# Research Project #22

## Performance & Systems Impact of Emerging Photovoltaic Technologies (IMD-3 & ICE-2)

**Introduction & Novelty**

The transition to a sustainable energy system depends on widespread adoption of renewable energy sources. Photovoltaics (PV) are expected to account for nearly 80% of all new renewable electricity capacity by 2030. Although silicon-based PV technology is well-established, emerging technologies such as perovskite, organic PV, and silicon-perovskite tandems offer the potential for greater efficiency and reduced manufacturing costs. However, the long-term performance and system integration implications of these novel PV technologies remain largely unexplored. This project addresses this gap by combining the detailed outdoor performance characterization of emerging PV modules with the system-level analysis of their potential impact on German and European energy systems. This analysis considers performance as well as the security of the material supply chain. The project's novel approach integrates granular, module-level data with macro-level energy system modeling, incorporating performance degradation and acclimatization effects that are crucial for reliable system assessment. This integration will provide a more realistic assessment of the viability and resilience of future renewable energy systems.

**Project Description & Work Packages**

This project will be undertaken by a PhD candidate jointly supervised by researchers at IMD-3 and ICE-2. The PhD candidate will spend time at both institutes, facilitating knowledge transfer and ensuring effective collaboration.

- **WP1: Outdoor Performance Monitoring (IMD-3)**: Establish and maintain a comprehensive monitoring campaign of standard (Si) and emerging (Si/Perovskite, Organic, etc.) PV modules at IMD-3's outdoor testing facility. This includes continuous monitoring of weather parameters (global/diffuse irradiance, temperature, wind) and electrical performance (IV curves, MPP tracking).

- **WP2: Data Analysis & Performance Modelling (IMD-3):** Develop robust data processing and analysis methods to account for outdoor data noise and variability. This will involve analyzing the influence of irradiance, spectral effects, and temperature on module performance. Crucially, the work will focus on identifying and modelling acclimatization effects, seasonal performance variations, and degradation mechanisms in both standard and emerging PV technologies.

- **WP3: Material Requirements and Supply Chain Analysis (ICE-2):** In parallel with performance data generation, the PhD candidate will work with ICE-2 to analyze the material requirements for each PV technology, per kWh generated, and assess the associated supply chain vulnerabilities and geopolitical dependencies. This will involve a literature review and implementation within the ETHOS model suite [5] to derive meaningful scenarios for supply options.

- **WP4: System-Level Impact Assessment (ICE-2):** Utilizing the performance and degradation models developed at IMD-3, and material data from WP3, ICE-2 will integrate these findings into its ETHOS model suite [5], which will involve different open-source tools like ETHOS.RESKit [4] and ETHOS.FINE [3]. This will enable assessment of the potential for new PV technologies to contribute to German/European energy security, considering both

cost and resilience of supply chains. Focus will be on identifying scenarios where emerging PV technologies can enhance security of supply and reduce reliance on critical materials.

- **WP5: Dissemination and Reporting (Joint):** Active participation in conferences, workshops, and publications to disseminate research findings. Preparation of regular project reports and a final PhD thesis.

**Research Context & References**

The project builds upon existing research at IMD-3 on outdoor PV module characterization and degradation modelling [1,2] as well as its network within SolarTab. ICE-2's expertise in energy systems modelling and the ETHOS model suite provides a strong foundation for the system-level analysis, which was and is contributing to several flagship reports of the IEA [6]. Recent publications highlight the urgent need for a comprehensive understanding of emerging PV technologies [8, …], and the importance of supply chain security for renewable energy deployment [9, …]. This project directly addresses these challenges by combining detailed module characterization with system-level analysis, providing a more holistic, technology-rich assessment of the potential of emerging PV technologies. The project directly supports the goals of the German energy transition ("Energiewende") and contributes to the development of a sustainable and resilient energy system.

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| **Location** of the HITEC Fellow | Forschungszentrum Jülich, Institute of Energy Materials and Devices - Photovoltaics (IMD-3), Director: Prof. Dr. Christoph Brabec<br>https://www.fz-juelich.de/en/imd/imd-3 |
| **Partners** of the HITEC Project | Forschungszentrum Jülich, Institute of Climate and Energy Systems - Jülich Systems Analysis (ICE-2), Director: Prof. Dr.-Ing. Jochen Linßen<br>https://www.fz-juelich.de/en/ice/ice-2 |
| Specific **requirements** | Affinity for modelling and simulation works. Experience with Python (or a similar language) is required.<br>Interest in contributing to the energy transition and to the security of supply.<br>Master's in energy, process, or mechanical engineering, natural science, or related fields, with very good grades |
| For **project-specific** questions, please **contact** | Supervision team (first supervisors underlined)<br>Dr. B. Pieters, IMD-3, b.pieters@fz-juelich.de<br>Prof. Dr.-Ing. Heidi Heinrichs, ICE-2, h.heinrichs@fz-juelich.de<br>Dr. A. Gerber, IMD-3, a.gerber@fz-juelich.de |

[1] Vaas, Timon S., Bart E. Pieters, Evgenii Sovetkin, Andreas Gerber, and Uwe Rau. "A Gaussian process regression IV model for PV outdoor data." *Progress in Photovoltaics: Research and Applications* (2025).

[2] Vaas, T. S., J. Körtgen, E. Sovetkin, U. Rau, and B. E. Pieters. "Plausibility Filtering of PV Outdoor Data." In *2023 IEEE 50th Photovoltaic Specialists Conference (PVSC)*, pp. 1-4. IEEE, 2023.

[3] ETHOS.FINE - Framework for Integrated Energy System Assessment, https://github.com/FZJ-IEK3-VSA/FINE.

[4] RESKit - Renewable Energy Simulation toolkit for Python, https://github.com/FZJ-IEK3-VSA/RESKit.

[5] Open-source part of the ETHOS model suite: https://github.com/FZJ-IEK3-VSA.

[6] Global Hydrogen Review 2023, 2024, and 2025, Energy Technology Perspective 2024, Empowering Ukraine Through a Decentralized Electricity System, Latin American Energy Outlook, Renewable Energy Opportunities for Mauretania, all from IEA.

[7] Renewable 2025, report, IEA.

[8] F. Rehman et al. (2023) Fourth-generation solar cells : a review, Energy Advances, Issue 9, https://doi.org/10.1039/D3YA00179B.

[9] S. Caravella et al. (2024) Technological sovereignty and strategic dependencies: The case of the photovoltaic supply chain, Journal of Cleaner Production, Vol 434, 140222, https://doi.org/10.1016/j.jclepro.2023.140222.