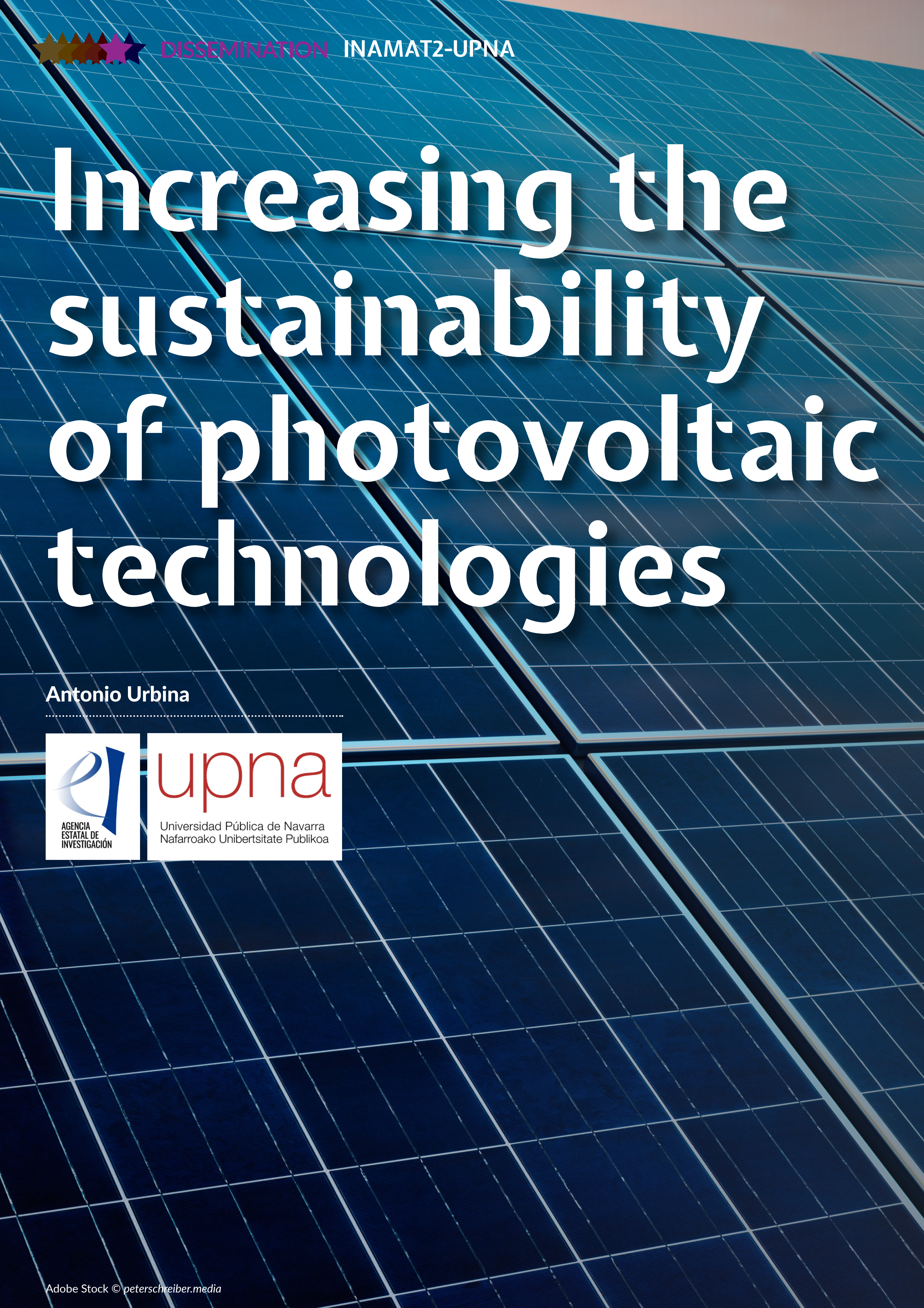

Increasing the sustainability of photovoltaic technologies

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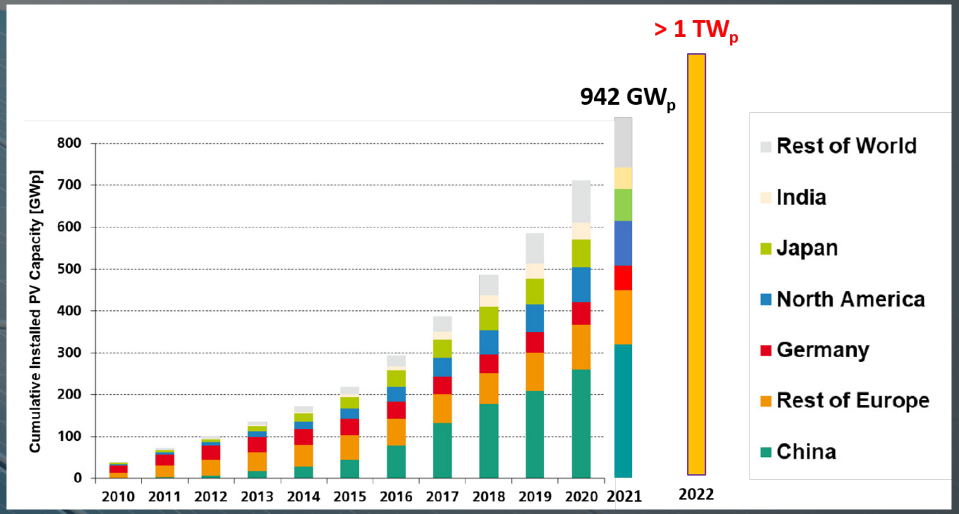

Figure 1: Evolution of cumulative installed photovoltaic capacity (2010–2021, in GW) and the milestone achieved in 2022 by surpassing 1TW. China is the country with more PV capacity installed (> 300GW) followed by the European Union. Data from: IEA-PVPS Snapshot (2022).

The world reached 1 TW (1 terawatt) of cumulative installed photovoltaic capacity in 2022 (Figure 1). That is one thousand million kilowatts. This symbolic milestone illustrates the impressive growth of solar electricity, both in terms of installed capacity, with increments higher than 100 GW annually in the past five years and in terms of solar electricity generation, which achieved a world average of 5 per cent with seven countries surpassing 10 per cent in 2021 (Australia, Spain, Greece, Honduras, Netherlands, Chile and Germany) (IEA-PVPS, 2022).

This trend is expected to grow in scenarios oriented toward reducing greenhouse gas (GHG) emissions, the main cause of climate change. In particular, the International Energy Agency "Net Zero Emissions by 2050" scenario points to an installed capacity of 5 TW by 2030 (33 per cent of total electricity capacity worldwide), producing 7000 TWh of electricity (20 per cent of electricity generation worldwide) (IEA, 2021).

Therefore, photovoltaic technology will be a main contributor to future renewable energy generation, which advances with increasing energy consumption electrification (lighting, cooling and heating, transport, computing, industrial manufacture, etc.). All economic sectors are accomplishing the challenge to become 'electrical', and photovoltaics will be the main source of electricity in the next decade.

But is this history of success sustainable?

Deployment of photovoltaic technology began in the early 70s to generate electricity in locations where the grid was unavailable, such as very remote mountains, islands or orbital satellites. The number of modules manufactured was small and posed no sustainability concern. The main discussion was if the energy invested in manufacturing a PV module was higher or lower than the energy delivered by the PV module throughout its lifetime. This discussion was solved many years ago, and today it has been demonstrated that all PV technologies have an 'energy pay-back time' (EPBT) much shorter than their lifetime. For example, a PV module manufactured in China and installed in Europe has an EPBT of 1.26 years, while its lifetime is higher than 25 years, thus providing a net benefit of electricity production for more than 23 years (Fraunhofer-ISE, 2022). Today, the concerns differ: 1 TW of photovoltaic modules roughly represent 2000 million PV modules, weighing 56 million tonnes (assuming 500 Wp and 28 kg per module, a standard figure in current technology). Furthermore, since the trend is moving towards double-glass PV modules, the weight per module increases to around 40 kg, delivering a total of 80 million tonnes. If the glass thickness in this new generation of modules is reduced to 2 mm (still a challenge), the weight per module could be lower. This is an open question.

Many of these PV modules have been installed in the past ten years and will reach their end of life within 15 years, and sometimes older modules are replaced by new, more efficient ones without waiting to reach their lifetime. In any case, a large amount of photovoltaic waste is expected in the coming years; the International Renewable Energy Agency (IRENA) estimates that around eight hundred thousand tonnes in 2020 and more than 7 billion tonnes in 2030 of PV modules will reach their end of life (Weckend, Wade and Heath, 2016). This waste is considered electronic waste, and regulations apply for their treatment and recycling (for example, the European Directive 2012/19/EU), but the technology to reuse, recover and recycle materials from PV modules is still in a very preliminary stage. Additionally, the end-of-life of PV modules also poses an important logistic challenge; since the manufacture of modules is strongly localised in Asia, the modules are then deployed worldwide, and the recycling points are still almost inexistent.

Furthermore, despite the main PV technology being based on silicon, the most abundant material on Earth's crust, other substances included in the modules may pose a risk for the value chain of PV module manufacture. It has been pointed out that for current c-Si PV technology, scarcity of silver could be a risk, and important efforts are being carried out to look for replacements. Other PV technologies, such as thin film (CdTe or CIGS) or III-V tandems (which use indium, gallium and selenium), are more dependent on the supply of scarce materials (Urbina, 2022). And when we analyse the locations of raw materials production required for PV technologies and where solar cells and modules are manufactured, a clear picture emerges: China is dominating the market, with a very large share of production of all required materials and more than 80

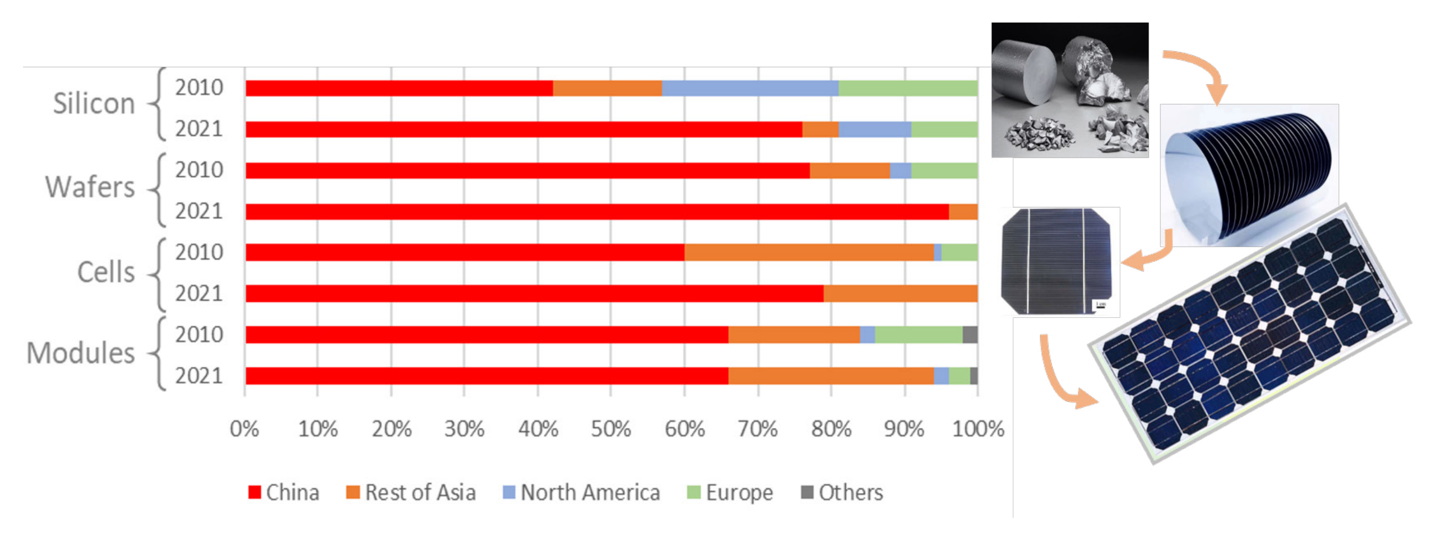

Figure 2: Photovoltaic crystalline-Si technology manufacture location along the value chain showing the increasing dependence on Asian countries for this technology which represents more than 90 per cent of the PV market (comparison of 2010 vs 2021). Data from: British Geological Survey, 'World Mineral Production' (2021) IHS, '10 Cleantech Trends in 2022', IHS Markit (2022).

per cent of crystalline silicon cells manufacture, a figure which increases to 100 per cent when other Asian countries are included (see Figure 2).

With these sustainability challenges in mind, including the geopolitical risks, our research group has been studying the life cycle assessment (LCA) of different photovoltaic technologies, ranging from crystalline silicon (more than 90 per cent of the market) to emerging organic and hybrid perovskite technologies, which still have to reach the market. The LCA methodology provides a quantitative, standardised measurement of environmental and human health impacts in several categories. The standards ISO14040 and ISO14044 enable a common framework to carry out LCA studies which can then be used to compare different forms of supplying electricity, either by PV technologies or by other electricity generators, being renewable or not. These LCA studies show that PV technology is progressing to very impressive power conversion efficiencies from light to electricity, and it is doing so with extremely thin layers of active materials (a few microns) and low environmental and human health impacts; that is, the use of materials within the solar cell is highly optimised, and every small progressing step requires a large research effort and a huge economic investment to improve the manufacturing lines.

But another interesting finding of LCA studies is that there is room for improvement in the sustainability of PV technologies by focusing on materials and components other than the cells themselves. In particular, the use of glass or plastic in PV modules can be more sustainable for all actual and emerging PV technologies.

The improvement of sustainability of glass in PV modules can be accomplished by two main routes: a mechanical, passive way, by reducing its thickness, which requires strategies to strengthen the glass in order to make possible thicknesses of 2 mm or lower (specially for double-glass modules) and a functional, active way in which the glass become an important part of light management and reduction of degradation factors of the solar cells. This double route can strongly reduce the environmental impacts of the PV modules throughout their lifetime in many impact categories. In the current project (ION4PV) the methodology to achieve these aims can be summarised in four groups of research actions:

(i) fine tuning the composition of oxides for soda-lima-silica (SLS) glass (and including them in PET plastic for some flexible emerging PV technologies);

(ii) applying thermal toughening strategies to create strain gradients within the glass that ultimately delivers higher strength to impacts and scratches in the surface and bulk mechanical resilience to bending;

(iii) applying chemical toughening by adding potassium ions to the surface, which contribute both to create strain in the surface and to block the sodium ions that can escape the glass and that is the main cause of potential induced degradation of solar cells; and

(iv) including a very small doping of bismuth oxide that has been proved as a potential 'photon recycling' material by converting ultraviolet (UV) photons into lower energy photons, thus acting as an active UV filter without loosing photons that can be used to excite additional electrons and therefore increase the photocurrent; the use of bismuth oxide will permit to get rid of iron oxides that are an important cause for glass degradation (by 'yellowing').

Our project aims to improve the power output of the PV module without acting on the solar cell itself. We are convinced that significant progress can be achieved by improving glasses whose production is targeted at the PV industry. Moreover, since LCA studies are being carried out for every step of the proposed physical and chemical processes used in the demonstrator samples, we can provide recommendations for more sustainable manufacturing lines for an upscaled industrial output.

Finally, in the project ION4PV we have another objective: how to make the PV module more recyclable and provide recommendations for a 'design for recycling' new generation of PV technologies. Glass is, by weight, the main product to be recycled at the end of life of a PV module, representing around of 75 per cent of weight for a framed crystalline silicon module to more than 95 per cent for a frameless thin film module. If improved glasses can be reused without the need for grinding and remelting, this will be a huge step towards the sustainability of the PV industry (it is a target still far away). But if improved glasses allow the recovery of cells that are not contaminated by ions from the glass, this will also make an important contribution which is within reach in the shorter term. Exploration for improved plastics for encapsulation (currently ethylene-vinyl acetate, EVA, which is used in all PV technologies) will also facilitate the recycling of the solar cells at their end of life.

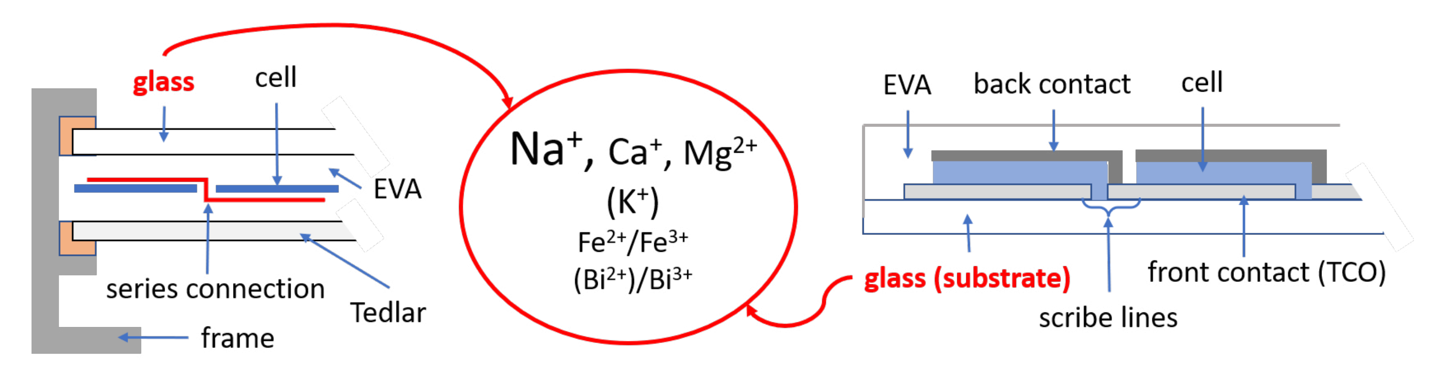

Figure 3: Ion migration from the module glass to contaminate the solar cell for two technologies (c-Si, left and thin film, right). The project ION4PV aims to better understand this effect and provide recommendations to control it as a step towards extended lifetime and increased recyclability of the PV modules.

References

Fraunhofer-ISE (2022) *Photovoltaics Report 2022*. Germany: Fraunhofer Institute for Solar Energy Systems, ISE, p. 52. Available at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

IEA (2021) *Net Zero by 2050. A Roadmap for the Global Energy Sector*. International Energy Agency, p. 224. Available at: https://www.iea.org/reports/net-zero-by-2050.

IEA-PVPS (2022) *Snapshot of Global PV Markets 2022*. Report IEA-PVPS T1-42: 2022. International Energy Agency - Photovoltaic Power Systems Programme - Task1, p. 23.

Urbina, A. (2022) 'Sustainability of photovoltaic technologies in future net-zero emissions scenarios', *Progress in Photovoltaics: Research and Applications*, pp. 1–15. doi: 10.1002/pip.3642.

Weckend, S., Wade, A. and Heath, G. (2016) *End-of-life management: Solar Photovoltaic Panels*. Report Number: T12-06:2016. IRENA in collaboration with IEA-PVPS Task 12, p. 100. Available at: https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels.

PROJECT NAME

Controlling ion dynamics in glass and plastic to reduce degradation and environmental impacts of photovoltaic modules (ION4PV)

PROJECT SUMMARY

Building upon previous life cycle assessment of photovoltaic technologies, the sustainability of photovoltaic modules will be increased by improving the mechanical and optical properties of the glass and plastics (PET and EVA) used for the manufacture of the modules. The reduction of ion migration towards the active solar cell will extend the lifetime of the modules and facilitate their recyclability at the end of life.

PROJECT PARTNERS

The project is being carried out at two Spanish universities that work in coordination: Universidad Pública de Navarra (UPNA, researchers: A. Urbina (PI), V. Sánchez-Alarcos, V. Recarte, J. I. Pérez-Landazábal and A. López-Ortega) and Universidad Rey Juan Carlos (URJC, researchers: L. Serrano (PI), B. Romero and B. Arredondo.

PROJECT LEAD PROFILE

After working on the study of electronic transport in low dimensional systems, Antonio Urbina has devoted the past years to fundamental and applied research on photovoltaic systems. He was a postdoctoral researcher at the University of Wisconsin (Madison, USA), the University of Cambridge and Imperial College London. He is Professor of Physics at Universidad Pública de Navarra and has recently published the monographic book "Sustainable Solar Electricity" (2022, 317 pages) in Springer International Publishing (ISBN: 978-3-030-91770-8).

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