Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

International Workshop on Solar Applications For Environment

Abstract Book

Orto Botanico - Palermo

2-4 Ottobre 2024

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NEST NETWORK FOR ENERGY SUSTAINABLE TRANSITION

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Obiettivo principale dell'operazione
"Scenari energetici del futuro"

Spoke 1 aims at boosting the Photovoltaics (PV) and Concentrated Solar Power/Concentrated Solar Thermal (CSP/CST) sectors toward higher amount of renewable energy production at competitive costs, overtaking actual limits and introducing innovative research at low Technology Readiness Level (TRL).

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Program

Day 1 – Wednesday 02 October 2024

9:00	9:30	**WELCOME SESSION** Prof. **M. Midiri** (Rector UniPa) Prof. **A. Pace** (Delegate UniPa)
Session I: **Solar cells and PV modules**		Chair: **Maurizio Cellura**, **Mario Tucci**
9:30	10:00	**Ivan Gordon**, IMEC *Innovative High-Performance Crystalline-Silicon Solar Cells: State-Of-The-Art and Future Challenges*
10:00	10:20	**Jessica Jazmine Nicole Barrantes**, University of Padova *LBIC Analysis of Heterojunction Silicon Solar Cells for Photocurrent Mapping and Surface Recombination Detection*
10:20	10:40	**Salvatore Antonino Lombardo**, CNR-IMM *Bifacial Photovoltaics, Four-Terminal Systems, and their Coupling: Modeling and Data*
10:40	11:00	**Mario Tucci**, ENEA *Selective Contacts by Evaporation Process for Heterojunction Solar Cell*
11:00	11:30	Coffee break
Session II: **Solar systems sustainability**		Chair: **Maurizio Cellura**
11:30	11:50	**Massimo Izzi**, ENEA *PHOTORAMA, A New European Methodology Route to Recover and Recycle the Components from End-Of-Life PV Modules*
11:50	12:10	**Teresa Gulotta**, University of Messina *Life Cycle Thinking analysis of Unitized Regenerative Fuel Cells: from literature review to applicative key findings*
12:10	12:30	**Sonia Longo**, University of Palermo *Life Cycle Assessment of Solar Heating and Cooling Systems*
12:30	12:50	**Marina Mistretta**, Mediterranean University of Reggio Calabria *High-resolution electricity generation mixes in net zero energy building*
12:50	13:10	**Le Quyen Luu**, UniPa *Application of product environmental footprint method for life cycle assessment of concentrating solar technologies*
13:10	15:00	Lunch
Session III: **Photovoltaic Integration I**		Chair: **Laura Maturi**
15:00	15:20	**Daniele Bricca**, Sapienza University of Rome *GKN for future: an effective and socially responsible re-industrialization plan boosting building integrated photovoltaic offer to european market*
15:20	15:40	**Gianfranco Modoni**, CNR STIIMA *BIPV designing by VR/AR and DT. The case of Parma Municipality administrative building*
15:40	16:00	**Roberto Speranza**, Politecnico di Torino *Integrated solar cells and supercapacitors for self-rechargeable power sources*
16:00	16:20	**Francesco Guarino**, University of Palermo *Towards implementation of the concept of Positive Energy Districts in the EU: state of the art and case-studies*
16:20	16:40	**Gabriella Gonnella**, Eurac Research *Exploring Optical Properties and Assembly Techniques for IPV prototypes*
16:40	17:00	Coffee Break

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Day 2 – Thursday 03 October 2024

Session IV: Photovoltaic Integration II		**Chair: Maurizio Cellura**
9:00	9:20	**Leonardo Micheli**, Sapienza University of Rome *Soiling of Photovoltaic Systems in the Era of High PV Penetration: Impact and Mitigation Strategies*
9:20	9:40	**Cristina Cornaro**, Tor Vergata University *Modelling Performance in Agri-PV Systems*
9:40	10:00	**Girolamo di Francia**, ENEA *Robotics For PV Large Utility Visual Inspection*
10:00	10:20	**Salvatore Fabozzi**, ENEA *Optimizing energy efficiency and sustainability in smart microgrids through polygenerative hybrid systems: a case study at the ENEA research center in portici*
10:20	10:40	**Antonino Alessi**, Ecole Polytechnique Paliseau *Solar Cells in Space Environment*
10:40	11:20	Coffee Break
Session V: Innovative Materials for PV & Solar Thermal		**Chair: Michele Saba**
11:20	11:40	**Alessandro Mattoni**, CNR-IOM *Classical Molecular Dynamics Simulations of Hybrid Perovskites: Towards the Modeling of Crystal Growth and Complex Interfaces*
11:40	12:00	**Aurora Rizzo**, CNR Nanotec *Engineering Perovskite materials from solution to solar cells*
12:00	12:20	**Simone Barbarossa**, University of Palermo *The effects of cation mixing in optoelectronic properties of lead-free double perovskites for solar applications*
12:20	12:40	**Erica Magliano**, Tor Vergata University *Two-Step Hybrid Perovskite Deposition: Organic Cations Interdiffusion through Spin-Coating and Blade-Coating for Tandem Applications*
12:40	13:00	**Elisa Sani**, CNR-INO *Optimization approaches of Ultra-High Temperature Ceramics for new high-temperature solar absorbers*
13:00	15:00	Lunch
Session VI: Thermal and Concentrated Photovoltaic		**Chair: Alessandro Galia**
15:00	15:20	**Francesca Fabris**, FuturaSun *How to bring photovoltaic module production back to Europe*
15:20	15:40	**Marina Foti**, 3Sun *3Sun The First European PV Gigafactory: Enabling Progress with Sustainable Energy*
15:40	16:00	**Arianna Berto**, University of Padova *Harvesting the solar energy by means of carbon nanofluids: a way to decarbonize heat in the building sector*
16:00	16:20	**Roberto Pagano**, CNR-IMM *Breakdown in industrial grade silicon monocrystalline solar cells*
16:20	16:40	**Alberto Giaconia**, ENEA *Integration of photovoltaic and concentrating solar technologies for high-efficient solar hydrogen production by high temperature water electrolysis*
16:40	17:00	Coffee Break
17:00	18:00	Visit to the Botanic Garden
20:30		Social Dinner

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Day 3 – Friday 04 October 2024

NEST Session		Chair: Maurizio Cellura
9:00	9:30	**WP 1.7**, UNIPA/ENEA *Dissemination and Communications*
9:300	10:00	**WP 1.1**, ENEA *Technologies for innovative high performance solar cells and PV module*
10:00	10:30	**WP 1.2**, CNR/UNICA *Innovative solar cell architectures for high conversion efficiency*
10:30	11:00	**WP 1.3**, EURAC *Advanced technologies and solution for BIPV and BAPV*
11:00	11:30	Coffee Break
11:30	12:00	**WP 1.4**, UNIPA/ENEA *New concept for CSP/CST systems*
12:00	12:30	**WP 1.6**, UNIPA *Sustainable Eco-Design*
12:30	13:00	***Final Remarks***
13:00		Lunch

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ABSTRACTS

INNOVATIVE HIGH-PERFORMANCE CRYSTALLINE-SILICON SOLAR CELLS: STATE-OF-THE-ART AND FUTURE CHALLENGES

Ivan Gordon[1,2,3]

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In this presentation, an overview will be given of the state-of-the-art of crystalline silicon (c-Si) photovoltaics (PV). Technology trends as well as market trends will be described for c-Si solar cells and modules. The concept of silicon-based tandem devices will be introduced as the way forward for the c-Si PV industry in the mid-term future. Finally, it will be shown that for sustainable Terawatt production of PV in the coming decades, a lot of R&D is still needed.

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LBIC ANALYSIS OF HETEROJUNCTION SILICON SOLAR CELLS FOR PHOTOCURRENT MAPPING AND SURFACE RECOMBINATION DETECTION

Jessica Jazmine Nicole Barrantes[1], Carlo De Santi[1], Matteo Buffolo[1,2], Francesco Piva[1], Alessandro Caria[1], Nicola Trivellin[1,3], Matteo Bronzoni[4], Massimo Mazzer[4], Luca Martini[5], Luca Serenelli[5], Mario Tucci[5], Gaudenzio Meneghesso[1], Enrico Zanoni[1], and Matteo Meneghini[1,2]

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5 ENEA Research Center "Casaccia", Italy, via Anguillarese 301, 00123 Rome.

Laser Beam-Induced Current (LBIC) analysis is a powerful technique for the spatial characterization of solar cells, enabling high-resolution photocurrent mapping and surface recombination detection. This study focuses on the development and optimization of an LBIC setup on heterojunction silicon solar cells. By fine-tuning, the system is able to provide detailed maps of local photogenerated carrier dynamics, offering insights into the uniformity of the device and revealing defects that lead to performance degradation.

A comparative study between LBIC and Electron Beam-Induced Current (EBIC) techniques is also presented to evaluate issues related to recombination and conduction near the edges of the device caused by mechanical damage. The results showed a compatibility between the two procedures in detecting recombination and conduction issues, particularly near damaged edges.

Additionally, results from preliminary stress tests and the impact of surface recombination will be discussed.

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BIFACIAL PHOTOVOLTAICS, FOUR-TERMINAL SYSTEMS, AND THEIR COUPLING: MODELING AND DATA

S. A. Lombardo

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Photovoltaic (PV) science and technology constantly pursues the objective of improving energy yield and reducing PV system cost. In this paper we report our experience in such general workstream by following two approaches: bifacial photovoltaics (BPV) and 4-terminal (4T) PV systems.

The first part of the talk is devoted to the description of a numerical model to evaluate the energy yield of bifacial PV modules and strings [1-3]. The model, validated by comparison with experimental data of module temperature, short-circuit current, open-circuit voltage and energy yield of bifacial and monofacial mini-modules, takes into account the three-dimensional geometry of the whole PV system to accurately evaluate the irradiance impinging on the rear side of each module, which depends on its position within the system. The model takes also into account the voltage / current mismatch of the cells and the modules, deriving the overall current, voltage, and power characteristics as a function of the solar irradiation.

In the second part of the talk we discuss a Monte Carlo simulation algorithm [4], validated on experimental data, to evaluate the power conversion efficiency of 4 terminal multijunction systems by obtaining the absorption spectrum of each sub-module and then calculating the current-voltage characteristics of the overall 4T system. We then pass to describe experimental data on a bifacial 4T PV system based on combining a III-V semiconductor with the silicon heterojunction technology [5]. By exploiting the wide band gap energy of GaAs, the bifaciality of the Si heterojunction and the spectrum-splitting capability of dichroic mirrors, an optimal voltage match between mini-modules of the two types of solar cell was achieved with promising results. Experimental data taken on the 4T system both in indoor and in outdoor are shown and discussed. Possible further solutions are then proposed.

I gratefully acknowledge the contribution to this work of various researchers from CNR, University of Catania, and Enel Green Power: A. Scuto, R. Corso, M. Leonardi, F. Ricco Galluzzo, R. G. Milazzo, S. M. S. Privitera, P. Zani, M. Foti, F. Bizzarri, C. Gerardi. Work partially funded by PON Ricerca e Innovazione 2014-2020, contract code ARS01_00519, BEST-4U Project

1 Galluzzo, F.R., Zani, P.E., Foti, M., Canino, A., Gerardi, C., Lombardo, S, 2020. Numerical Modeling of Bifacial PV String Performance: Perimeter Effect and Influence of Uniaxial Solar Trackers. Energies 2020, 13, 869.

2 Leonardi, M., Corso, R., Milazzo, R.G., Connelli, C., Foti, M., Gerardi, C., Bizzarri, F., Privitera, S.M.S., Lombardo, S.A, 2022. The Effects of Module Temperature on the Energy Yield of Bifacial Photovoltaics: Data and Model. Energies 2022, 15, 22.

3 Privitera, SMS; Muller, M; Zwaygardt, W; Carmo, M; Milazzo, RG; Zani, P; Leonardi, M; Maita, F; Canino, A; Foti, M; Highly efficient solar hydrogen production through the use of bifacial photovoltaics and membrane electrolysis, Journal of power sources, 473, 228619, 2020, Elsevier

4 Corso, R.; Leonardi, M.; Milazzo, R. G; Scuto, A.; Privitera, S. M.S.; Foti, M.; Gerardi, C.; Lombardo, S. A; Evaluation of Voltage-Matched 2T Multi-Junction Modules Based on Monte Carlo Ray Tracing, Energies, 16, 11, 4292, 2023, MDPI

5 Scuto, A; Corso, R; Leonardi, M; Milazzo, RG; Privitera, SMS; Colletti, C; Foti, M; Bizzarri, F; Gerardi, C; Lombardo, SA; Outdoor performance of GaAs/bifacial Si heterojunction four-terminal system using optical spectrum splitting, Solar Energy, 241, 483-491, 2022, Pergamon

SELECTIVE CONTACTS BY EVAPORATION PROCESS FOR HETEROJUNCTION SOLAR CELL

L. Martini, L. Serenelli, F. Menchini, C. Malerba, M. Izzi, A. Mittiga, and Mario Tucci

ENEA TERIN-SPV-IIF Research Centre Casaccia, Italy, Via Anguillarese 301, 00123 Roma.

The heterojunction (HJ) technology currently holds the world record in terms of conversion efficiency of silicon based single junction device, thanks to the key elements of substrate passivation and selective contacts. Recent relevant innovations in the HJ pursue the replacement of the doped amorphous silicon (a-Si:H) layers with novel materials to reduce the parasitic absorption of a-Si:H film and make the industrial processes safer removing toxic gasses from the doping process.

While not stochiometric molybdenum oxide MoOx is commonly suggested as hole transport layer (HTL) for emitter side on n-type doped silicon substrate, an effective electron transport layer (ETL) as base contact still remains under study to achieve an efficient contact with transparent contact oxide (TCO) layer and improve the resilience to subsequent thermal treatments.

In this work we investigated MgF_2/ZnS-Ti/TCO heterostructure as ETL in which the MgF_2 very thin layer works as decoupling material between silicon surface passivation, as ensured by SiOx thin film, and ZnS-Ti film. This layer is a ZnS film doped by Ti and is fabricated by co-evaporation procedure. To complete the ETL contact an evaporated TCO is suggested A numerical model is proposed to deeper investigate the undesired barrier at the ETL/TCO interface.

Finally, a novel process for HJ solar cells is proposed in which both the HTL and ETL selective layers, as well as TCO layer are fabricated by evaporation procedure.

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PHOTORAMA, A NEW EUROPEAN METHODOLOGY ROUTE TO RECOVER AND RECYCLE THE COMPONENTS FROM END-OF-LIFE PV MODULES

Massimo Izzi

ENEA, Italy, Lungotevere Thahon Di Revel, 00100, Roma

The global growth of renewable energy technology will be accompanied by a parallel growth of end-of-life (EOL) products which bring new technological challenges.

Cumulatively, by 2050, estimates project 78 million tons of raw materials present in end-of-life photovoltaic modules. The expected growth of renewable energy technologies could be limited by the scarce availability of raw materials, so a circular economy vision is necessary to support the green transition by increasing the contribution of recycling and production of secondary row materials. [1]. However, PV panels only have a lifespan of nearly 25-30 years [2] and the mass of end-of-life panels worldwide is expected to reach between 2 and 8 million tonnes by 2030 [2], practically with a low recycling rate of precious and critical metals and which instead will represent a great economic and environmental challenge for the next few years. It is estimated that by 2050 [2], the global PV waste category could exceed and account for 10% of the total Waste Electrical and ElectronicEquipment (WEEE) generation. Additionally, it could represent the mostsignificant e-waste stream if there is not a correct and preventative measure about how to manage and recycle future wastes of this type.

The current technologies for the recovery of materials from PV waste are energy intensive and have an impact from an environmental point of view. PV modules contain rare and precious metals that are mined from the earth such as silver, copper, aluminium, Indium. Promoting a circular economy strategy (as opposed to the linear economy of the landfilling) is the way to unlock and recover value from EoL PVs and to reuse it in new products.

The main goal of PHOTORAMA (PHOtovoltaic waste management – advanced Technologies for recOvery and recycling of secondary Raw Materials from end-of-life modules) is to demonstrate innovative solutions dedicated to Raw Material recover and recycling from PV EoL and promote a profitable production perspective of new products from SRM. PHOTORAMA is setting up a full management-Pilot Line including all needed interrelated successive steps needed for the management of end-of-life panels, i.e., disassembly, smart separation of the panels, and innovative recovery of metals (Si, Ag, In, Ga). In total, more than six technologies that strongly depend on each other are being brought to TRL 6-7 and implemented in a pilot line. Besides, the technologies developed to produce high-quality, high-purity secondary raw materials are also very efficient for the treatment of manufacturing waste.

The target will be reached with the implementation of a PILOT LINE (TRL 7) that will be able to demonstrate the technical, economic and environmental feacibility of the innovative technologies proposed.

1 IRENA, Future of solar photovoltaic : Deployment, investment, technology, grid integration and socio-economic aspects, International Renewable Energy Agency, 2019.

2 IRENA, End-Of-Life Management: Solar Photovoltaic Panels, Int. Renew. Energy Agency Int. Energy Agency Photovolt. Power Syst. (2016).

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LIFE CYCLE THINKING ANALYSIS OF UNITIZED REGENERATIVE FUEL CELLS: FROM LITERATURE REVIEW TO APPLICATIVE KEY FINDINGS

T.M. Gulotta, R. Salomone, G. Mondello, G. Saija, F. Lanuzza

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Unitized Regenerative Fuel Cells (URFCs) are an emerging technology that integrates both fuel cell and electrolyser functionalities, enabling energy generation and storage. These technologies could play a crucial role in storing surplus renewable energy produced by photovoltaic panels in hydrogen and reconverting it in electricity when required, increasing self-consumption. However, their potential benefits across the whole life cycle must be thoroughly evaluated. This work presents some of the results of the ELETTRORIGENERA project (PO FESR SICILIA 2014-2020 AVVISO 1.1.5 – PROGETTO ELETTRORIGENERA N. 08ME2899200216) where a Proton Exchange Membrane (PEM) URFC prototype, realized by the project's partners, was analysed with a life cycle thinking (LCT) approach, through Life Cycle Assessment (LCA), environmental Life Cycle Costing (eLCC), and Social Life Cycle Assessment (S-LCA) methods.

First, a literature review was carried out to identify trends, methodological choices, and critical issues in applying LCT methods to URFCs [1]. LCA and environmental eLCC methods were used to identify the main environmental, economic and energy hotspots of core component of the device - the stack. The analysis revealed that the main impacts are associated with the membrane electrode assembly (MEA), characterized using critical raw materials (e.g., Platinum) [2]. The literature review also identified a gap in evaluating potential social concerns related to URFC development. Then, as an additional activity within the project, the S-LCA method was applied to the PEM-URFC stack prototype to provide an initial understanding of the social risks and limitations involved in methodological application. The results highlighted that certain materials in the MEA are significant hotspots in terms of social risks during production. These assessments were conducted using laboratory data, while background data were sourced from the Ecoinvent database, PSILCA database, and other economic databases.

Finally, to assess the stack's contribution to the entire URFC system's life cycle, a case study applying LCA to a URFC system in residential buildings was conducted. This analysis allowed identifying the main environmental hotspots during manufacturing, operation, and end-of-life phases and highlighted that the operational phase accounts for over 65% of potential environmental impacts. Recycling metals could reduce all the potential impacts of about 38%.

The study also pointed out the need for improved data reliability and harmonized methodologies in life cycle thinking for URFCs, in order to support a sustainable design and implementation of these promising energy technologies.

1 Gulotta, T.M., Salomone, R., Lanuzza, F., ... Mondello, G., Ioppolo, G. (2022). Life Cycle Assessment and Life Cycle Costing of unitized regenerative fuel cell: A systematic review
Environmental Impact Assessment Review

2 Gulotta, T.M., Salomone, R., Mondello, G., Saija, G., Lanuzza, F., Briguglio, N. (2023). Life Cycle Assessment and Environmental Life Cycle costing of a unitised regenerative fuel cell stack

LIFE CYCLE ASSESSMENT OF SOLAR HEATING AND COOLING SYSTEMS

S Longo, M. Beccali, M. Cellura, F. Guarino

Department of Engineering – University of Palermo, Italy, Viale delle Scienze Bld. 9, 90128 Palermo

Space heating and cooling has a significant impact on the total energy consumption of buildings, up to 75% of the total buildings energy demand. Moreover, the trend for energy demand is growing annually and, since much of energy used comes from fossil fuels, greenhouse gas (GHG) emissions are increasing as well.

In such a context, renewable heating and cooling technologies play an important role among the available options since they allow for the reduction of the use of primary energy from fossil fuels needed for heating and cooling applications and, consequently, the reduction of GHG emissions.

Among renewable heating and cooling technologies, solar thermal cooling systems have already proven to be a viable and effective alternative.

However, the above energy technologies cannot be considered totally clean because they require energy consumption and have environmental impacts that cannot be neglected during their life cycle. The benefits of these technologies should be evaluated taking into account their life-cycle energy and environmental impacts, calculated by applying the Life Cycle Assessment (LCA).

In the above context, the study presents some applications of LCA to solar heating and cooling systems, also integrated with PV.

In detail, the first part illustrates a comprehensive compared investigation of solar assisted cooling systems with solar thermal or PV. Results indicate that, in many cases, the systems with the PV grid connected plant perform better. If PV assisted systems include electricity storages to minimise the interaction with the grid, worse performance are observed than the PV grid connected systems and the solar thermal assisted systems in nearly all the analysed cases [1].

The second part of the study illustrates the tool “ELISA - Environmental Lifecycle Impacts of Solar Air-conditioning systems”, that is a user-friendly simplified tool for estimating the life-cycle energy and environmental benefits/impacts of solar technologies for heating and cooling in different geographic contexts and comparing them to conventional systems. ELISA can be used by researchers, designers and decision-makers to introduce the life-cycle thinking in the early design phase of heating and cooling systems [2].

1 M. Beccali, M. Cellura, P. Finocchiaro, F. Guarino, S. Longo, B. Nocke, Life Cycle performance assessment of small solar thermal cooling systems and conventional plants assisted with photovoltaics, Solar Energy, Volume 104, (2014), 93-102, doi:10.1016/j.solener.2013.10.016, ISSN 0038-092X.

2 S. Longo, M. Beccali, M. Cellura, F. Guarino, Energy and environmental life-cycle impacts of solar-assisted systems: The application of the tool “ELISA”, Renewable Energy, 145 (2020), 29-40, https://doi.org/10.1016/j.renene.2019.06.021, ISSN 0960-1481.

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HIGH-RESOLUTION ELECTRICITY GENERATION MIXES IN NET ZERO ENERGY BUILDING

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1 University Mediterranean of Reggio Calabria, Department of Information Engineering, Infrastructure and Sustainable Energy (DIIES), Italy, Via Graziella, Feo di Vito, 89122, Reggio Calabria
2 University of Palermo, Department of Engineering, Viale delle Scienze Building 9, Italy, 90128, Palermo

Temporal fluctuations of the electricity grid generation composition, variability of electricity consumption in building operation over the year and of the on-site renewable energy systems are factors that should be properly considered, using high-resolution data in the building energy and environmental performance assessment. With the growth of building electricity demand and of renewable energy sources, temporal changes and variability in electricity generation systems become increasingly significant, depending on which time the energy is generated [1]. This is particularly significant for solar systems, which show important hourly variations across the day and from a season to another, with the highest contributions in spring and summer.

In this study a methodological framework is proposed to detect the composition of high-resolution electricity mixes in building operating phase, considering the interaction between the grid and the on-site PV systems, and to assess the related energy and environmental impacts throughout the year.

Hourly-based electricity mixes are developed, by matching the national hourly electricity mix with two different hourly load profiles of a Mediterranean Net Zero Energy Building (NZEB), related to the onsite PV plant/battery storage systems [2-3].

Life cycle inventories of such electricity generation mixes are modelled, and the related ecoprofiles are assessed, including a wide set of impact indicators [4-5]. For most impact categories, the imported electricity generation mixes, to meet the residual building demand, show impact variations not higher than +20 % and not lower than -38 % at seasonal and daily time compared with the annual average values. Temporal variations are even more relevant in building consumption electricity mixes, which are significantly characterized by self-consumption, and show noticeable reductions compared to the annual electricity generation mix in both assessed scenarios. As an example, summer and spring energy generation mixes show the best results for climate change (0.09 $kgCO_{2eq}$/kWh) compared to the annual ones, while in winter and autumn mixes the contribution to climate change overcomes the respective annual results. Both summer day-mixes contribute to climate change for about 0.12 $kgCO_{2eq}$/kWh, with a reduction of nearly 30 % if compared the annual data. Conversely, in the winter day mixes the contribution to climate change is about 0.20 $kgCO_{2eq}$/kWh and comes mostly from the grid.

The results highlight that assessed temporal variations are significant through the year for the most assessed environmental indicators. Since the eco-profile of hourly electricity mixes varies with generation system and load, high-resolution mixes refine environmental impact assessment of building use phase because. Furthermore, the use of high-resolution electricity generation mixes allows to optimize efficiently the temporal use of electricity in buildings, in sight of energy and environmental impact reduction also thanks to the employment of life cycle-oriented approaches. The results also highlight the relevance of the storage system in fulfilling periods of peak demand or low renewable generation. Self-consumption by PV plant/battery storage systems plays a significant role in varying the electricity import from the grid and enables efficient use for electricity and reduce impact.

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APPLICATION OF PRODUCT ENVIRONMENTAL FOOTPRINT METHOD FOR LIFE CYCLE ASSESSMENT OF CONCENTRATING SOLAR TECHNOLOGIES

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Solar energy technologies have the potential to reduce the carbon emissions in the economy and energy sector [1-2]. In order to achieve the target of net zero by 2050, innovative materials, systems and technologies of solar photovoltaics (PV) and concentrating solar power (CSP) / concentrating solar thermal (CST) have been studied under the NEST – Spoke 1 project. Besides, the project facilitates further cost reduction, improving the eco-profiles of materials, technologies and systems within the solar energy sector to overcome the obstacles from lab to fab production. Under the framework of the project, this paper quantifies the life cycle environmental impacts of CSP technologies to identify which factors causing the most significant impacts, consequently aiming at further reducing the pollutants in the design phase and leading the design towards an eco-improvement of the solar energy technologies.

The paper applies Product Environmental Footprint (PEF), the life cycle impact assessment method developed by the European Commission and for the European (EU) products [3-8], to quantify the life cycle environmental impacts of CSP technologies. Various CSP receiver systems are examined, alongside with different heat transfer fluids, which make up four CSP technologies being studied, namely parabolic trough with hitec salts, parabolic trough with solar salts, solar tower with hitec salts, and solar tower with solar salts. Moreover, another popular method being applicable at the global scale, e.g. ReCiPe [9, 10], is applied for comparison of methodologies. The obtained results show that regarding the overall life-cycle impact, solar towers are shown to have advantages over parabolic troughs. Most of the life-cycle impacts of solar towers are lower than those of parabolic troughs, ranging from 8% to 112%, except for human toxicity and land use impacts. However, there is not much difference between the studied heat transfer fluids, with the variance of most impacts being less than around 1%. The most critical impact is identified as toxicity such as human toxicity and ecotoxicity, with ReCiPe method, and the global warming potential and resource use including fossil fuels, minerals and metals, with PEF method. The result is interesting because with the same dataset, these two methods show difference in the most critical impact. This can be explained by the nature of the methods, especially one is regional, particularly design for EU, while other is for the global context. Meanwhile, the comparison of components' contributions quantified by the two methods shows the same results for more than half of the impact indicators, indicating that both methods are reliable for life cycle assessment and sustainable design of the energy technologies.

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GKN FOR FUTURE: AN EFFECTIVE AND SOCIALLY RESPONSIBLE RE-INDUSTRIALIZATION PLAN BOOSTING BUILDING INTEGRATED PHOTOVOLTAIC OFFER TO EUROPEAN MARKET

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In the summer of 2021, over 400 GKN driveline employees in Campi Bisenzio (Florence, Italy) faced an unlawful dismissal attempt. In response, the workers established a permanent assembly and have since organized and participated in mobilizations across the country. With the support of academics, scientists, researchers, and climate activists, they are working to revive production at the factory.
Here, we present the industrial and social plan being developed by the joint-stock cooperative GKN For Future (GFF). This plan aims at achieving an ecological and industrial transformation of the former GKN plant, envisioning it as a hub for renewable energy and light mobility, in line with the principles of the circular economy and sustainability [1]. Beyond recovering jobs for former GKN employees, this pioneering plan seeks to create an alternative, socially inclusive supply chain in the energy sector. It focuses on the production, installation, and recycling of photovoltaic (PV) panels, the development of electric cargo bikes, and the establishment of an innovative research center involving universities, research centers and cutting-edge startups.
A detailed analysis of the state-of-the-art in PV panel production is also presented, focusing on the bill of materials and the automated and semi-automated lines currently used. This analysis aims at identifying the most suitable PV panel technology for GFF to enter the market, aligning with principles of circular economy and sustainability.
The GFF reindustrialization plan stands as a pioneering example of ecological transition, facilitating an effective technological transfer of knowledge from laboratories, research centers, and university departments to civil society. This ambitious plan will contribute to maximizing its societal impact by engaging citizens, policymakers, and industrial stakeholders, thereby enhancing awareness and social acceptance of the energy transition and reducing perceived societal barriers.

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BIPV DESIGNING BY VR/AR AND DT. THE CASE OF PARMA MUNICIPALITY ADMINISTRATIVE BUILDING

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The authors illustrate the main results achieved in the Italian research project CANVAS, funded by the Ministry of the Environment and Energy Security. First, the authors present a study of the state-of-the-art design tools for PV systems and BIPV, focusing on the major gaps in the solutions so far available in the literature: lack of functionalities for more interactive and engaging visualization for real-time monitoring and simulation integrated with design [1-4].
Second, the authors present a new software solution to overcome the identified gaps. In particular, the solution is based on Virtual Reality (VR), Augmented Reality (AR), and Digital Twin (DT) technologies, which proved to be enabling for visualization and simulation. In particular, the authors introduce the application of this solution to the case study of the Parma Municipality administrative building.

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INTEGRATED SOLAR CELLS AND SUPERCAPACITORS FOR SELF-RECHARGEABLE POWER SOURCES

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The rapid development of low-power connected devices, widely useful in fields like the Internet of Things (IoT), building automation, smart agriculture, and wearables is encouraging the research on novel technologies able to harvest energy from ambient sources and possibly store this energy in order to make these devices energy independent. Indeed, commonly used batteries need to be periodically recharged or replaced, which become a limitation in terms of user friendliness or maintenance costs, hindering the development of large networks of connected devices [1]. In our contribution, we present different approaches to integrate dye-sensitized solar cells and supercapacitors in a single harvesting and storage device, with the goal of achieving better processability, higher sustainability and wider application possibilities. Tackling the design of the device and its conversion efficiency, we will present a dye-sensitized solar module (DSSM) integrated with an electrical double-layer capacitor showing one of the highest indoor conversion efficiencies for high-voltage DSSMs (16.27%) and an overall photoelectric conversion and storage efficiency of 9.73%, with a maximum charging voltage higher than 3V [2]. Moreover, we will present a simple yet effective strategy to increase the conversion efficiency, regardless of the selected active materials. Combining tandem configuration and bifaciality we observed a 37% relative increase in indoor conversion efficiency [3]. Secondly, from the point of view of device flexibility and processability, we will demonstrate how vacuum sealing technology can be effectively used to encapsulate DSSCs, allowing their integration with supercapacitors in the same flexible enclosure, resulting in a maximum overall conversion and storage efficiency of 6.1%, demonstrating high stability and performance under various bending conditions [4]. The, in the same configuration, we demonstrated how laser-induced graphene (LIG) can work as a flexible counter electrode material for DSSC, showing superior catalytic activity and mechanical stability over conventional materials (Pt, PEDOT) deposited on flexible conducting polymers. DSSCs with flexible LIG electrodes were integrated with LIG-based supercapacitors, offering a promising energy solution for flexible self-powered IoT devices [5]. Finally, we will suggest a sustainable and low-toxic alternative to most common organic solvents (acetonitrile, 3-methoxypropionitrile) used to fabricate integrated energy harvesting and storage systems for application under indoor illumination conditions.

This work was partially funded by the project “nuovi Concetti, mAteriali e tecnologie per l’iNtegrazione del fotoVoltAico negli edifici e in uno scenario di generazione diffuSa” (“CANVAS”), funded by the Italian Ministry of the Environment and the Energy Security, through the Research Fund for the Italian Electrical System (type-A call, published on G.U.R.I. n. 192on18-08-2022).

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TOWARDS IMPLEMENTATION OF THE CONCEPT OF POSITIVE ENERGY DISTRICTS IN THE EU: STATE OF THE ART AND CASE-STUDIES

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Urban areas are at the forefront of global energy consumption and carbon emissions, highlighting the need for innovative solutions to drive sustainable urban development. Positive Energy Districts (PEDs) have emerged as a promising concept [1,2], offering a comprehensive strategy to not only reduce urban energy use and environmental impact but also serve as scalable models for broader regional applications.

This analysis delves into the implementation of PEDs across the European Union, focusing on their transformative potential for urban energy systems. PEDs are designed to create energy-positive urban areas that generate more energy than they consume by integrating renewable energy sources—particularly photovoltaic (PV) systems—along with energy-efficient urban planning and advanced smart technologies. The aim is to reduce carbon emissions while promoting long-term sustainability within urban settings.

Key aspects explored include energy planning and urban renovation, with special attention to the integration of photovoltaics systems into existing city infrastructure. This highlights how renewable energy technologies can be seamlessly incorporated into urban environments, optimizing energy production while improving both the functionality and visual appeal of the spaces and pushing towards the Positive Energy level at the district scale encompassing energy efficiency and renewable energy planning.

Additionally, the presentation draws on various case studies from PED projects implemented and / or planned across the EU. These case studies, set in diverse geographical and environmental contexts, reveal the strengths, challenges, and potential for replicating PED concepts in other urban settings. By examining technical, economic, and social dimensions, the analysis provides critical insights into the scalability of PEDs and their role in shaping sustainable urban development across Europe.

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EXPLORING OPTICAL PROPERTIES AND ASSEMBLY TECHNIQUES FOR IPV PROTOTYPES

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This work presents the development and testing processes carried out in the PV Prototyping Laboratory, funded and implemented under the NEST project, with a focus on customized PV modules. Various materials used in module fabrication, such as encapsulants, front glasses, and backsheets, were studied through spectrophotometric measurements to assess their optical properties and estimate potential current generation. In parallel, differential scanning calorimetry (DSC) tests were performed on the encapsulants to evaluate their thermal properties and ensure optimal lamination conditions.

In the assembly phase, glass-backsheet (GBS) modules were successfully laminated and validated through flash tests to measure electrical performance and electroluminescence (EL) analysis to detect any defects or anomalies. Experimental lamination trials were conducted on different technologies, as amorphous selenium (ASe) cells, to explore new approaches and setups, as part of the continuous effort to refine and innovate. These activities aim to refine both the material selection and the assembly techniques, improving module manufacturing and testing procedures in the laboratory. Through experimentation, the capabilities of the laboratory have been enhanced through the integration of different materials and technologies. The ultimate goal is to refine the development of PV prototypes to various technological needs and applications.

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SOILING OF PHOTOVOLTAIC SYSTEMS IN THE ERA OF HIGH PV PENETRATION: IMPACT AND MITIGATION STRATEGIES

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As the penetration of photovoltaics (PV) grows, electricity grids increasingly rely on this technology. Therefore, any disruption in PV performance can have severe local, regional, and national repercussions, potentially affecting the reliability of the national energy systems. Soiling is one of the most common performance issues affecting PV systems worldwide and is responsible for substantial revenue losses every year. However, differently from other PV losses, soiling can be reduced through appropriate soiling mitigation strategies.

This presentation examines the impact of soiling as PV plays an increasingly significant role in national electricity mixes. For instance, the potential impact of dust storms is analyzed, as these events can threaten PV systems across large areas or entire countries, even in non-desert environments [1]. Additionally, the presentation reviews the status and limitations of current soiling monitoring and mitigation strategies [2], including clipping and curtailments—two increasingly common mechanisms that can reduce the perceived impact of soiling [3].

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MODELLING PERFORMANCE IN AGRI-PV SYSTEMS

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Agri-PV systems, which integrate photovoltaic (PV) solar panels with agricultural practices, are promoting sustainable farming by optimizing land use and enhancing productivity. The dual-use approach not only contributes to cleaner energy production but also helps in reducing the carbon footprint of agriculture. By providing shade, Agri-PV systems can improve crop yields and conserve water, addressing some of the most pressing challenges in agriculture. Agri-PV systems in greenhouses represent an innovative fusion of solar energy and controlled environment agriculture. By installing photovoltaic panels on greenhouse roofs or structures, these systems harness sunlight to generate renewable energy while still allowing sufficient light to penetrate for plant growth. This dual-purpose approach helps regulate greenhouse temperatures, reducing the need for additional cooling or heating. Moreover, the energy generated can be used to power greenhouse operations, including irrigation, lighting, and climate control systems, leading to greater energy efficiency and cost savings.

The REGACE project, funded by Horizon Europe, aims to develop innovative technology for PV in greenhouses to ensure uninterrupted food production. Six pilot greenhouses have been installed in Europe and Israel to test this new technology. One of the main objectives of the project is to create a Digital Twin (DT) ecosystem, REGACE DT that integrates crop production, PV production and microclimate modelling with the final objective of integrating these aspects using Artificial Intelligence techniques. REGACE DT will help to optimize the PV system control, responsive to the plants needs and to evaluate and optimize the ecosystem performance at various locations. The presentation will give an overview of the last achievements of the modelling activity within the project.

ROBOTICS FOR PV LARGE UTILITY VISUAL INSPECTION

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With the standardization of production processes related to the photovoltaic sector, there is now an ever-increasing demand for automation of inspection and maintenance phases, especially for large photovoltaic energy supply plants [1].
Inspection and maintenance (I&M) robotics was introduced decades ago, precisely in correspondence with the standardization of production processes, especially in the automotive industry. With the increasing pervasiveness of digitalization also in the industrial sector, these techniques have been used in complex scenarios, also thanks to robots with arms or systems that allow their movement on uneven terrain and increasingly autonomous drones. Until now, robotic inspection of photovoltaic systems was considered only as one of the possible I&M strategies that can be implemented for this category of energy systems, which is also quite secondary. In this work, the advantages of autonomous inspection systems for large photovoltaic systems are discussed by connecting them to the specific characteristics of a large utility photovoltaic system. The aim is to highlight that, based on extensive research, in the case of photovoltaic energy, robotic inspection is a necessity rather than an option.

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OPTIMIZING ENERGY EFFICIENCY AND SUSTAINABILITY IN SMART MICROGRIDS THROUGH POLYGENERATIVE HYBRID SYSTEMS: A CASE STUDY AT THE ENEA RESEARCH CENTER IN PORTICI

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The integration of accurate photovoltaic (PV) generation forecasts with advanced simulation techniques in smart microgrids presents a significant opportunity to enhance energy management and sustainability [1]. This study combines machine learning-based PV power predictions with the modeling of polygenerative hybrid systems within the smart microgrids of the ENEA Research Center in Portici, Italy. The accurate prediction of PV generation is crucial for managing power system resources, particularly in microgrids, where the effective operation of generation, load, and storage resources is essential to avoid grid imbalances. By employing a combination of PV forecasts generated from weather models and machine learning methods—such as linear models, Long Short-Term Memory, eXtreme Gradient Boosting, and Light Gradient Boosting Machine—the research highlights how linear models, in particular, improve forecast accuracy, achieving an RMSE improvement of 3.7% compared to traditional numerical weather prediction baselines [2].
This enhanced forecasting capability is integrated into the simulation of polygenerative hybrid systems, where advanced control strategies are modeled using TRNSYS software to assess the interplay between thermal and electrical components. The comprehensive analysis emphasizes the potential of machine learning-enhanced PV predictions in refining energy utilization strategies within microgrids. The results underscore the importance of optimized control approaches in achieving primary energy savings and reducing CO_2 emissions, offering valuable insights for policymakers and energy planners in their pursuit of sustainable energy solutions amidst escalating climate challenges.
The integration of polygenerative hybrid systems within the smart microgrid at the ENEA Research Center in Portici demonstrates the critical role of advanced control strategies in optimizing energy utilization and reducing environmental impacts [3]. Using TRNSYS for modeling, this research evaluates various control approaches, highlighting their efficacy in managing the interplay between electrical and thermal components. The study underscores that strategic control of combined heat and power (CHP) systems and renewable sources can lead to significant primary energy savings and CO_2 emissions reductions. The findings provide valuable insights for policymakers and energy planners seeking to enhance the sustainability and resilience of microgrids.

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SOLAR CELLS IN SPACE ENVIRONMENT

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Solar cells are essential for powering satellites, however the environmental conditions in space are very severe and have a strong impact on the performance of photovoltaic cells. One of the main source of the degradation is represented by electron or proton irradiation [1]. The origin of this degradation is linked to the generation of point defects that, with their energy levels, alter the IV curves of the cells, causing a decrease of their efficiency. To ensure the duration of the missions of each type of satellites, it is therefore necessary to carry out a series of tests including those of the response to radiation. In addition to the simple irradiation tests, the increase in the number of missions, their diversification and the desire to reduce the launch costs push the community to research new materials or architectures that can work in space and to test them in the real operation conditions.
To investigate the generation of point defects and their impact on the electrical properties of solar cells, and more in general of semiconductors, our laboratory is equipped with an electron accelerator named SIRIUS and with different irradiation set-up such as Cirano and the Grande Surface (GS). SIRIUS is a pelletron electron accelerator produced by NEC [2], which can generate electron beams with energies in the range 150 keV-2.5 MeV and current in the range 10 nA-50 µA. The GS is an irradiation set-up that allows to test solar cells with the same sizes as those used in space and to test them at low temperature (100 K) under illumination with a solar simulator.
During the conference we will illustrate some of the possible investigation that can be performed with the electron beam generated by SIRIUS. In fact, we will report the dependence on the fluence (e/cm^2) of the IV parameters of a GaInAsP single junction solar cell produced for the RadHard H2020 project and the temperature impact on the performance degradation of other kinds of cells.
Finally, we will put in evidence that the point defects generated in semiconductors, and more in general in any materials, can be used to adapt the material properties to a specific application, which changes the usual paradigm that defects are a negative product of irradiation.

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CLASSICAL MOLECULAR DYNAMICS SIMULATIONS OF HYBRID PEROVSKITES: TOWARDS THE MODELING OF CRYSTAL GROWTH AND COMPLEX INTERFACES

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Hybrid lead halide perovskites (HLPs) have emerged as one of the most important class of materials in the field of photovoltaics due to their exceptional optoelectronic properties and compositional flexibility. The optimization of chemical methods has allowed the synthesis of HLP semiconductive active layers with power conversion efficiency in state-of-the-art perovskite solar cells above 25%. Yet, the thermal and chemical material instability in operational conditions, the need of large area synthesis and the toxicity of lead cations are still open problems that require a precise control and understanding of the crystal growth and microstructure at the atomic scale.
In this talk, it will be discussed the progress of physics-based models [1] as well as advanced machine learning approaches [2] for the large-scale molecular dynamics simulations. Showcase applications will be presented based on the MYP potential related to the mobility of ionic defects and their interaction with surfaces [3] or boundaries [4] in lead and tin based systems.
We will report the development of a new MYP2 model that, by the introduction of many-body interatomic terms, improves the description of clusters and make it possible to simulate the crystal growth from precursors in vacuum [5].
Results related to crystallization kinetics, activation energies, morphology and defects formation will be discussed. Finally, we will discuss attempts to study complex 2D/3D interfaces and crystallization in solution.

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ENGIGNEERING PEROVKITE MATERIALS FROM SOLUTION TO SOLAR CELLS

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In the field of photovoltaics, the advent of solar cells based on metal halide perovskite materials has brought about a revolution, overcoming the extremely high-power conversion efficiency of 26% at laboratory scale in a short period of time [1]. The mild temperature processing, combined with the possibility to be fabricated on any type of substrate and the easy composition-dependent bandgap tunability, make perovskite materials suitable for different device architectures, from single junction to tandem-multijunction solar cells, and very attractive for various applications, from utility scale, to building integrated and indoor photovoltaics. To bring perovskite solar cells to maturity, the next big step is to focus efforts on the development of reproducible and high-quality perovskite materials deposited on a large scale via high-throughput manufacturing.

In this context, the processing of perovskite materials using a solution-based approach can integrate printing technologies such as gravure, screen printing, slot die, etc., which can be upscaled to roll-to-roll and sheet-to-sheet lines, allowing the deposition of large volumes of materials at a wide range of speeds, up to about 900 m/min, depending on the techniques employed [2]. When perovskite is deposited from solution, the thickness, morphology and optoelectronic quality of the resulting films are strictly related to the ink properties (i.e. precursor concentration, solvent or solvent mixture, viscosity, etc.). Therefore, in solution-based deposition, the ability to tailor the ink composition is a crucial aspect to develop high quality perovskite materials.

This talk will first give a general overview of the correlation between the properties of perovskite precursor solutions and the formation of a perovskite film with the desired properties [3-5]. Then, the use of polymeric additives is proposed as an effective approach to influence the nucleation and growth processes of the perovskite polycrystalline films, ultimately influencing their optoelectronic, mechanical, structural and stability control the formation of the material via wet processing [6-8]. With this approach, the precursor inks can be tailored according to the technique used and adapted to the needs of large area coating or printing processes.

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THE EFFECTS OF CATION MIXING IN OPTOELECTRONIC PROPERTIES OF LEAD-FREE DOUBLE PEROVSKITES FOR SOLAR APPLICATIONS

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In the past decade, significant efforts have been dedicated to enhancing the efficiencies of both solar cells and optoelectronic materials, aiming to support the green energy transition. Perovskite composites have remained a key focus in these fields due to their unique properties, versatility and vast potential. For solar cell applications, lead-halide perovskites are becoming ever-more appealing due to the constant increase in performances, with a steady improvement of their notorious drawbacks. An alternative field in which lead-halide perovskites have shown remarkable properties is lighting, indeed, such materials present some impressive features such as Photoluminescence Quantum Yield (PLQY) exceeding 100% [1]. However, as for the case of the solar cells, intrinsic lead toxicity and low thermal and environmental stability are still challenges that need to be overcome [1]. As an alternative route, a similar class of materials known as double perovskites has recently been proposed. The difference, with respect to the lead-halides, is the substitution of the Pb^{2+} ion in the octahedral structure with equimolar proportions of M^{+} and M^{3+} metal ions (e.g., $Cs_2AgInCl_6$) [2]. Double perovskites exhibit excellent thermal stabilities (up to 500°C) and appealing luminescence spectra, with broad-band emissions covering the entire visible spectrum [3]. Doping the matrix with suitable additives has shown to significantly improve performances, including a sharp increase in PLQY. This improvement is believed to be due to enhanced lattice crystallinity and the introduction of new parity-allowed radiative recombination paths [4]. Despite these advancements, extensive research is still needed to fully understand these materials, both for solar cells and/or lighting applications, among many others.
The current study aims to bridge this knowledge gap by examining various co-doped compositions of double perovskites $Cs_2Na_{1-x}[X_xY_yZ_{1-y}]Cl_6$ with Ag, Er, Yb, and Bi, using both Raman spectroscopy and PL measurements. This will help correlate changes in composition and crystallinity due to dopant addition with variations in quantum yields and photoluminescence properties. Specifically, a multi-line Raman study from IR to UV combined with micro-luminescence techniques provides detailed insights into the structural characteristics of these perovskites and their correlation with emission properties. This approach enhances our understanding of the mechanisms governing the emission behavior of this innovative class of materials.

This study was developed in the framework of the research activities carried out within the Project "Network 4 Energy Sustainable Transition—NEST", Spoke 1., Project code PE0000021, funded under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.3— Call for tender No. 1561 of 11.10.2022 of Ministero dell'Università e della Ricerca (MUR); funded by the European Union—NextGenerationEU.

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TWO-STEP HYBRID PEROVSKITE DEPOSITION: ORGANIC CATIONS INTERDIFFUSION THROUGH SPIN-COATING AND BLADE-COATING FOR TANDEM APPLICATIONS

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Perovskite/silicon tandem solar cells represent a promising solution to overcome single junction limit [1,2]. A conformal deposition of the perovskite top cell on silicon substrates represents a crucial aspect in monolithic tandem architecture. In this context, a two-step hybrid deposition (consisting of evaporation of the inorganic components and subsequent solution-processing of the organic salts solution) can ensure the advantages of vacuum deposition, such as layer conformality, while overcoming the drawbacks encountered in the evaporation of organic cations [3,4].
In this work, the two-step hybrid method is employed for perovskite deposition in inverted p-i-n solar cells. The inorganic components (PbI_2 and CsBr) are thermally evaporated, whereas the infiltration of the organic cations is performed by either spin-coating or blade-coating. The optimization of the former technique allowed us to achieve a power conversion efficiency (*PCE*) of 19.5% with fill factor (*FF*) around 82%. In order to apply this process to a monolithic tandem solar cell, we developed a simple solution-process buffer layer strategy to sputter ITO without damaging the underlying layers. The fabrication process was then successfully transferred on fully-flat front-side polished p-type silicon-based heterojunction with an efficiency of ~ 18%. The resulting monolithic tandem cells showed an efficiency of ~ 25%, thus achieving a 40% relative efficiency gain as compared to the standalone SHJ. However, spin-coating can hinder film uniformity and scalability. Blade-coating represents a promising alternative approach for organic cations infiltration to meet the demands of large-scale manufacturing. Nonetheless, the control of solvent volatilization kinetics in blade-coating can be more arduous. In order to optimize the solvent evaporation rate, we tuned the blading substrate temperature and gas quenching parameters. An improved crystallization and film morphology was obtained with substrate temperature at 30°C and high-pressure air knife (flow rate of 150 L min^{-1}). Additionally, the optimal solvent and concentration were investigated, resulting in devices with *FF* slightly lower (~ 77.5%) than the spin-coated counterpart.
Future steps will explore the implementation of the optimized evaporation/blade-coating perovskite on Si HJT in tandem configuration. Thus, the present study paves the way for developing highly efficient tandem solar cells.

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OPTIMIZATION APPROACHES OF ULTRA-HIGH TEMPERATURE CERAMICS FOR NEW HIGH-TEMPERATURE SOLAR ABSORBERS

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The creation of innovative methods and materials for sustainable energy harvesting, particularly in harnessing solar power, is crucial for the future. Solar tower plants, which are key examples of Concentrating Solar Power (CSP) technology, capture and transform solar radiation into electricity, with current operational temperatures below 600 °C. However, it is essential to raise the temperature of concentrating solar systems to both enhance the efficiency of thermodynamic cycles for power generation and to support new and emerging thermal applications.
The solar absorber component is a key obstacle to increasing temperatures in CSP systems. In this summary, we present the main findings from over 10 years of research on Ultra-High Temperature Ceramics (UHTCs) for innovative high-temperature solar absorbers. Our studies demonstrate that UHTCs have promising characteristics, such as low thermal emittance and high spectral selectivity, and identify the crucial parameters along with the best optimization strategies [1]–[6]. By employing a comprehensive multi-scale optimization approach—spanning from macro- to micro- to nano-scale—primarily focused on UHTC borides, we demonstrate that adjustments of primary and secondary phases, density, porosity, and surface finishing can alter the optical properties of ceramics. Moreover, through a similarly integrated approach from macro- to micro-scale, other inherent weaknesses (e.g., brittleness, low damage tolerance, heavy weight) can be addressed by developing composite materials, specifically new carbon fiber-reinforced UHTCs [7]. This novel class of materials, known as Ultra-High Temperature Ceramic Matrix Composites (UHTCMCs), combines the oxidation resistance of UHTC phases with the damage tolerance of carbon fibers, and in a preliminary study, has also shown significantly improved optical properties [8].

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HOW TO BRING PHOTOVOLTAIC MODULE PRODUCTION BACK TO EUROPE

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The production of photovoltaic modules in Europe has been continuously decreasing for about 15 years. It has now reached a minimum threshold that in no way allows the upstream supply chain to develop, but rather, year after year sees new company closures. As several studies [1] have shown, more than 95% of the market now depends on products of Chinese origin. In fact, over the past 15 years, a complete supply chain has developed in China from scratch and now includes all the qualitatively and technologically most advanced suppliers in every component sector (from cells to encapsulants, from jboxes to glass). This dependence on external production makes one of the three cornerstones of the so-called 'trilemma' of energy extremely weak [2]. That is why it is crucial to rethink the supply model, while not forgetting all the advantages that China can offer. European companies will have to be ready when NZIA [3] is implemented by the individual nation states: under this directive, a share of the market will be dedicated to products that have other characteristics outside of price as benchmarks (from product origin, to sustainability, to traceability). FuturaSun intends to play a unifying role between the current Chinese-driven industrial scenario and local production in Europe, diversifying its investments within the framework of a balanced development plan that also protects intellectual property developed in Europe. We will then present our plans for developments, prospects and current risks.

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3SUN THE FIRST EUROPEAN PV GIGAFACTORY: ENABLING PROGRESS WITH SUSTAINABLE ENERGY

Marina Foti

3SUN, Italy, Contrada Blocco Torrazze – Catania

3SUN is a PV cell and module manufacturing company owned by Enel. Established in Catania, Italy, in 2010, the plant is being expanded to a yearly production capacity of 3GW, that will make it the largest factory of high-performance PV cells and modules in Europe. 3SUN offers modules for different market applications: ground-mounted plants, commercial, residential, and industrial rooftops. All products are powered by 3SUN's own CORE-H heterojunction technology.
In this talk, we delve into the technology research and development at 3SUN on HJT and Tandem Silicon/Perovskite solar cells.

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HARVESTING THE SOLAR ENERGY BY MEANS OF CARBON NANOFLUIDS: A WAY TO DECARBONIZE HEAT IN THE BUILDING SECTOR

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Solar thermal collectors are expected to play a key role in the decarbonization of the thermal needs in the residential and industrial sectors. The main challenges for this technology are linked to the need of improving the thermal efficiency of solar collectors, which is penalized by the multiple conductive and convective thermal resistances between the working fluid and the absorber, and reducing the investment costs, for example by eliminating the absorbing plate. With the aim to overcome such limits, Direct Absorption Solar Collectors (DASCs) using nanofluids with appropriate optical properties as absorption media have been recently proposed [1]. In this type of solar collector, the working fluid directly absorbs the solar radiation and converts it into heat. Such basic concept could lead to a technological simplification and to a different temperature distribution in the fluid, with higher temperatures in the bulk fluid, instead of the external surface, thus enhancing the thermal efficiency of the system [2]. In the present work, an experimental and numerical study has been performed to evaluate the thermal performance of DASCs operating with suspensions of Single-Wall-Carbon-NanoHorns (SWCNHs) in deionized water. The effect of circulation, working temperature and nanoparticles concentration on the stability of the nanofluids and, therefore, on the thermal performance of the DASC is discussed. The optimization of the collector geometry, as well as the proper selection of materials and the tuning of the nanoparticles concentration in the base fluid, are proved to be fundamental for future deployment of direct absorption solar collectors in the building sector [3].

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BREAKDOWN IN INDUSTRIAL GRADE SILICON MONOCRYSTALLINE SOLAR CELLS

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Hot spots in a photovoltaic module, caused by partial or complete shading of cells, significantly decrease module performance and reliability [1,2]. A hot spot occurs in a PV module when its operating current exceeds the reduced short-circuit current of a shadowed or faulty cell. If such a condition occurs, it forces into reverse bias the affected cell that dissipates power, which can cause local overheating and the destruction of the cell itself.
This study involves detailed investigations of industrial monocrystalline silicon solar cells of different technologies: passivated emitter and rear contact (PERC) [3], amorphous-silicon/silicon heterojunction (HJT) [4], and n-type Tunnel Oxide Passivated Contact (TOPCon) [5]. The cells were fully experimentally characterized, and the main degradation mechanisms are explained through in-depth TCAD simulation both for PERC and HJT. The possible failure mechanism in TOPCon will be discussed.

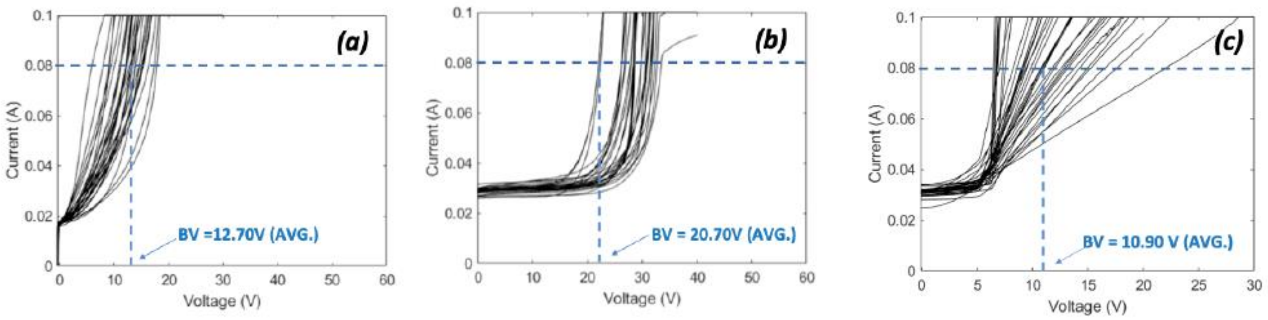

Figure 1. Reverse VI of monocrystalline Si Solar Cell, showing the Breakdown knee for (a) PERC and (b) HJT technologies and (c) n-type TOPCon.

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INTEGRATION OF PHOTOVOLTAIC AND CONCENTRATING SOLAR TECHNOLOGIES FOR HIGH-EFFICIENT SOLAR HYDROGEN PRODUCTION BY HIGH TEMPERATURE WATER ELECTROLYSIS

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Green hydrogen is an energy vector produced out of water and electricity from renewable energy sources (e.g. solar, wind). At present, the use of green hydrogen in industrial processes is challenged by the intermittent supply of renewable electricity, which does not guarantee continuity of hydrogen production. This issue can be mitigated by developing innovative electrolysers characterized at the same time by improved efficiency, reliability and flexibility for meeting the energy demands of different industries.

In this context, the European project PROMETEO (Hydrogen PROduction by MEans of solar heat and power in high-TEmperature Solid Oxide Electrolysers [1]) proposes an innovative system based on high-temperature electrolysis for the production of green hydrogen; it aims to make the most efficient use of heat and power generated from renewable sources and, in particular, from solar energy to optimize solar hydrogen production in line with the energy demand of three industrial sectors.

Renewable power can be supplied by a dedicated photovoltaic (PV) facility; low-cost and low-carbon power can also be made available through the power grid during curtailments, specifically in site with high direct renewable power intensity. The electrolyser should be ready to start as soon as the renewable power is available and, during these periods, heat should be available to drive the steam generator. The project considers the production of high-temperature solar heat generated from Concentrating Solar technologies (CST) equipped with Thermal Energy Storage (TES) to ensure hydrogen production when solar resource is not directly available (e.g. during the night) and/or when power is less expensive.

A prototype with at least 15 kg/day of hydrogen production (about 25 kWe SOEC) and TES has been designed to be connected to external power/heat sources. Operation under partial load conditions, transients, hot stand-by periods and night mode operation have been analysed.

An innovative TES-SG (steam generator) driven with the CST system has been specifically developed and tested to generate the feed steam for the SOE at a controlled temperature and rate (> 130°C) when the power is available. The TES makes use of a ternary molten salt mixture with a single-tank layout integrated with MS/Thermal Oil heat exchanges [2] operating in the range of 180-310°C.

Industrial end-users lead to techno-economic and sustainability studies to select the best conditions to apply the technology in on-grid and off-grid scenarios and for different end-uses: utility for grid balancing, power-to-gas, and hydrogen as feedstock for the fertilizer and chemical industry.

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