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Editorial

Building Integrated Photovoltaics—The Journey So Far and Future

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1. Introduction

The road to decarbonization has led to the exploration of sustainable energy sources for domestic and industrial use. Various nations have shown commitment and, hence, set ambitious targets, with the overall aim of cutting down greenhouse gas (GHG) emissions across the board. The fight against climate change seems to be intensifying, partly due to the visible signs of environmental hazards and threats to human life and the ecosystem. Environmental policies, behavioural changes and complex decisions have been taken in various sectors to ensure set targets are met.

The options are becoming slimmer by the day; hence, a swift, feasible and sustainable paradigm shift has become necessary to meet the carbon neutrality target by 2050. Major targets set by nations require an increase in energy efficiency, especially in buildings, transport and industry. A recent target set by the European Union in its Energy Efficiency Directive seeks to achieve 32.5% efficiency by 2030 [1]. The EU Renewable Energy Directive (RED) also seeks to achieve 32% renewable penetration by 2030 [2]. These are clear indicators of commitment towards promoting renewable adoption.

Renewables have been raised as the most feasible energy alternative to replace high CO_2 emitters such as fossil fuel and coal. In the last half-century, various renewable technologies have been developed to high standards. The technology has moved from the ability to produce basic electricity to sophisticated and modern application which considers aesthetics. Solar, at the forefront of renewables, is one of the cleanest, most cost effective and abundant energy sources.

Solar applications in buildings have gone through several faces. Famous amongst them is building applied photovoltaics, where PVs are added after building [3]. These days, solar technology has advanced to a more sophisticated way of applying PVs in buildings, such that they form part of the building envelope without pouting. Among recent advancements in PV application, BIPV has become one of the most promising, especially in the built environment. Although building-integrated photovoltaics (BIPVs) have been around since the early 1990s [4], the rate of adoption and dissemination has been relatively tardy.

In basic terms, BIPV provides an architecturally appealing way of integrating PVs into buildings such that they form part of the building envelope [5]. Technically, BIPVs replace conventional building materials; hence, there is no clear difference. The advantages are numerous, therefore making it a worthwhile venture. Some identified advantages are cost efficiency, aesthetics, energy producing ability, noise reduction, sun protection, land space saving, privacy screen, among other safety features. The "big-deal" about BIPV is its aesthetic premium [6–10].

The aesthetically appealing application of PVs in buildings make BIPVs the best fit for modern sustainable architecture. BIPV deserves extensive research and continuous

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academic commitment in all aspects, hence the introduction of MDPIs Special Issue on BIPVs. The architectural appeal and possibility of replacing conventional building materials makes BIPV an appealing option. It quietly fulfils its energy-producing requirements, as well as delivering other benefits. BIPV remains the game changer in photovoltaic applications, especially in the built environment.

This short paper summarises the journey so far and the future of MDPIs Special Issue on BIPVs. The next section highlights the need for this Special Issue. The next outlines the highlights of various publications in this Special Issue so far. The final section draws conclusions.

2. Need for Special Issue in BIPV

Despite the numerous advantages of BIPVs, its inception and dissemination, especially in developing countries, has been relatively slow. The BIPV market is still considered as niche; however, current trends in green building technologies (GBTs) and the consciousness of sustainability mean that its prospects are extremely high. Promising efforts have been made by various stake holders to push the BIPV market. In recent years, the technology is becoming logically appealing as concerns about environmental aesthetics, renewable appeal, design and appearance are growing [11–14].

A holistic approach to the adoption of solar PV is, therefore, imminent. Aesthetic consideration is very important in the long run as a "compromise today means an environmental mess tomorrow". BIPV has therefore proven to be a viable solution, hence a deliberate effort must be made to promote research on pertinent topics in the area. As the name implies, a "special issue" is a collection of related comprehensive research articles within a specific research area with high impact. Special Issues are created to fill in an identified gap in the literature. A topic must be of academic, industrial and societal interest to merit being considered a "special issue". This offers an indication of the momentousness of BIPVs.

The effort to popularise BIPV across the board must be a joint one, and a conscious approach must be inculcated to overcome the existing limitations within the cultural, legal, technical, technological and research space. BIPV appears to be a viable link between modern photovoltaic application and traditional/modern architecture. BAPV appears to be the most feasible option when it comes to PV applications in buildings. However, BIPV have proven to be a practically feasible alternative for conventional BAPV applications. The challenges and prospects of BIPV have been tackled by many within construction, engineering, design and research spaces. Although the answers to existing limitations have not been met yet, a great transformation has been witnessed, at least in the last decade.

The projections appear prosperous, hence the need to invest time, effort and resources to surmount the existing limitations and to further validate adoption. Education and technical training form the bedrock of the growth and adoption of every technology including BIPV. In recent years, a deliberate effort has been made to promote adequate knowledge spread, research, awareness and technical training of personnel. For instance, in 2015, the "Dem4BIPV" project was initiated with the overall aim of bringing together a number of leading research universities, as well as experts within Europe and other developed countries, to train graduates within the engineering, design, construction and architectural space in BIPV design, installation and maintenance [15]. Research interest is heightened, technical knowledge in the area is on the rise and public awareness and acceptance is gradually taking shape; hence, a conscious effort within the research fraternity is key. The need for this "special issue" on BIPV cannot be overemphasised. The key summaries are as follows:

I. This Special Issue provides a leveraged research premise for academics, researchers and industry experts within the BIPV space to exhibit recent works and areas of study. A Special Issue can be a fulfilling "podium of relevance", as a specific topical issue of relevance is given all the attention to highlight the nitty gritty. It offers a rewarding and exceptionally gratifying experience for all contributors as they receive the opportunity to pay their quota to the advancement of the knowledge in BIPVs. The same can be said for editors involved in promoting the Special Issue. In a discussion with one of the guest editors of this Special Issue, he emphasised that; "this special issue was particularly curated with the idea of promoting knowledge and literature in BIPVs. It could encourage other research works in the field, while setting as a good direction for the market, manufacturers and technicians. He also emphasised that, this special issue will give the due recognition to various contributors in the field. He counted it as a privilege to be part of the editors of this special issue".

II. This Special Issue provides the grounds to network among researchers within the BIPV ambit. The ability to network is highly relevant, especially in research. Engaging and building solid relationships and networks with other researchers could secure future collaborations. It is easy to identify experts and other researchers within the BIPV space; hence, using this Special Issue is an excellent way to collaborate and build a healthy professional network.

III. This Special Issue is hotspot for advancing research in this field of expertise. Having a say in the field of BIPV within this Special Issue provides verifiable evidence for future grant applications. Topical discussions in BIPV shared in this Special Issue could potentially attract funding from various sources. This is an easy way to locate key researchers in the field, thereby enhancing ones prospects and future collaborations. The conversations and topical discussions raised have also attract readers from diverse fields.

IV. This Special Issue particularly propels the discussion around BIPVs. BIPV is a relatively modern addition within the solar application space; hence, "hype" is an added advantage. This Special Issue provides a platform to boastfully promote BIPVs in all areas.

V. This Special Issue provides easy reference and accessibility to readers within the field. The ability to easily access information and research papers is as important as being published; this is why researchers take keen interest in the impact factor and overall status of a journal. This journal has a high impact factor; hence, articles published in this Special Issue have the potential to reach a larger audience.

A leveraged ground for an excellent peer review within the BIPV space is essential for the championing of this technology. The future seems promising; hence, an intensive call for contributions from various researchers is key, especially as the need for GBT adoption heightens within the built environment. It is becoming increasingly pressing to consider collaborations between various researchers, ranging from design, manufacturing, economics, efficiency, and marketing to application. The next section highlights summaries of the articles published in this Special Issue.

3. Summary of Publications

Scholars from divergent backgrounds have published in this Special Issue. Very important aspects of BIPV manufacturing, efficiency, prospects and limitations to adoption have been tackled. This section provides a brief synopsis of the publications in this journal so far.

In a comprehensive study conducted by [16] on the "contribution of BIPV to the concept of Nearly Zero Energy cities in Europe: Potential and Challenges ahead", the foreseeable limitations to the adoption of BIPVs in Europe are discussed in depth. The study highlights the possibility of scaling up BIPV projects from individual buildings to bigger cities. Furthermore, they provide valid metrics for the architectural assessment of BIPV efficiency when adopted for building skins. The study concludes that the EU can benefit greatly from adopting BIPV by 2030. Eighteen major limitations were identified as hindrances to the adoption of BIPVs in the EU. This study offers useful perspectives on BIPV for stake holders. It serves as a solid premise for future studies.

The authors of [17] throw light on the BIPV-levelized cost of electricity (LCOE) in the capital cities of European States, as well as Norway and Switzerland. It presents the possibility of offering better incentives and subsidies to help promote BIPV adoption. The study found that, in most of the examined cities, BIPV's cost had reached grid parity. This offered a relative advantage for BIPV adoption in the various cities. The study stipulates that, in an average case, BIPV systems could thrive even without policies such as feed-in tariffs, especially if the selling and purchasing prices of the grid are equal. Despite the fact that this study is based on assumptions, the findings are relevant and could aid the penetration of BIPV within Europe and other selected cities.

The adoption rate of BIPV in recent times indicates a high acceptance by various stakeholders. Its ability to replace conventional building materials promises to place it on par with other building materials such as conventional roofing sheet, bricks, tiles, etc. However, the climate has its own effects on building materials, including BIPVs. A study by [18] investigates the effects of climate on BIPV and solar radiation components in the Northern Hemisphere. It is demonstrated that areas with high radiation levels have a significant reduction in infrared radiation (IR); therefore, BIPV materials that rely on IR will simultaneously observe a reduction in efficiency. The study concludes that climate and temperature can affect the performance of BIPV, and specific materials must be considered depending on the climate. The authors of [19] assess "visual comfort of semi-transparent Perovskite based BIPV window for hot desert climate". The study suggests that daylight has the tendency to improve the health, mood and mindset of occupants. Although daylight is essential, it must be controlled by a semi-transparent window type rather than highly transparent windows. The study recorded that an average of between 50 and 70% transmission range was required for optimum comfort in a selected building office in Riyadh. There was evidence of excellent colour comfort for a 90% transmission rate.

Semi-transparent BIPV application offers an interesting blend of energy efficiency with modern building aesthetics. A review paper by the authors of [20] provides an overview of the "energy performance of Semi-Transparent Building Integrated Photovoltaics across a range of different climatic and environmental conditions". This paper proposes an efficient framework which is considered relevant to ascertain an accurate configuration of a semi-transparent BIPV system.

The final paper in this Special Issue offers a review on improving the performance of BIPV [21]. The study conducted in-depth analysis into the efficiency of various types of PV cells adopted for BIPV systems. Temperature elevation was realised in outdoor BIPV application. Solutions, such as water circulation, used phase-changing materials and improved air-flow ventilation. The study also proposes that the heat collected from PV cells could be used for other purposes. The study concludes that BIPV performance partly depends on factors such as "location, tilt and azimuth angles and transmittance of surface glazing".

4. Conclusions

A Special Issue in BIPV is crucial, especially in this era of renewables and commitment towards achieving net zero in buildings. Understandably, this Special Issue provides an established platform for the visibility of one's research work, which comes with numerous benefits, as discussed. This paper has emphasised the need for this Special Issue and further provided a summary of various articles published so far. It is expected that this paper will serve as a solid, short piece that will encourage researchers and various stake holders to make a collective effort to contribute to this Special Issue.

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References

1. EUR-Lex—32018L2002—EN—EUR-Lex 2022. Available online: https://eur-lex.europa.eu/eli/dir/2018/2002/oj (accessed on 8 February 2022).
2. EUR-Lex—02018L2001-20181221—EN—EUR-Lex 2022. Available online: https://eur-lex.europa.eu/eli/dir/2018/2001/2018-12-21 (accessed on 8 February 2022).
3. Kumar, N.M.; Sudhakar, K.; Samykano, M. Performance comparison of BAPV and BIPV systems with c-Si, CIS and CdTe photovoltaic technologies under tropical weather conditions. *Case Stud. Therm. Eng.* **2019**, *13*, 100374. [CrossRef]
4. Benemann, J.; Chehab, O.; Schaar-Gabriel, E. Building-integrated PV modules. *Sol. Energy Mater. Sol. Cells* **2001**, *67*, 345–354. [CrossRef]
5. Shukla, A.K.; Sudhakar, K.; Baredar, P. A comprehensive review on design of building integrated photovoltaic system. *Energy Build.* **2016**, *128*, 99–110. [CrossRef]
6. Sánchez-Pantoja, N.; Vidal, R.; Pastor, M.C. Aesthetic impact of solar energy systems. *Renew. Sustain. Energy Rev.* **2018**, *98*, 227–238. [CrossRef]
7. Awuku, S.A.; Bennadji, A.; Muhammad-Sukki, F.; Sellami, N. Myth or gold? The power of aesthetics in the adoption of building integrated photovoltaics (BIPVs). *Energy Nexus* **2021**, *4*, 100021. [CrossRef]
8. Attoye, D.E.; Aoul, K.A.T.; Hassan, A. A Review on Building Integrated Photovoltaic Façade Customization Potentials. *Sustainability* **2017**, *9*, 2287. [CrossRef]
9. Ziuku, S.; Meyer, E.L. Implementing building integrated photovoltaics in the housing sector in South Africa. *J. Energy S. Afr.* **2013**, *24*, 77–82. [CrossRef]
10. Zomer, C.; Nobre, A.; Cassatella, P.; Reindl, T.; Rüther, R. The balance between aesthetics and performance in building-integrated photovoltaics in the tropics. *Prog. Photovolt. Res. Appl.* **2014**, *22*, 744–756. [CrossRef]
11. Porteous, J.D. *Environmental Aesthetics: Ideas, Politics and Planning*; Routledge: New York, NY, USA, 2013.
12. Klæboe, R.; Sundfør, H.B. Windmill Noise Annoyance, Visual Aesthetics, and Attitudes towards Renewable Energy Sources. *Int. J. Environ. Res. Public Health* **2016**, *13*, 746. [CrossRef] [PubMed]
13. Levenda, A.M.; Behrsin, I.; Disano, F. Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies. *Energy Res. Soc. Sci.* **2021**, *71*, 101837. [CrossRef]
14. Wuebben, D. From wire evil to power line poetics: The ethics and aesthetics of renewable transmission. *Energy Res. Soc. Sci.* **2017**, *30*, 53–60. [CrossRef]
15. Dem4BiPV Project. Innovation and Entrepreneurship Centre n.d. Available online: https://www2.deloitte.com/cy/en/pages/about-deloitte/articles/dem4BiPV-consortium.html (accessed on 9 February 2022).
16. Gholami, H.; Røstvik, H.N.; Steemers, K.; Lo Brano, V. The Contribution of Building-Integrated Photovoltaics (BIPV) to the Concept of Nearly Zero-Energy Cities in Europe: Potential and Challenges Ahead. *Energies* **2021**, *14*, 6015. [CrossRef]
17. Gholami, H.; Røstvik, H.N. Levelised Cost of Electricity (LCOE) of Building Integrated Photovoltaics (BIPV) in Europe, Rational Feed-In Tariffs and Subsidies. *Energies* **2021**, *14*, 2531. [CrossRef]
18. Gholami, H.; Røstvik, H.N. The Effect of Climate on the Solar Radiation Components on Building Skins and Building Integrated Photovoltaics (BIPV). *Materials* **2021**, *14*, 1847. [CrossRef]
19. Ghosh, A.; Mesloub, A.; Touahmia, M.; Ajmi, M. Visual Comfort Analysis of Semi-Transparent Perovskite Based Building Integrated Photovoltaic Window for Hot Desert Climate (Riyadh, Saudi Arabia). *Energies* **2021**, *14*, 1043. [CrossRef]
20. Khalifeeh, R.; Alrashidi, H.; Sellami, N.; Mallick, T.; Issa, W. State-of-the-Art Review on the Energy Performance of Semi-Transparent Building Integrated Photovoltaic across a Range of Different Climatic and Environmental Conditions. *Energies* **2021**, *14*, 3412. [CrossRef]
21. Dai, Y.; Bai, Y. Energies Performance Improvement for Building Integrated Photovoltaics in Practice: A Review. *Energies* **2020**, *14*, 178. [CrossRef]