University of Applied Sciences and Arts of Southern Switzerland
Department of Environment Constructions and Design
Institute of Applied Sustainability to the Built Environment

SUPSI

Photovoltaics: made to last.

The 40 years of the TISO PV plant

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Preface

Prof. Franco Gervasoni
General Director SUPSI

FRANCO GERVASONI

A civil engineering graduate of ETH - Swiss Federal Institute of Technology in Zurich, he began his career with the engineering firm Ceresa Rezzonico in 1992, becoming its co-owner a few years later. Initially he combined his profession as a lecturer in civil engineering and architecture degree courses at the Scuola Tecnica Superiore (now the University of Applied Sciences and Arts of Southern Switzerland - SUPSI). In 2001 he was appointed Director of SUPSI's Department of Environment Constructions and Design and in 2003 he received the title of Professor. Since 1 January 2008, he has been General Director of SUPSI. Within swissuniversities, he has been a member of the Board, Chair of the Strategic Planning Delegation and has been a member of the SUDAC network since 2017. He is also active as an individual member of SATW (Swiss Academy of Engineering Sciences) and engaged in initiatives to raise young people's awareness of technical professions in the Canton of Ticino.

Since its establishment in 1997, the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) has distinguished itself in the Swiss University landscape by its ability to develop its applied research mandate in multiple disciplinary areas, drawing on competitive national and EU programme funds.

We undoubtedly owe this success to the many colleagues who have been able to develop quality projects and academic and industrial collaboration networks over the past 25 years, thus ensuring our continued competitiveness. But we also owe this success to the pioneers of applied research in Ticino who were involved in the decades preceding the creation of the University institutes in our Canton, and who helped to create the solid foundations on which the SUPSI we know today was built. Among them were those who, in May 1982, led by the tireless Mario Camani, installed Europe's first grid-connected photovoltaic system on the roof of our historical headquarters in Lugano-Trevano, consisting of 288 modules with monocrystalline silicon cells with a power output of 10 kW: the Ticino Solare (TISO) PV plant. It was a group of outstanding high school teachers of physics and engineering, many of them active in the then Earth Physics Laboratory, created in the 1970s at the Lugano Lyceum, who also offered their expertise in many other areas of activity that later merged with SUPSI, such as earth sciences, materials testing, electronics, information technology and, indeed, solar energy and energy saving.

When SUPSI was created 25 years ago, the TISO team was integrated as a group into the Laboratory for Energy, Ecology and Economics (LEEE) within the Department of Construction and Territory, now the Institute of Applied Sustainability to the Built Environment (ISAAC) of the Department of Environment, Construction and Design (DACD). Giorgio Travaglini, Angelo Bernasconi and Roman Rudel, who headed LEEE and ISAAC, together with all their colleagues active in the photovoltaic sector, were able to take over and pass the baton, believing in this technology that turned out to be even more sustainable and effective than the project initiators had probably imagined. Over the years, a laboratory for testing the quality of modules unique in Switzerland - the SUPSI PVLab - and, also taking advantage of the interdisciplinary expertise present within the DACD, a Swiss BIPV Competence Centre related to the integration of solar energy in buildings, has been set up. A Centre that has carried out many projects that have also motivated architects and other planners to consider not only functionality and efficiency, but also the aesthetics of innovative and future-oriented solutions. In these months of energy crisis on our continent, generated by the conflict in Eastern Europe, we realize the importance of reduced consumption, independence from foreign supply, the value of renewable energies, and how far-sighted the work of recent years has been.

As was the case with the Chernobyl catastrophe in 1986 and Fukushima in 2011, the war in Ukraine will mark an epochal turning point in which renewable energies, solar first and foremost, will find a growing place in local and global energy policies. TISO's 40th anniversary celebrations are an opportunity to tell and enhance our story by thanking all those who have contributed with vision, commitment and expertise to its development. Competent people who have enabled and continue to enable SUPSI to make a name for itself in this fundamental sector and to provide qualified support for the definition of concrete measures to support the Swiss federal government's energy strategy and ensure the sustainable development of our society in the coming decades.

Introduction

Roman Rudel
Director of the Institute of Applied Sustainability
to the Built Environment at SUPSI

ROMAN RUDEL

Roman Rudel, head of the Institute of Applied Sustainability to the Built Environment at SUPSI since 2008, has an academic background in geography with particular focus on the complex relation between socio-economic development and the environment/climate change. He received a Ph.D. from the University of Fribourg (Switzerland) for a thesis on the ecological transformation of the industrial society he carried out with the Human Ecology Group of ETH Zurich (Switzerland). After 5 years of research assistant at the University of Fribourg he moved to Ticino in 1992 working for a research institute in the field of regional innovation systems. He has over 20 years of research experience in the field of technological and institutional innovations applied to the mobility and energy sector and was member of the first national action plan on sustainable development in Switzerland.

Forty years of the TISO 10 kW PV array is undoubtedly a proud age for this energy technology and is worth recording. However, our goal with this small booklet is not to indulge in celebration but to present highly prominent testimonials relating the TISO 10 kW adventure to their personal experiences and episodes in their professional careers in the photovoltaic (PV) sector. The various contributions shed a unique light on the “small” history of the TISO 10 kW and relate it to the historic challenge humankind is facing with the energy transition to mitigate the risks of global climate change. Several testimonials remind us that these risks were already clearly present in 1982, when the TISO 10 kW was linked for the first time to the grid, and photovoltaics represented one of the most promising technologies to cover the future energy demand. However, the sense of urgency was hardly present. It took at least another ten years until 1992, when politics and the general public became aware of the environmental and social impact of the fossil fuel economy during the United Nations Earth Summit on sustainable development in Rio de Janeiro.

Mario Camani, the visionary mind behind the TISO 10 kW PV plant, traces back the primary motivation of his initiative to the fuel energy crisis in 1973, one year after the report of the Club of Rome on "The limits to growth". He was profoundly convinced of the potential of photovoltaic systems and was somehow part of a strong PV pioneering movement in Switzerland, well known under the name Tour de Sol, with various lightweight and electrical mobility initiatives leading to industrial activities, especially in the machine tool industry for photovoltaic.

The oil crisis of 1973 also played an essential role in the development of the PV industry in the US, fostered by the big oil and gas industries with their technology diversification initiative, remembered by Charlie Gay. He also provides a first impression of the scale of progress the industry underwent in these 40 years, producing the yearly output of roughly 1 MW of PV modules in 1982 in less than one hour in giant PV factories today.

From the beginning in 1982, the team of Mario Camani, later guided by Domenico Chianese, the dean of the PV sector in SUPSI, used the TISO 10 kW array as a showcase to demonstrate the performance of the PV technology and its potential application for a renewable energy generation. They benefited in many ways from the nearby European JRC in Ispra, where talented researchers like Heinz Ossenbrink started their brilliant career and spent their whole professional life establishing PV as a reliable and cost-friendly energy technology. Despite its proximity, the access to the JRC turned out to be quite tricky for Swiss researchers, who had to learn quickly to overcome institutional barriers, as Giambattista Ravano, one of the young scientists in the TISO team, nicely recalls.

From his privileged position and great experience in the photovoltaic sector, Stefan Nowak puts the early efforts with TISO 10 kW into a historical perspective of the evolution of PV technology. He effectively illustrates the various milestones in what turned out to be an exponential PV growth. Considering the TISO 10 kW among these milestones paving the renewable energy future honours the pioneer spirit of Mario Camani and his team, who faced criticism and skepticism and, sadly enough, were ridiculed by narrow-minded politicians, who were unable to imagine the profound transformation of the energy system and the role PV could play in future. Christophe Ballif focuses on the evolution of solar cell technologies and the competition between three categories of cell technologies with their pros and cons and alternating market share. As in many other sectors, the intrinsic technological properties and sophistication do not necessarily guarantee economic success.

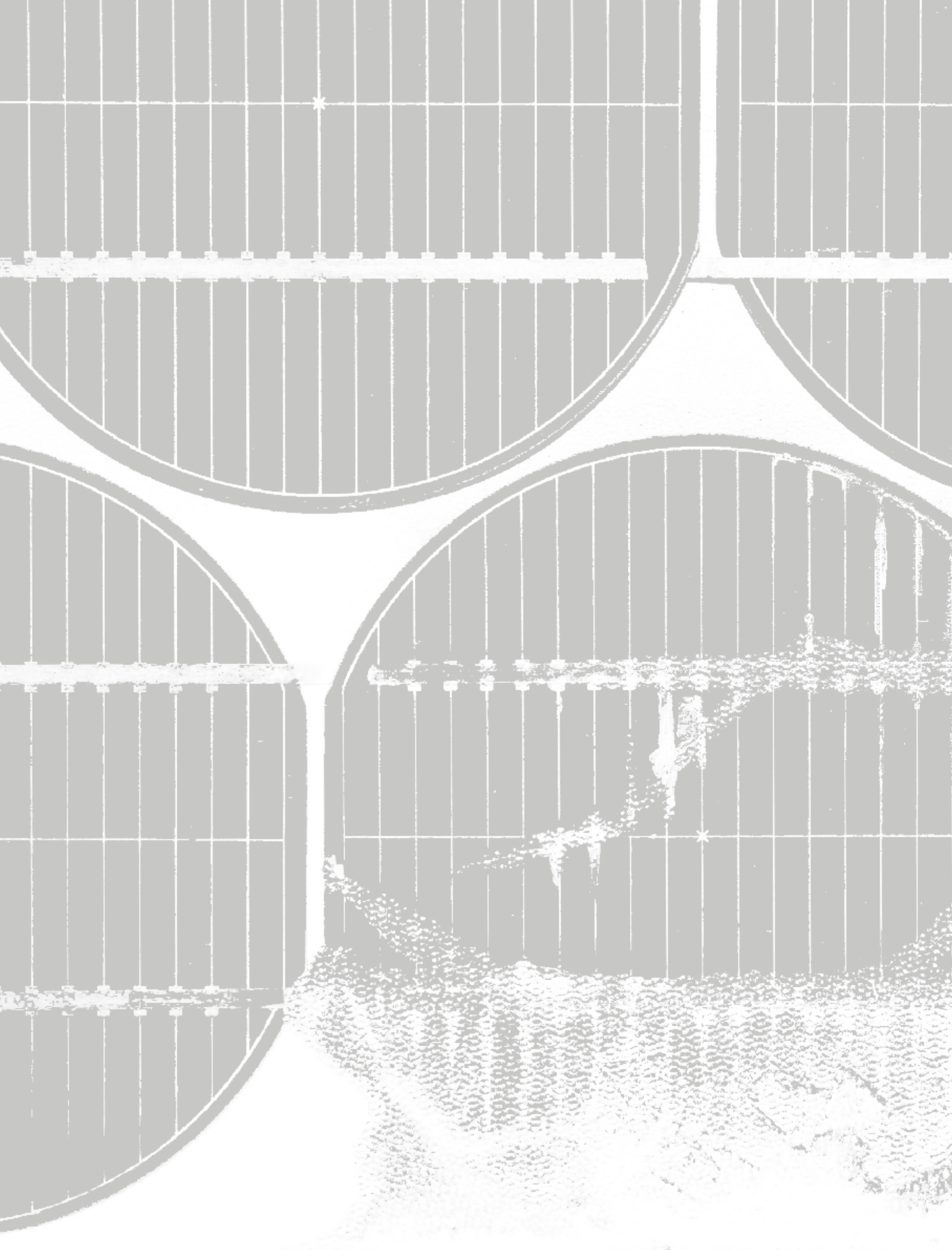
The research endeavours to develop even more efficient cells, described by Christophe Ballif, are very impressive. The use of new materials with extraordinary semiconducting properties like perovskite are likely to be used in future solar cells. However, many challenges must be overcome to make them as stable and reliable as the solar cells used in TISO 10 kW. In any case, more conventional and new PV technologies play a crucial role in the energy transition and have a high potential to substitute fossil fuels, as Stefan Oberholzer highlights. Considering the future evolution of PV technologies, firm PV power integrates perfectly with flexible hydropower and some storage to build the most cost-effective solution, and curtailment is likely to be used for green hydrogen. For the reason of this massive use of photovoltaics, it is necessary to understand the degradation process of the TISO array during its lifelong exposure to adverse ambient conditions and extreme weather events. Mauro Caccivio - responsible for the SUPSI PVLab - and Dirk Jordan, provide valid arguments to understand the degradation mechanism and the relevance of appropriate testing to maintain and improve quality even in a rapidly growing market.

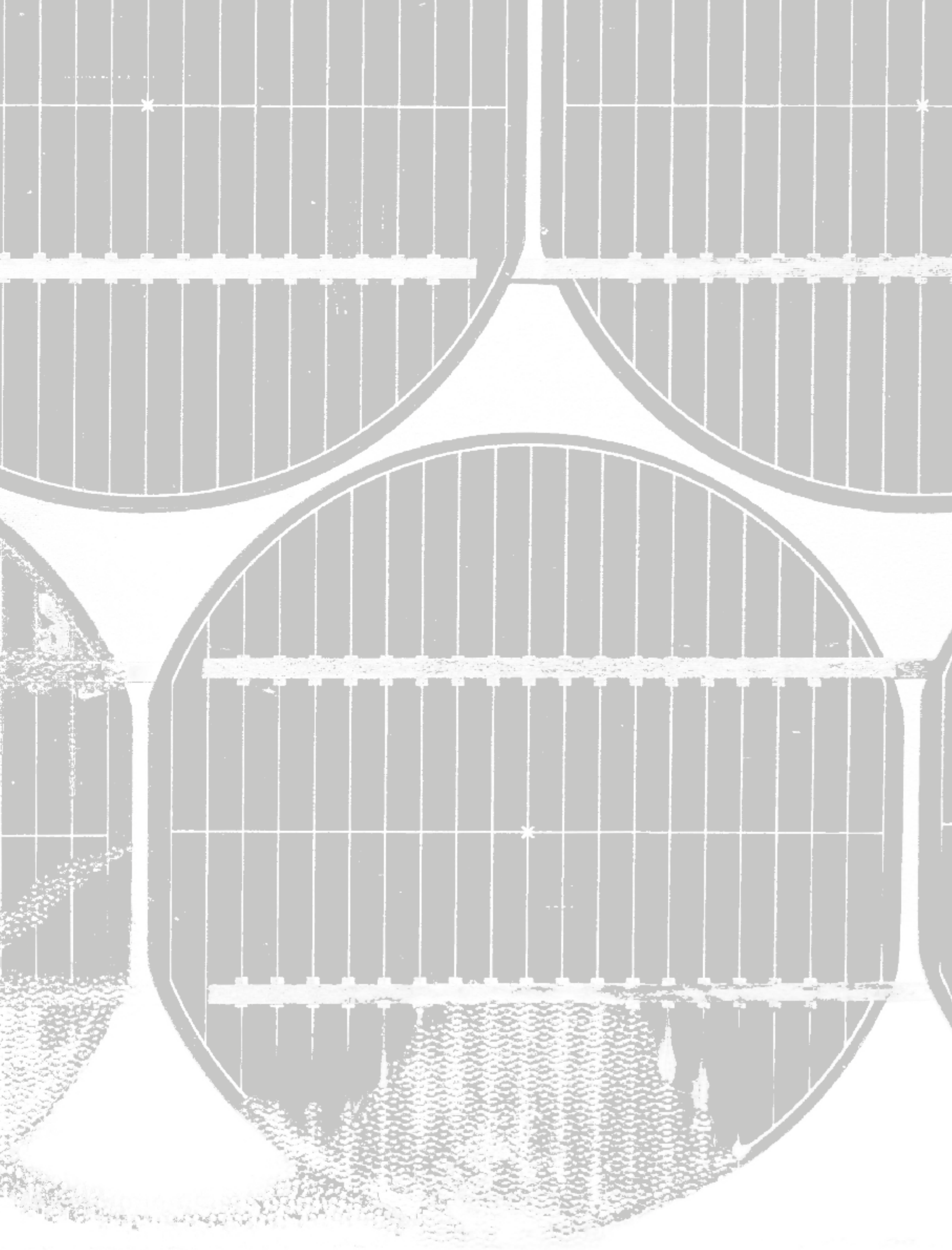
After the PV market take-off in Europe in the first decade of the 21st century, the production of PV modules rapidly moved to China. The European Commission intends to reduce this dependency by launching its REPowerEU package almost precisely on the 40th anniversary of TISO 10 kW. Gunter Erfurt illustrates the strategy of Meyer Burger with its new cell factory in the “solar valley” of Saxony-Anhalt. These projects align with the ambitious energy transition goals and contribute to a revival of the European PV module industry, giving further advantages to this renewable energy source by cutting its footprint. In a similar vein, Fabrizio Bizzarri recalls the development of ENEL Green Power (EGP), collaborating in its early days with SUPSI on PV characterization and disposing now of its extensive testing facilities. In 2022 EGP started its first gigafactory with the ambitious target to increase its production capacity to 3 GWp by 2024 and contributes to the renaissance of the European PV industry. Despite the clear transition targets, the European Policy approach to support the photovoltaic industry was confused and complex, as Gaëtan Masson resumes. He argues, and Gunter Erfurt and Fabrizio Bizzari might testify, that Europe took a leading role by introducing feed-in tariffs to boost the PV market for a short period around 2010. After losing the PV industry to Asia in the following decade and opening the doors for Chinese imports due to cost-oriented tendering schemes, it became clear that the neglection of the European PV industry created a dangerous dependency.

Recently, the EU policy has recognized the need for a European PV industry supporting it with credits and policy schemes for the smart development of photovoltaics, including self-consumption and energy communities. Contrary to the early pioneers and PV supporters in Switzerland, the Swiss energy policy was somewhat reluctant to favour PV and combine energy policy with an industrial policy strategy, which is almost absent in Switzerland. According to David Stickelberger the upswing in PV started in Switzerland around 2009 with the first feed-in tariff scheme. Yet, the diffusion of PV is still relatively slow compared to its vast potential and the essential role it has to play in the energy transition. Switzerland remains a laggard, and new topics like large ground-mounted systems in the alpine space entered only very recently into the public debate. Wieland Hintz presents very recent figures on the market evolution and describes different policy interventions which improve the situation in Switzerland. It emerges that the PV module market gets strong momentum. The recent introduction of the possibility of self-consumption and peer-to-peer communities, as well as the rapid adoption of electric vehicles, trigger this current evolution even further. Switzerland is among the leaders in Building Integrated Photovoltaics (BIPV) due to the lack of open spaces and the need to exploit rooftop and façade surfaces. Pierluigi Bonomo and Francesco Frontini emphasize the possibilities of BIPV to open the field of PV technology applications in the built environment and its role in the energy transition, turning the building stock into a decentralized renewable energy producer. In the BIPV research area, SUPSI can blend its competency in PV technologies with contemporary architecture's aesthetic requirements, keeping the TISO 10 kW pioneering spirit alive. In the concluding contribution I report briefly on the impact of public support in energy research and I illustrate the main research areas of SUPSI's Institute of Applied Sustainability to the Built Environment (ISAAC) originating from the TISO 10 kW initiative.

In this sense, I would like to thank all the authors for contributing to this kaleidoscopic view of 40 years of the TISO 10 kW PV array. They help us appreciate the boldness and courage of Mario Camani and his team, and reading these pages gives us a feeling of the time and effort necessary to achieve relatively modest goals but also the power and energy to continue thriving for the same ideals.

Authors





Historical background

TEXTUAL INTERVENTIONS BY
MARIO CAMANI [PP. 25-27] ; GIAMBATTISTA RAVANO [PP. 28-29] ; DOMENICO CHIANESE [PP. 30-32] ;
CHARLIE GAY [PP. 33-34] ; HEINZ OSSENBRINK [PP. 35-36]

Author	Article
Mario Camani	TISO: a project to promote photovoltaics

Mario Camani graduated in physics from ETH Zurich (Switzerland), Physics and Mathematics Section. After having earned his doctorate in physics in the solid body physics laboratory, he moved to Yale University for two years as scientific collaborator. In 1972 he was then back to Zurich, where until 1978 he worked at the High Energy Physics Laboratory of ETH Zurich in Villigen. In 1979 he joined the Cantonal Administration in Ticino, where he ruled at the beginning as head of energy issues, to become in 1985 Head of Energy and Air Protection Section (afterwards named Air, Water and Soil Protection Section). After retiring in 2006, he started his new career as juggler and clown. Mario Camani has been president of the Swiss Solar Energy Society from 1983 to 1987; since 1987 he is honorary president.

Giambattista Ravano

The first modules and the monitoring system with IT

Giambattista Ravano graduated in physics from ETH Zurich (Switzerland). As an IT specialist, he played a key role in the development of IT curricula in baccalaureate schools in Ticino. He further specialized in IT in the private industry, working as analyst and project manager for an international IT consulting company, of which he is currently the President. At the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) he was Professor of software engineering, database management and IT systems. He held the position of Director of Research Development and Knowledge Transfer and member of the SUPSI Executive Board, before becoming Director of the Department of Innovative Technologies at SUPSI. He was a member of the Swiss Science and Innovation Council from 2012 to 2015 and is Vice-Chairman of the Swiss Accreditation Council, where he has been active since the Council's inception (2015).

Domenico Chianese

The project: engineering, measurements and research

Domenico Chianese has decades of experience in photovoltaics. He graduated in industrial electronics from the School of Engineering ETS in Yverdon-les-Bains (Switzerland) in 1987 and has been working at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) since 1988, first as TISO researcher and senior researcher, then as head of the PV sector and head of the photovoltaic and electrical system group. In his career he carried out research, training and development projects in Nepal, Ethiopia, Togo and Cameroun. As a scientific senior researcher he was involved in the analysis of PV modules. He set up the Swiss Testing Centre for PV modules in 1991 and developed the relevant electronic instrumentation for the analysis of the PV modules (MPPT). He is also a teacher and has won three Swiss Solar Prize: in 2001 for the TISO project, in 2005 for the CPT project, in 2017 for the Sahay project in Ethiopia.

Author

Article

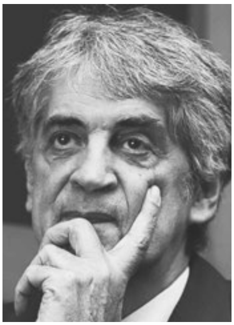
Charlie Gay

Industrialisation of photovoltaics at ARCO Solar

Charlie Gay has over 45 years of solar experience. He served most of his career in the private sector, at ARCO Solar, Siemens Solar Industries, ASE Americas, and Applied Materials. Dr. Gay also led the Solar Energy Technologies Office and the National Renewable Energy Laboratory for the U.S. Department of Energy. He was elected to the U.S. National Academy of Engineering in 2013 for his pioneering work in the commercialization of silicon solar cell manufacturing.

Heinz Ossenbrink

JRC activities at TISO and development of IEC standards



Heinz Ossenbrink holds a PhD from Berlin in Nuclear Physics. He founded the European Solar Test Installation at the European Commission's JRC in 1982; later he became Head of Unit Energy Efficiency and Renewables from 1996-2016. He was Chairman-elect of the IEC TC82 for 12 years, chaired the EUPVSEC twice and was 14 times its Programme Coordinator. Since his retirement in 2016 he is scientific consultant on renewables, including biomass. He advises Solar United and a number of professional clients. He serves currently as chair of the International Advisory Committee for the 8th World Conference on PV Energy Conversion 2022.

MARIO CAMANI

TISO: a project to promote photovoltaics

The soaring price of fuel oil in 1973 and the potential supply difficulties had prompted the Swiss federal government to look for alternatives to the use of fossil fuels. To this end, it was assumed that consumption would be reduced, energy sources would be diversified, and more use would be made of regenerative energies, hydroelectricity, wood, ambient heat, biogas, solar, geothermal heat, etc.

In 1979, the Department of the Environment of the Ticino Canton hired a specialist to deal with the Canton's energy supply. The principles remained broadly the same as those listed above. Implementation was promoted by means of information and advisory campaigns for the population, training courses for professional groups, legal measures and financial aid, and projects to test and demonstrate the use of renewable energy.

In the late 1970s, the use of solar energy was limited to solar thermal and passive solar for heating homes. Due to the high price of solar modules, electricity production was limited to small photovoltaic installations of a few tens of watts to power small consumers far from power lines such as antennas and radio repeaters in high mountains or for light or small appliances in isolated huts and cottages. In other countries, such as California, the first installations with a power of a few tens of kilowatts had been realized, but always for consumers far from existing power grids. In 1980, the European

Community had announced its intention to build some thirty photovoltaic installations with a capacity of between 30 and 300 kW, almost all of them located far from the grid. Only a couple would be connected to an existing local electricity grid.

For the Department of the Environment, however, it was clear that a substantial contribution to the Canton's energy supply through photovoltaics could only come from plants working in parallel with the electricity grid, given that all large consumers were connected to the grid. Against this backdrop and in view of the fact that the price of photovoltaic modules was steadily decreasing, the project later called TISO 10 kW (Ticino Solare) was born. The main motive for the initiators was to show that photovoltaic systems, although still very expensive, were safe, reliable and grid-compatible. Of the possibilities examined, a 10 kW PV system connected directly to the electricity grid was chosen.

The installation on the roof of the Higher Technical School (STS), which then became SUPSI, would have facilitated its control by the scientific staff present and made the system accessible to interested parties. The research project drawn up was to examine the technical and economic aspects relating to the construction and operation of the plant, as well as the stability and safety problems associated with its interaction with the power grid.

The results would have made it possible to assess the potential impact on the grid of even higher power plants, respectively a large number of decentralized plants. This information was essential for assessing the potential contribution of photovoltaics to the Canton's electricity supply. It was also intended to stimulate Ticino companies to produce components for these plants such as inverters, respectively to offer information and experience to companies that could build such plants. The concrete project was developed by the Department of the Environment (M. Camani), assisted by physicists D. Bozzolo, O. Daldini, R. Pamini, G. Salvadè, F. Solcà, C. Spinedi and F. Zamboni from the Earth Physics Laboratory, engineer Tino Celio from Ambrì for the electrical set-up, and engineer Claudio Giovannini from the company Invertomatic for the selection and commissioning of the inverter. The monitoring of the system was entrusted to engineer P. Ceppi for two years. The project was financed by the National Energy Research Fund (NEFF) and contributions from the Società Elettrica Sopracenerina and the Federation of Migros Cooperatives as well as a private foundation. As of 1985, the Swiss Federal Office of Energy had taken over the main financing of further research.

In December 1981, it was possible to start constructing the plant. The modules for the system were chosen after examining and measuring modules from 6 manufacturers. The system consisted of 288 monocrystalline silicon modules (ASI 2300 from the company ARCO Solar) with a total nominal output of 10.6 kW mounted on 3 planes 10 meters apart to avoid shadows and inclined by 65° to maximize winter production. The modules were electrically connected in a horizontal series of 12 modules for a total of 24 series. The total surface area of the modules was 107 square meters, the active surface area of the photocells was 79 square meters. Grid connection was provided by an inverter from Abacus Controls Inc. (USA) with a rated power of 10 kW.

On 13th May, 1982, shortly after 7 a.m., at sunrise, the system started to feed the power supplied by the photocells into the grid. By 2 p.m. the first 52 visitors had arrived from the 4th European Community Photovoltaic Solar Energy Conference held that week in Stresa (Italy) from all over the world. TISO 10 kW was at that time the only plant in Europe connected to the grid. One or two grid-connected but lower power plants existed in the United States. Shortly afterwards, researchers from the European Centre in Ispra (Dr. K. Krebs) proposed detailed measurements on the TISO 10 kW plant with equipment developed for monitoring European Community plants, the realization of which had been severely delayed. Among the planned measures was the measurement of the I-V curve of the entire plant. The collaboration continued for several years.

In 1987, alongside the TISO 10 kW, three other systems of lower power output were constructed and commissioned with amorphous silicon modules from three different companies - ARCO Solar (96 G4000 modules of 30 W), Chronar (46 CSB 13.E modules of 12 W) and SOLAREX (22 SA20 modules of 20 W). This was the first attempt to connect amorphous silicon modules to the electricity grid. Two types of modules had rapidly degraded and became unusable. The ARCO Solar modules had stood the test of time and had above all provided interesting data on the strong relationship between efficiency and temperature.

In 1990, the study of the behaviour of modules of different technologies under real operating conditions began. Output was analyzed as a function of irradiation and air temperature, and the degradation of output over time observed in continuity.

GIAMBATTISTA RAVANO

The first modules and the monitoring system with IT

This solar power plant, the first in Europe to be connected to the electricity grid, represents one of my most important memories from the beginning of my career. It was in 1981, a year before it went into operation, that I began to collaborate with schools and institutions in the Ticino Canton in research activities. A few years later, I was working as a physicist at the Water and Air Protection Section directed by Dr. Mario Camani who, together with then State Councilor Fulvio Caccia, was the main actor in the birth of the TISO 10 kW.

The first implementers were my dear colleagues such as Paolo Ceppi, supported by Renato Pamini and Carlo Spinedi, but many others collaborated and I would not like to be remiss by forgetting to mention them. In any case, this activity, which can be described as pioneering, was the basis for many later developments that also led to the establishment of SUPSI as a professional university. They certainly originated the electronics section, in the engineering school that later became SUPSI, and thus created a road traveled by many young people who later became engineers.

However, I think it is only fair to recall some important steps that took place at the time and in which I was also involved. I personally devoted space and time to the issues of air and environmental protection and at the same time was a lecturer in the computer science section. But I also had an uncommon characteristic among my colleagues, namely that I possessed a passport from a member nation of the European Union. This meant that I was able to enter the Joint Research Centre in Ispra without having to go through the heavy administrative hurdles for citizens of non-member countries.

Basically, I found myself keeping in touch with Ispra quite frequently, because I was in and out easily and I was a physicist who should have understood something about it. And I took part in various meetings, exchanges of data, information and small workshops, even bringing representative modules of the power plant for additional tests to Ispra.

What is most interesting to point out is that at that time, forty years ago, there was an extremely active and enthusiastic spirit of enterprise towards these new power generation technologies. And the production of energy, with a technology that had yet to be proven, demonstrated a willingness that paradoxically today, when the technology is now settled and applied extensively, appears less supported.

However, the anecdotal memories of that time are also very indicative of the development of the use of solar technology for electricity production. In Lugano we were busy figuring out the best angles of the modules with respect to the horizontal at various times of the year, we paid a lot of attention to atmospheric phenomena, including snow, which influenced and still influence the efficiency of the modules and their durability, and in addition, being among the first, we could boast long periods of use of certain types of modules at that time, so we were the reference for their durability.

Another aspect to highlight of the pioneering work - which is very important in settling the technology - is the special attention paid to the management and processing of the data that from all components of the system, arrived at the control computers. Evidently, the focus was mainly on the serious deficiencies, which at the time were lower than they are today, and had to be increased, but also the entire transposition of energy to the public grid produced information for those who then had to try to find marketable systems.

It was therefore a special moment of concentration also on data management, today we would say big data, from which we learned a lot as engineers, as physicists and also as computer scientists. In addition to growing expertise on solar power modules, many other scientific skills grew, which allowed that group of people to grow and generate a university-level school.

The story is therefore also that of the birth of SUPSI. It is worth remembering this to the extent that an innovative effort by a few often generates, if the soil is fertile, a prolusion and growth both scientific and social, cultural and moral. And so it was in this case.

DOMENICO CHIANESE

The project: engineering, measurements and research

When I arrived to work at TISO in January 1988, all I found was a mini-desk, a semi-empty room with the first inverter that connected the TISO 10 kW system to the grid and the data acquisition system box. Although the equipment was few in number, it was of high quality for the time!

The inverter, a 10kW ABACUS, came from the USA. It was built with a bridge (H) circuit consisting of bipolar transistors in darlington configuration and had a heavy 50Hz transformer at the output. With a switching frequency of 5kHz, the noise in the room was annoying, to say the least, and on jobs that took too long we even had to switch off the inverter. The maximum power point control was analogue, and used the open circuit voltage measurement of a reference module.

The DAQ data acquisition system (a Solartron loaned by ICTS, as was all the measuring equipment used at this time), consisted of a 16-bit ADC with a multiplexer formed by a series of reed relays. It allowed the measurement of dozens of channels of both voltages with different measurement ranges and temperatures using PT100. The data acquisition program was realized in the Fortran77 language on a PDP11 computer, which in turn was connected to the centralized VAX computer of the STS at the time (High Technical School). The data was transferred onto magnetic tapes for long-term storage. When it was replaced by a new DAQ in 1991, the magnetic tapes occupied an entire cabinet. The acquired data found a place on just two CDs a few years later. Data processing was done in Fortran77 on the VAX computer and an A3 plotter was needed to display the graphs. It is hard to imagine today how a simple graph required hours of work!

In addition to the project to analyze the operation of the 10kW TISO plant, we started a project to analyze modules made with thin-film cells. A 4kW system was realized, one of the first systems with grid-connected amorphous silicon (a-Si) cells. As part of this project, I had the opportunity to develop the first MPPT (Maximum Power Point Tracker) made by our institute. It had an analogue control with perturb and observe search for the maximum power point. The maximum power was only 50W, but the largest modules barely reached 30W. The two analogue outputs Im and Vm were measured by the Solartron DAQ on PDP11 and the energy was measured with an electromechanical pulse meter. This first MPPT was used to analyze the initial degradation (Staebler-Wronski effect) of a dozen a-Si modules.

From this first MPPT, subsequent MPPTs were developed, but above all, the idea was born to carry out stand-alone tests to test and compare the modules under real environmental conditions. Between 1991 and 1993, the 'PV module test Centre - TISO' was thus born. The idea of a complete laboratory with indoor measurements was already there but was only realized in its current form 15 years later.

For the construction of the 'TISO Test Centre" we used part of the roof of the a-Si plant and later the roof of the TISO 10 kW. Modules from different manufacturers were compared. Of the six PV modules purchased, three were placed at MPP, one at Isc and one at Voc, while one remained in the dark as a reference. The measurement cycles lasted 15 months and the modules were dismantled, transported to JRC in Ispra and measured under STC conditions every three months. The research at that time focused on the comparative analysis of the energy yield under different environmental conditions and the analysis of the initial degradation (LID) of the PV modules. The measurement cycles continue to these days, but in a different form and timing.

In 1996, the second generation of MPPTs with higher power and performance was developed and installed. The new crystalline silicon modules on the market reached powers of up to 120W and the new MPPT was built for maximum values of 150W, 10A and 100V. As with the new on-grid PV inverters at that time, the control was digital and no longer analogue. The microcontroller measured and calculated the parameters Im, Vm, Pm and the daily and total energy. Analogue outputs allowed an additional connection to the external DAQ with which weather and temperature values were also measured.

The evolution of PV modules became more and more rapid and 10 years later, in 2006, we put into operation the new MPPT3000 (250W, 20A, 150V), which is still functioning today and is equipped with a DSP controller, new power electronics and precision converters for measuring meteorological parameters. An RS485 communication bus allows connection to the school's computer network.

In the meantime, the old first ABACUS inverter could no longer be repaired. The TISO 10 kW system was equipped with a digitally controlled SOLCON prototype inverter for a test project. This inverter was the first product of what was to become the Swiss inverter company Solarmax. Over the years, other inverters were installed on the TISO 10 kW system. The reliability of the PV modules has always been greater than the reliability of the electronics!

In those years, the old DAQ was changed to a different system and, later on, a HP34970A data logger with GPIB communication was used. All channel programming, database and processing was carried out using the Labview acquisition program and the data saved on a server. During the first 20 years of the TISO's life, we also continued to record the daily energy production values of the TISO 10 kW and TISO 4 kW plants by hand, and this practice allowed us to avoid data acquisition system failures and to guarantee continuity and reliability of energy production data.

The relocation of the SUPSI Department of Environment Constructions and Design to the new Campus in Mendrisio was the opportunity to purchase the new DAQ system with integrated MPPT from Gantner, which allows us to better manage outdoor measurements on both standard and BIPV modules on the new Campus roof. The data management has followed the evolution of the technology and the database is on the cloud while only a browser is needed for visualization.

The reference measurements of the I-V characteristic at STC always took place in Ispra at the JRC (Joint Research Centre), with which we had a deep collaboration since the early years of TISO. Both a batch of the reference modules of the TISO 10 kW plant, the a-Si TISO 4kW modules, and the modules of the outdoor stands were periodically re-measured under standard STC conditions in the laboratory. Trips to Ispra followed at an ever-increasing pace, complicated by the preparation of customs transit documents. At the turn of the century, the foundations were then laid for the purchase of a solar simulator for the indoor measurement of the I-V characteristic, temperature coefficients and spectral response of PV modules. In 2000, the new dark room in Trevano was opened with a PASAN IIIa solar simulator. This marked the start of our laboratory's ISO17025 accredited indoor measurement activities as early as 2001. It was only at the end of 2007 that we were able to obtain funding from the Swiss Confederation to expand the indoor measurements and complete the PVLab, and in 2010 to obtain the ISO17025 certification for some 30 PV tests. After various vicissitudes, the indoor test laboratory was moved first to Lamone and then back to Trevano, finally arriving at the new premises in Mendrisio, acquiring new space, new equipment and young staff for a new start.

And the rest is future history!

CHARLIE GAY

Industrialisation of photovoltaics at ARCO Solar

The first “oil embargo” of 1973 triggered the start of extensive efforts across the world to utilize manufacturing techniques to make cost-effective energy producing products, without reliance upon fossil fuels. Many companies in the oil and gas industry were among the first to launch “high technology” diversification initiatives. Among these were Atlantic Richfield (ARCO), BP, Exxon, Mobil, Shell, SHOWA, Amoco, and Total. In the case of solar photovoltaics (PV), their long-term financing and expertise in polymer chemistry merged with consistent, long term government policies to give PV a jump-start. In 1980 ARCO Solar celebrated manufacturing 1 MW of PV panels in less than one year. 1982 saw the deployment of the first 1MW grid-tie PV system at the Southern California Edison substation in Hesperia.

Today, large PV companies can produce 1MW in less than 1 hour and there are over fifty PV power plants exceeding 365MW in size with the largest reported as 2,700 MW in India. PV has led to factories that produce clean energy power plants every day. These sources of distributed generation bring more value than just low cost and minimal carbon footprint. They enable greater energy security and resilience in electric grid networks.

Solar photovoltaics is the ultimate capital good requiring upfront capital investment. Thus, maximizing predictable power generation over a lifetime establishes project bankability and cash flow. Design guidelines for reliability have their roots with the engineering talent that staffed the race to space in the 1960s. Among the leaders of these activities, special mention of the unique role of the Jet Propulsion Lab (JPL) in California is especially noteworthy. PV module optical and photothermal degradation mechanisms, encapsulation design practices, materials and test techniques, reliability prediction and accelerated aging methods were simultaneously optimized. PV panels were fabricated and deployed to refine and validate theory.

The goal was a PV power plant that matched the lifetime of nuclear or coal burning power plants, which was 40 – 50 years. This was too long to wait for an existence proof. So, a virtuous cycle of progressive improvements was launched, matching real world outcomes with prediction. But, there is no substitute for real time results. Forty years ago, the visionaries at Ticino Solare (TISO) recognized the importance of establishing a "gold standard" benchmark for PV reliability. Three groups of modules from ARCO Solar were connected to the European grid. They were produced in accordance with the JPL "Block IV" design criteria. The construction integrated water white tempered glass front surfaces with Tedlar® coated steel foil backsheets. Sandwiched in between were crystalline silicon solar cells in three variations of polyvinyl butyral (PVB) thermoplastic blended with UV and quaternary ammonium salt stabilizers. The encapsulation tactics and manufacturing equipment sets were adapted from automotive laminated glass production. The results are noteworthy for firmly establishing an "existence proof" that well-designed PV modules can outlive and outperform alternative forms of generation.

The ARCO Solar pioneers wish to express a debt of appreciation and offer special thanks to the visionaries at the Institute of Applied Sustainability to the Built Environment of the Department of Environment Constructions and Design of the University of Applied Sciences and Arts of Southern Switzerland. Today, and every day in the future, we celebrate the credibility that comes from proven, decades-long predictability.

HEINZ OSSENBRINK

JRC activities at TISO and development of IEC standards

It is of particular significance for me, to write some lines of my memories regarding TISO 10 kW, because the founding of TISO 10 kW is very close to my own start into photovoltaics. On 12th July 1982 I became employed by the European Commission, Joint Research Centre, just two months after the 10 kW array on the roof of LEEE in Trevano became operational. My initial assignment was developing measurement equipment and test procedures for photovoltaic cells, modules and systems, as an accompanying measure to the first European Pilot Programme financed by the European Commission's Research Programme. However, as these pilot plants were still under construction, testing the newly developed measurement equipment for full-size systems would be quite difficult.

Here came the 10 kW array at TISO as a rescue: in autumn 1982 we made three measurement campaigns at TISO 10 kW in Trevano, which is only 50 km away (but could take a 3 hour drive, see below) and we were impressed of the availability of their staff, and here a particular thank you goes to the visionary Mario Camani. Measuring the TISO 10 kW plant meant that we had to rip apart their carefully wired array of 288 Arco Solar Modules, in order to access substrings and modules separately.

We were in very pioneering times in PV, not only did I blow up our whole, self-constructed data-acquisition system due to a dispute about grounding, we learned also the hard way that Switzerland was not in the European Union, and it has cost us a lot of time and money to bring our equipment through customs at the border in Ponte Tresa. Not only there… also, through the customs at JRC Ispra, as this Euratom European research centre was extraterritorial to Italy (and still is). Meanwhile we know precisely what a "Carnet ATA" is. Finally, the equipment worked perfectly, we could precisely measure the "Peak Power" of the plant (slightly above 10 kWp) and were in December on our way to Crete for the measurement of the first European PV plant.

The researchers at TISO were keen on a follow-up of the PV performance, and what followed was a collaboration over many years where the TISO people regularly every year measured 8 modules taken out from the array at the ESTI lab in Ispra with a solar simulator. They learned about the Carnet-ATA too, I guess…

From our side, we soon included the TISO 10 kW plant into our European PV-plant Monitoring Programme and could provide them with monthly and yearly reports about the performance of the system. Today it is evident that the success of measuring 15 pilot PV plants across the European Union would not have been possible without our early collaboration with TISO. Altogether, it turned out that this very first, grid-connected PV system in Europe was the best monitored and measured system we had in our files. From the data it appeared, that the plant only slowly lost power in the years, but it wasn't known quantitatively, more were the failure modes known. We had the impression the lifetime could go well beyond the then assumed 20 years. As TISO had in addition to the module and system monitoring data a very nice logbook of exchanged modules, we could embark 1997 together on a research project, giving it the title "Mean Time Between Failure". The remarkable results have been published in 2001 [1] and are still today quoted as the first well documented analysis that PV systems will operate even 40 to 50 years, before power decreases to 50% of the initial value.

The TISO 10 kW plant had not only technical value for us, the co-operation between JRC Ispra and then SUPSI continued to last, in a very unique way: many of ESTI staff which had only a non-renewable contract have been seconded to SUPSI, they brought a broad understanding of PV from JRC and continued to learn at SUPSI professional management of projects, and deeper involvement into the Swiss R&D programmes. Names which come into my mind include Gabi Friesen, Antonella Realini, Alessandro Virtuani, Diego Pavanello, … to name just a few. A big thanks also to Domenico Chianese who always kept contact with us at the JRC in Italy.

However, my personal contacts to SUPSI remained alive even after I retired end of 2017. I had the honour to give on behalf of ETA Florence a contribution to their latest Project Proposal for European funding. I do wish that this project is successful in receiving funding, as it will give me the pleasure to work with SUPSI and Francesco Frontini and his team even in the next years. What could be a measure of success of TISO is checking with Google Earth how many grid-connected PV plants are today within close distance of the TISO 10 kW plant! I wish SUPSI continued success for their visions and want to express my gratitude for staying close the last 40 years.

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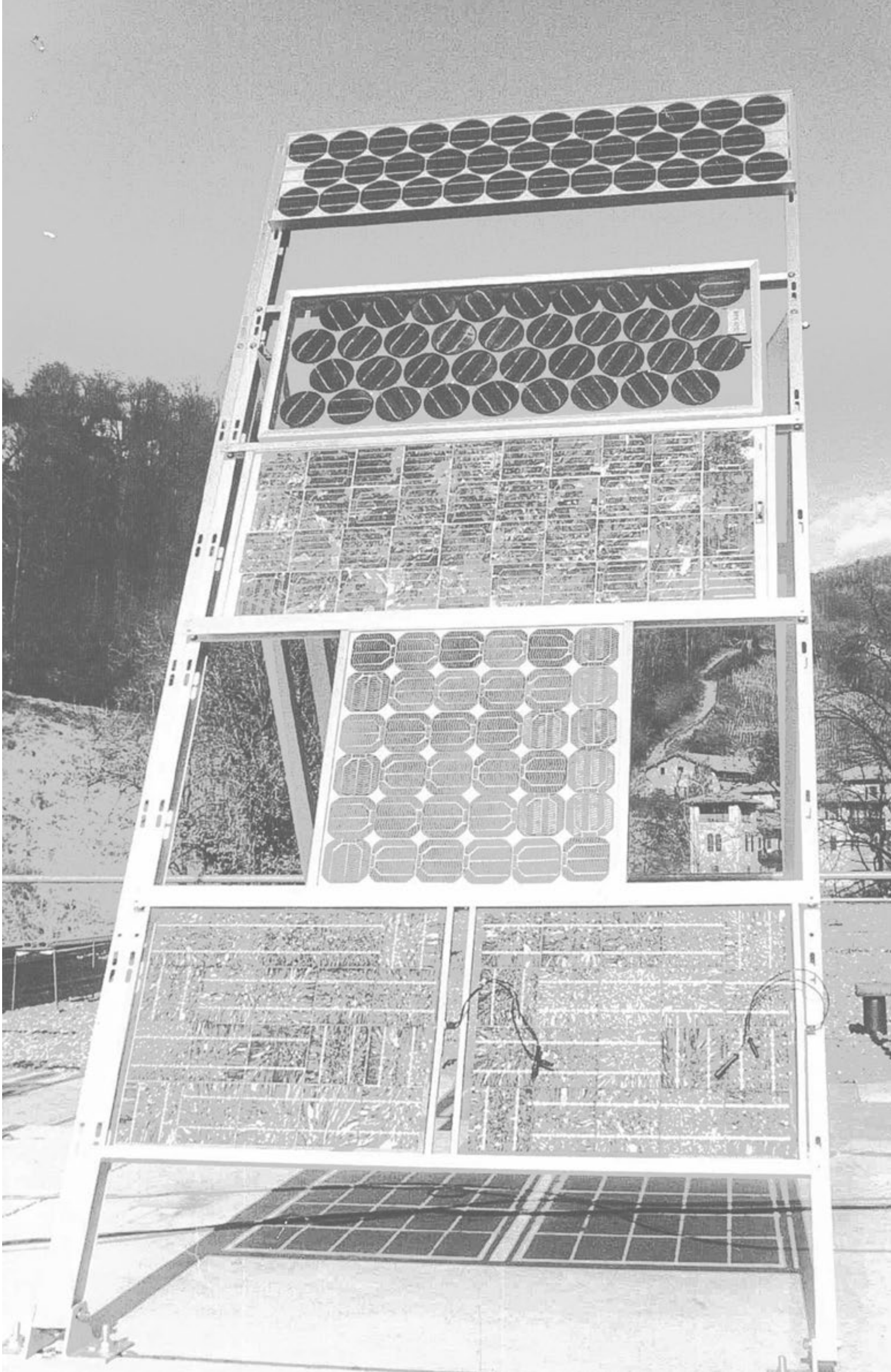


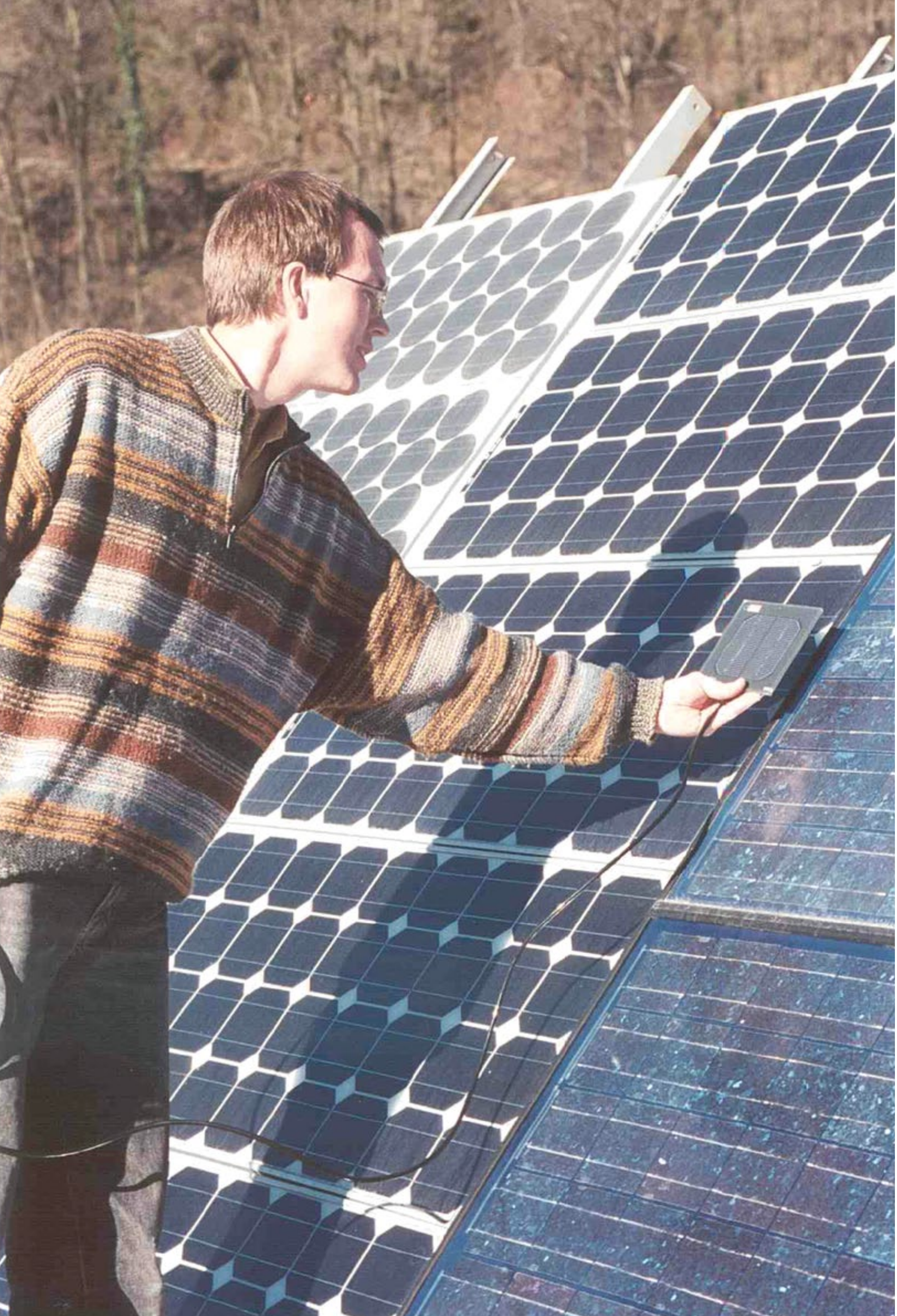
Fig. 01 ON THE PREVIOUS PAGE. TISO - Outdoor stand for the selection of modules (1981) ©SUPSI
Fig. 02 TISO - First control room, with inverter and monitoring system ©SUPSI

Fig. 03 TISO - First configuration of the 288 modules (1982) ©SUPSI

Fig. 04 R&D Outdoor test facility (1991) - TISO research group ©SUPSI

Fig. 05 LEFT. TISO - Inspection of the Ecopower inverter (1992) ©SUPSI
Fig. 06 TISO - Configuration in 1995 ©SUPSI

Fig. 07 Outdoor test stand (1995) - TISO research group ©SUPSI
Fig. 08 RIGHT. Domenico Chianese at the outdoor test stand (1997) - TISO research group ©SUPSI



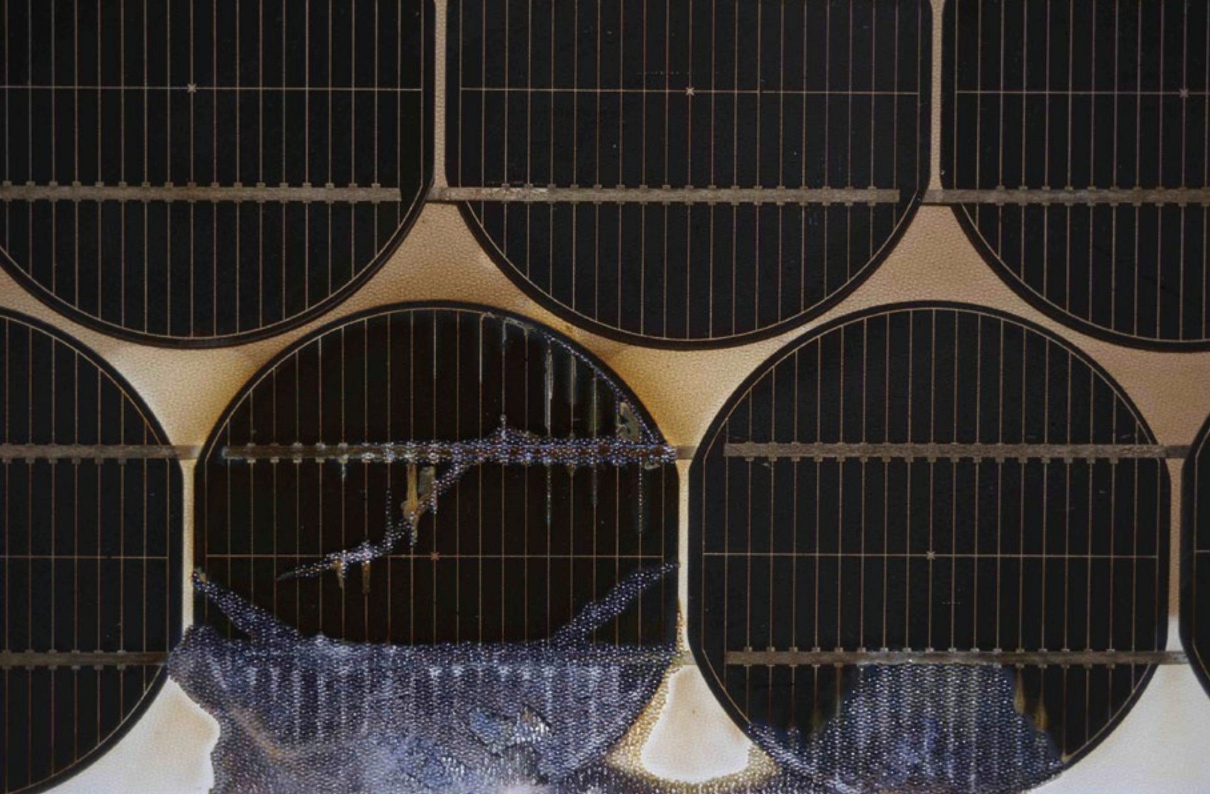
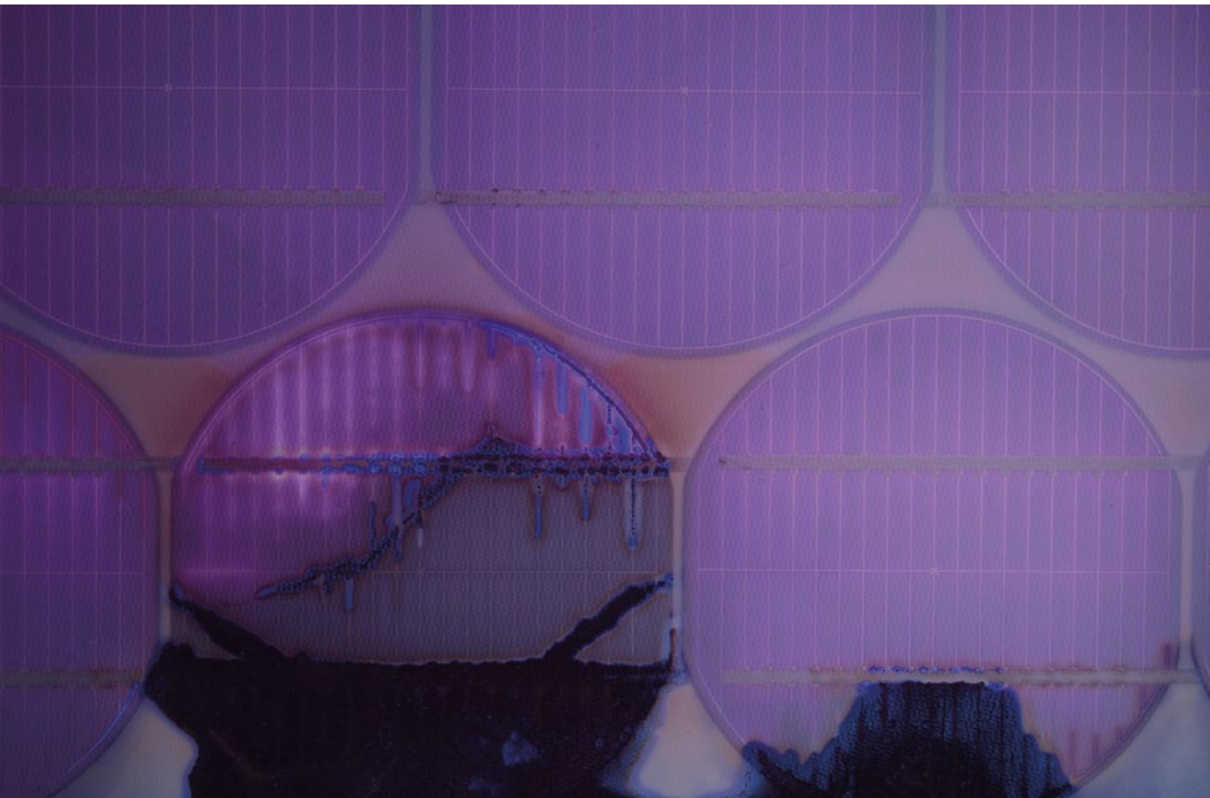


Fig. 09/10 TISO - Visual and multi-spectral image of a defected PV module ©SUPSI



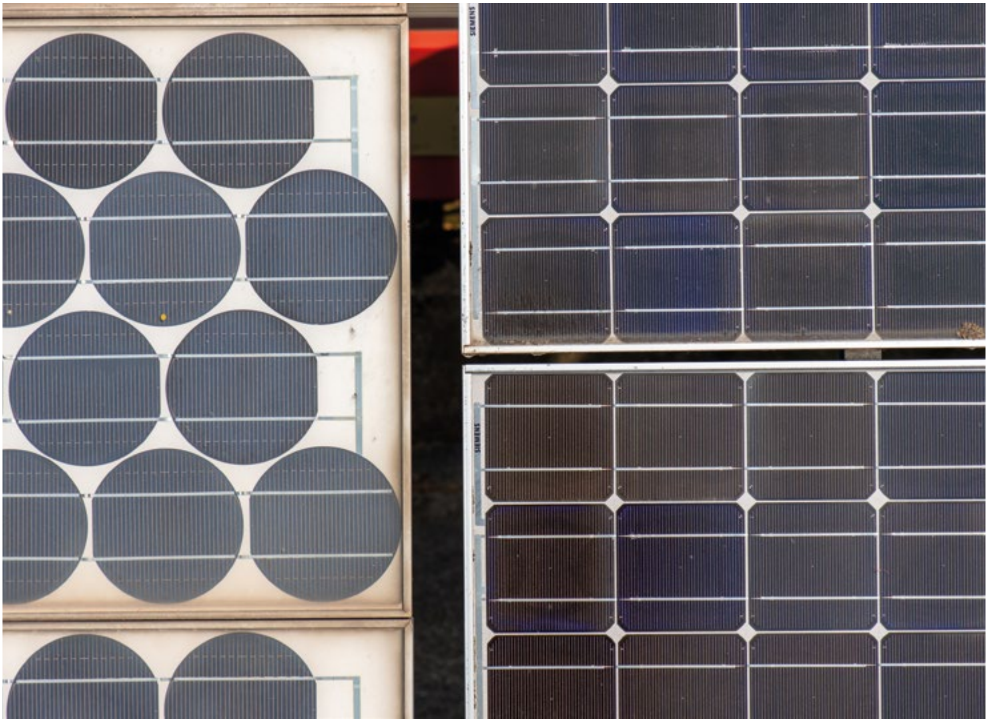


Fig. 11 Different technologies tested at the outdoor test stand (1990) - TISO research group ©SUPSI
Fig. 12 RIGHT. TISO - Configuration of the PV plant in 2005 ©SUPSI

Fig. 13 TISO - panoramic picture of the 288 modules in the last configuration.
The different classes of modules are well recognised from their colours ©SUPSI

Fig. 14 TISO - Detail of the fifth configuration of the PV plant ©SUPSI

Photovoltaics: from niche product to main source of the energy system

TEXTUAL INTERVENTIONS BY

STEFAN NOWAK [PP. 57-58] ; CHRISTOPHE BALLIF [PP. 59-63] ; STEFAN OBERHOLZER [PP. 64-66]

Author	Article
Stefan Nowak	History of PV (from 1980 until now); IEA PVPS

Stefan Nowak is an experimental physicist by training with a PhD from Fribourg University and EPFL, Switzerland. His academic research activities covered thermonuclear fusion, plasma and surface physics as well as thin films. In 1997, Stefan founded NET Ltd., a consultancy in renewable energy, energy efficiency and environment. Stefan has held various positions on a national and international level. He was manager of the photovoltaic research programme for the Swiss Federal Office of Energy from 1993 to 2019 and Chairman of the Photovoltaic Power Systems Programme of the International Energy Agency (IEA PVPS) from 2001 to 2021. Beyond PV, Stefan substantially contributed to the Swiss interdepartmental REPIC platform on renewable energy, energy and resource efficiency in international cooperation. Stefan has worked as an expert for various agencies, such as Innosuisse, the European Commission (DG Research/DG TREN), the IEA and various national research agencies across the world. In 2017, Stefan Nowak received the European Becquerel Prize in honour of his merits in integrating photovoltaic electricity into the future global sustainable energy system.

Christophe Ballif	Technology evolution in photovoltaics

Prof. Christophe Ballif is director of the Photovoltaics and Thin-Film Electronics Laboratory @ EPFL and of the Sustainable Energy Center @CSEM and, which specializes in research and technology transfer along the value chain of photovoltaics and energy systems. With his teams, he has contributed to numerous innovations, products and start-up in the field of photovoltaics and energy (PV) and collaborates with close to 40 companies in Switzerland and worldwide.
His current research and industrialization interests include materials and manufacturing processes for PV, high-efficiency crystalline and tandem perovskite/silicon solar cells, module technology and reliability, specialty PV products for building integration or mobility, as well as all aspects linked to storage and management of energy systems. He is (co-) author of more than 600 scientific papers and of numerous patents. In 2016, he received the Becquerel award for his contribution to the field of Photovoltaics. He is an elected member of the Swiss Academy of Engineering Sciences.

Stefan Oberholzer	Photovoltaics in the overall energy system

Stefan Oberholzer has been working at the Swiss Federal Office of Energy (SFOE) since 2008 and is responsible for the SFOE research programmes on photovoltaics and hydrogen. He represents Switzerland in various international research bodies, such as the IEA Photovoltaics Programme (IEA PVPS) and the International Partnership for Hydrogen and Fuel Cells in the Economy. He holds a PhD in physics and has held various academic positions in Switzerland and abroad for around 10 years, as well as a short-term industrial position.

STEFAN NOWAK

General introduction - history of PV (from 1980 until now); IEA PVPS

Let us try to put TISO's remarkable early efforts in the photovoltaic field into a historical perspective. Following the discovery and various demonstrations of possible applications of silicon solar cells starting in 1954, the initial real use of photovoltaics was to power the very first terrestrial satellites in 1958. With the subsequent possibility to bring electric power to remote locations, off-grid systems gradually emerged in the 1970s as commercial and economically viable applications, opening up broader markets. On the other side, deemed as hardly ever commercially viable and competitive with costs of electricity from the grid, the first grid connected photovoltaic power systems were realized in the 1980s – among which the TISO plant in 1982. TISO's 10 kW grid connected PV system of that time is considered by many as the first grid connected PV system in Europe and certainly one of the most and longest monitored PV systems ever. Realising this very early attempt to demonstrate and showcase the applications of PV in spite of all scepticisms and critics marked an unpaired visionary and innovative approach of Mario Camani and his team.

Looking further, in the 1990s, many public and private initiatives were taken worldwide to demonstrate the large diversity of photovoltaic systems, from small scale off-grid to grid-connected on and integrated in buildings to "large scale" (MW) ground mounted systems. In 1999, the global annual installed capacity had reached more than 100 MW. When the Photovoltaic Technology Collaboration Programme of the International Energy Agency, IEA PVPS, was conceived in 1992, a "diffusion model" was introduced which schematically proposed how different photovoltaic applications could evolve over time. Retrospectively, this approach proved to be fairly descriptive of the actual development.

The changeover to the 21st century marked the start of mass manufacturing and deployment of photovoltaics for terrestrial applications. Pioneered by Germany, the concept of the feed-in tariff (FIT) was introduced in legislation (Erneuerbare Energie Gesetz EEG) in 2000, thereby providing a very effective market support scheme. The FIT was subsequently introduced in many countries in Europe (e.g. in Italy, Spain, France, Belgium, UK, Switzerland), in Asia (e.g. in China, Korea, Japan), in Australia and in the Americas (e.g. in the US, Ontario Province in Canada). In 2002, the total global installed capacity reached more than 1 GW, an important milestone in the photovoltaic market development. At the same time, there was heavy political debate about the right design of a sustainable FIT (or other) support scheme, with some countries having only short peaks of market growth, partially followed by market collapse, for example in European countries such as Spain, Italy, the Czech Republic, the UK or Greece. In spite of such unsustainable policy frameworks, the overall PV market continued to grow substantially over the past 20 years. Utility scale PV systems became larger and larger and have surpassed the GW mark, not imaginable just a few years before. Since the early 2000s, the worldwide photovoltaic market has rapidly grown to reach roughly 140 GW of annual installed capacity in 2021 and surpassed 1 TW of total installed capacity in early 2022. In 2016, for the first time, photovoltaics accounted for the largest capacity increase of all energy technologies (when retirements of fossil power systems are counted in). Over time, driven by policy and economics, the market shifted gradually from mostly off-grid to mostly on-grid. More recently, through growing applications such as floating PV, agri-PV or vehicle integrated PV, the term "PV everywhere" has emerged.

Summarizing, it took more than 40 years of development (about 1960 to 2000) to reach the first GW of installed PV capacity. The next 20 years (2000 to 2020) have, however, brought photovoltaics from a negligible contribution (below 0.01%) to a relevant role (close to 5% in 2022) in the world's electricity supply, entering the TW era in the present decade. The initiative of TISO 10 kW and its first grid connected PV power system 40 years ago proved to be a remarkable milestone in the development of PV.

The rapid growth of installed PV capacity worldwide was accompanied by an unprecedented cost reduction of PV modules and systems which was by far greater than anticipated by many experts, in particular over the past decade. For PV modules, the historical learning rate has for a long time been estimated to be around 20% (20% cost reduction per doubled cumulative production). More recently, over the past decade, cost reduction has been even higher, resulting in present PV module prices around 0.2 – 0.3 US$/W, down from about 100 US$/W in the early 1970s. TISO's 40-year anniversary thus also highlights the enormous cost progress made over its lifetime, bringing PV solar electricity from exceptionally expensive to the cheapest source of electricity in many regions of the world.

CHRISTOPHE BALLIF

Technology evolution in photovoltaics

The TISO 10 kW power plant, built 40 years ago, offers an excellent illustration of technology evolution: it used, 37W, 10% ARCO Solar monocrystalline modules based on round 4 inches solar cells, purchased at 20.8 CHF/W (in 2022 equivalent ~ 35 CHF/W). ARCO was, in the early eighties, one of the first companies to exceed 1 MW annual production capacity. In 2022, the mainstream solar industry is bringing to the market mono-crystalline modules with 20-22% efficiency at around 1/100th of the price, in manufacturing lines of several GW annual production capacity[1]. Those modules also come with much less material usage per Watt (around 3g of silicon per W against around 15g, twenty years ago) and much less grey energy, ensuring full system energy payback time in the range of one year in central European climate.

Historically, there has been competition between three major classes of solar cell technologies to gain market share:

- In *thin-film solar* cells, thin layers of semiconductors (typically 0.1 to 5 µm thick) are deposited directly onto glass substrates, or on foils. Examples of materials used are CdTe, Cu(In,Ga)Se2 (CIGS), and amorphous silicon (a-Si). Between the processing steps, the deposited layers are usually patterned and interconnected into solar cells by conductive layers, in a process called monolithic integration. The market share of thin films reached close to 20% in 2009, during a high pricing period for polysilicon. The cost reduction and efficiency increase in c-Si have driven out of the market most of the thin film mass manufacturers, with the exception of CdTe which still represents around 5% of the market. CIGS and a-Si do retain a role for consumer or specialty flexible PV applications.

- The *III-V based multi-junction* solar cells were originally developed for space applications. The cells are grown epitaxially on crystalline wafers (Ge or GaAs) and can reach efficiencies over 39% in the laboratory (and 47% under concentration). As they are costly (by a factor of 1000 per W compared to Si), concentrated photovoltaics (CPV) needs to be used for terrestrial applications. Despite high efficiencies, cost and system aspects (needs for light focusing and accurate sun tracking, soiling issues) have not allowed CPV to gain sizeable market shares.
- Finally *crystalline silicon* solar cells (c-Si), which are based on silicon wafers cut from ingots. The wafers, which are now typically 140 to 180 µm thick, are processed into solar cells; the latter are then interconnected by soldering before they are packaged into modules. In 2021, c-Si made for more than 95% of all shipped solar modules. The average efficiency of mainstream Si modules has followed a steady improvement over the last 20 years, of around 0.4-05% annual absolute efficiency increase, as illustrated in Fig. 15. It is foreseen that c-Si will dominate the PV market for the next decade at least.

The challenges to bring c-Si to low-cost, efficient products have been numerous all along the value chain: those included:

- Developing the materials, mass production tools and processes allowing a transfer from laboratory results to mass productions, and increasing steadily the throughput of all the process steps.
- Reducing the material usage (mostly) Si, Ag and reducing the energy consumption in all manufacturing steps, in particular in the energy intensive polysilicon manufacturing.
- Further increasing efficiency to keep up with competition, as well as to reduce the other costs per W: glass, frame, encapsulant, junction box, interconnects, as well as the area related installation costs.

The past module efficiency gains, illustrated in Fig.15, can be understood as following: from around 2004 to 2017, the markets grew with the so-called Aluminum back-surface field (Al-BSF) solar cell where Al directly contacts the full rear-side of the silicon cells.

A continuous improvement of all manufacturing processes took place (better front surface passivation with SiNx, diffusion, screen-printing pastes, narrower lines), as well as better Si material quality (e.g. using high-performance multi-crystalline silicon wafers).

Since 2017, the market has shifted to an advanced cell structure, by adding at the rear side a thin layer stack of aluminum oxide and silicon nitride, and by creating contacts with Al only locally. This so-called PERC (Passivated Emitter and Rear Contact) cell had already been proposed in 1989[2] but required much effort of researchers, equipment manufacturers and industry to be turned into a low cost technology. It allows for higher efficiency than Al-BSF, and even higher efficiency with monocrystalline Si, which is leading to the fast disappearance of multi-crystalline Si. This effect has been reinforced by the industry shift to diamond wire sawing, reducing strongly the kerf losses (from 200 to 60 microns) associated to the wafer cutting processes, and making, jointly with improvements in crystal pulling, monocrystalline Si a mainstream material. In the last 5 years, the designs of the modules have started to evolve drastically: first by moving to more interconnecting ribbons (5, 9 12 busbars or even multi-wires) to reduce Ag costs, then by cutting the solar cells in two or three (or even by shingling ¼ or 1/6) to reduce the ohmic and optical losses of the interconnects. Finally larger cells (up to 210x210 mm2 cut in two or three parts) and larger modules, help reduce both the cell electrical edge losses and the module inactive edge areas, further contributing to module efficiency increase.

The PERC concept, which still relies on direct metal contacts to silicon, is limiting the solar cell voltage to around 680-700 mV. To go higher in voltage and efficiency, two major options are followed: first, the use of high temperature passivating contacts (now often referred to as TOPCON), where a thin “tunnel” SiO2 layers is covered by a polysilicon layers at the rear of the solar cells in a new standard industrial approach. And second the silicon heterojunction solar cell (SHJ), where thin layers of amorphous silicon, capped by transparent conductive oxides, provide near ideal surface passivation of the silicon cells, with the highest achievable open-circuit voltage in the range of 740-750 mV. Although the concepts had been demonstrated for a long time, equipment and processes are now available to make these technologies become more ubiquitous. Large capacity increases are announced for the TOPCON technologies worldwide, and to a lesser extent for SHJ, for which several new GW of manufacturing for cells and modules are now been ramped up in Europe by companies such as Meyer Burger or Enel. TOPCON and SHJ marries ideally n-type wafer polarity (against p-type for PERC) and are thus expected to gain market share over PERC during the next decade, thanks to a module efficiency gain of 1 to 1.5% absolute. Further variations of these technologies exist, for instance, with all contacts at the back of the solar cells in the so-called IBC configuration (Interdigitated back-contacted design, as pioneered industrially by Sunpower). Such cell structures, combined with SHJ contacts allowed so far record cells for c-Si (26.7% by Kaneka) and one-cell module laminates (24.7% by Meyer Burger and CSEM).

All these approaches combined with mass manufacturing experience should bring the average module efficiency into the range of 23.5-24% by 2030 (for cells between 25 and 26%). Noticeably, increasing the efficiency also comes with challenges in terms of reliability: modern solar cells rely more and more on surface electronic passivation as well as on an extremely high Si material quality. Both cell and module materials need to be adapted and heavily tested, to ensure long module lifetimes, as the cells tend to be more sensitive to intrinsic (e.g. light induced defects) and extrinsic defects (e.g. sodium migration from the glass) compared to those made 40 years ago.

Silicon solar cells are, from their material parameters, limited to ~29.5% efficiency and reaching 25-26% cells on average in production will be a huge challenge. Going beyond that, will most likely require switching to tandem or multi-junction devices. So far the only approach which seems compatible both with cost and increased efficiency is based on combining silicon and perovskite solar cells. The latest can use the high energy part of the solar spectrum more efficiently than silicon (with voltages over 1.25 V). The team of PV-lab at EPFL, supported by CSEM, has indeed just announced a new certified efficiency of 31.25% for such a laboratory solar cell, breaking for the first time the 30% barrier for tandem Perovskite/silicon solar cells. Perovskites come with amazing semiconductor properties but also challenges linked to stability. Making fully reliable modules, able to survive as long and as good as the TISO 10 kw plant [3-4], will still require strong efforts in science, research, development and industrialization.

Fig. 15 Past and expected average efficiency of c-Si modules manufactured (n.b. note best efficiency). Adapted from Nature Review Materials [1].

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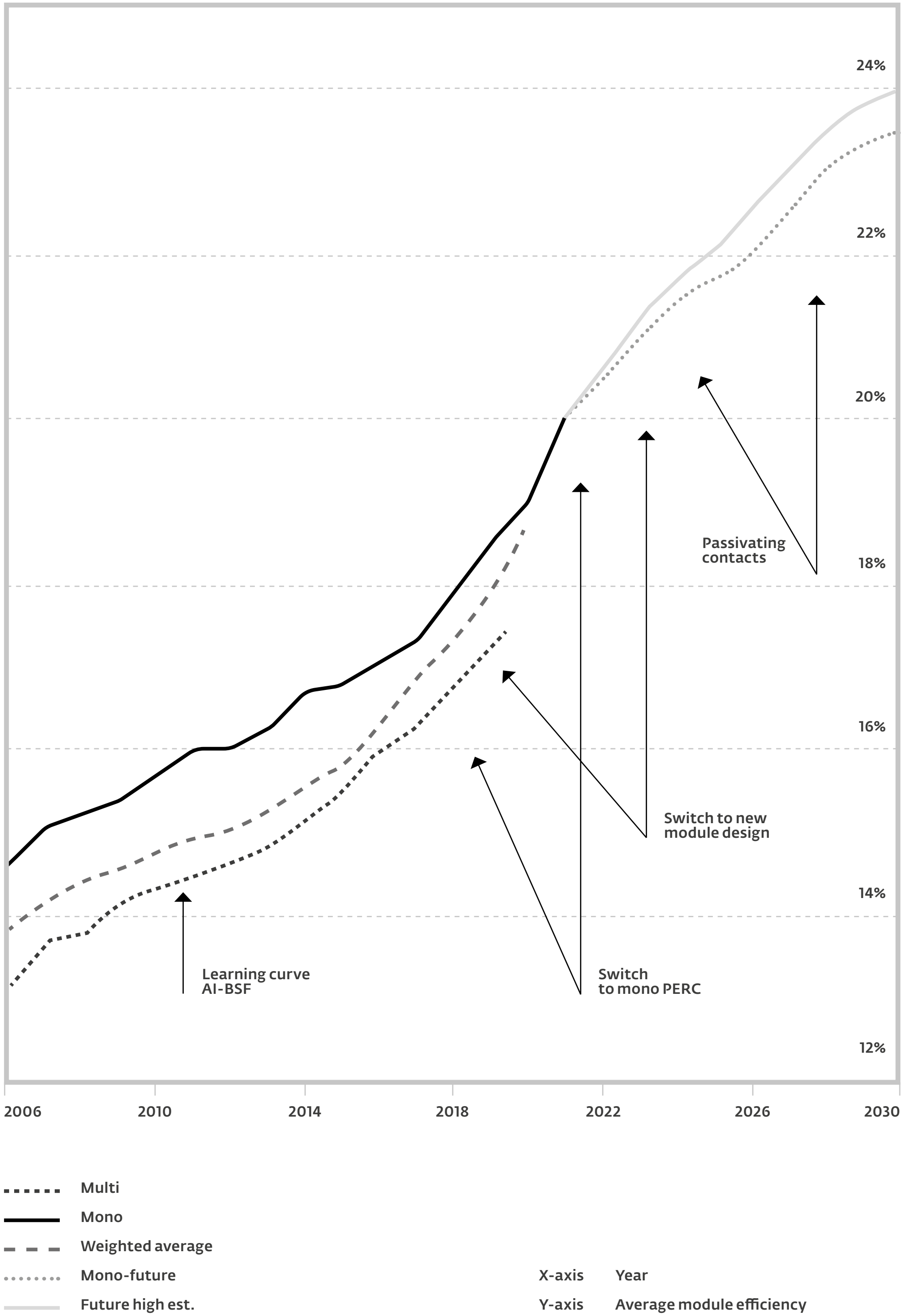

24%
22%
20%
18%
16%
14%
12%
Passivating contacts
Switch to new module design
Learning curve Al-BSF
Switch to mono PERC
2006
2010
2014
2018
2022
2026
2030
Multi
Mono
Weighted average
Mono-future
Future high est.
X-axis Year
Y-axis Average module efficiency

STEFAN OBERHOLZER

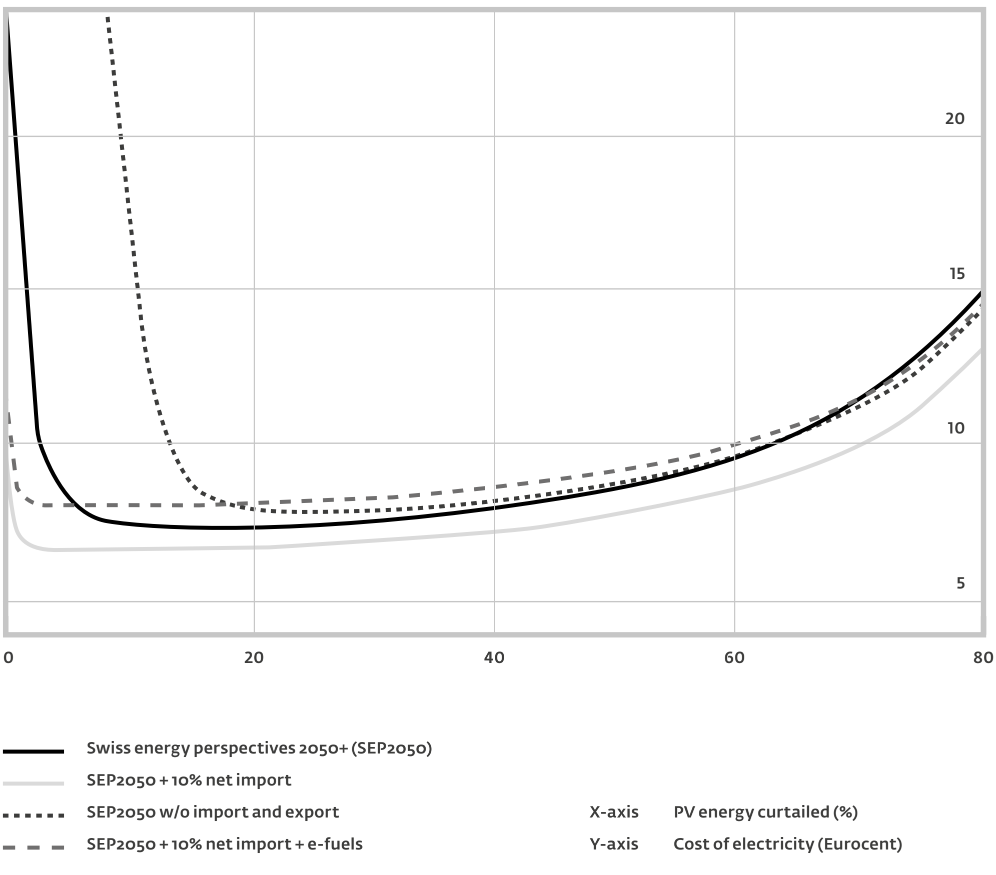
Photovoltaics in the overall energy system

According to the International Energy Agency (IEA), 37% of the world's final energy is consumed in the form of oil, 16% in the form of natural gas, 10% in the form of coal and 22% in the form of electricity [1]. Today, still more than 60% of the electricity sector is based on the use of fossil energy resources. These figures show the great global potential of renewable power generation from photovoltaic energy generation to replace the consumption of fossil sources in the final energy use. However, according to the IEA, electricity demand is currently growing at 5% per year, and only about half of this growth is being met by the addition of renewable power generation capacity [2].

The systemic benefit of photovoltaic electricity is repeatedly called into question on the grounds of a (too) low capacity factor, seasonal and diurnal production differences, grid bottlenecks with large installed capacities and enormously high storage requirements. In a recently published paper, for example, it was questioned whether the electricity contribution from today's nuclear power plants in Switzerland could be replaced to a large extent by domestic photovoltaic electricity in the long term (by 2050) [3], as outlined in the “Swiss Energy Perspectives 2050+”[4].

Interestingly, just recently another research study was presented that examined in detail how much and, above all, at what cost electricity from photovoltaics in Switzerland can contribute to the Swiss electricity supply in combination with flexible production from hydropower and a certain amount of battery storage [5]. This work is about "Firm PV Power", referring to photovoltaic power that is guaranteed to be available all year round, either directly produced and used or as temporarily stored electricity. Taking into account the flexible hydropower resources in Switzerland, the optimal PV/battery configurations were analysed to meet the country's growing electricity demand for every hour of the year at the lowest possible cost, nota bene, without using nuclear power. Since storing electricity is more expensive than producing it with solar PV, there is an optimum between adding more storage and oversizing solar PV, where part of its production is not used directly and is curtailed.

Fig. 16 Modeled cost of electricity in Switzerland as a function of the amount of curtailed PV energy. Storage is expensive, so it pays off to curtail a certain amount of photovoltaic energy in the system. Depending on the scenario, the optimum lies between 10 and 25% (from [5]).



A similar study was recently conducted for the USA, with the conclusion that oversized solar PV (curtailement) could meet the bulk (50%) US energy demand firmly and affordably [6]. In the Swiss case, the lowest electricity costs in the range below 10 eurocents per kWh were presented in a 2050 scenario with 40 GW of PV combined with 15% curtailment, 15 GWh of battery storage, some net imports (10%), a slight increase in the hydropower contribution and increase in pumping capacity, and with an import of some synthetic fuels (see Figure 16).

Electricity from photovoltaics, while not used directly, can significantly contribute to areas of the energy system that are difficult to decarbonise, namely through the production of hydrogen (H2) via electrolysis from photovoltaic (and wind) electricity and, subsequently, other synthetic chemical energy carriers. In its 2019 report "The Future of Hydrogen" [7], the IEA highlighted that hydrogen from hybrid photovoltaic and wind plants could be produced at low cost (< 2 USD/kg H2) in many regions of the world. Today, with Europe in particular being concerned with replacing fossil natural gas as quickly as possible, not only for climate policy reasons but also for supply guarantee issues, these developments are gaining momentum. In early May 2022, representatives of European electrolysis manufacturers announced their intention to increase their production capacities for electrolysers in Europe tenfold to around 18 GW of electrolysis capacity per year by 2025. The build-up of these production capacities should make it possible to produce 10 million tonnes of renewable hydrogen per year in Europe by 2030. Particularly in Denmark, 5-6 GW of hydrogen projects are to be realised by 2030 with energy from wind power, of which around 10 % had already secured funding [8]. In other regions, larger solar PV-focused projects are underway, such as the Spanish HyDeal consortium, which intends to install solar PV farms with a total capacity of 9.5 gigawatts by 2030, powering 7.4 gigawatts of electrolyser capacity [9], or in Western Australia with planned GW plants for renewable hydrogen production with wind and photovoltaics.

In short, as the IEA stated in its World Energy Outlook 2020 [10], solar PV will become the "king" of power supply, and moreover a key input for other forms of energy.

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[2] International Energy Agency IEA, "Electricity Market Report" (2021)
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Reliability and durability testing today

TEXTUAL INTERVENTIONS BY
DIRK JORDAN & MAURO CACCIVIO [PP. 71-74]

Author	Article
Dirk Jordan	The progress towards long-lasting PV systems

Dr. Dirk Jordan has been at the National Renewable Energy Laboratory, USA for 13 years. He leads efforts in the reliability, performance and degradation of PV modules and systems. Previously, he worked as a materials scientist at Motorola from 2000 to 2008. He received a Ph.D. in physics from Arizona State University in 1999 and a B.S. in Physics from the University of Heidelberg in Germany.

Mauro Caccivio	The progress towards long-lasting PV systems

Mauro Caccivio got a Master degree in Electronics at Politecnico di Milano. He has been working in photovoltaics since 2002, first in the Leonardo group as project leader for the realization and testing of photovoltaic panels for space use, mainly for ESA scientific missions, then in Pramac Swiss, a PV manufacturer of amorphous silicon thin film double-junction modules, in the roles of product engineer, certification manager, and responsible for customer service. Since 2012 he has been working as a researcher at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), coordinating the research and service activities of the SUPSI PVLab with specific focus on testing and reliability of PV.

DIRK JORDAN
MAURO CACCIVIO

The progress towards long-lasting PV systems

There are important parallels between the Vanguard 1 satellite and the TISO 10 kW PV plant. Vanguard 1, launched in orbit in 1958, was the first satellite powered by photovoltaic cells, while TISO 10 kW was the first PV system connected to the electrical grid in Europe, in 1982.

Vanguard 1 is still in orbit today, qualifying itself as the oldest artificial object launched in space. Also, TISO 10 kW is still operating today, after 40 years, being thus the longest continuously running solar system in the world.

These two different and long-lasting objects share the same testing approach to prove and qualify their reliability: the accelerated testing procedures used for the qualification of satellites and their solar cells were used as basis for the qualification of terrestrial photovoltaics and, in both cases, they worked very well. Now the question is: with the increasing and rapid innovation in the photovoltaic industry, are the standard procedures sufficiently advanced to grant a reliable production of clean energy over forty years or more?

Dependable electricity delivery over such a long time period is vital not only for its economic success but also is a life-improving, life-saving necessity especially in times with more frequent extreme weather events. Because solar systems are exposed to various weather extremes, guaranteeing their functionality over many decades is challenging that few if any other consumer products approach.

Naturally, solar technology has also and will continue to evolve since the TISO 10 kW array was installed, however many important and useful lessons can be learned from this 40-year-old system.

TISO 10 kW system at various stages of ageing has provided insights into the degradation of PV modules, the slow gradual loss of some performance over time. Many financial models assume a linear decline, yet TISO 10 kW studies over the years demonstrated that the decline is nonlinear, the exact size and shape of the decline depending on the mechanism taking place inside the modules.

Examining the modules also provides information on the science of degradation that will depend on the exact of module components. The details of how a module is built, the bill-of-materials (BOM), has an important impact on field performance. Three different classes of modules differing slightly in the packaging, as shown in Fig. 17, were found, showing different stages of discoloration and power loss. Although caution is required because visual defects do not necessarily correlate with power loss. Some degradation modes are widespread but have minor impact on power production. Others are not very common but have a high impact on power and or safety.

Sometimes older technology has surprising similarities to more modern technology, e.g., the backsheets of the TISO 10 kW module contained a metal foil providing a seal that may be compared to more modern glass-glass modules.

Understanding these details and the interactions of various mechanisms will allow to successfully model and predict power loss in modules. More predictive tests are required because the common PV qualification test is very good in minimizing early-life failures but makes no attempt in lifetime prediction. More predictive tests can be applied to the rapidly changing module technology. Some of these tests currently in development combine stresses, as they are experienced in the field. Others use a sequence of tests to simulate the stresses experienced by modules in nature.

The possibility to accelerate in short times and proper way the aging of different materials will be an important instrument in the hands of the solar industry, leading to better products, adapted to the environmental conditions or typology of use, optimization of costs and a more uniform decrease of performances with time.

These tests should also be extended to include systems components because module and system degradation can differ, as shown in Fig. 18. Recoverable losses such maintenance events, soiling or snow can lead to higher performance losses if not mitigated.

In summary, continuing to invest and understand the science of degradation and develop predictive testing will ensure long-term reliability that are keys to renewable energy both for cost and environmental impact.

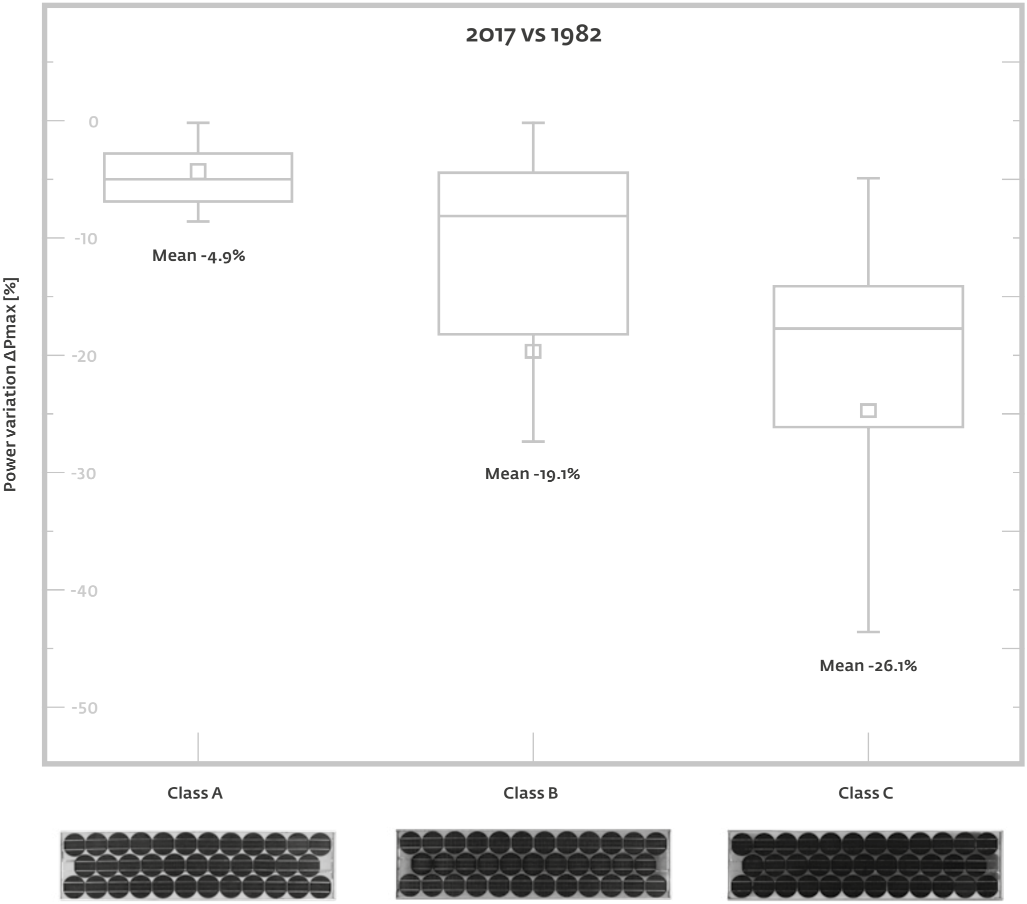
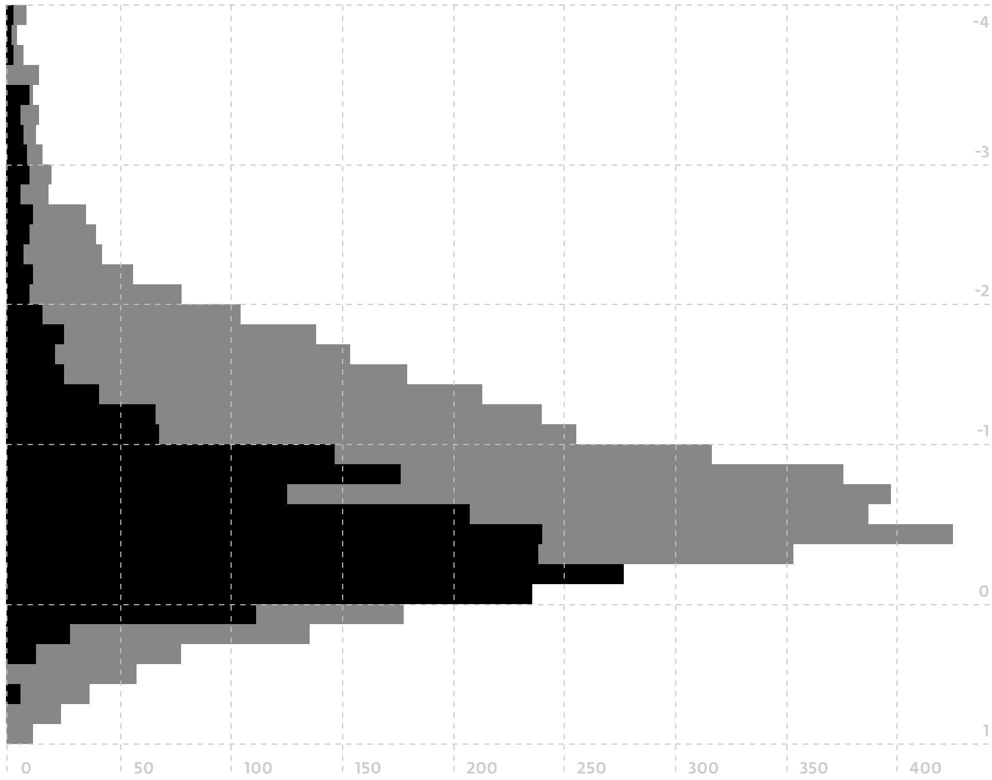


Fig. 17 Differently aged classes of modules and their impact on power loss.
Fig. 18 ON THE NEXT PAGE. Performance loss rates of modern systems (gray) and module degradation from the literature (black).



PV Fleet:
Median = -0.75 %year

N:
4915

Literature:
Median = 0.50 %/year

N:
2161

X-axis Frequency

Y-axis Performance loss rate (%/year)

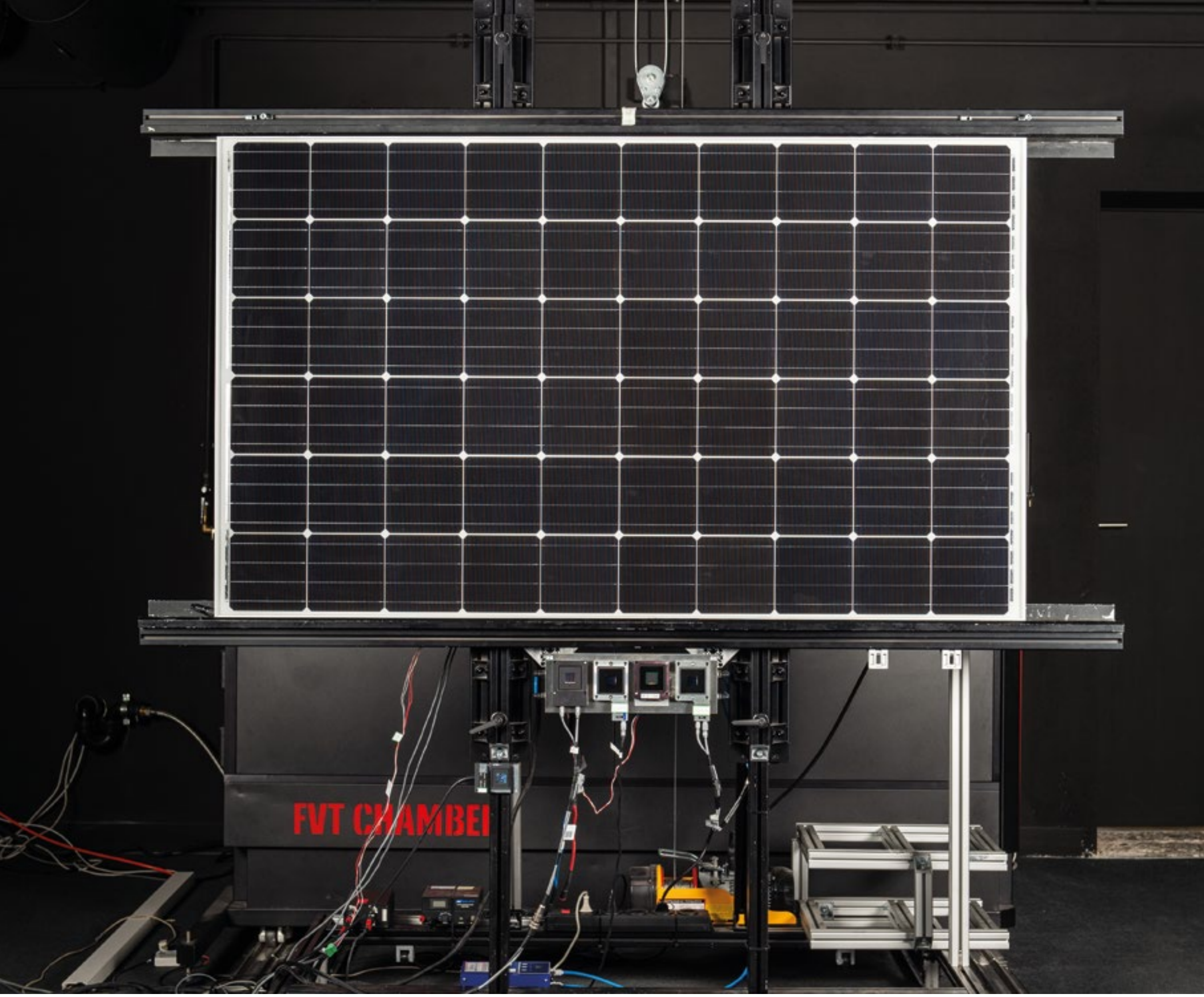


Fig. 19 SUPSI PVLab - Electrical performance measurement with Pasan 3B flasher ©SUPSI

Fig. 20 LEFT. SUPSI PVLab - Pasan 3B flasher for electrical characterization ©SUPSI
Fig. 21 SUPSI PVLab - Determination of temperature coefficients ©SUPSI

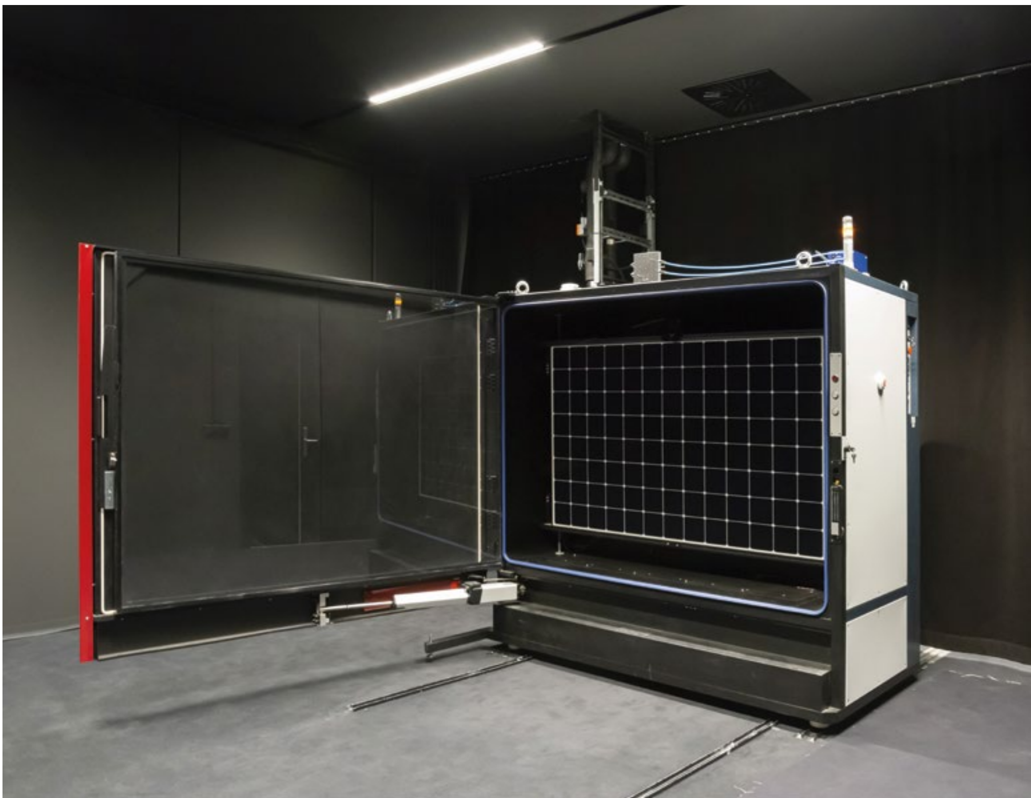


Fig. 22 SUPSI PVLab - Insulation test ©SUPSI
Fig. 23 RIGHT. SUPSI PVLab - Visual inspection with the use of a portable high magnification microscope ©SUPSI

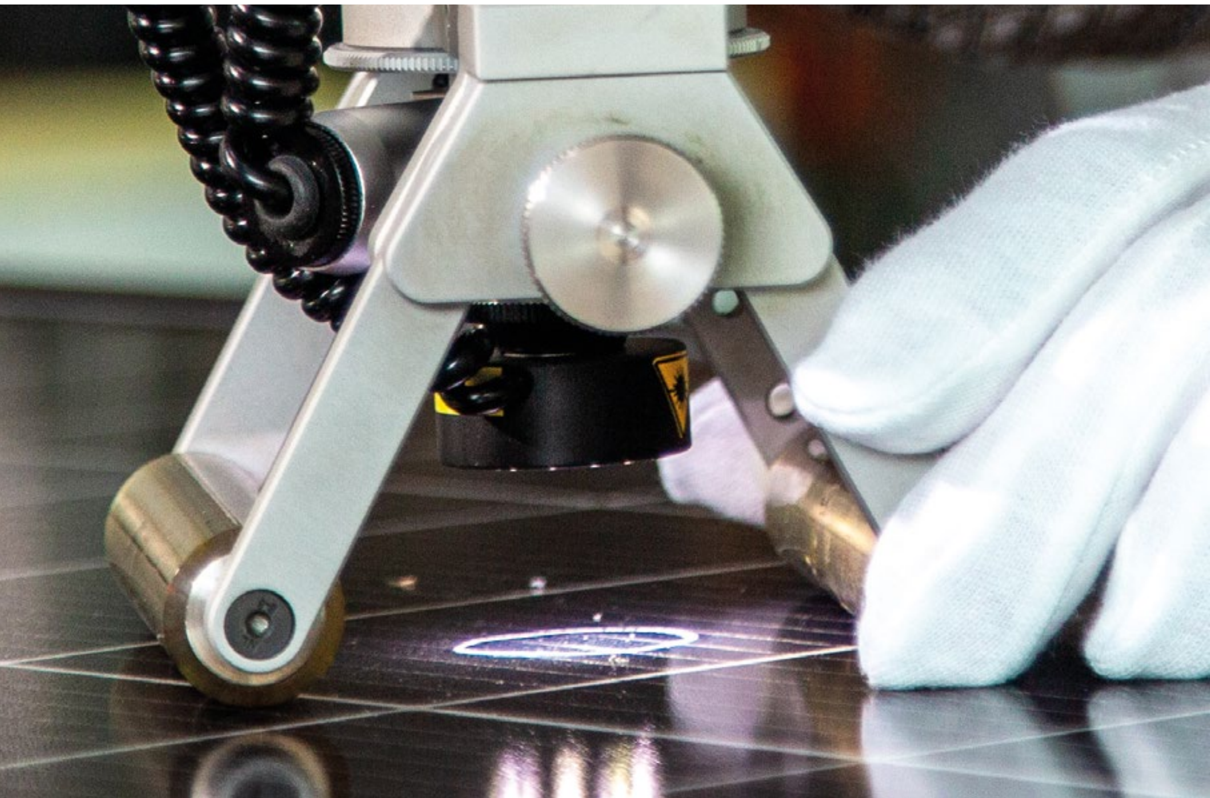
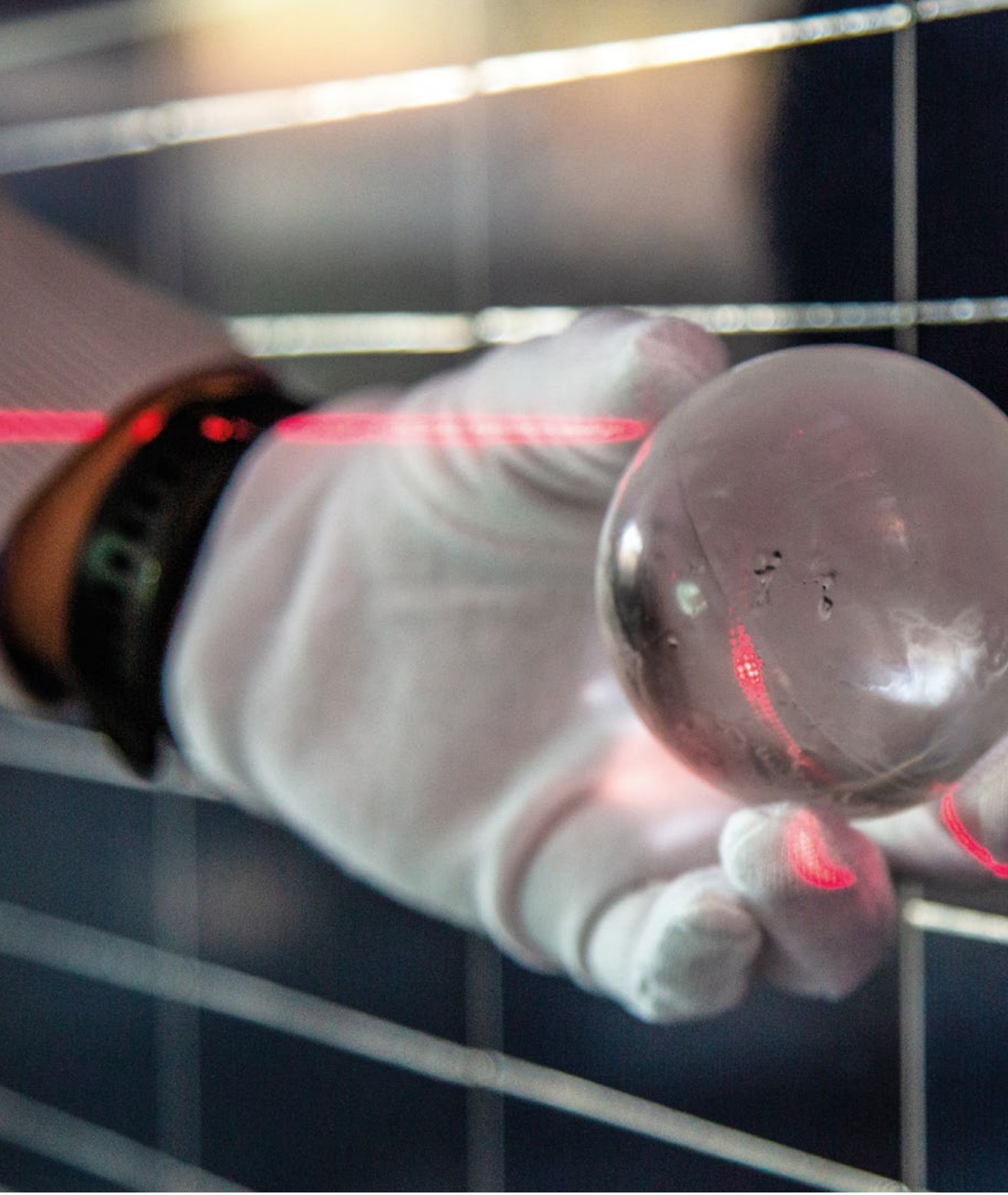


Fig. 24 SUPSI PVLab - Stabilization of a PV module under the light soak bench ©SUPSI
Fig. 25 RIGHT. SUPSI PVLab - Accelerated testing in the UV chamber ©SUPSI



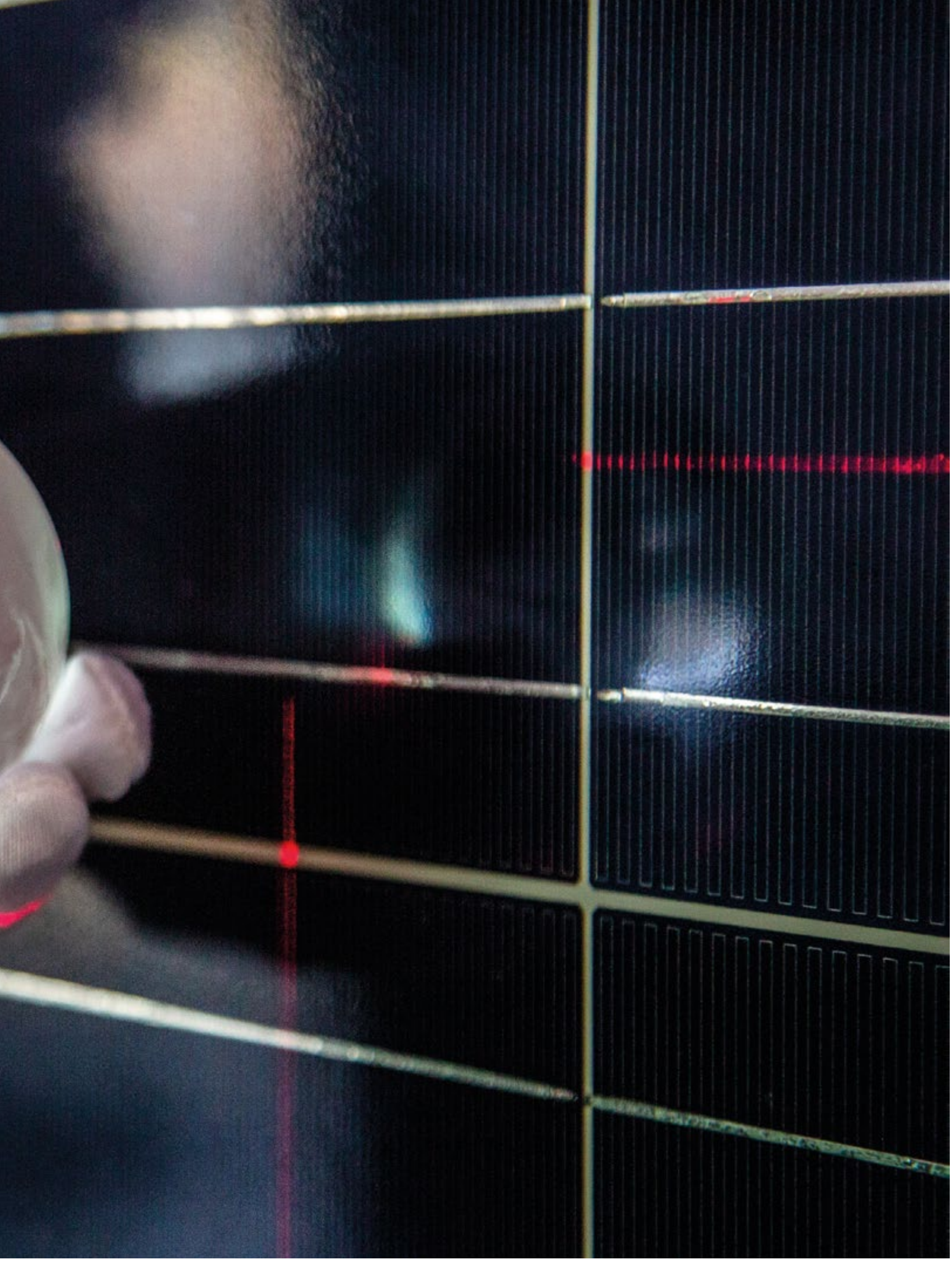


Fig. 26 SUPSI PVLab - Large diameter hail testing ©SUPSI

Fig. 27 SUPSI PVLab - Hail test: loading of the hailstone and target placement ©SUPSI
Fig. 28 BELOW. SUPSI PVLab - Module breakage test ©SUPSI

The European photovoltaic industry

TEXTUAL INTERVENTIONS BY

GUNTER ERFURT [PP. 89-90] ; FABRIZIO BIZZARRI [PP. 91-96]

Author | Article

Gunter Erfurt

Meyer Burger: the switch from technology supplier to module manufacturer, the strategic choice to produce in Europe

Gunter Erfurt has been CEO and a member of the Executive Board of Meyer Burger Technology Ltd since April 2020. Erfurt, who holds a doctorate degree in physics, has been active in the photovoltaic industry for more than 20 years. He also serves as a board member of Solar Power Europe and the German Solar Industry Association. He is on the Scientific Advisory Board of the Institute for Solar Energy Research (ISFH) and on the Board of Trustees of the Fraunhofer Institute for Electron Beam and Plasma Technology in Dresden.

Fabrizio Bizzarri

ENEL Green Power: solar energy supplier and module manufacturer

Fabrizio Bizzarri is Head of Solar Innovation at ENEL Green Power. He is an electrical engineer involved in the PV sector since the beginning of the new millennium, actively working in the construction of earlier PV plants and following the boom of installations in Italy. He has a long standing experience of more than 25 years in the engineering and construction activities and he is extremely active in the R&D field launching many financed projects. He launched the first department in Enel dedicated to innovation and a new approach to PV installation as well, sponsoring – among other initiatives – the construction of the first bifacial HJT factory in the world to produce cells and modules at industrial scale. He is responsible in Enel Green Power for the Solar Innovation, managing the solar R&D (of the PV factory and PV value chain) and the Enel Innovation LAB/HUB with more than 15 laboratories accredited dedicated to startups and where Enel makes experimentation of new projects, ideas and accelerates innovative companies.

GUNTER ERFURT

Meyer Burger: the switch from technology supplier to module manufacturer, the strategic choice to produce in Europe

What a great coincidence that the EU Solar Strategy was launched exactly the same day when Meyer Burger celebrated its first anniversary of restarting PV production in Europe. On May 18, 2021 the new cell fab in the Solar Valley of Saxony-Anhalt was opened up. On May 18, 2022 the European Commission published the REPowerEU package, including an ambitious set of targets for Europe and the expansion of renewables – especially photovoltaics. So the PV production of Meyer Burger in Germany as well as the Solar Strategy of the European Commission in Brussels mark the beginning of a new era of clean energy technology.

We can only applaud these ambitious plans. In addition, we can assure that Meyer Burger and the solar industry are ready to increase capacities and are glad that these goals are being supported with the needed sense of urgency. In order to fully support energy transition, Europe needs to quickly create optimal conditions for domestic photovoltaic production in Europe. This means unleashing investments to rapidly scale up the industry and a decisive strategy that supports manufacturers – with a special focus on reshoring European value chains. For just over a year, Meyer Burger has been manufacturing successfully in Europe and now even scales up its solar production – with truly sustainable products, focusing on premium materials, maximum recyclability, resource-conserving production processes, reliable and transparent supply chains, and optimised transport distances towards a green, save and climate-friendly future. How did we get there? Two years ago, we set out to transform ourselves from a global leader in machinery manufacturing and technology development for the solar industry to a leading module manufacturer. Today, we can proudly report that we have achieved this ambitious goal. Our new business model has been proven to function. The technologies developed at Meyer Burger in Switzerland and the production systems for solar cells and modules built in Germany have been put into operation in early summer 2021. At the same time, we established all supply chains and set up our new sales organizations. We have also started setting up our U.S. business, where we are planning to set up a module production facility in Arizona.

As it has been for the last decade, we manufacture our innovative PV production systems at the Meyer Burger site in Hohenstein-Ernstthal, Germany, a small town on the outskirts of the Ore Mountains in Saxony. In the so called "Solar Valley" in Thalheim (City of Bitterfeld-Wolfen, Germany), the cradle of the global PV manufacturing industry, Meyer Burger's new solar cell production is located. The almost 27,000 sqm hall was used for PV production at the time of the solar boom starting in 2005. We have brought it back to life, equipped with 400 MW of cell capacity, which is now being expanded to reach 1.4 Gigawatt of capacity. The cells produced in Thalheim are an essential intermediate step in the PV production process. Many hundreds of thousands are being produced in a fully continuous production 24/7 and afterwards are transported to Freiberg in Saxony. There, production of the solar modules takes place in Europe's largest and most modern module factory which was acquired by Meyer Burger in 2020. Almost 400 new employees were hired at the two production sites last year, and nearly 2,000 hours of qualification and further training were carried out to get PV production up and running again. Several thousand modules roll off the production line in Freiberg every day, where they alternate between white and black back sheet modules and glass-glass modules on a weekly or monthly basis. Alongside ongoing 24/7 manufacturing, production capacity is being expanded simultaneously. Some of the machines, in particular the core components of the Swiss made SmartWire technology are manufactured in Hohenstein-Ernstthal. This is how Meyer Burger's triad of machine, cell and module works true to the motto: Made in Germany, designed in Switzerland for a bright future.

It comes as no surprise that unforeseen difficulties sometimes arise when the pace is so fast. Module production requires a lot of coordination. Moreover, there were global disruptions in the supply chains due to the COVID pandemic. Thanks to valuable experience gained in this intensive development phase, we are optimistic about further expansion. Not only have we significantly improved processes, we have also achieved the right level of quality in our modules. The market's interest in "Made in Europe" solar modules is huge and the need for energy independence is more current than ever. The production of climate-friendly and competitive electrical energy is the order of the day. Let's seize this climate opportunity together.

FABRIZIO BIZZARRI

ENEL Green Power: solar energy supplier and module manufacturer

Enel Green Power (EGP) has been a world leader in the renewable energy industry for a long time. To maintain this role, it is important to always be competitive from sustainability, economic and technical point of view.

In the photovoltaic sector, EGP is also a pathfinder thanks to its strong open innovation approach with the entire ecosystem: in the past, at the beginning of the Italian PV feed-in tariff, it was very useful to collaborate with SUPSI to increase the knowledge on PV modules.

EGP leverages a well-established vocation for Solar PV technology (in 1993 it built and operated the biggest PV plant in Europe) and more than 10 years ago created a true solar energy valley in Catania: it built the first industrial-scale factory of cells and modules and the Innovation Hub & Lab, a facility offering more than 100'000 sqm and indoor accredited labs for testing and demonstrating innovative solutions, also accelerating start-ups in the energy field.

EGP continuously implements a large number of new solutions covering the entire PV value chain, including PV modules, mounting structures, inverters, electronic optimization, data monitoring, module cleaning, predictive monitoring, degradation analysis, and automation for mounting and cleaning.

3SUN was established in 2011 as a joint venture of three major companies (Enel Green Power, Sharp and STMicroelectronics) from which the name 3SUN was derived. From 2012 to 2017, the factory produced about 7 million modules in thin-film amorphous silicon, pushing this technology to its practical limits.

In 2017, EGP decided to convert the production lines from thin film to crystalline silicon, while maintaining the use of amorphous silicon as an innovative passivating layer in the solar cell architecture. The new solar cells developed in 3SUN are based on silicon heterojunction solar cell technology.

At the end of 2015, through the construction of the world's first utility-scale industrial plant in Chile, EGP introduced bifacial PV modules, demonstrating, validating, and making bankable the HJT technology. In 2018 EGP started production at the Catania plant of the first bifacial modules. Mass production of the new HJT technology with 200MWp capacity and higher efficiency begins in 2019, producing bifacial cells with the highest bifacial coefficient, highest producibility, and lowest degradation, and targeting module lifetimes of more than 35 years.

Bifacial HJT combines the advantages of crystalline silicon technology with those of amorphous silicon, enabling solar cells to significantly increase power conversion efficiency and output stability with temperature. The process relies on a few innovative technological steps: advanced HJT processes do not exceed 200°C and involve only a few nanometers on the surface of the silicon wafer. 3SUN, with a manufacturing development center with a capacity of 200 MW/year, has been able to produce 100,000 high-efficiency silicon solar cells per day and assemble more than 1,000 PV modules per day, with a fully digitized and automated factory fully aligned with the industry 4.0 approach.

In 2020, EGP, in collaboration with a major EU research center, achieved a record 25 percent efficiency, achieved on commercial solar cells manufactured in a factory using high-throughput industrial equipment.

Single-junction silicon cells have a theoretical efficiency limit of 29%; due to the fact that they can use mainly high wavelength (near-infrared) light, their practical limit is set at 26-27%. Leveraging this strong experience and contributing to the reshore of PV production in Europe, 3SUN has decided to scale up to GigaWatt capacity, designing a new roadmap for future development.

In 2022, we began construction of the new gigafactory, with the goal of reaching a capacity of 3 GWp by 2024.

To go beyond what commercially available photovoltaic technologies offer, EGP is designing a new high-efficiency photovoltaic module based on an innovative cell concept: a double junction in which the upper cell, transparent to longer wavelengths of the light, is a perovskite solar cell that converts at the best the visible part of the solar spectrum, with a lower Si-HJT cell that uses the infrared component most efficiently.

Through collaboration with a major research institute, 3SUN achieved an important first result at the end of 2021, with an efficiency of 28 percent for a tandem configuration using our industrial HJT cell as the bottom cell. The figure 32 shows the expected trend in photovoltaic technology over the next few years, with the transition from the HJT silicon era to the tandem double-junction era and the development of a new solar cell capable of achieving an efficiency of

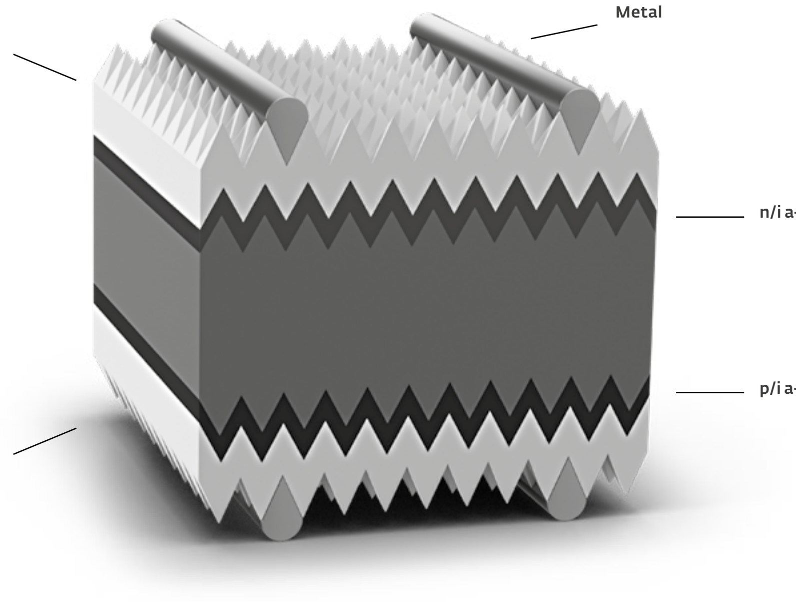


Fig. 29 Schematic representation of a Bifacial silicon heterojunction solar cell (HJT) and module application

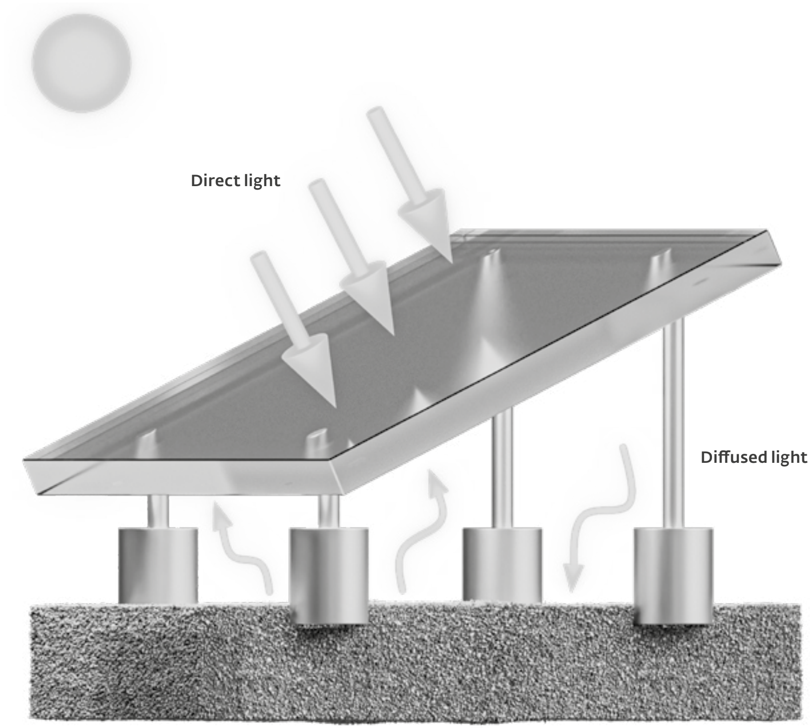
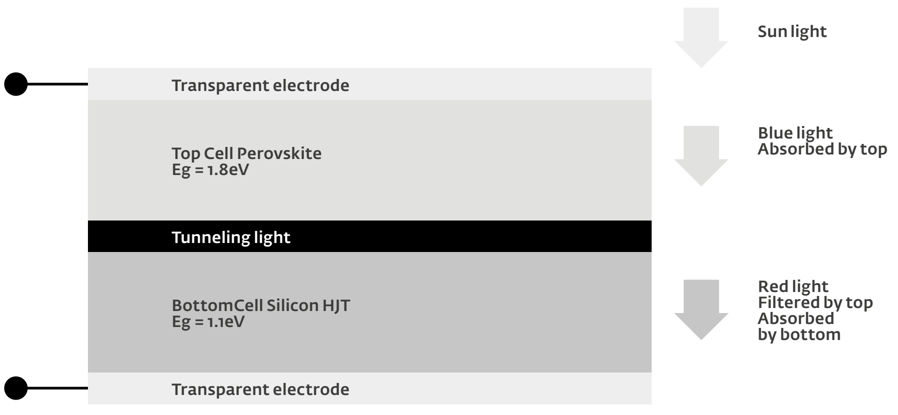
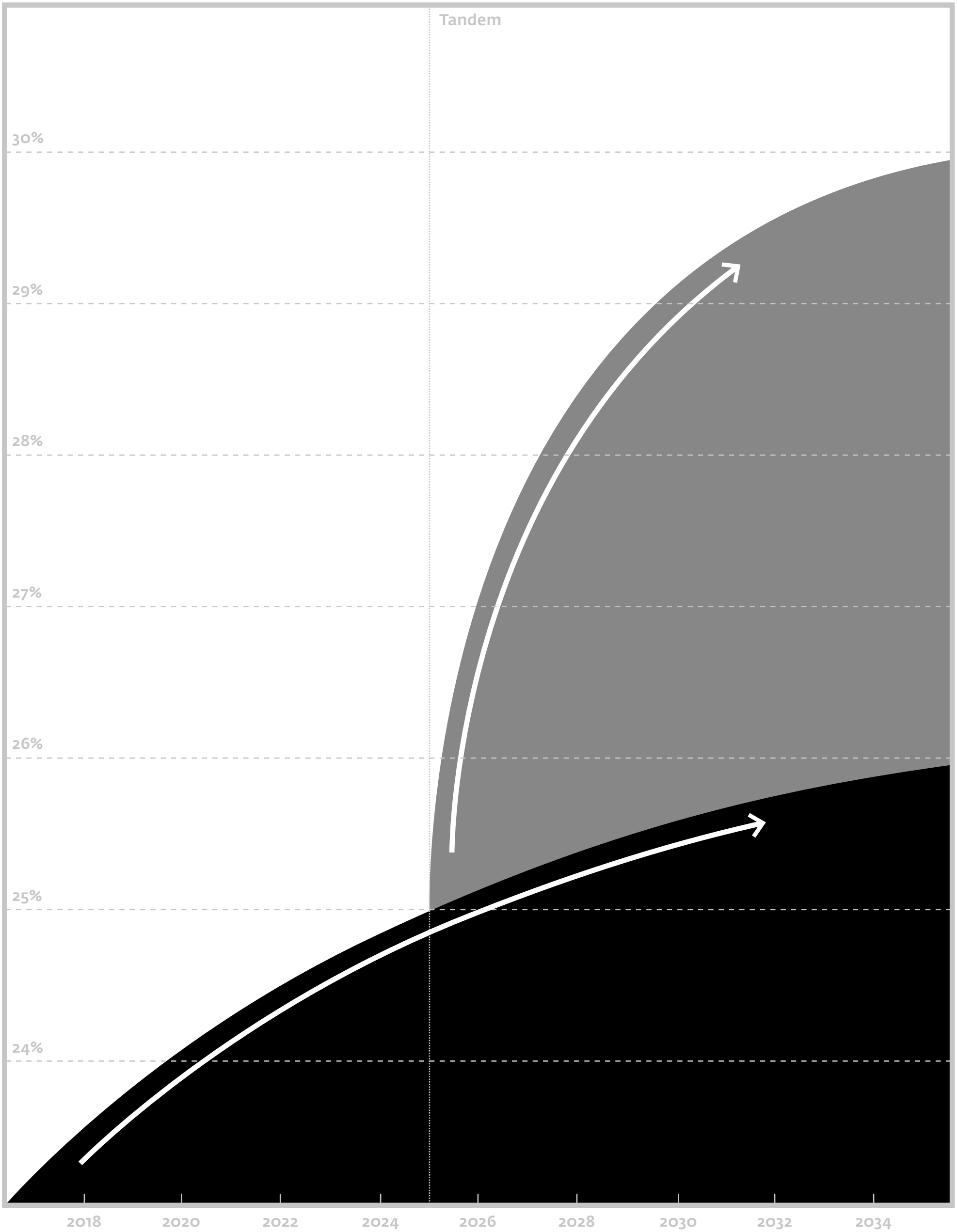


Fig. 30 Schematic representation of a Bifacial silicon heterojunction solar cell (HJT) and module application

more than 30 percent. Module sizes will also be larger (nearly 3 sqm) due to the adoption of a 210 mm wafer size (G12). The future of module assembly is also challenging: the main development directions for us are to decrease weight by also using new sustainable, recycled and recyclable materials with optimization of optical and electrical losses that determine the cell-to-module ratio. With high-efficiency cells and new cost-competitive materials, we could also push the development of special modules that can introduce disruptive applications for distributed generation. Finally, the TANGO project will strengthen the value chain in Europe's upstream PV industry, as the establishment of other announced gigawatt-sized factories in Europe will boost the production of raw materials and components (e.g., glass, plastics, aluminium, polysilicon wafers, and ingots).

Fig. 31 The TANGO configuration overcomes the state of the art cell in terms of theoretical silicon efficiency limit
Fig. 32 ON THE NEXT PAGE. Technology roadmap of the solar cells trend of the PV EGP technology





HJ: Cell efficiency from 22.5% to 25.7%

Tandem: Cell efficiency near to 30%

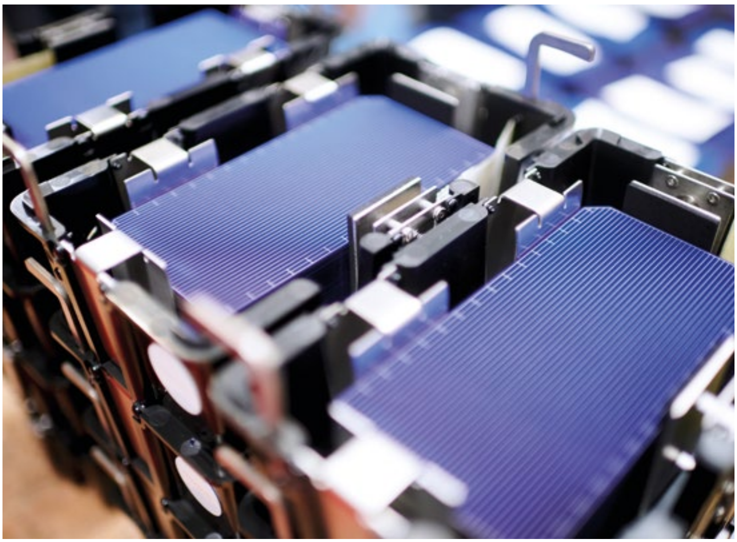
X-axis Evolutions steps (timeline)

Y-axis Cell efficiency (%)

Fig. 33 **Testing of the solar cells ©Meyer Burger**

Fig. 34 **In wet chemistry, the wafer is prepared for processing ©Meyer Burger**

Fig. 35 **Solar cells from Thalheim to be used in module production ©Meyer Burger**



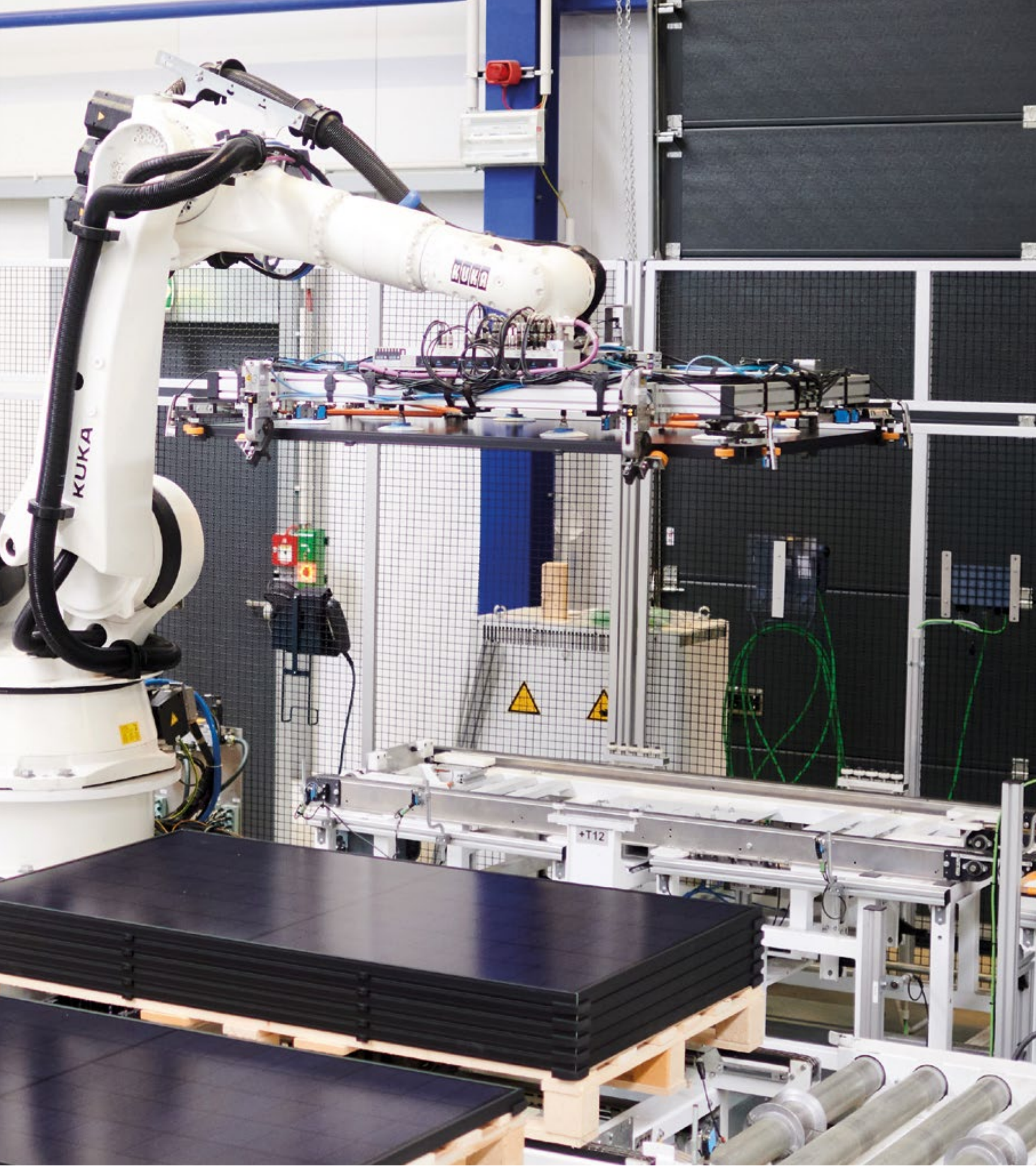
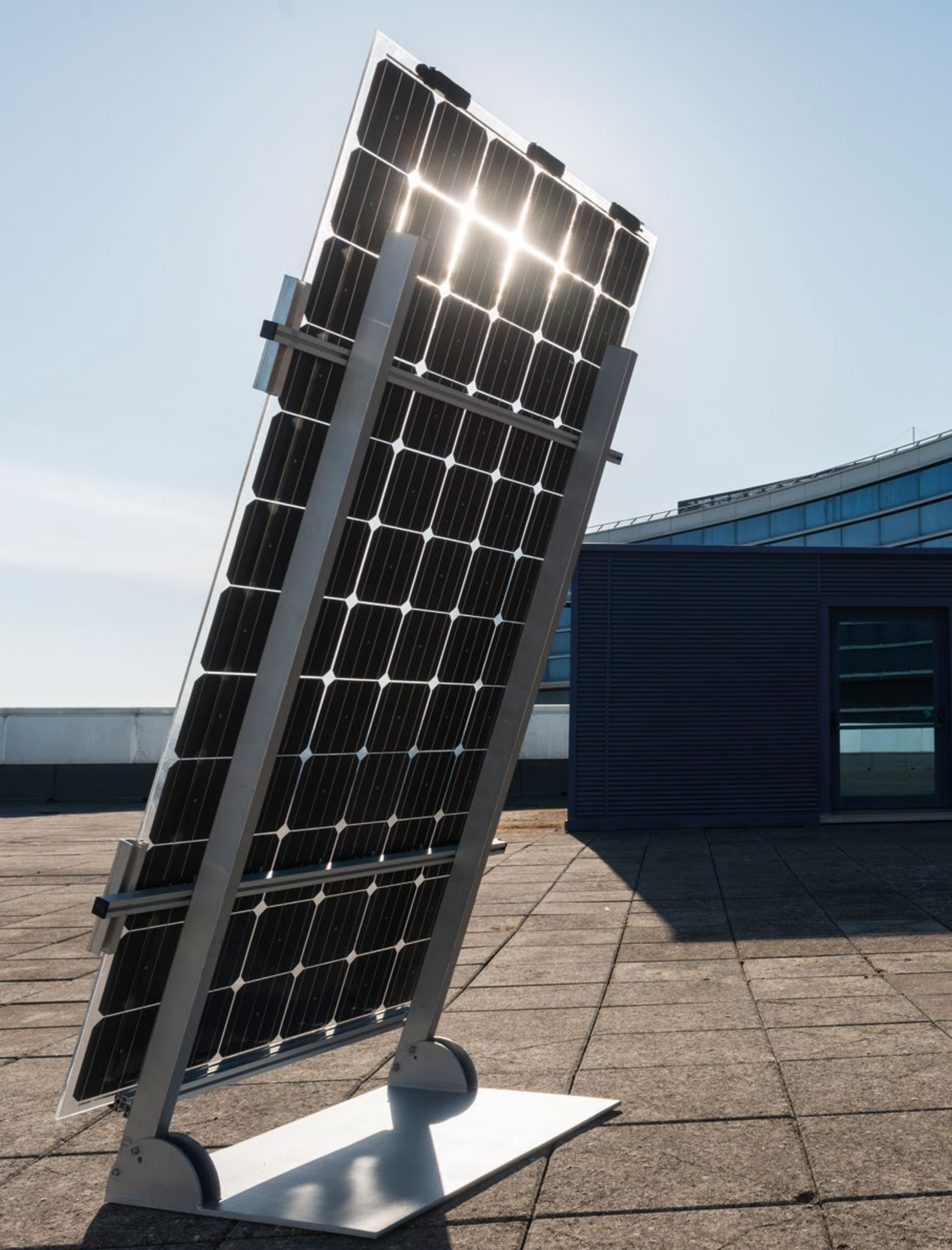


Fig. 36 **Sorting by performance at the module station ©Meyer Burger**

Fig. 37 3SUN production site in Catania, Italy ©Enel Green Power

Fig. 38 RIGHT. Latest generation photovoltaic modulel with bifacial cells in heterojunction technology of amorphous and crystalline silicon (Hetero Junction Technology - HJT) ©Enel Green Power



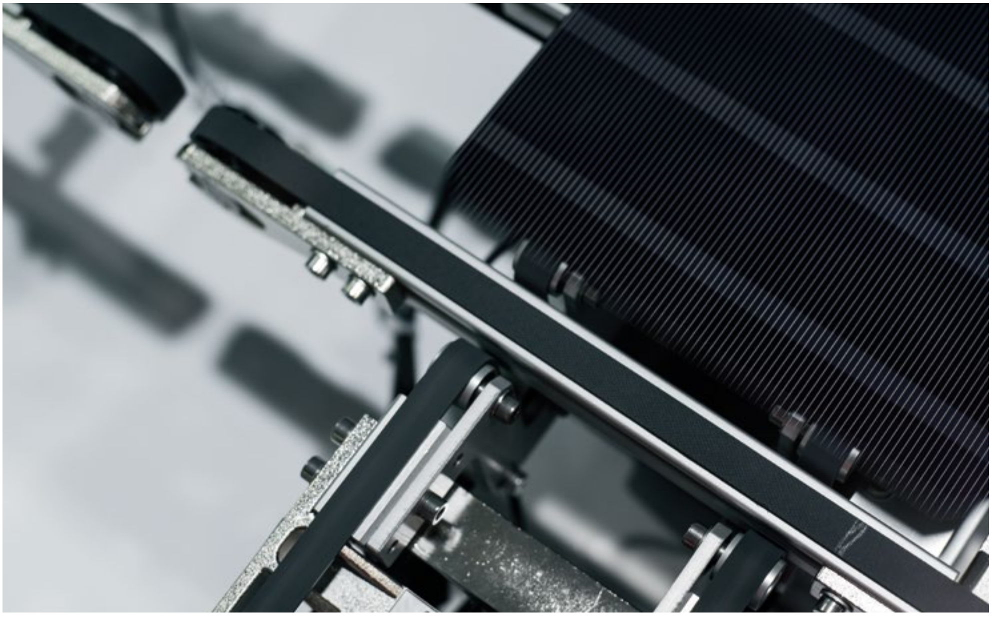


Fig. 39 Production of Bi-facial solar HJT solar cells at 3SUN production site in Catania, Italy. ©Enel Green Power
Fig. 40 Solar park Finis terrae, 286 MW, mono and bi-facial technology, Antofagasta, Chile. ©Enel Green Power

Politics and photovoltaic market

TEXTUAL INTERVENTIONS BY

GAËTAN MASSON [PP. 109-111] ; DAVID STICKELBERGER [PP. 112-113] ; WIELAND HINTZ [PP. 114-116]

Author | Article

Gaëtan Masson

European perspective of PV - today and tomorrow

Electromechanical Engineer, Gaëtan Masson is the Director and co-founder of the Becquerel Institute. After more than 10 years in the financial and IT sectors, he moved to the PV industry and developed the Business Intelligence of EPIA, the European PV Industry Association. Since 2013, he is the Operating Agent (chairman in IEA language), and vice-chairman of the European PV technology Platform.

David Stickelberger

Swiss Perspective of PV: finally on a rapid growth path

David Stickelberger graduated from Zurich University, Switzerland, with a master in Geography in 1986 and a postgraduate course in environmental sciences in 1992. He worked in the field of environmental consultancy for municipalities and was climate and energy campaigner for Greenpeace Switzerland. Since 1998 he is Managing Director of Swissolar. The Swiss Solar Energy Professionals Association has today approximately more than 800 members along the whole solar value chain and an agency in Zurich with 13 employees. The fields of activity include communication, training, quality assurance and lobbying.

Wieland Hintz

PV incentive policies and their impact on installations: the case of Switzerland

Dr. Wieland Hintz is Responsible for Solar Energy Swiss Federal Office of Energy SFOE, Bern. He holds a particle physicist at the ETH. He has gained professional experience in the electricity industry as a nuclear engineer and as a technical expert for wind energy at Alpiq and as an expert for energy management at VSE.

GAËTAN MASSON

European perspective of PV today and tomorrow

The complex relationship between policies and the energy transition in Europe has driven the chaotic development of the PV market in the last 15 years. At first sight, policymakers have massively supported the development of renewable energies and the prospects of the energy transition. Long term targets to decarbonize the society have been accepted and approved for years, while the translation into concrete measures has always been more complex and delayed. This dichotomy is unfortunately the key aspect of the discrepancy between announcements and real policies for solar PV in Europe.

Early days

The first tangible policies supporting smart PV development were developed under the name of "feed-in tariffs". It is commonly accepted that the initiatives leading to the boom of PV in Germany during the first years of this century can be attributed to a German policymaker, Hans-Josef Fell. Smart and efficient, these policies can be considered as the real initiators of the PV market, the beginning of its European then global development and hence the precursors of the entire industry that we experience today. Building on the German example, several other countries deployed feed-in tariffs, often badly conceived and not properly framed, but extremely efficient in developing GW-scale markets in Spain, Italy, Belgium just to mention a few.

The leading role of the European Union

These policies found a fertile ground at European level where the vote of the Renewable Energy Directive in 2009 led to constraining renewable energy targets by 2020. While the initial share between renewables didn't comprehend the future development of PV, the directive itself allowed and pushed member states to develop ambitious policies that allowed during some years significant market development. Instead of the 84 GW initially planned, close to 140 GW were finally deployed.

Retroactive and punishing policies

The reaction from conventional stakeholders, especially in the gas industry, was swift and aggressive. The cost of unframed feed-in tariff policies became rapidly a political subject and the reaction of policymakers turned into a general assault on renewables and especially PV. From 23 GW installed in 2011, the market went down to 6 GW in 2014. The damage was considerable and the market decline triggered the endgame for a large part of the manufacturing base in Europe, while the global PV market was developing fast.

In addition to lowering the market, some policymakers worked hard to damage the very idea of solar PV: in several countries retroactive measures were taken, sometimes under discussable legal provisions, to reduce the level of the feed-in tariffs granted to existing PV plants. In Czech Republic, Belgium, Italy, Spain, Bulgaria or Romania, retroactive measures decimated the plants under the excuse of protecting the electricity prices or public finances. One after the other, the key markets declined, including Germany, and the PV market was framed waiting for more competitive solutions.

Age of competitiveness

Such solutions took almost a decade in the making, a time during which the industry developed in Asia, and in particular in China, while the European market and industry were significantly constrained. In some countries like Belgium or Czech Republic, it became almost impossible for policymakers to support PV development again, due to the disastrous image created from 2010 onwards. Poorly conceived feed-in tariff laws had created tremendous temporary markets, such as the Italian market that recorded more than 9 GW of installations in one year (2011) before collapsing, leaving a trail of 6.7 billion EUR of annual feed-in payments, capped by the parliament.

The decline of prices of PV components and installations became then an essential requirement and policies started to favor the most competitive PV development options: tenders were established almost everywhere in western European countries, with declining PV system prices and electricity costs. The objective was double: showing that governments were supporting PV development at the most competitive cost, while controlling it. The control element was definitely the most important, with most countries installing only a fraction of the capacities that would have been needed to reach climate goals.

Industry policies

The other impact of these tenders was the absolute need to source the cheapest PV components: the door was open even larger to imports from China and European manufacturers were struggling to simply stay in the market. The policy obsession for constraining the market to avoid damaging the conventional electricity industry led to neglecting completely industry development: European companies disappeared one after the other with little reaction of policymakers: importing from China was not dramatic, and most European PV trade associations were blocking any attempt to regulate imports. The use of trade defense mechanisms helped a part of the industry to survive but at the same time the market continued in most countries to be dedicated to the most competitive components. Only France set up specific tenders with a CO_2 content threshold.

And now

While PV has reached a decent level of competitiveness in most segments and most European countries, the need for financial support has given space to policies supporting a smart developing of PV: self-consumption policies, energy communities, specific market niches are the current focal point while the smothering and acceleration of the energy transition should be the next one. Permitting is still often complex and slow, while punishment policies like the prosumer's tax in Belgium continue weighting on the speed at which the market could develop.

The articulation between the need for a local industry (that policymakers seem to finally understand) and the shape of the market is still either not understood or not implemented: most market development policies are still far from comprising the need for local content or non-cost related parameters in tenders. Policies are also far from integrating cross-cutting issues and system related stability, with the integration of storage, smart charging for electric mobility and V2G) and DSM capabilities.

Conclusion

The distributed nature of PV doesn't reduce the concern for controlling the energy sector which is at the core of all sound policies. The speed at which PV developed created huge delays in policy processing to the extent almost 15 years were needed to simply acknowledge the importance of PV development for the energy transition and the need for policies framing smarty its development. And we are not there yet. European policies have definitely a competitive advantage with regard to setting the pace in Europe and accelerating the adoption of smarter policies, at market and industry level. However, much remains to be done and ongoing files such as the Ecodesign/Ecolabel, the IPCEI for supporting PV manufacturing in Europe and smarter self-consumption policies will require additional months and years to finally support the expected massive PV deployment in the European Union.

DAVID STICKELBERGER

Swiss Perspective of PV: finally on a rapid growth path

The beginnings of photovoltaics in Switzerland were marked by a remarkable pioneering spirit. Inspired by the oil crisis and the report of the "Club of Rome", a group of researchers at the former Swiss Federal Institute for Reactor Research EIR (now the Paul Scherrer Institute) worked on a project on solar energy from the end of the 1970s, focusing on thermal power plants with large mirror fields in addition to hot water collectors. In 1978, the predecessor association of Swissolar was also founded in this environment. After the researchers came into possession of solar modules with an output of 1.2 kW, they connected them, mounted on a tool shed, to the public grid in April 1981 using an inverter they had developed themselves - apparently the first solar grid feed-in in Europe. The second time was in May 1982 with the 10 kW system of the Ticino Solare group (TISO), whose modules, unlike those of the EIR, are still in operation. Another brilliant idea of the pioneers of the time was the "Tour de Sol", a solar car race from Lake Constance to Lake Geneva, which was held nine times starting in 1985. The competition was intended to demonstrate that solar energy can be used not only in hot regions, but also in Central Europe.

At the time, however, Swiss energy policy focused on nuclear power. It was not until the Chernobyl disaster in 1986 that the last planned nuclear power plant was abandoned and interest in energy efficiency and the use of renewable energies increased abruptly.

In 1990, the promotion of these areas was stipulated in the Federal Constitution as a task of the state. To implement this, the then Energy Minister, Federal Councillor Adolf Ogi, introduced the Energy 2000 programme, which promoted many innovative projects, not least in the solar sector. A small solar boom was the result, which was the envy of solar pioneers in neighbouring countries. The energy industry also began to take an interest in the sun: in 1991 Elektrowatt and BKW built a 500-kilowatt ground-mounted photovoltaic plant on Mont Soleil, the largest in Europe at the time. However, malicious tongues claimed that the initiators wanted to show that solar power was far too expensive. In fact, a kilowatt hour cost about 20 times more than it does today.

The boom soon came to an end and subsidies were cut. It was not until the introduction of the feed-in tariff for electricity from renewable energies in 2009 that there was a strong upswing in photovoltaics, but this was slowed down by the strictly limited subsidies. Thousands of projects ended up on a waiting list. It took another catastrophe, this time that of Fukushima, to put an end to new nuclear power plant projects and to push ahead with the expansion of renewables. In 2018, the Energy Strategy 2050 came into force, which restructured the funding and provided it with significantly more resources. The results so far are encouraging: since 2019, annual additions have risen by almost 50 percent each year, and the share of solar power in annual consumption is now around 6 percent.

From Swissolar's perspective, this is just the beginning.
According to our models, around half of the electricity must come from solar plants by 2050 in order to replace electricity from nuclear power plants and at the same time ensure the replacement of fossil fuels. The Swiss parliament is currently working on a law for a "secure electricity supply with renewable energies". We are confident that this will create the conditions for a further acceleration of the solar boom.

In contrast to most other countries, ground-mounted systems have played practically no role in Switzerland so far, even though the discussion about large-scale alpine systems with high winter yields is currently gaining momentum. High land prices and limited space are the reasons that solar plants are mainly installed on roofs and increasingly also on façades. The big advantage is that production is always close to consumption, thus relieving the electricity grids. And this focus ensured that Switzerland became the global stronghold of BIPV. Several research institutes are working on the topic of building integration, innovative companies offer products, and aesthetically convincing buildings can be found throughout the country that produce significantly more energy on their roofs and façades than they consume.

WIELAND HINTZ

PV incentive policies and their impact on installations: the case of Switzerland

Installing a photovoltaic system has become a matter of course in Switzerland. In the first half of 2022, 320 MW systems were registered for a subsidy at Pronovo: 60% more than in the first half of 2021. It should be noted that already in 2021, according to preliminary figures, the development of Swiss PV was at a record high of about 700 MW. This puts Switzerland in fourth place in a European comparison in terms of the total installed power per capita in 2021. The development of photovoltaics is also going extremely well with regard to the expansion targets of the federal government. The goal of the Energy Strategy 2050 is an electricity production of 11.4 TWh per year in 2035. Thanks to the boom of photovoltaics, this goal can probably be reached already in the mid to late 2020s. In addition, due to the decarbonization now targeted by 2050, the Federal Council has proposed to Parliament in 2021 to raise the target to 17 TWh of electricity from renewables per year in 2035, of which 14 TWh/y from photovoltaics. Even this target seems realistic, because for this an annual development of 730 MW would be necessary in the period 2021 to 2035, in 2021 this was already almost achieved!

How did this extraordinary boom come about? The granting of government subsidies has certainly made a weighty contribution. In 2009, the cost-covering feed-in tariff (KEV) was introduced, which led to a first significant push within a few years. With the security of receiving a fixed price for every kilowatt hour fed into the grid over

25 years, the attractiveness of investing in photovoltaics increased massively. Consequently, the development of 32 MW in 2009 increased tenfold to 329 MW in 2012.

Unfortunately, the KEV became a victim of its own success. The funds made available by parliament for the KEV were far from sufficient to satisfy the large demand. The famous waiting list for the KEV was created and operators had to invest at their own risk and hope for a funding commitment. Under these general conditions, the addition of new capacity collapsed again from 2015 onwards.

In order to cushion the slump due to the KEV waiting list, Parliament introduced another subsidy model for plants with an output of up to 30 kW from 2014 onwards in the form of a one-off payment, which covers up to 30% of the investment costs. Together with the simultaneously created possibility of self-consumption, it now became possible to operate small PV systems profitably even without KEV. This subsidy model struck a nerve: generating one's own electricity for the household consumption, heat pump or electric car, while still saving electricity purchase costs and thus becoming less dependent on grid electricity, appealed to many Swiss. The Energy Strategy 2050 adopted in 2017 consequently extended this subsidy model to all system sizes and at the same time decided to end the KEV by 2022. This proved to be a liberating blow for PV expansion. While the development of only 240 MW in 2017, the market volume almost tripled within only four years to about 700 MW in 2021.

From 2023, the subsidy model of the one-off payment is to be further developed. Up to now, self-consumption has been an important prerequisite for the profitability of an investment. Large systems on the roofs of buildings with low electricity consumption (e.g., barns or warehouses) were hardly worthwhile and were therefore rarely realized. From next year on, the high one-time compensation will be introduced, which can be up to 60% for PV systems without self-consumption. The electricity can then be marketed either by the local utility company, on the electricity market or via a power purchase agreement. The latter is becoming increasingly attractive for many companies with high electricity consumption, because it enables them to protect themselves against fluctuations and high prices on the electricity market. From a plant size of 150 kW, the high one-off payment is to be awarded by auction. Based on this new subsidy, the Swiss Federal Office of Energy expects an increase in new installations to well over 1000 MW per year in the short term.

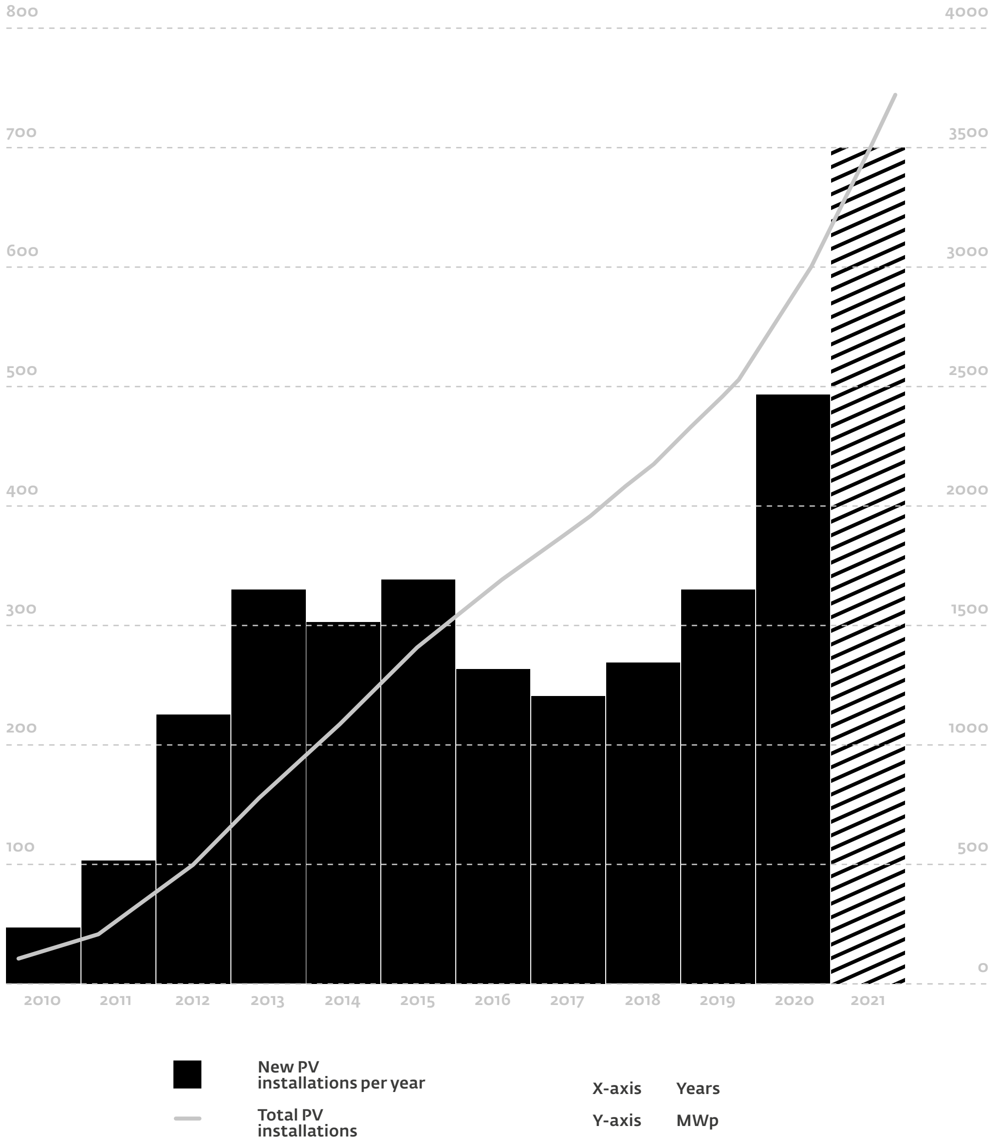


Fig. 41 Trend of the PV plants' installations in Switzerland (2010-2021)

Building Integrated Photovoltaics

TEXTUAL INTERVENTIONS BY

FRANCESCO FRONTINI & PIERLUIGI BONOMO [PP. 121-124]

Author | Article

Pierluigi Bonomo

BIPV today: challenges and opportunities

Dr. Pierluigi Bonomo (Head of Innovative envelope Team). He is researcher and head of BIPV innovative building envelope team at Institute for Applied Sustainability to the Built Environment of SUPSI. He graduated and got a Ph.D. in Construction-Engineering/Architecture. He is specialized in the design and envelope engineering of Zero Energy Buildings on which he also made real experimentations receiving different prizes and acknowledgements. He actively works in different innovation actions at European and federal research projects on building Integrated Photovoltaics (BIPV) and he's author of many publications in this fields. He's part of the expert group of International Energy Agency Task 15, and of TC82 IEC and JWG11 ISO/IEC for BIPV standardization.

Francesco Frontini

BIPV today: challenges and opportunities

Prof. Dr. Francesco Frontini since 2011 is the head of the Building Sector at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI). He graduated in Building Engineering and Architecture from Politecnico di Milano (Italy). In 2009 he got a PhD cum laude in Building Engineering where he developed, together with different manufacturers, a new multifunctional BIPV façade for solar control and glare control. He worked as researcher (post-Doc) in the Solar façades group at Fraunhofer Institute for Solar Energy Systems (in Germany), one of the largest Research institute in the World, where he gathered extensive experience in Building simulation and in Building Integrated Photovoltaic (BIPV) solution. Research activities have always been supported by experimental work on the design of real buildings and solar envelopes. He is a member of the standardisation bodies SIA, CENELEC and IEC with which he is developing a new international standard for photovoltaics in buildings. Since 2021, he is Co-Manager of the IEA PVPS Task 15. Frontini is author of several publications and coordinates several international research projects.

PIERLUIGI BONOMO
FRANCESCO FRONTINI

BIPV today: challenges and opportunities

"Architecture starts when you carefully put two bricks together. There it begins" (cit. Mies van der Rohe).

A year after the Bauhaus centennial, a new "European Bauhaus" is expected to put Europe on track to be carbon neutral by 2050 and to promote "smart building" technologies as ways to reduce the environmental impact of constructions, and to jump-start the post-COVID economy recovery. Building integrated photovoltaics (BIPV) is the example of a co-creation platform for architects, engineers, and designers started almost 40 years ago, when solar cells progressed from technologies merely used for satellites application to become an integral part of construction design and materials.

The built environment is a strategic domain in view of a full decarbonization of our economy and building skin surfaces, thanks to BIPV, represent a huge potential in turning the building stock into a decentralized renewable energy producer. In recent years, BIPV, from being a niche market, became a well-established and dynamic sector. Concrete paths are ongoing to bridge the gap between building and solar industries, architecture and research, design and technology.

Even if one of the first examples of integration and innovation of PV in building goes back up in 1979 (a solar settlement in Munich designed by Thomas Herzog), it is in the early 2000s that, driven by incentives and increasing demand, more and more multifunctional solutions such as PV tiles, ventilated façade cladding and curtain walling have started to be developed. Until 2009, building-integrated solar systems worldwide accounted for only 1 per cent of the total installed capacity of photovoltaic systems. Although a wide range of solar building products were then available at attractive prices, the initial investment of BIPV systems at that time was still too expensive to compete with building materials and traditional photovoltaic systems, so the priority was to maximize annual energy production while reducing costs.

Following the development of PV technology, an architectural language based on standard solar panels accompanied the first age of integration in opaque surfaces, mainly building roofs. However, these conventional PV elements displayed all the limitations of a functional approach, so the drastic change of today's second age involves a technology that has to comply with key market-driven demands, such as aesthetics, flexibility, building skin performance, durability and cost-effectiveness. The development of modern production techniques, of increasingly automated and customisable cell stringing (as proposed for example by the European project BIPVBOOST www.bipvboost.eu), and collaboration with the glass industry, make it possible to create semi-transparent surfaces or multifunctional systems that combine thermal insulation, acoustic protection and photovoltaics in a single prefabricated component. In more recent years, new coloured photovoltaic products appeared on the market. Thanks to special glass processing techniques, they give even more flexibility to the technology, providing homogeneous coloured surfaces or ad-hoc and custom-designed solutions according to the architect's needs, where the PV cell disappears, thus being a true customisable building material. This trend can be referred to as 'camouflaged' PV, where the key material to be designed and engineered is glass, but not in its commonly held embodiment of a transparent and dematerialized skin. Under the banner of 'invisible PV', there is currently a promising joint effort between PV and the glass industry with the aim of combining high production of solar energy with attractive visual design aesthetics. No technical limits seem to be applicable to the revolutionary flexibility of design. The main customization techniques, typically considering the layering of a glass-based module, can be applied to glass, intermediate foils and PV cells. Patterns and sketches can be obtained by treating the outer glass surface (eg, by sandblasting) which, in turn, can be combined with a glass colour to dissimulate the solar cells behind it.

A design (coloured) on the front glass can be obtained for example with a silk screen printing process that deposits a special ink on the glass surface, such as digital ceramic-based printing or, alternatively, by stabilizing the colour at high temperature with mono- or multichromatic scales used to obtain high-resolution images or prints. By combining the satin finishing on the outer glass surface with silkscreen printing on the inner side, a resulting coloured matte surface can make the glass opaque and active. Scattering and reflection filters have also been developed, and they can be added as internal foils to reflect and diffuse the visible spectrum, thus providing a coloured appearance. All of these techniques are progressively being developed to find the best compromise between visual effect and efficiency of PV production, and they represent a dynamic branch of the 'active glass' industry which is the current frontier of BIPV for the coming years. This innovation trend aims to facilitate the transition to active buildings while providing endless possibilities for aesthetic variation.

The transfer of photovoltaics in contemporary architecture, as the use of active facades, roofs and urban surfaces, is much more than a technical possibility: it is a true new opportunity in building skin aesthetics, ethics and technology. On one side mimicry could appear a manipulation of the basic photovoltaic material since for many architects "the material itself should speak through its own". On the other hand, semantics of PV cells could appear as a technocratic language transferred from aerospace to buildings. Thus, an infinite discussion. But the right question, in our opinion, would be: what does "integration" mean in relation with aesthetics in architecture? Is it just a superficial cosmetic technique to express or dissimulate technology appearance? How should architecture be inspired by technological meanings of beauty?

BIPV products quality is a key-aspect for the market uptake. Integrating PV in building skin today requires an accurate performance assessment in accordance with construction norms and PV standards, depending on the type of use and function. Since BIPV is typically operating at non-conventional scenarios (shading, temperature, environment, etc.), the topic of BIPV as multifunctional product deals with harmonizing performance and finding new approaches considering its dual function as an electrical and construction component ensuring product quality, cost reduction and stronger penetration of BIPV in the market.

Thanks to research efforts, increasingly efficient and financially sustainable construction solutions and solar cells are introduced to the market, and in 2016 the first international standard to guarantee the quality of integrated photovoltaic modules, EN 50583 "Photovoltaic in Buildings", is published. In Switzerland pilot and flagship buildings have defined reference milestones in recent years, by demonstrating "technology to market" transfer. Examples are the multi-family house in Seewadelstrasse in Affoltern am Albis designed by the Viriden+Partners studio, and the recent POLIS project in Pregassona, designed by architect Mario Campi, to date the building in Ticino with the largest photovoltaic façade, with an installed power of about 170 kWp, corresponding to a surface area of over 1,600 square metres. For this latest project, the City of Lugano chose to change the concept of the façade, moving from a classic fibre-cement cladding to an entirely photovoltaic surface, without renouncing the architectural language thanks to innovative coloured glass modules made to measure to make the building almost self-sufficient in terms of energy.

These and other examples are documented in detail on the Solarchitecture digital platform (www.solarchitecture.ch) that SUPSI manages with the collaboration of ETH Zurich and Swissolar, thanks to the support of SvizzeraEnergia. Various other techniques are being developed and the end result is that we no longer have to talk about the integration of photovoltaics into the building skin, but rather it is precisely the skin of the building that is changing to accommodate photovoltaic technology to produce renewable energy. Solar architecture, together with bioclimatic architecture, should not be considered anymore a specialist field, but rather an architecture that is aware of the current challenges, that wants to identify an healthy relationship between the built environment and nature by relating man's activities, the true protagonist of architecture and result of its emotions, and the external environment, the "climate" and the earth, finding the right balance.

Cost efficient mass customization is expected to further support the market pull in the EU and worldwide, including aspects of quality, reliability and safety. However, further aspects also contribute towards the wide range of possibilities such as the construction innovation of solar skins. For example, the flexibility and lightness of thin film solar strips introduced the possibility to radically overcome some issues of PV integration by simply embedding PV in tents, ultrathin or multiperformance membranes or in multifunctional buildings element such as integral blind as the one proposed by iWin (www.iwin.ch). Some emerging trends are ultrathin solar modules which can be applied on low-load-bearing roofs, facades and streetlights or inkjet 'roll to roll' printing, in combination with organic light-emitting diodes, that in the future will supply flexible and eco-friendly supports, allowing the building to act as a self-sufficient organic system, offering a spectacular application of PV for media functions and digital art. The innovation in these trends lies both in the component technology and in the fact that the building image becomes a clear manifesto of a new 'solar age' in architecture.

Solar, beyond technology. Solar energy is today not simply about innovation but a matter of ethics and environmental responsibility and we should act with a clear motivation. What can we do? Do, and do well, in order to make ambitious policies a reality to accelerate the deployment of solar buildings and also to drive the highest level of local, qualified and sustainable jobs created of any energy generation technology.

Solar, to transform our living environments. Solar integration is not a dream anymore. Today we don't have to be ecologists or pioneers for conceiving and realizing solar buildings. It's enough to be a citizen. Building owners can transform the building skin into a decentralized energy power station. Industries make available plenty of technical alternatives, producing active glasses rather than PV panels. Architects can flexibly design a solar building by balancing aesthetics and efficiency. Quality, aesthetics, feasibility and cost-effectiveness of a solar building is not to be invented, but just to be demonstrated.

Solar, is beauty. A technology doesn't make architecture itself. But, as Mies once said, "architecture depends on its time and it should be a true symbol of its time: one should be the expression of the other". Today the building accumulates a lot of complex needs and functions: we should consider architecture as a global issue. In this way there is only good architecture.

Fig. 42 ON THE PREVIOUS PAGE. Close up of the cSi and aSi photovoltaic façade of the Palazzo Positivo in Chiasso (Switzerland), by TUOR Baumanagement AG and Gasser Baumaterialien AG ©SUPSI
Fig. 43/44 Z3 building of Ed. Züblin AG in Stuttgart, Germany. The design and the modules have been developed within the European project Construct PV ©SUPSI

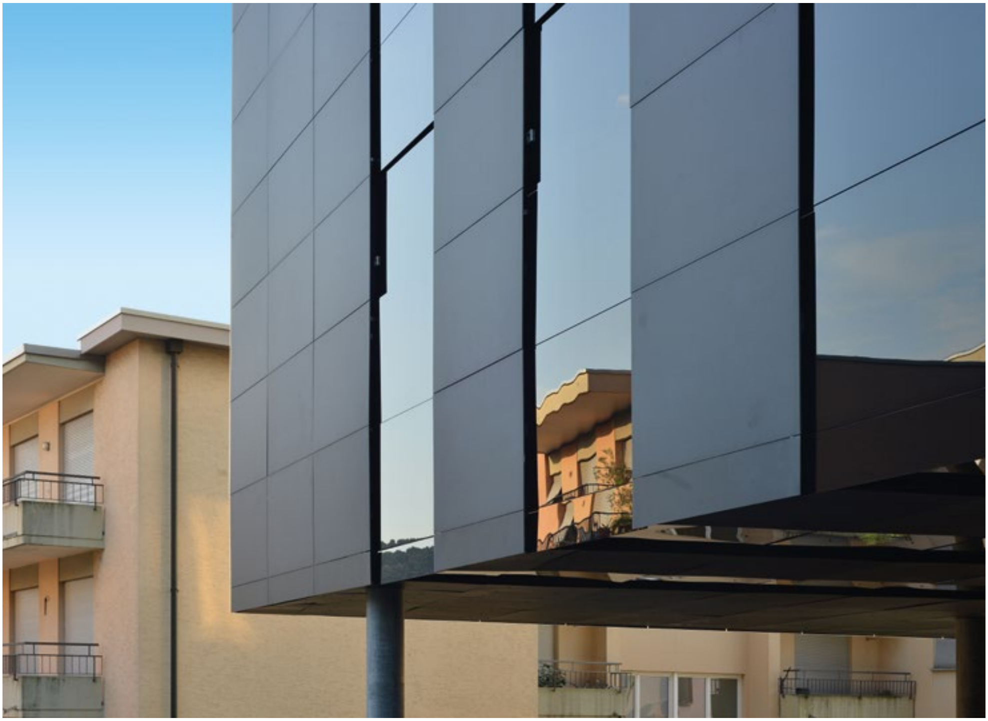


Fig. 45 Detail of the DeltaROSSO façade, by architects Stefano de Angelis and Maria Mazza, Vacallo, Switzerland ©SUPSI
Fig. 46 ON THE NEXT PAGE. DeltaROSSO, by architects Stefano de Angelis and Maria Mazza, Vacallo, Switzerland. The whole south facade has been realized with fully black modules similar to the non-active cladding panels ©SUPSI

Fig. 47 ABOVE. "Solar energy: a construction material". Exhibition on 40 years of evolution in PV-powered solar architecture curated by SUPSI ©SUPSI

Fig. 48 BELOW. Real scale outdoor mock up of a multifunctional solar façade tested, validated and monitored at SUPSI Campus in Mendrisio, developed in collaboration with PIZ Cladding System in the framework of BIPVBOOST project (www.bipvboost.eu). The goldish solar cells have been selected according to the architect wish to better integrate the modules in the existing façade ©SUPSI

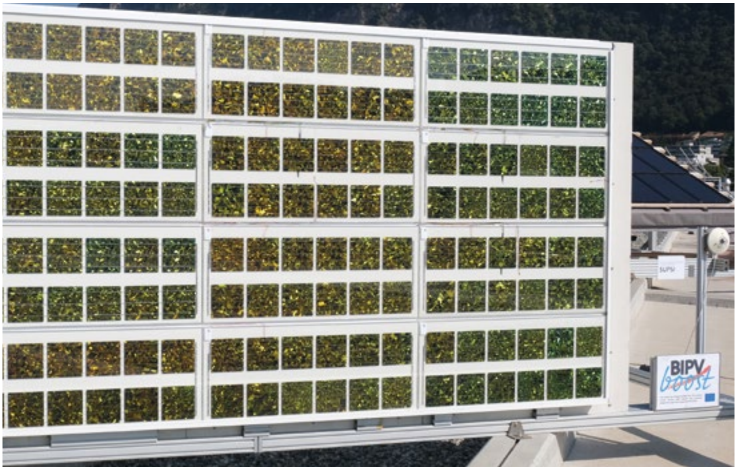


Fig. 49 ON THE NEXT PAGE. Polis Multifunctional Centre of Lugano Municipality, Switzerland, by Mario Campi architects, Lugano, Switzerland ©SUPSI

SUPSI and photovoltaics

TEXTUAL INTERVENTIONS BY
ROMAN RUDEL [PP. 137-138]

Author

Roman Rudel

Article

Yesterday, today and tomorrow - ISAAC in the energy strategy of the Swiss Confederation

Roman Rudel, head of the Institute of Applied Sustainability to the Built Environment at SUPSI since 2008, has an academic background in geography with particular focus on the complex relation between socio-economic development and the environment/climate change. He received a Ph.D. from the University of Fribourg (Switzerland) for a thesis on the ecological transformation of the industrial society he carried out with the Human Ecology Group of ETH Zurich (Switzerland). After 5 years of research assistant at the University of Fribourg he moved to Ticino in 1992 working for a research institute in the field of regional innovation systems. He has over 20 years of research experience in the field of technological and institutional innovations applied to the mobility and energy sector and was member of the first national action plan on sustainable development in Switzerland.

ROMAN RUDEL

Yesterday, today and tomorrow ISAAC in the energy strategy of the Swiss Confederation

The research activities of the Institute of Applied Sustainability to the Built Environment (ISAAC) at SUPSI are rooted in the PV sector, and its origins go back to the pioneering initiative TISO 10kW in Trevano in 1982. The very first activities were linked to continuous monitoring of the performance of this grid connected PV plant, facing significant problems with the electronic components of the inverters and the hardly imaginable challenges with the data acquisition and storage, being in the Stone Age of the computer industry and informatics. The TISO 10kW was not only the origin of the ISAAC research institute but also the playground for young scientists in electronics and informatics, who contributed to the foundation and the development of the University of applied Sciences and Arts in Southern Switzerland (SUPSI) in 1997.

The TISO team's integration in SUPSI favoured a gradual growth of ISAAC into an interdisciplinary research institute with a full-fledged PV module test laboratory, which is still the only ISO 17025 accredited facility in Switzerland. Today, the SUPSI PVLab disposes of highly sophisticated testing infrastructures and aims to position itself among the most advanced and precise testing labs in Europe. Moreover, the laboratory also has the ambition to develop relevant tests for the Swiss and Alpine climates beyond the IEC standards, guaranteeing the reliability and durability customers expect from the industry.

Around 2010 the SUPSI PVLab was facing ups and downs of the first boom in the photovoltaic industry in Europe. It became clear that a massive diffusion of the PV technology would lead to decentralized energy production and profoundly change the way to manage the power grid, known as a centralized unidirectional demand-driven system with large power stations. ISAAC engaged in research activities on an algorithm based and fully decentralized smart grid approach, taking full advantage of the local grid data from smart meters. The first steps in this emerging research field were in contrast to the mainstream, based on central control with massive communications systems integrating data from hundreds to thousands of smart meters.

ISAAC started also investigating the opportunity to integrate photovoltaic technologies into the building skin in the same period, aiming to transform the PV module into a multifunctional building component. Combining the knowledge of architects and civil engineers with experience in PV technology gave rise to successful research activities and plays a fundamental role in the interface between the research institute and the teaching activities for young architects. The efforts to transform PV modules into esthetically attractive building components were and still are crucial in attracting the interest of architects for this energy technology. It also helps overcome barriers and prejudices against PV technology, making it very often not the first choice.

In both research areas of smart grids and BIPV, ISAAC recently has given origin to 2 start-ups, HivePower and iWin. HivePower offers SaaS for managing self-consumption communities and focuses on the intelligent integration of electric vehicles in flexibility markets. Meanwhile, iWin is developing an innovative shading system with active Venetian blinds integrated into the window chamber. Both initiatives support the accelerated electrification of the housing and mobility sector and decarbonization of the most relevant CO emission sources. The start-ups will also benefit from collaboration in joint research projects with ISAAC. They will also face the research teams of ISAAC with new practical challenges stemming from implementing the energy transition strategy.

The SUPSI PVLab has to anticipate the new testing requirements for new technologies in the PV sector, guaranteeing longevity, an essential characteristic of PV products, also in the future. It will also play a role in developing new and even more attractive BIPV products and support the definition of new product standards reflecting the overall footprint of the module and its recyclability.

These are the necessary conditions for a massive diffusion of photovoltaics. At the core of this democratically distributed energy landscape is emerging the new figure of the prosumer, radically changing the attitude towards the energy of the fossil fuel addicted consumers and likely shaping a new energy paradigm part and parcel of a more sustainable lifestyle.

Aknowledgements

Aknowledgements

SUPSI would like to acknowledge all the authors for their time, commitment, and energy in sharing their professional experience in photovoltaics and their witnesses related to the TISO 10 kW PV system. These contributions make the publication a milestone in a moment when PV receives unprecedented attention. We are also very grateful to all the scientists, researchers, and technicians who contributed to the design, construction, and testing of the TISO 10 kW PV plant in different moments of this 40 years journey. Finally, we also thank all the industries and public entities contributing, either technically or financially, to the development and research projects on the TISO 10 kW PV system.

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