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EES Solar 2025 Outstanding Papers

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We are proud to announce the launch of the *EES Solar* Outstanding Papers. This is an opportunity to recognise the exceptional work published in the journal and celebrate the authors behind the work by selecting one Outstanding Article and one Outstanding Review each year.

These papers are chosen from a shortlist compiled by the Editorial Office using a range of metrics. The journal's Editorial and Advisory Boards review and vote on these papers based on the science presented and the potential impact. The Editor-in-Chief selects the final winning papers, taking the Board members' votes into account.

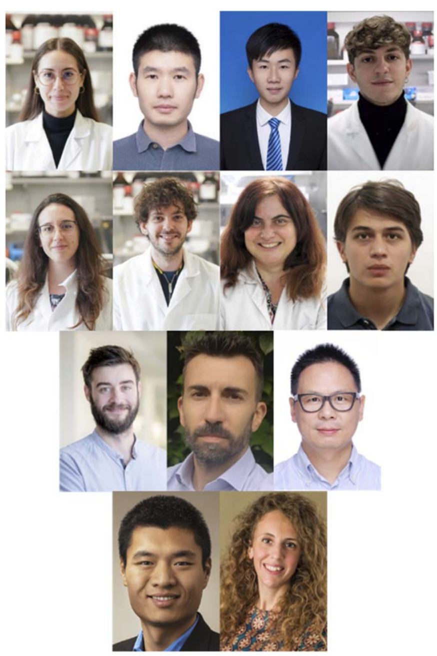
We are delighted to introduce the inaugural Outstanding Article and Outstanding Review. Please join us in congratulating the authors behind these exceptional contributions.

"*These two outstanding articles highlight a central challenge for the future of photovoltaics: how to pair high performance with sustainability. The paper on circular management of perovskite solar cells is significant, as it demonstrates a practical route toward recovering and reusing critical materials with minimal performance loss, supported by life-cycle assessment.*[1] *The review on crystalline-silicon PV module recycling provides a timely and important framework for scaling end-of-life management through both technological innovation and policy development.*[2] *Together, these papers exemplify rigorous and forward-looking research that will be essential for building a circular solar economy.*" – Michael Saliba, Editor-in-Chief, *EES Solar*

EES Solar 2025 Outstanding Article

Circular management of perovskite solar cells using green solvents: from recycling and reuse of critical components to life cycle assessment

Valentina Larini, Changzeng Ding, Bingzheng Wang, Riccardo Pallotta, Fabiola Faini, Lorenzo Pancini, Zhenhua Zhao, Silvia Cavalli, Matteo Degani, Michele De Bastiani, Filippo Doria, Chang-Qi Ma, Fengqi You and Giulia Grancini



We spoke to the authors Valentina Larini, Changzeng Ding, Bingzheng Wang, Riccardo Pallotta, Fabiola Faini, Lorenzo Pancini, Zhenhua Zhao, Silvia Cavalli, Matteo Degani, Michele De Bastiani, Filippo Doria, Chang-Qi Ma, Fengqi You and Giulia Grancini, about their work.

Which part of this paper do you think will have the greatest impact?

Valentina Larini: *I believe the most impactful aspect of this work is the combination of laboratory-scale recovery experiments with a life cycle assessment (LCA) based on experimentally derived parameters. This approach allows for a more realistic evaluation of the environmental implications of the recycling process. Moreover, the simultaneous recovery of multiple materials from the solar cell demonstrates the potential for more integrated and practically viable recycling strategies, which will be essential for the sustainable deployment of perovskite photovoltaic technologies.*

Changzeng Ding: *The key finding is that devices fabricated using recycled PbI_2 and Spiro-OMeTAD—as shown in Fig. 3 in our paper—still achieve high power conversion efficiency. This demonstrates the strong feasibility of the recycling approach and lays a solid foundation for the sustainable development of the technology in future industrial applications.*

Fabiola Faini: *I believe the most impactful aspect of this work is the* *demonstration of how the recycling strategy can preserve the excellent optoelectronic properties of the material while enabling its reuse. Beyond showing that recycling is feasible, the study provides a comprehensive understanding of the mechanisms that allow high device performance to be maintained after the recycling process. By combining structural, electrical, and optical characterization, we were able to identify the origin of the retained performance and offer valuable insights into how recycling processes can be designed without compromising device quality. This mechanistic understanding is particularly important for advancing sustainable photovoltaic technologies, where both efficiency and circularity are essential.*

Silvia Cavalli: *The development of strategies that allow a simultaneous recovering of several materials from spent perovskite solar cells (PSCs) using approaches based on green chemistry, demonstrates the feasibility of exploit recycling strategies that promote truly sustainable deployment of perovskite photovoltaic technology.*

Matteo Degani: *The development of a complete circular process using green solvents that achieves 98.4% efficiency retention after recycling is likely the most impactful part.*

Michele De Bastiani: *I believe this work will attract attention due to the importance of recycling perovskite photovoltaics, in case this technology hits the market.*

Giulia Grancini: *Our study showed that it is technically possible to recycle all key parts of perovskite solar cells with sustainable methods. This approach can help alleviate concerns about environmental impact and create viable paths for using perovskite solar cells also on a larger scale.*

What was the most challenging part of completing this research?

Valentina Larini: *The most challenging aspect of this work was establishing a clear correlation between the recovery of individual components and the simultaneous recovery of multiple materials from the solar cell. Bridging these two aspects required careful experimental optimization and interpretation, in order to understand how the recycling of one component could influence the recovery efficiency of the others.*

Silvia Cavalli: *The primary challenge in this work involved establishing a clear relationship between the recovery of individual components and the concurrent extraction of multiple materials from the solar cell. Effectively bridging these areas necessitated meticulous experimental optimization and analysis to determine how the recycling of one component could impact the overall recovery efficiency of others.*

Michele De Bastiani: *The experimental part was quite challenging. I commend Valentina for setting up a recycling protocol for small area devices with such amazing recovery processes.*

Filippo Doria: *Balancing efficient material recovery with the preservation of device performance and interface quality.*

Chang-Qi Ma: *This paper clearly confirmed that recycling of perovskite solar cells is technologically feasible, thereby alleviating concerns about the potential environmental impact of large-scale deployment of perovskite solar cells.*

Giulia Grancini: *Using green solvents to recover and reuse all PSC components was the most difficult aspect. I am proud that my team and my collaborators worked together to achieve this important goal.*

What are the next steps for this research?

Valentina Larini: *The next steps will focus on extending and adapting the protocol to different architectures and configurations of perovskite solar cells. In parallel, further work will aim to improve the sustainability and efficiency of the recovery process, with the broader goal of contributing to the development of circular strategies for emerging photovoltaic technologies.*

Riccardo Pallotta: *One next step could be the development of a strategy for recycling the entire stack in a one-pot process, avoiding sequential recycling procedures.*

Giulia Grancini: My team is currently dedicated to developing sustainable methods also for manufacturing along with recovering PSCs, aiming for a truly closed-loop circular process that supports their successful and sustainable launch to the market as next-generation photovoltaics.

EES Solar 2025 Outstanding Review

Review of c-Si PV module recycling and industrial feasibility

Ganghui Wei, Yihao Zhou, Zhongren Hou, Yanzheng Li, Qiming Liu, Jun Chen and Deyan He

The authors Ganghui Wei, Yihao Zhou, Zhongren Hou, Yanzheng Li, Qiming Liu, Jun Chen and Deyan He were invited to answer a few questions about their review.

What do you see as the most significant insights or conclusions from your review?

This review provides a systematic examination of the recycling technologies and industrial feasibility of crystalline silicon photovoltaic modules. It categorises photovoltaic recycling technologies explicitly into two main types: non-destructive and full-component recycling. It then summarises the research progress, core advantages and inherent limitations of these two technical approaches systematically. Non-destructive recycling technology enables the direct reuse of silicon wafers, effectively reducing production costs. However, this approach is significantly constrained by the trend towards thinner wafers, process contamination and economic viability issues. In *contrast, full-component recycling technology offers strong adaptability and scalability, enabling the comprehensive recovery of all module components. Nevertheless, this approach still faces challenges such as insufficient purity in the recovery of high-value materials and room for improvement in economic efficiency. This paper also conducts a comprehensive analysis of the feasibility of the PV recycling industry from technological, economic, and policy perspectives. The paper identifies the constraints currently facing the industry's development and proposes a core direction for its future growth: leveraging coordinated efforts across technology, policy and market dimensions to overcome development bottlenecks through technological innovation, standardisation and market incentives. Furthermore, it advocates the early establishment of recycling systems for emerging PV technologies such as perovskites to support the PV industry's sustainable development throughout its entire lifecycle.*

What are the biggest challenges currently facing researchers in this area?

Current research on photovoltaic recycling faces four core challenges: technical, economic, policy-related and standard-related, as well as the adaptation of emerging technologies. These dimensions are interdependent, creating key barriers to industrial implementation. In terms of technology, non-destructive recycling methods encounter problems such as secondary pollution from chemical processes, harmful gas emissions from pyrolysis and the fragility of silicon wafers, which results in high material loss. Meanwhile, full-component recycling struggles with low purification efficiency for mixed components and low sorting purity, which makes efficient resource utilisation difficult to achieve. From an economic perspective, the entire recycling process is complex and persistently costly in terms of equipment, raw materials, transportation and storage. Furthermore, low recycling returns discourage companies from scaling up operations, and technological R&D struggles to optimise due to insufficient industrial test data. In terms of policy and standards, there are currently no globally unified technical or environmental standards for PV recycling. There are significant policy disparities across regions, and the absence of a unified 'design for recycling' approach during the manufacturing stage of modules limits the universality of recycling technologies. Furthermore, the volume of end-of-life PV modules is set to surge, and existing processing capacity is struggling to meet demand. Recycling technologies for new types of PV modules, such as perovskite, are still in their infancy, and there is an urgent need for breakthroughs in the efficient recovery of scarce metals such as silver and indium.

What do you hope readers take away from your review?

By reviewing existing research and industrial status of crystalline silicon photovoltaic module recycling, this paper demonstrates the necessity of improving photovoltaic recovery rates through interdisciplinary approaches such as technological innovation, policy support, and the establishment of globally unified standards. It aims to clarify research directions and policy-making ideas for stakeholders in the renewable energy sector, thereby promoting the full life-cycle sustainable development of the photovoltaic industry.

We extend our sincerest congratulations to the authors of our 2025 Outstanding articles whose work will continue to advance and shape solar energy and photovoltaic research. We look forward to celebrating more exceptional work in the years to come.

Author Biographies

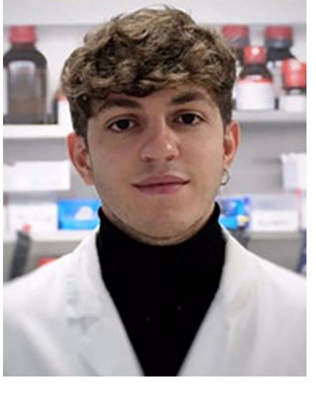
***EES Solar* 2025 Outstanding Article**

Circular management of perovskite solar cells using green solvents: from recycling and reuse of critical components to life cycle assessment

Valentina Larini obtained her PhD in 2025 under the supervision of Prof. Giulia Grancini at the University of Pavia, Italy. Her research focuses on perovskite solar cells, spanning device fabrication, passivation and interface engineering, as well as the development of sustainable recycling strategies for critical materials in emerging photovoltaic technologies. In parallel with her academic research, she has developed a strong interest in innovation and business development, which led to an invitation to the Micro, Small and Medium-sized Enterprises Day at the United Nations in 2023.

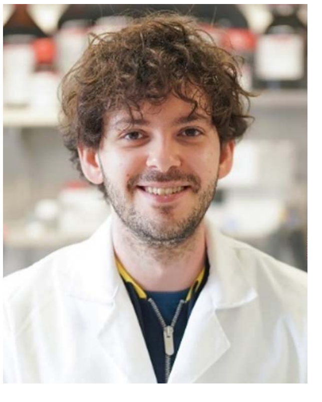
Changzeng Ding received his PhD (2022) from the School of Physical Chemistry at the University of Science and Technology of China (USTC). He is currently an associate professor at the Suzhou Institute of Nano-Tec and Nano-Bionics (SINANO), Chinese Academy of Science. His research focuses on understanding ion migration mechanisms in perovskite materials and their correlation with charge transport in perovskite solar cells (PSCs), as well as developing new methods to address the stability issue of PSCs.

Bingzheng Wang is currently a PhD student in systems engineering at Cornell University, working under the supervision of Prof. Fengqi You. He received his Bachelor's degree in energy and power engineering from Wuhan University in 2020 and his Master's degree in intelligent vehicles from Zhejiang University in 2023. His research focuses on the environmental impacts of emerging technologies like the perovskite solar cell. His work aims to quantify trade-offs between technological performance and environmental risks to support more sustainable development pathways.



Riccardo Pallotta is a postdoctoral researcher in Prof. Christoph Brabec's group at Friedrich-Alexander-Universität Erlangen. He obtained his Master's degree in materials chemistry in 2022 and completed his PhD in 2025 in Prof. Giulia Grancini's group, where he worked on the design of functional interfaces to improve charge collection in perovskite solar cells. His research interests include the fabrication of perovskite-based solar cells, with a focus on the use of multi-solvent systems to optimize perovskite crystallization and minimize bulk trap-assisted recombination.

Fabiola Faini is an alumna of the PVsquared2 Group led by Prof. Giulia Grancini. She obtained her MSc in Physics from the University of Pavia, Italy in 2021 and completed her PhD in 2025 (Italy), specializing in the spectroscopy of low-dimensional perovskites (LDPs), with a focus on charge carrier dynamics at LDP/2DP and 3DP/2DP interfaces. Her research aimed to elucidate the photophysics of LDPs, enabling the rational optimization of perovskite solar cells through time-resolved and ultrafast (fs) optical techniques, as well as machine learning approaches. As an emerging researcher at the Photonics and Optical System Design Europe conference, she was awarded a prize by the *Journal of Materials Chemistry A* in 2024.



Lorenzo Pancini was born in Mede, Italy, in 1996. He received his BS degree in chemistry in 2018 and his MS degree in chemistry in 2021 from the University of Pavia, Italy. He was a PhD student in chemistry at the University of Pavia under the supervision of Prof. Giulia Grancini. His research focused on perovskite solar cells, with particular interest in the development of new encapsulant materials.

Silvia Cavalli obtained her Master's degree in chemistry (2002) from the University of Milan in Italy and her PhD (2006) under the direct supervision of Prof. Dr Alexander Kros at Leiden University, The Netherlands. During her research experience, she worked on different interdisciplinary projects related to the field of nanotechnology (from synthetic and physical chemistry to biology). She recently joined Prof. Giulia Grancini's group at the University of Pavia as a Research Technologist, where she is currently involved in developing routes for Efficient and Sustainable Perovskite Solar Cells exploiting "Smart" Materials and Green Chemistry.

Matteo Degani is an assistant professor (RTD-A) within the research group led by Prof. Giulia Grancini at the University of Pavia, Italy. He earned his Master's degree in materials science and engineering from the University of Genova in 2019 and completed his PhD at the University of Pavia in 2023, with a dissertation focused on the design and characterization of hybrid perovskites for next-generation photovoltaic devices. His current research interests lie in the development and optimization of functional interlayers to enhance charge carrier dynamics and mitigate non-radiative recombination losses at interfaces in perovskite solar cells. In recognition of his contributions to the field, Degani was recently awarded the Cariplo Research Grant 2024 for Young Researchers, supporting his innovative approach to advancing sustainable energy technologies.

Michele De Bastiani is a senior R&D engineer who has dedicated his career to studying and developing advanced technologies for photovoltaic applications. With more than 15 years of experience, he has worked on both emerging technologies—such as organic, perovskite, and tandem solar cells—and more industrially mature solutions, including silicon heterojunctions. He is currently focused on exploring the potential of perovskite solar cells within the modern photovoltaic landscape, particularly in terms of efficiency and stability. He has co-authored more than 80 peer-reviewed publications, founded a start-up focused on manufacturing foldable solar modules, filed two patents, and submitted ten additional patent applications.

Filippo Doria is associate professor at the Department of Organic Chemistry at the University of Pavia. He has produced more than 100 publications on peer-reviewed journals with a H-index of 33 and 3200 citations, according to Scopus. His main research interest is focused on the use of organic synthesis for developing selective multifunctional ligands, targeting DNA/RNA secondary structures in human telomeres, oncogene promoters, viruses, and bacteria for theragnostic applications. Alongside, he often collaborates with Prof. Giulia Grancini for the exploitation of sustainable strategies for the development of Perovskite Solar Cells.

Chang-Qi Ma received his PhD at the Technical Institute of Physics and Chemistry, Chinese Academy of Sciences in 2003. After being a postdoctoral research assistant at Heriot-Watt University in Edinburgh, UK, he joined the research group of Prof. Peter Bäuerle at the University of Ulm in 2004 as a Humboldt research fellow. From January 2007 till May 2011, he did his Habilitation at the Institute of Organic Chemistry II and Advanced Materials, Ulm University. Since June 2011 he joined Suzhou

Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences, as a full professor. His research interests include: synthesis of organic/inorganic semiconductors, printing processing for organic/perovskite solar cells, degradation and stability of organic/perovskite solar cells. He has published over 220 papers and filed over 50 patents. He has a research group of 48 people, including 5 academic staff, 3 postdocs, 11 PhD students, and 28 Master students.

Fengqi You is the Roxanne E. and Michael J. Zak Professor in Energy Systems Engineering at Cornell University. He holds affiliations with multiple Graduate Fields at Cornell, including Chemical Engineering, Computer Science, Electrical and Computer Engineering, Operations Research and Information Engineering, Systems Engineering, Mechanical Engineering, Civil and Environmental Engineering, and Applied Mathematics. Within Cornell, he serves as the Co-Director of the Cornell University AI for the Science Institute (CUAISci), Co-Director of the Cornell Institute for Digital Agriculture (CIDA), and Director of the Cornell AI for Sustainability Initiative (CAISI). Before joining Cornell in 2016, he worked at Argonne National Laboratory's Mathematics and Computer Science Division and served as a faculty member at Northwestern University. His research focuses on fundamental theories and methods of systems engineering, with applications in materials informatics, smart manufacturing, digital agriculture, energy systems, and sustainability. You has an *h*-index of 101 and has authored over 300 refereed articles in journals. His research has garnered editorial highlights in *Science* and *Nature*, and featured on dozens of journal covers. He is an award-winning scholar and teacher, having received over 25 major national and international awards in the past six years from leading professional organizations such as the American Institute of Chemical Engineers (AIChE), American Chemical Society (ACS), Royal Society of Chemistry (RSC), American Society for Engineering Education (ASEE), and American Automatic Control Council (AACC). He is an elected Fellow of the Royal Society of Chemistry (FRSC), Fellow of the AIChE, and Fellow of the American Association for the Advancement of Science (AAAS).

Giulia Grancini is full professor at the Chemistry Department of the University of Pavia, leading the PVsquared2 team and several international projects, such as the ERC Consolidator Grant "ELOWDI" for the development of lowdimensional perovskite solar cells for indoor applications, and previously the ERC Starting Grant "HY-NANO" and the ERC POC "Spike", developing advanced hybrid perovskite solar cells. She obtained her PhD in physics from Politecnico di Milano in 2012 and worked as a postdoc researcher at IIT in Milano. From 2015 to 2019, she joined the EPFL awarded by SNSF with the Ambizione Energy Grant. Since 2019, she has been among the highly cited scientists from Web of Science with an *h*-index of 57 and more than 24 000 citations. She also co-coordinates the EU project GoPV, a large European consortium focused on perovskite photovoltaics. She has been appointed "Cavaliere della Repubblica" for scientific merits by the President Mattarella.

EES Solar 2025 Outstanding Review

Review of c-Si PV module recycling and industrial feasibility

Ganghui Wei received his BS degree in polymer materials science and engineering from the South China University of Technology in 2019. He is currently a PhD candidate in the School of Materials and Energy, Lanzhou University. His research is focused on crystalline silicon solar cells and organic thermoelectric materials.

Yihao Zhou received his Bachelor's degree in materials physics from Lanzhou University in 2024. He is presently working on his postgraduate degree at the University of New South Wales. His research interest focuses on reliability on next-generation silicon solar cells and new materials for the top cell in tandem solar cells.

Zhongren Hou received his Bachelor's degree in materials chemistry from Lanzhou University in 2024. During his undergraduate studies, he participated in the College Students' Innovative Entrepreneurial Training Plan Program, focusing on the recycling of crystalline silicon photovoltaic modules. He is currently working as an assistant engineer in Ultrasonic Inspection at Suzhou Nuclear Power Research Institute Co., Ltd, China General Nuclear Power Group.

Yanzheng Li obtained his BS degree in materials physics from Shaanxi University of Science and Technology China in 2022. In 2025, he received a Master of Engineering degree from the School of Materials and Energy at Lanzhou University. His research interests lie in the preparation of crystalline silicon hybrid heterojunction solar cells and the modification of solar cell encapsulation materials.

Qiming Liu received his BS and MS degrees in physics from Lanzhou University China in 2008 and 2011, respectively. After that, he pursued his PhD—under financial support from the Japanese Government Scholarship—in materials science from the Graduate School of Science and Engineering in Saitama University, Japan, in 2015. Currently, he is an associate professor in the School of Materials and Energy, Lanzhou University, China. His research focuses on the use of an integrated approach combining materials, interface, device, and process engineering to improve energy devices, especially in the field of photovoltaics and rechargeable batteries.

Jun Chen received his Master's degree in materials chemistry from Nanjing Tech University, China, in 2008. Thereafter, he held R&D and management positions in several photovoltaic companies. Currently, he serves as the Head of Module Product Development at LONGi Green Energy Technology. He has spearheaded multiple key projects in module technology and pioneered the development of innovative module architectures that offer generational advantages, achieving world-record performance. His research focuses on material development, process engineering, and reliability of photovoltaic modules, with a particular emphasis on advancing next-generation module technologies.

Deyan He received his BS and MS degrees in physics from Lanzhou University China in 1982 and 1985, respectively. After that, he pursued his PhD in electronic chemistry from Graduate Interdisciplinary Faculty of Science and Engineering in Tokyo Institute of Technology, Japan, in 1995. Then he stayed at the Tokyo Institute of Technology as a project researcher for 1 year. Currently, he is a professor in the School of Materials and Energy, Lanzhou University, China. His research focuses on the development of electronic thin film materials, semiconductor new energy materials and their devices.

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