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Floating Solar Power Plants as a Sustainable Solution in Land-Constrained Areas: A Bibliometric Analysis

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ABSTRACT

This study aims to analyze the development of research on floating photovoltaic (FPV) power plants as a sustainable solution for land-limited areas using a bibliometric approach. Data were collected from the Scopus database during 2015–2025 and analyzed using VOSviewer and Bibliometrix to examine publication trends, country productivity, keyword networks, and thematic development. The results show that FPV-related publications have increased significantly in recent years, with China emerging as the leading contributor to scientific output. Keyword analysis reveals that major research themes include *solar energy*, *renewable energy*, and *solar power generation*, while *floating photovoltaic* remains an evolving topic. In addition to addressing land scarcity issues, FPV technology offers additional benefits such as improved solar panel efficiency and reduced water evaporation. However, technical, economic, and environmental challenges remain important concerns for future studies. Overall, FPV demonstrates strong potential as an innovative renewable energy solution that supports sustainable energy development in areas with limited land availability.

1. INTRODUCTION

The increasing global energy demand driven by population growth, urbanization, and industrialization has intensified pressure on conventional energy systems, which remain heavily dependent on fossil fuels[1], [2] This dependence not only triggers energy crises due to resource limitations but also significantly contributes to greenhouse gas emissions that accelerate global climate change. Numerous studies indicate that the energy sector is the primary contributor to carbon dioxide emissions, making the transition toward low-carbon energy systems a strategic global priority[3], [4]. In this context, the development of renewable energy has become increasingly urgent as a long-term, sustainable, and environmentally friendly solution. Solar energy, particularly through photovoltaic (PV) technology, holds

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a strategic position due to its abundant availability and continuously improving energy conversion potential driven by technological advancements[5], [6].

However, the implementation of conventional ground-mounted solar power plants faces significant challenges, particularly related to land availability. This issue becomes critical in regions with high population density and rapid urbanization, where competition for land use among residential, industrial, and agricultural sectors is increasingly intense[7]. These limitations have driven technological innovation in the form of floating photovoltaic (FPV) systems, which utilize water surfaces such as reservoirs, lakes, and dams as installation sites for solar panels. FPV not only provides a solution to land scarcity but also opens opportunities for the simultaneous optimization of water and energy resources[8].

These limitations have driven technological innovation in the form of floating photovoltaic (FPV) systems, which utilize water surfaces such as reservoirs, lakes, and dams as installation sites for solar panels. FPV not only provides a solution to land scarcity but also opens opportunities for the simultaneous optimization of water and energy resources[9]. In addition, the presence of panels on water surfaces can reduce evaporation rates, contributing to water conservation, particularly in arid and semi-arid regions[10]. FPV also allows for more efficient space utilization without sacrificing productive land. However, this technology faces several challenges, including structural design complexity, relatively high installation costs, the need for mooring systems, potential ecological impacts on aquatic ecosystems, and long-term operational and maintenance issues[11]

Although research on floating photovoltaic (FPV) systems has increased significantly, previous studies have mostly focused on technical performance, economic feasibility, or case-specific environmental impacts. Limited studies have systematically mapped the global research landscape of FPV in relation to land constraints and sustainability challenges using bibliometric approaches[12]. Although research on floating photovoltaic (FPV) systems has increased significantly, previous studies have mostly focused on technical performance, economic feasibility, or case-specific environmental impacts. Limited studies have systematically mapped the global research landscape of FPV in relation to land constraints and sustainability challenges using bibliometric approaches[13].

2. METHOD

This study employed a quantitative bibliometric approach to analyze the scientific development of floating photovoltaic (FPV) research as a sustainable solution in land-constrained areas. Bibliometric analysis was selected because it enables a systematic and objective evaluation of publication trends, research productivity, collaboration networks, and thematic evolution within a specific field. The data were collected from the Scopus database, which was selected due to its broad coverage of peer-reviewed international publications and reliable indexing system. Data retrieval was conducted in April 2025. The search was limited to publications published between 2015 and 2025. The search query used in Scopus was formulated as follows: TITLE-ABS-KEY (“floating photovoltaic” OR “floating solar” OR “floating solar power plant” OR “floating PV” OR FPV) AND PUBYEAR > 2014 AND PUBYEAR < 2026. This query was designed to capture relevant studies discussing FPV systems and related terminology. The inclusion criteria consisted of: (1) journal articles, (2) English-language publications, and (3) documents directly related to floating photovoltaic systems. Meanwhile, conference papers, book chapters, editorials, notes, and unrelated publications were excluded. Duplicate records were also removed during the screening stage.

The inclusion criteria in this study consisted of: (1) peer-reviewed journal articles, (2) English-language publications, (3) studies within the fields of energy, environment, and sustainability, and (4) documents explicitly addressing FPV or related technologies. Meanwhile, the exclusion criteria included conference proceedings, books, editorials, and articles lacking substantive relevance. The data selection process was conducted in three main stages: identification, by collecting all documents based on the defined keywords; screening, by reviewing titles and abstracts to remove duplicates and irrelevant documents; and final inclusion, which involved determining the final set of articles that met all criteria.

Subsequently, bibliographic data were extracted, including information on authors, publication year, country affiliations, journals, citation counts, and keywords. These data were then processed using VOSviewer and Bibliometrix (R package), which are widely used tools in bibliometric analysis for mapping knowledge structures and relationships among publications[14], [15]. The analyses conducted included co-

occurrence analysis to identify relationships among keywords, co-authorship analysis to map collaborations among authors and countries, citation analysis to determine publication impact, and trend analysis to examine the dynamics of research topic development over time.

In the process of bibliometric network mapping, several analytical parameters were defined, such as minimum occurrence thresholds (e.g., ≥5 keyword occurrences), citation thresholds, and clustering techniques to group research topics into thematic clusters based on relational proximity. The research stages were systematically structured, beginning with data collection, followed by data cleaning, bibliometric analysis, network visualization, and result interpretation. Narratively, the research flowchart begins with database selection, followed by keyword formulation, data retrieval, screening and eligibility checking, data extraction, bibliometric analysis, and concludes with interpretation and synthesis of findings.

This approach enables a comprehensive identification of research patterns while providing a strong foundation for formulating future research directions related to FPV as a sustainable energy solution in land-constrained regions.

3. RESULTS AND DISCUSSION

3.1 Authors' Production over Time

As an initial step in understanding the dynamics of scientific contributions, the following visualization presents the pattern of author productivity over a given period. This graph provides an overview of publication intensity as well as the consistency of contributions from leading authors in the field of floating photovoltaic (FPV) and renewable energy[13], [16].

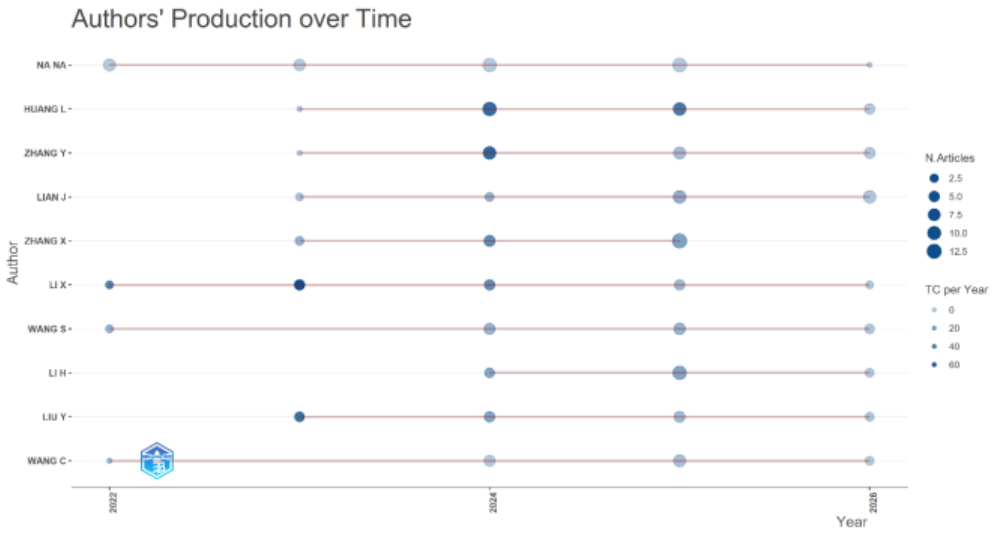

Figure 1. Co-authorship network among researchers in FPV studies

Based on the graph, it can be observed that several authors, such as Huang L., Zhang Y., and Li X., demonstrate a significant increase in productivity, particularly during the 2024–2025 period. Larger circle sizes indicate a higher number of publications, while the color gradient reflects the number of citations per year. This suggests that not only has the quantity of publications increased, but their scientific impact has also grown[17].

On the other hand, there are also authors who exhibit relatively stable but less dominant productivity patterns. This phenomenon indicates an uneven distribution of contributions, where only a small number of authors act as key drivers in the development of FPV research. Such a condition is common in emerging research fields, where core authors play a central role in shaping the direction of scientific advancement.

3.2 Country Scientific Production

To obtain a broader perspective, the subsequent analysis focuses on the geographical distribution of scientific production. The following world map illustrates the contribution of each country to publications related to the research topic..

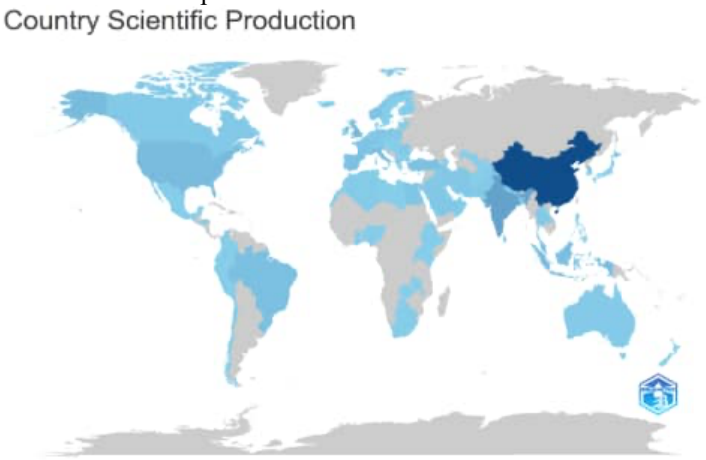

Figure 2. Global distribution of FPV research publications by country

The visualization shows that China significantly dominates scientific production compared to other countries, followed by nations such as the United States, India, and several European countries. This dominance can be associated with substantial investments in renewable energy technologies as well as high energy demand in these countries. In addition, the availability of research infrastructure and strong policy support plays an important role in increasing publication output[12].

Meanwhile, developing countries in Southeast Asia, Africa, and Latin America demonstrate relatively lower contributions. This indicates the existence of a global research gap, particularly in the context of FPV implementation in regions with abundant water resources that remain underutilized. These findings highlight the importance of international collaboration to expand the global adoption of FPV technology[18].

3.3 Thematic Map

In order to identify the conceptual structure of the research, the following thematic map is used to classify topics based on their level of importance and stage of development. emerging/declining themes.

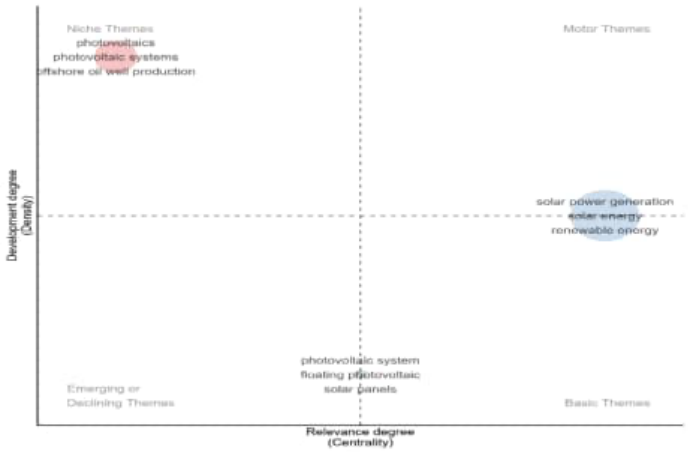

Figure 3. Thematic map of FPV research based on keyword clustering

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The analysis results indicate that themes such as “solar energy,” “renewable energy,” and “solar power generation” are located in the motor themes quadrant, signifying that these topics possess both high importance and a well-developed level of maturity. These themes serve as the primary foundation in renewable energy research and act as the main driving forces in the advancement of the FPV field[19].

In contrast, themes such as “floating photovoltaic,” “solar panels,” and “photovoltaic system” are still categorized as basic themes, indicating that although they are relevant, their development has not yet reached full maturity. This suggests the presence of further research opportunities to deepen the technical and applied aspects of FPV, allowing these themes to potentially evolve into motor themes in the future[20].

3.4 Network Visualization (VOSviewer)

As part of the analysis of relationships among concepts, the following network visualization presents the interconnections between keywords in FPV research using a co-occurrence approach. This representation helps identify the main clusters within the research landscape.

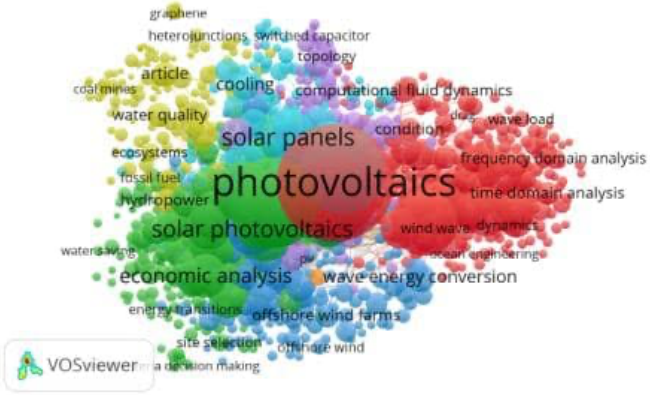

Figure 4. Keyword co-occurrence network of FPV research

It can be observed that the keywords “photovoltaics” and “solar photovoltaics” occupy central positions in the network with high connectivity, indicating their pivotal role in the research domain. The green cluster reflects a focus on economic aspects, such as economic analysis and energy transitions, while the red cluster is associated with technical aspects, including computational fluid dynamics and wave dynamics[21].

In addition, the emergence of clusters related to environmental and water resource topics, such as water quality, ecosystems, and hydropower, indicates the presence of multidisciplinary integration in FPV research. This finding underscores that the development of FPV is not limited to energy aspects alone, but also encompasses broader environmental and sustainability dimensions[17].

3.5 Documents by Year

As a concluding part of the analysis, the following graph presents the trend in the number of publications over time. This visualization is essential for understanding the temporal development of research interest in the FPV field

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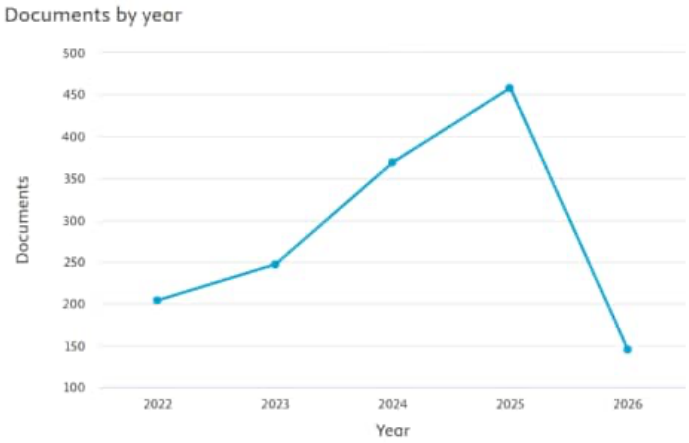

Figure 5. Annual publication trends of floating photovoltaic (FPV)

The graph shows a significant increase in the number of publications starting from 2022 and reaching its peak in 2025. This surge reflects the growing academic attention toward FPV technology as a sustainable energy solution, particularly in addressing land constraints and the challenges of global climate change[9], [22].

However, a decline is observed in 2026, which is likely due to data limitations or incomplete indexing of publications for the current year. Therefore, the overall trend still indicates positive growth, suggesting that FPV research will continue to expand and become a major focus in renewable energy studies in the future.

4. CONCLUSION

Based on the results of the bibliometric analysis, research on floating photovoltaic (FPV) systems has shown significant development and has become an increasingly prominent topic in renewable energy studies. The continuously rising trend in the number of publications, particularly in recent years, indicates that FPV is regarded as a promising innovative solution to address land constraints in the development of sustainable solar energy..

The analysis reveals that China dominates scientific productivity in the FPV field, followed by several other developed countries such as the United States and India. This dominance reflects substantial research investment, strong policy support, and high energy demand in these countries. However, the contribution from developing countries remains relatively low, thereby presenting significant opportunities to expand international collaboration and promote research development in regions with abundant water resource potential.

Furthermore, the keyword network analysis indicates that FPV research is evolving in a multidisciplinary manner, encompassing technical, economic, and environmental aspects. Core themes such as *solar energy*, *renewable energy*, and *solar power generation* emerge as dominant focal points, while topics such as *floating photovoltaic* remain in a developmental stage. This highlights opportunities for further research, particularly in system optimization, operational efficiency, and environmental sustainability.

Overall, FPV technology holds significant potential as a sustainable energy solution in land-constrained regions, as it enhances spatial efficiency, supports water conservation, and expands clean energy capacity. Nevertheless, challenges such as high installation costs, technical complexity, and potential ecological impacts must still be addressed through technological innovation and further research to ensure the optimal and sustainable implementation of FPV in the future.

5. REFERENCES

[1] Z. Zhao, Q. Ma, C. Wei, and R. Han, "Stackelberg game optimization method for virtual power plant and electric vehicle considering coupled green certificates and spot markets," *Expert Syst. Appl.*, vol. 299, 2026, doi: 10.1016/j.eswa.2025.130202.

[2] Z. Hasrudy Siregar *et al.*, "Ahmad Yani, Kisaran Naga, Kec. Kota Kisaran Timur, Kisaran, Sumatra Utara 2,3 Teknik Industri, Fakultas Teknik dan Komputer," *Jln. Sos. km 5 Jl. Sos. No*, vol. 2, no. 2, pp. 2022–2808, 2022.

[3] Y. Zhang, C. Wang, Z. Que, S. Gong, J. Liu, and X. Lv, "Automatic evaporator: Fully invasive plant derived carbon@ cellulose aerogel for highly-efficient interfacial solar evaporation," *Desalination*, vol. 615, 2025, doi: 10.1016/j.desal.2025.119313.

[4] Z. H. Siregar *et al.*, "The Effect of Fuel Mixture Composition on Gasoline," *J. Ilm. Tek. Mesin, Ind. Elektro,an Sipil*, vol. 05, no. 02, pp. 394–402, 2024, doi: 10.54123/vorteks.v5i2.389.

[5] A. Choumal and M. Rizwan, "RR-LTNet: Ramp-Rate-Centric Deep Learning Framework for Short-Horizon Photovoltaic Power Prediction," *IEEE J. Photovoltaics*, vol. 16, no. 1, pp. 176–186, 2026, doi: 10.1109/JPHOTOV.2025.3625301.

[6] Z. H. Siregar, S. L. Siregar, and A. Effendi, "From the experimental results of briquettes using a portable," *J. Vor.*, vol. 02, no. 02, p. 115, 2021.

[7] A. Fathy, "A novel synthetic inertia scheme using fractional-order proportional integral controller for multi-interconnected microgrids utilizing supercapacitors and electric vehicles," *J. Energy Storage*, vol. 148, 2026, doi: 10.1016/j.est.2025.120167.

[8] N. Gupta, A. Priyam, and M. K. Sahu, "Impact of Thermal Performance of Floating Solar Panel on Power Generation," in *AIP Conference Proceedings*, S. M.K., B. L.R., S. R.S., K. S., M. K.N., S. D.S., K. S., B. M., and P. R.D., Eds., Department of Mechanical Engineering, Mukesh Patel School of Technology Management and Engineering, SVKM's NMIMS University Mumbai, Maharashtra, Mumbai, 400056, India: American Institute of Physics, 2026. doi: 10.1063/5.0316249.

[9] A. Mouhaya, A. El Hammoumi, A. El Ghzizal, and S. Motahhir, "Evaluation of the impact of floating photovoltaic systems on reducing water evaporation and enhancing energy production at Al Wahda Dam in Morocco," *Discov. Sustain.*, vol. 7, no. 1, 2026, doi: 10.1007/s43621-025-02419-8.

[10] O.-I. Bratu, E.-I. Tică, A. Neagoe, and B. Popa, "Hydropower–FPV Hybridization for Sustainable Energy Generation in Romania," *Water (Switzerland)*, vol. 17, no. 21, 2025, doi: 10.3390/w17213144.

[11] M. Tekin and A. Kadirlioğlu, "Meeting the Power Demand in the Microgrids of University Campuses by Floating Photovoltaic," *Iran. J. Sci. Technol. - Trans. Electr. Eng.*, vol. 50, no. 1, pp. 665–680, 2026, doi: 10.1007/s40998-025-00900-8.

[12] R. Hao, X. Sun, Y. Zhao, R. Zhang, H. Li, and J. Shang, "Advancing floating photovoltaic systems: trends, challenges, and future directions in sustainable energy development," *Int. J. Green Energy*, vol. 22, no. 4, pp. 688–709, 2025, doi: 10.1080/15435075.2024.2423264.

[13] S. Rehman *et al.*, "Synergistic sizing and energy management strategy of combined offshore wind with solar floating PV system for green hydrogen and electricity co-production using multi-objective dung beetle optimization," *Results Eng.*, vol. 25, 2025, doi: 10.1016/j.rineng.2025.104399.

[14] Z. Szamosi and M. Rosas-Casals, "Safety aspects of torrefied biomass: Prosperous and dangerous process for green transition," *J. Loss Prev. Process Ind.*, vol. 101, 2026, doi: 10.1016/j.jlp.2026.105975.

[15] A. Tiktas and A. Hepbasli, "Africa's green hydrogen trajectory: A multidimensional review of technology, economics, infrastructure, and social justice," *Int. J. Hydrogen Energy*, vol. 225, 2026, doi: 10.1016/j.ijhydene.2026.154321.

[16] G. Lopez, D. Bogdanov, R. Satymov, and C. Breyer, "Floating Offshore Solar Photovoltaics for Land-Constrained and Diverse Renewable Supply Conditions in the United States and Canada," *IEEE J. Photovoltaics*, vol. 16, no. 1, pp. 60–68, 2026, doi: 10.1109/JPHOTOV.2025.3616635.

[17] M. Zheng, G. Zhang, Y. Yu, Y. Xiang, and L. Liu, "Nationwide Spatial Distribution of Floating Photovoltaic Power Stations in China From High-Resolution Remote Sensing," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 19, pp. 9683–9703, 2026, doi: 10.1109/JSTARS.2026.3671822.

[18] D. Rudolph, M. Maulidia, and H. Busyrah, "Solar–water nexus: on local implications of the procurement and deployment of the first floating solar photovoltaics project in Indonesia," *Sustain. Sci.*, vol. 20, no. 4, pp. 1393–1406, 2025, doi: 10.1007/s11625-025-01637-3.

[19] Y. Su, Y. Lu, R. Gu, W. Wu, X. Yu, and S. Cheng, "Synergistic photovoltaic cooling and water-resource recovery enabled by a composite evaporation gel," *Desalination*, vol. 619, 2026, doi: 10.1016/j.desal.2025.119565.

[20] R. K. Singh, G. N. Tiwari, and A. S. K. Sinha, "Thermal modelling of semitransparent photovoltaic thermal and flat plate collector integrated biogas plant for slurry heating: An experimental validation," *Renew. Energy*, vol. 245, 2025, doi: 10.1016/j.renene.2025.122778.

[21] Y. Han, C. Li, S. Chen, J. Zhao, Y. Tian, and J. Wang, "Enhanced multi-horizon photovoltaic power forecasting: A novel approach integrating ICEEMDAN decomposition with hierarchical frequency neural networks," *PLoS One*, vol. 20, no. 11 November, 2025, doi: 10.1371/journal.pone.0334828.

[22] T. I. Ingo, L. Gyoh, Y. Sheng, M. K. Kaymak, A. D. Şahin, and H. M. Pouran, "Accelerating the Low-Carbon Energy Transition in Sub-Saharan Africa through Floating Photovoltaic Solar Farms," *Atmosphere (Basel).*, vol. 15, no. 6, 2024, doi: 10.3390/atmos15060653.