially resolve or at least ease these problems compared with standalone PV. For example, floating solar farms and solar canals could help reduce evaporation to conserve precious fresh water resources while at the same time benefit from higher electrical efficiency than conventional land-based PV systems (due to water's natural cooling effect) [4,5]. Solar pavement and building-integrated PV (BIPV) could reduce the land and materials footprints of PV. PV integrated with agriculture could also increase the productivity of land and may produce other benefits such as protection of crops against high temperatures [20].

3. Research needs

Although on paper IIPV offers opportunities to enhance the environmental sustainability of solar energy, the actual picture is far from clear. Teasing out the exact effects of IIPV is by no means straightforward as the challenges lie where its strength is, in the word "integrated". Little research has been done in this area apart from a few life cycle analysis (LCA) on BIPV [21–24]. Here, we briefly discuss a few key issues that need to be carefully considered in order to have a thorough understanding of IIPV's environmental impacts.

3.1. Multifunctionality

IIPV systems often kill several birds with one stone. This multifunctionality, however, brings a well-known methodological issue for quantitative environmental assessment techniques such as LCA. For example, how to apportion the land use impacts of a solar canal between energy generation and water transfer (i.e., the two products/services from the infrastructure) or the overall materials savings of BIPV [25] between energy and buildings? A system's approach is needed to evaluate IIPV within the context of the wider infrastructure systems.

3.2. Benchmarks

The choice of benchmarks can tip the balance in a comparative analysis. This certainly can be the case for IIPV systems as the appropriate benchmarks might not be obvious when comparing them with other energy technologies and standalone PV systems. In some cases, IIPV is "marginal" and can be added to existing infrastructure. An example would be floating PV farms on reservoirs where PV is not essential to the reservoirs with minimal effects on their functioning. Here, IIPV can be assessed relatively independent of the reservoirs provided that the added benefits such as reduced evaporation and increased electrical efficiency are taken into account. In other cases, IIPV is more integral to the infrastructure by design. BIPV is a prime example as it can influence building energy performance [9] and material requirements [25]. It is therefore necessary to compare the buildings with and without BIPV in order to accurately evaluate the effects of BIPV. This, however, is often not done in LCAs [21–24].

3.3. Performance

The performance of IIPV systems needs to be monitored or estimated carefully as this is a key parameter influencing their life cycle impacts. IIPV may not achieve the optimal levels of performance for key technical parameters such as electrical efficiency and system lifespan because of the need to accommodate other functionalities. For example, it might not be infeasible to use technologies such as solar tracker in IIPV systems to increase electrical efficiency given their inflexibility in terms of positioning. In addition, understanding IIPV's interactions with other parts of the infrastructure and as a consequence influences on their performance is crucial but no trivia task. Data generated from existing or demonstration projects will be invaluable but modelling and simulations are equally important, especially for emerging technologies.

3.4. Transdisciplinarity

Given the diversity and scale of IIPV applications, transdisciplinary insights are required to get a sound grasp of the impacts. Inputs from researchers in energy technologies, materials, design & architecture, civil engineering, urban planning, transport, water systems, agriculture, environmental science, ecology and data science as well as infrastructure providers and operators are relevant and necessary. Any future research should be designed with such a transdisciplinary approach in mind.

4. Conclusion

IIPV is a promising concept for smart and sustainable energy systems with great potential for large-scale deployment. However, research is urgently needed to better understand its potential environmental implications and wider impact on society to guide R&D efforts and investments strategically. This can only be achieved through a holistic and transdisciplinary view of IIPV in the wider infrastructure systems and in particular, urban environments. Incentives must be put in place by policy makers to encourage cross-sector collaboration and information sharing to make this happen.

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