FUTURE OF

Solar Photovoltaic Energy

How photovoltaic technology maintains competitiveness and contributes to the energy transition.

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Green Power

F U T U R E O F

Solar Photovoltaic Energy

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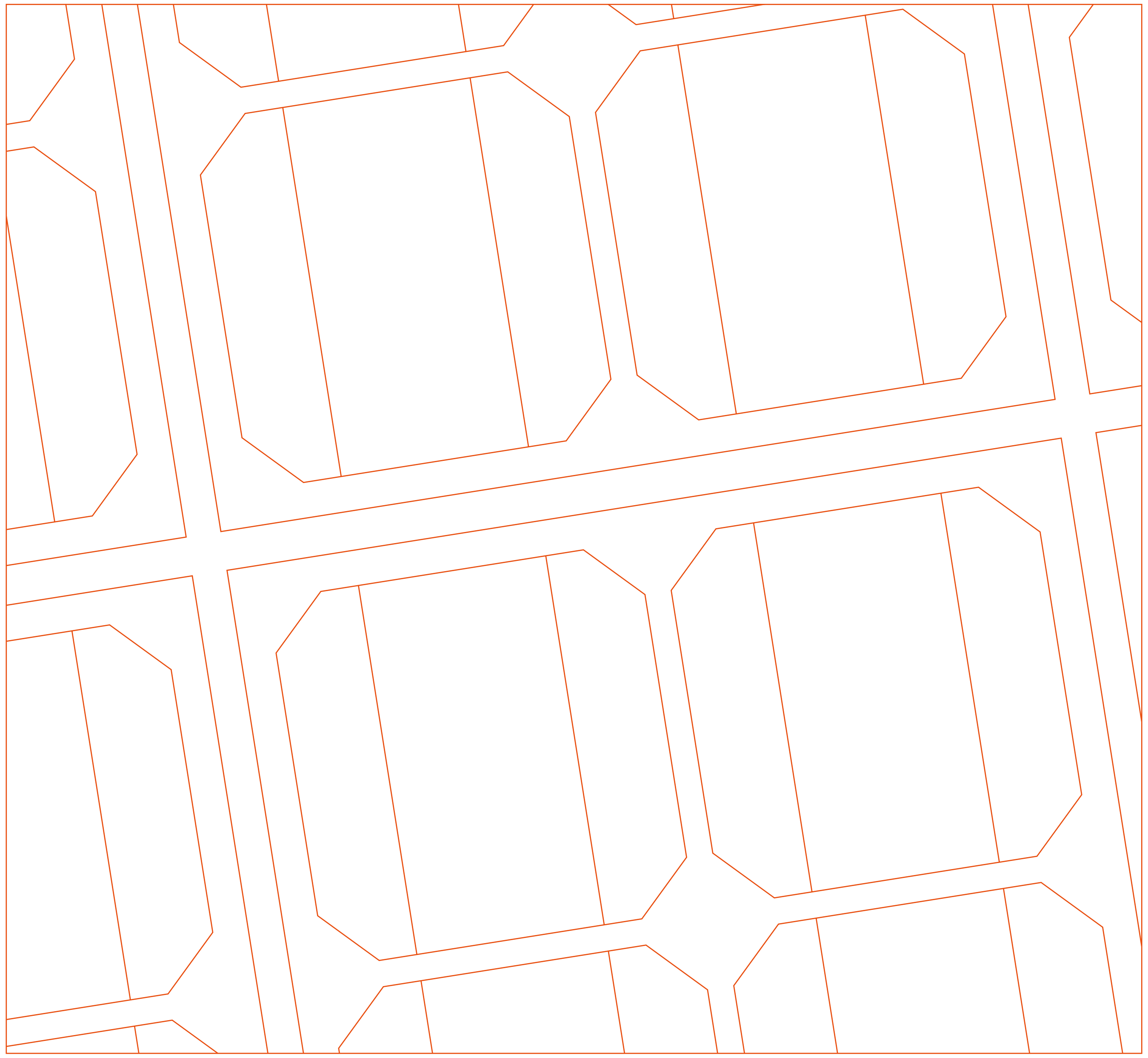
Index

Foreword



The issue of energy self-sufficiency has always been a central theme for many Countries, especially in order to ensure access to fossil sources. It is now clear that the Energy Transition is an inevitable path; this is changing the paradigm, with renewables having secure access to energy sources, means and technologies.

The Energy Transition will be one of the most important levers to give an answer to the GHG emission reduction, which will be one of the biggest challenges we will face with in the coming years: the Paris Agreement establishes a global framework to avoid dangerous climate changes due to the increase in greenhouse gases by limiting global warming below 2°C and continuing with efforts to limit it to 1.5°C.

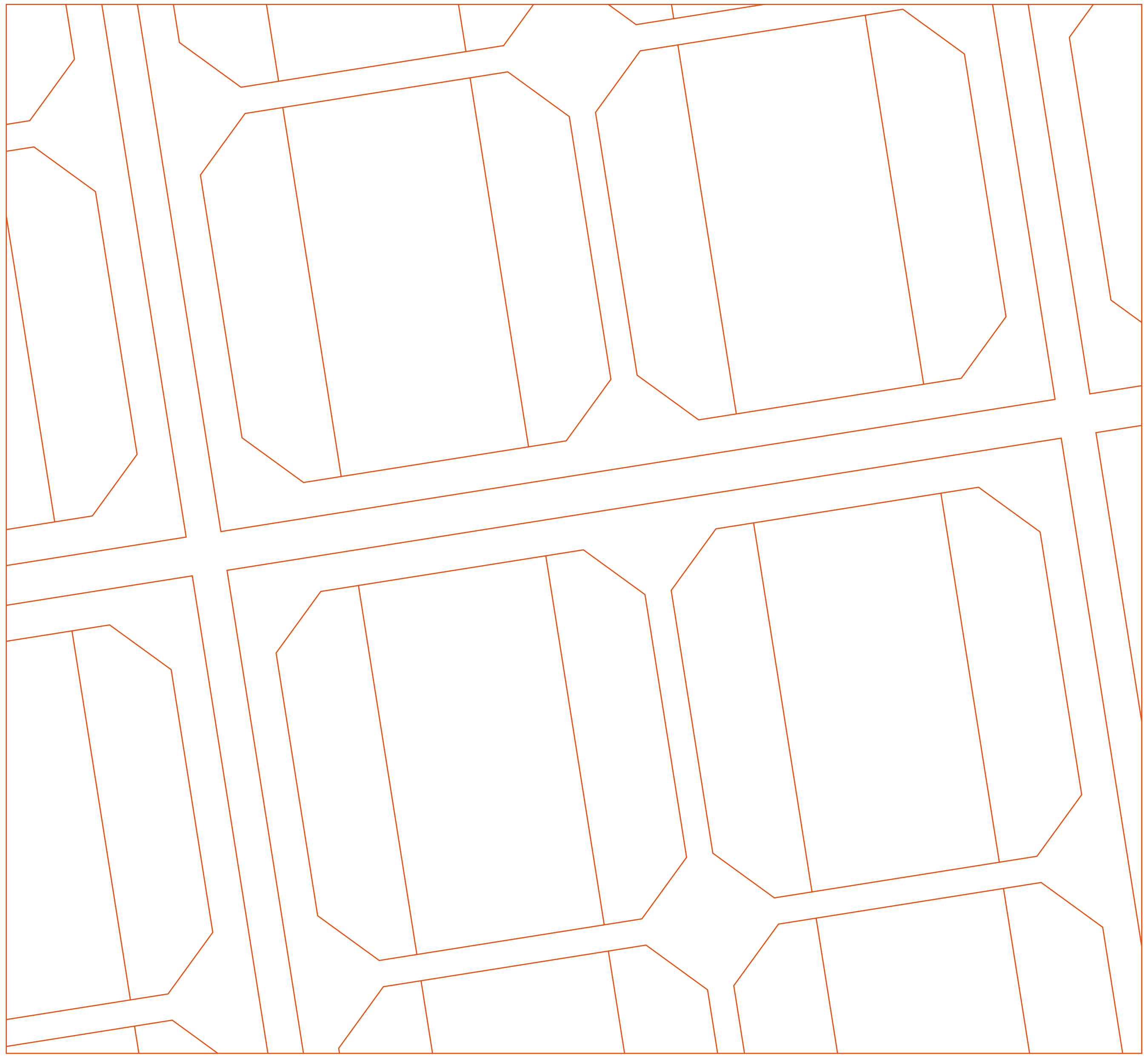
PV is the technology among renewable sources that will guide this new era; indeed, solar radiation is available (almost) everywhere and still has ample room for growth, has yet to express its full potential in terms of technological development, of competitiveness on the markets and of sustainability both in terms of reduction of the environmental footprint and, in particular, as regards the reduction of GHG. To be, therefore, key players of this energy transition, we must be at the forefront along the entire value chain from technology, to the plant, to the proposition on the market and for everything related to sustainability, so managing knowledge and innovation will, therefore, be essential.

We are only at the beginning of the photovoltaic games!

This document aims at providing an overview of the PV market and technology, thus showing where they are now and where they will go in the coming years. In particular, the growth margin that technology will have thanks to the innovations that will be introduced along the entire value chain and the potential in terms of market share growth is highlighted.

The document will show how EGP is on the right path for continuing to play a leading role in the world of PV, having a global vision, from the development of technologies (3SUN factory and Innovation Lab Solar) that allow for better performance with a continuous reduction of environmental footprint, in particular, GHG emissions, the Manufacture of PV systems where, thanks to innovation and digitalization, is always one step ahead than competitors and, last but not least, the great attention paid to the sustainability.

Executive summary



Market Overview

PV installed capacity has shown an exponential growth worldwide in the past few years; in 2019 the PV additional installed capacity has reached 117 GW and such growth will accelerate in the future. PV installed capacity will increase to 2.4 TW by 2030 and to 7.6 TW by 2050 globally, with approximately 27% of the total capacity in 2050 consisting of small-scale or rooftop PV and 73% of utility-scale PV. PV generated electricity will rise from 2% of worldwide-generated electricity today to 22% in 2050, with a CAGR (Compound Average Growth Rate) of around 9.1%.

This growth of solar, likewise few other generation technologies, is fuelled by competitive manufacturing industries that, thanks to continuous innovation, improve productivity and the products they manufacture.

The PV market expansion has dragged key technologies across the overall PV industry value chain, such as crystalline silicon manufacturing, wafer production, cell manufacturing, packaging and system integration. The rise of China's PV industry resulted in the reduction of solar energy utilization cost. Since 1976, a rapid fall in the price of crystalline silicon PV modules has taken place, from 80 $/Wp to about 0.20 $/Wp in 1H 2020; meanwhile, also inverters, balance-of-plant and engineering have shown a noticeable cost reduction. Combining the two effects, a cost decline of utility scale PV plant from an average value of 0.8 $/Wp in 2020 to 0.39 $/Wp global average is expected in 2040.

Some of the cheapest PV projects financed in the last six months will achieve LCOE (Levelized Cost of Energy) of 23-29 $/MWh. Furthermore, benchmark LCOE for solar PV is expected to drop by 61% between 2019 and 2050.

Major analyst firms report expected new investments in Renewables of about 10$ trillion. Solar technology will amount to 40% of those new investments that will be concentrated mainly in Asia-Pacific, Europe and USA.

Europe PV market is booming with a huge increase in 2019 and projections showing record-breaking installations in the coming years. This is a golden opportunity to revive the European photovoltaic industry and to implement an industrial strategy that can ensure the security of energy supply, the creation of highly-skilled and local jobs and to maintain Europe's world-leading R&D in solar industry.

Technology Overview

Solar Module

Due to the remarkable cost reduction, PV is well positioned as an important player in the race for global warming control. Today, PV technology provides for one of the most economically convenient solutions for generating electricity and it continues its growth with more emphasis on efficiency increase, which turns out to have the biggest impact on cost reduction. Raw polycrystalline silicon, commonly referred to as polysilicon, is a high-purity form of silicon that is used as an essential material component in the solar photovoltaic (PV) manufacturing industry. It is the primary feedstock material used for the production of solar cells today. With about 15% price share, poly-Si remains the most expensive material of a c-Si solar cell. The average cost of polysilicon in the last 15 has undergone a significant reduction from about 450 $/kg to about 6 $/kg.

During last 60 years of its life, the solar wafer is characterized by the faster evolution in the lasts 10 years. The drivers for its evolution are the PV technology evolution, thus searching the continuous improvement of the Power Conversion Efficiency (PCE), to reach the Silicon physical limit, and the costs impact of the material in the finished PV modules, thus guaranteeing an always-lower cost of energy for energy producers.

One of the major drivers for the industry has been the push to even higher efficiency; this impulse arises because cell processing costs are subject to the same downward price pressure as in microelectronics, through increased manufacturing volume and processing sophistication. Research activities results show that there are perspectives to further increase solar cells efficiency over 30% in the coming years, thus resulting in cost reduction at levels unconceivable few years ago. PV technology for terrestrial applications are mainly based on crystalline and polycrystalline silicon. Mainstream technologies are based on device architectures and processes proposed in the 80's and optimized to achieve maximum performance and lower costs in the last years. Since then, using the same device architectures, there has been a significant development in the materials performances. Chinese industry is very healthy and dominates the market with more than 90% of share. Some recent solutions, as bifacial modules, can even improve performances in terms of energy production, but a new innovative silicon-based technology is establishing and is known as Heterojunction Technology (HJT) that allows reducing LCOE thanks to higher efficiency and energy production.

Photovoltaic technology is constantly evolving. We have already talked about the technology that will join the HJT in the coming years, namely the tandem, where two cells with different technologies are superimposed to increase efficiency and reach over 30%.

Currently, with regard to the characteristics of the module technology, there is in a transition phase, with the introduction of the new types of larger wafers. The concept of cell division is taken to extremes, as it is divided into 2, 3 even 4 sections. This makes it possible to create modules of ever greater size and power, from about 400 Wp to 500 Wp, 600 Wp up to 800 Wp while maintaining the same level of efficiency. This is happening because the major companies in the market, which are vertically integrated into the value chain, have reached the limit of cell efficiency with the current mainstream technology (PERC), and before making huge investments to change technology, they have focused on methods (half-cell, shingling, multi-busbars, multi-wire, etc.) to increase the power of the module without acting on the cell. This is feasible in a shorter time and with limited investments. At the same time, they acted on the manufacture of wafers by increasing the size and, therefore, the power of the cells.

The first effects of downstream are certainly a reduction in investment (BOS, land and installation costs) for the construction of PV plants. However, some questions still remain (impact on logistics, mechanical resistance and operation issues, reliability, etc.) that do not allow currently clarifying which configuration of the module will become the reference.

With reference to sustainability, the photovoltaic industry is developing technologies to recycle more easily photovoltaic modules, thus reducing the use of high environmental impact and the environmental footprint of the manufacture process.

PV balance of plant

The System Balance involves the components of a photovoltaic solar system with the exception of photovoltaic modules. Following the significant reduction of PV modules prices, the balance of system (BOS) costs have become a crucial factor in overall system costs and thus the levelized cost of electricity (LCOE) as well. Besides warranties for the product and the product performances as well as the degradation of the modules during the operation lifetime, an increase in system voltage and the trend to install more 1-axis tracking systems are important parameters to reduce LCOE.

The inverter is one of the most important components in a photovoltaic system. It is responsible for transforming the direct current (DC) obtained from the sun's rays into alternating current (AC). Within an operating PV plant, inverters are also responsible for more operational functions than any other PV system component. Complex functions involving efficiency, safety, availability and communications are all required to perform consistently and reliably for decades, despite harsh environments with unpredictable and sometimes non-ideal behaviour on both the AC and DC sides. Central PV inverter was the dominant product segment for the global market. These equipment are mainly designed for large arrays of PV modules installed on industrial facilities, buildings and onsite installations. String inverters are the second most widely used product and can be used in an extensive range of applications. In the past few years, they have gained immense significance in terms of rapid technological advancements. These inverters are easier to install and offer lower initial cost per peak watt price. From the technology point of view, the high-power density is the most promising evolution for the next years. With breakthroughs in research of wide-bandgap semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), as well as advanced control algorithms, inverter power density is expected to increase by more than 50% in the next 5 years. Research has shown that SiC can be smaller, faster, tougher, more efficient and more cost-effective. SiC withstands higher temperatures and voltages than silicon, thus making it a more reliable and versatile inverter component.

With reference to the mounting structure, its goal is to support the PV modules sail and orient it properly towards the sun. At the beginning of the PV industry for utility scale projects, PV structures were most fixed ones, namely with a fixed annual tilt depending on the site latitude, facing north or south depending on the hemisphere. To catch an extra-energy, tracking structures started to evolve, mainly as horizontal single-axis trackers, with a single tube oriented north to south, parallel to the ground and able to make the PV modules sail able to rotate from east to west during the day, thus tracking the sun and increasing the yield from 20% to 30% depending on the sites.

From the market point of view, today fixed structures are used when they are more suitable for the installation due to land constraints or when the market prices for the produced energy do not add much value to the extra-energy that could be produced. As of today, fixed structures hold the maximum market share.

Leaving the main equipment of a PV power plant, another essential part of a PV plant includes the electric and civil activities required to connect PV main equipment each other. From technology point of view, an important change took place for DC voltage that passed from 1000Vdc to 1500Vdc in the last years. Increasing DC voltage to 1500Vdc has allowed to make longer strings, thus maintaining the PV design in the range of low voltage, reducing civil and electric costs.

The digitalization of the PV value chain supports the era of energy transition towards a low-carbon economy. It focuses on modules and components manufacturing, E&C design and O&M asset management. These are examples of the steps that have either already been highly digitalized or have the potential to reduce costs further with new technologies. Most of the digital solutions embrace nowadays a data-driven approach, thus trying to get the most from the huge amount of data from the power plants. Anyway, the data-driven nature of the solar energy industry transformation requires understanding the interdependence with the digital market, to ensure access to online activities for individuals and businesses.

Engineering and Construction of PV plant

The rapid expansion of PV plants has had a significant impact in the design and construction, in synergy with the guidelines of increasing safety, respecting the environment and improving competitiveness.
The evolution for safety on construction sites between the previous and the current approach is represented by the transition from a defensive role to an offensive one, so today it is possible to collect elements to predict, anticipate and, therefore, avoid an accident event.
Digitization has brought about very significant changes, starting from development design to construction. The expansion of the Clouds has allowed increasing the computing power and the access to different databases. Access to databases allows assessing the different technical and economic parameters, which can influence the preliminary selection of a project, thus avoiding most of the manual work necessary to generate a layout and the relevant bill of materials, which can be provided directly by the digital system.
Future challenges involve the need to design systems that take into account climate change and their influences on the planet. The PV plants will be increasingly modular and flexible, capable of expressing resilience and designed to be decomposable into materials and components in order to be easily recovered and reused. For this reason, for several years, the E&C Department of EGP has been committed to solving any environmental problem and reducing the impacts on local communities linked to the construction of its own power plants. Based on this objective and applying the created shared value (CSV) approach, E&C has developed the "sustainable construction site" model.
Our vision for the future is a construction site intended as a safe digitized, automated and robotized workplace, in harmony with the environmental context.

Operation and Maintenance

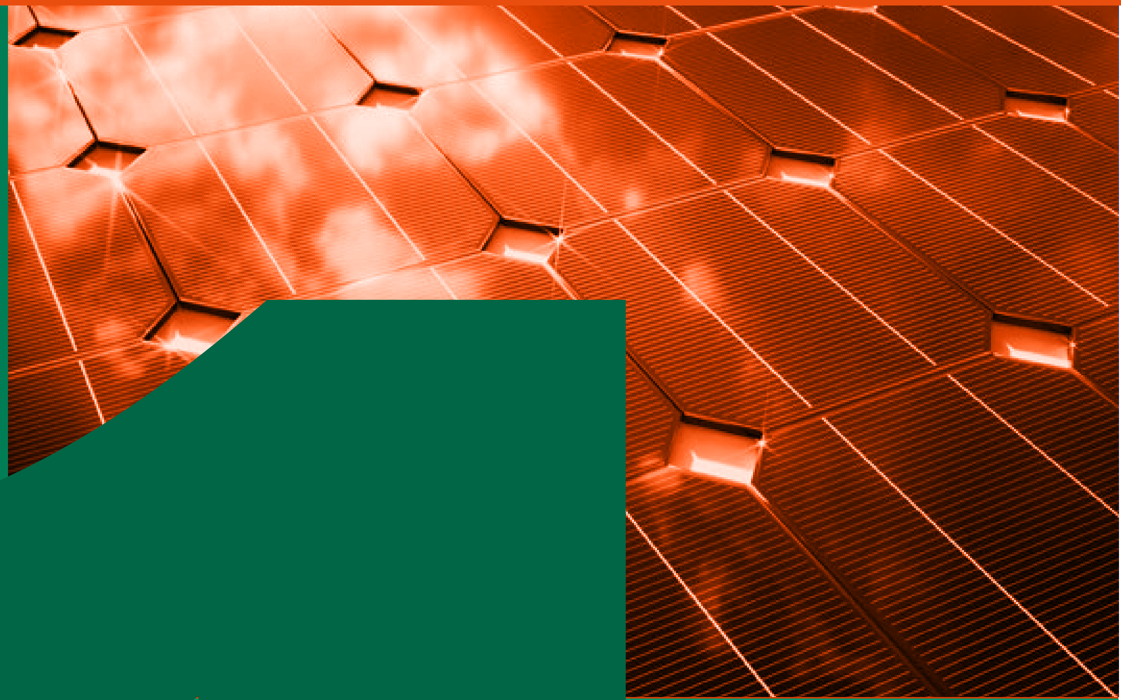
The lifecycle of a PV project is divided in the following main phases: development, engineering & construction; operation & maintenance and dismantling or repowering. The O&M phase is by far the longest, so a professional operation & maintenance service ensures that the photovoltaic system will maintain high levels of technical and, consequently, economic performance over its lifetime.
In fact, during the operation and maintenance period, EGP is studying and applying the newest and best technologies to better improve the performances of the plants, to reduce the labour costs, to forecast and detect the faults in the most efficient way and to help the workers, passing from a rough approach, made with screwdrivers and wrenches to a smart method, with high-tech tools and automated machines. In this context, EGP's O&M is leveraging also on RoBoost Program to deploy robotized ready-to-market solutions, ready to be integrated in the value chain of activities and the main purposes of robotization are economic benefits and savings and hours on added value activities for people in a total sustainable perspective.
The O&M phase looks also to the sustainability criteria to reduce the impact of the PV plants in the local environment, to be as green as possible and sustain the local community. In this way, the PV plants may be considered as an opportunity and as a resource for the local environment.

Innovation challenges from a utility perspective

To maintain its leadership on renewable sources, EGP strongly leverages innovation. In particular, with regard to solar, it covers the entire value chain, from the development and production of technologies with maximum efficiency and productivity to the development of various innovative projects concerning the development, construction and O&M plant, end of life and plant, in order to guarantee the reliability, duration and, consequently, the performance and environmental and economic sustainability of photovoltaic systems.
EGP leverages its internal skills to develop innovative solutions and implements an open approach towards the outside through the research and collection of innovative proposals and solutions (one of the most channels it uses is its global network of Innovation Hubs). With regard to solar, EGP has developed a technological hub that includes the research of the 3SUN factory and the Innovation Hub&Lab through which it develops and studies innovative solutions in the photovoltaic industry.

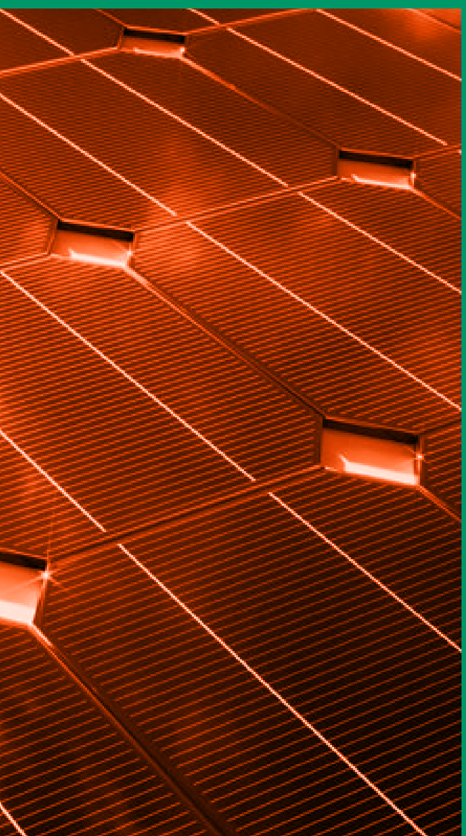
Sustainable impact in PV industry

In the last decade, sustainability awareness has been increasing in many ways, but one of the most remarkable shifts has been the growing focus on sustainability by citizens, pushing public and private sector to accelerate the transition towards a sustainable world.
Sustainability integration in the business of private sector companies is an ongoing unstoppable process in this period.
Environmental sustainability is one of the focus, considering the attention that climate change has reached and the importance of GHG emissions reduction in order to avoid the planet temperature increase.
Nevertheless, also social sustainability has been gaining more and more attention, especially for topics such as respect of Human Rights, as rejection of forced or compulsory labour and child labour guaranteeing just and favourable working conditions, thus taking into account the rights of communities and people.
Moreover, to speed up the transition to a sustainable world, the current way of manufacturing goods is going to be rethought, thus passing from a Linear to a Circular Economy model, based on the principles of redesign by avoiding waste and pollution and keeping products and materials in use and regenerating natural systems.



Chapter

1 Market overview



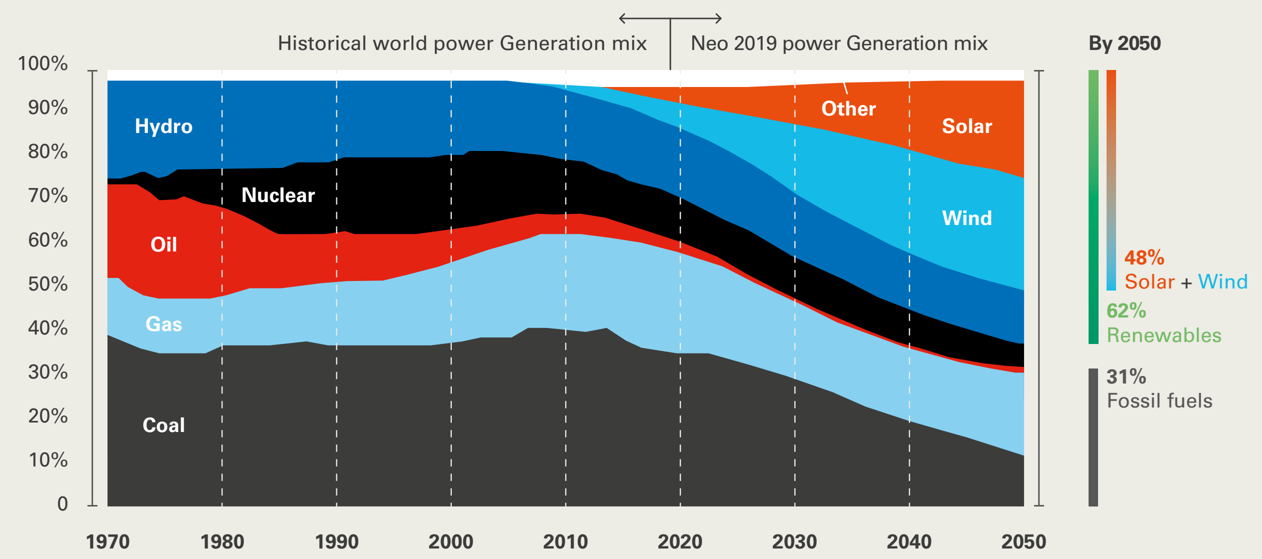
1.1

The role of PV in the energy transition era

Fossil fuels have governed a consistent 60-70% share of the global power generation mix since the 1970s. By 2050 cumulative installed capacity reach more than 19,000 GW, solar and wind provide almost 50% of the world's electricity, with hydro, nuclear energy and other renewables supplying a further 21%. Coal generation drops by half and accounts for 12% of electricity in 2050 compared with 37% today. It's expected only 31% of the electricity production worldwide to result from burning fossil fuels by 2050, down from 63% today.
Global installed capacity shifts from 57% fossil fuels today to two-thirds renewables by 2050. Least-cost deployment of cheap renewables, supported by li-ion batteries, demand-side flexibility and peakier gas plants, keep the power industry on a track compatible until 2030 with a 2 degrees Celsius scenario. An explosion of cheap wind and solar generation, and then cheaper batteries will likely push coal out, whose generation cost is worsened by fees on CO2 emissions, in many Countries. By 2032, there is more electricity coming from wind and sun in the world than from coal. Solar industry is characterized by the most growth, rising from 2% of world electricity generation today, to 22% in 2050, an annual average growth rate of 9.1%. Wind generates 26% of the world's electricity in 2050, compared with 5% today. Hydro industry is characterized by a very modest growth, and nuclear segment stays practically flat, the former constrained by resource availability and the latter by a combination of high costs and a lack of flexibility to complement cheap renewables. The 62% increase overall in electricity generation by 2050 requires 15,219 GW of new generation.

Fig. 1.1

Power Generation mix



By 2050, renewables reach very high penetration rates in markets across the world. Iberia, Brazil, Italy and Germany are close to 100% renewables as these Countries complement strong wind and solar growth with significant hydro resources. Nordics Countries, France, Canada, the U.K. and Mexico are all over 85%, Australia and Turkey are both around 80%. With reference to the other major economies, Japan reaches 78%, India 63%, China 62% and the U.S. 43%.
PV technology is modular and has no inherent economies of scale. Wind turbines have grown larger over time, but the technology is also modular, with wind farms composed of multiple individual units.

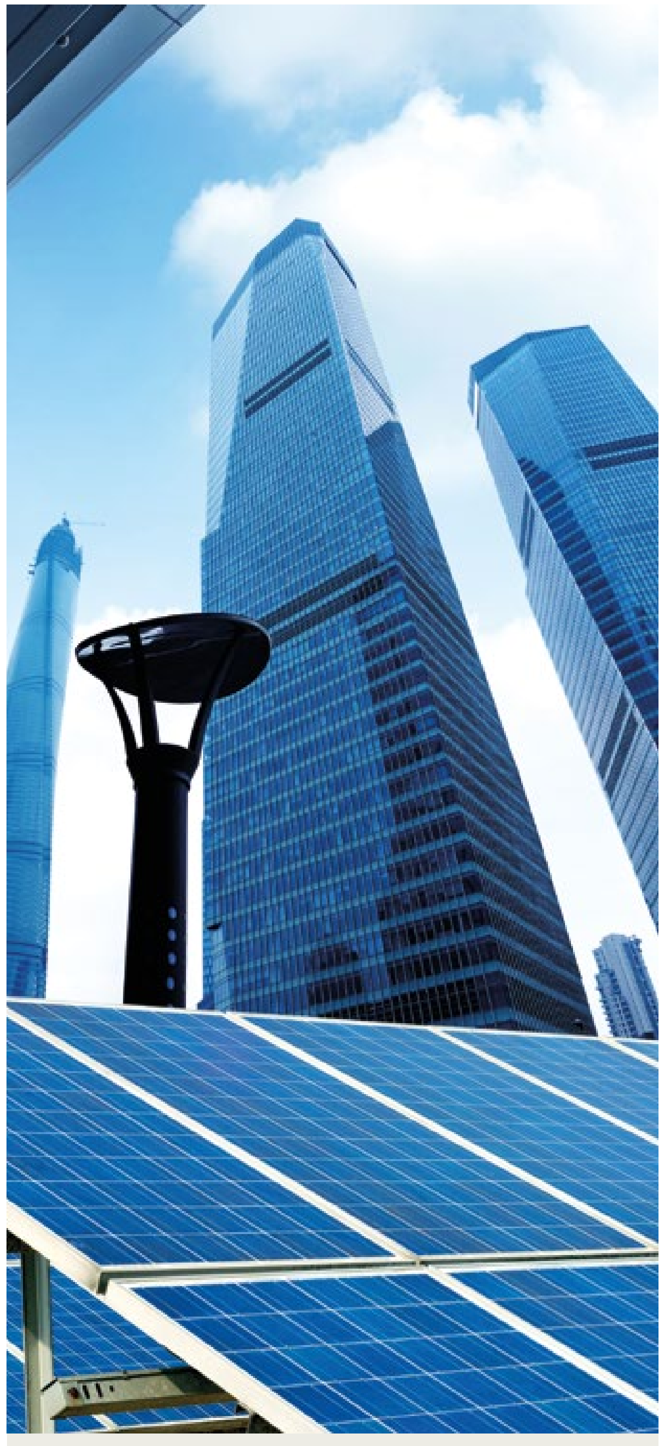
Since 1976, there has been a rapid fall in the price of crystalline silicon PV modules, from 80 $/W to 0.21 $/W in H1 2020. The combination of price and volume data describes a learning rate – the cost reduction per doubling of deployed capacity – of about 28.5%. This steep learning curve is the result of technology innovation, economies of scale and manufacturing experience. From early 2000, in the short terms, the PV modules prices fluctuations have been driven also from unbalances in the supply and demand. Every time that a shortage period arose, the market was characterized by huge investments for the development of additional manufacturing capacity, thus contributing to significant prices reductions.

1.2

Historical market development and short-term outlook

In 2019, 117 GW of solar was installed globally, thus representing a 13% growth over the 104 GW additions the year before and marking a new solar record. Cumulative installed solar PV power capacity increased by 23% to 634 GW by the end of 2019, up from 517 GW in 2018. That means that total solar power has grown by nearly 400 times since the start of the century, when the grid-connected solar era basically began with the launch of Germany's feed-in tariff law. Looking back only 10 years, the world's total installed PV capacity increased by over 1,500% – from 41.4 GW in 2010.
In 2019, more solar PV segment was deployed (117 GW) than all fossil fuels and nuclear ones together (48 GW). Solar segment also added more capacity than all renewables combined—including large hydro sector (15 GW) —and had twice as much installed than wind power (61 GW).
Slower growth in Asia's leading market, i.e. in China, and a somewhat smaller contraction in India, have stopped the further rise of the Asia-Pacific region. Asia Pacific area maintain its strong solar leadership in 2019, thus representing 58% of the global solar power generation capacities (the same percentage as 2018). Additions of 67 GW in 2019 resulted in 368 GW of total installed capacity.
The strong growth year of the European solar pioneers, on the other hand, had no effects on market shares either - the continent finally stopped its several yearlong market losses, but the 2019 shares stayed at the level of the year before, at 24%.
With additions of 23 GW, Europe kept its second position based on a cumulative PV capacity of 149 GW. The Americas were again the world's third largest solar area in 2019 – with a cumulative installed capacity of 99 GW and a 16% stake, which means 1%-point yoy growth.
The strong activity in the Middle East and Africa (MEA) had a little impact on the region's solar development last year. With a total solar capacity of 17 GW, its world market share moved up 2.7% in 2019, from 2.0% the year before.
China's market declined for the second year in a row led to 'only' 30 GW of newly-installed capacity in 2019. This is a 32% decrease from the 44 GW installed in 2018 and a 43% decrease from its all-time record of 53 GW in 2017; it was even 13% less than the 34GW of China added in 2016. Still, China remains the world's largest market by far, thus adding over twice as much solar power capacity than the second-largest market, and as much as the top three markets combined.
The United States were characterized by an almost 20% market uptick to 13 GW, from 11 GW the year before, thus providing enough cushion to comfortably maintain its rank as the world's second largest solar market. The main growth driver was the looming decrease of the federal solar investment tax credit (ITC), which dropped from 30% in 2019 to 26% in 2020, and was complemented by several State renewable portfolio standards. The bulk of new capacity came from utility-scale solar segment, which is traditionally the largest PV segment and was responsible for 63% of newly installed capacity. While residential solar segment grew by 15% for a new installation high of 2.8 GW, another very positive solar development took place in the corporate sourcing segment. From around 9.6 GW of solar PPAs signed in 2019, around 8.6 GW were inked in the US. With over 30 GW of new large-scale projects announced in 2019, a pipeline that has added up a total to 48 GW, solar's future looks bright in the US.
The world's third largest PV market, i.e. India, decreased in 2019. India added 8.8 GW, down 11% from 9.9 GW in 2018, which has been already significantly less than the record 11.5 GW installed in 2017. There are multiple reasons for the decrease of solar demand in India: beyond the earlier issues with the goods and services tax (GST), safeguard duties, land issues, access to financing and grid quality, or even missing transmission lines, a new State government in Andhra Pradesh started to renegotiate PPAs for multiple GWs with local solar power producers. In fact, due to liquidity constraints, there have been several instances in India's largest solar market in 2019, Karnataka, and Uttar Pradesh, where State power distribution companies attempted to renegotiate or cancel the signed PPAs with solar and wind power developers. The rooftop market, which represented only around 15% of 2019 installed capacity, also decreased, thus adding only 2.8 GW. Nevertheless, around 35 GW of tenders were announced.
Unlike in the previous three years, Japan added a little more solar segment than the year before, thus installing 7.0 GW in 2019, up 4% from the 6.7 GW connected in 2018. A new entry in the global top 5 is a Country that was probably not on many people's radars: Vietnam that added 6.5 GW in 2019, up 6,400% from 97 MW in 2018. The surge is due to a very attractive and uncapped feed-in tariff scheme, offering 20-year FiT contracts for 9.35 US cents/kWh.
When looking at individual Countries, it should be noted that China's 32% market contraction in 2019 has not affected its strong solar dominance (in 2018, China's share was at 34%). China was trailed by the United States (12%), Japan (10%) and Germany (8%). The US' cumulative installed PV capacity reached 76 GW, Japan's 63 GW meant a 10% share, and Germany's 50 GW resulted in 8% share. While India again had only a great solar year in 2019, its 1 GW market decline is not mirrored in the total global power rankings – its 42.0 GW of total installed solar capacity was good enough to easily defend its fifth place and even up its share to 7% from 5% in 2018.
All other solar markets considerably lag behind the top 5. In that group, there are only two noteworthy changes: following Italy at 21 GW, Australia at 16 GW and UK at 13 GW, South Korea now turned into a +10 GW solar power generation capacity market of 11 GW by the end of 2019. Moreover, Spain, on grounds of its massive growth streak adding 4.8 GW, which led to a total installed solar capacity of 10.6 GW, re-entered this top 10 list, thus replacing France.

Europe kept its second position based on a cumulative PV capacity of 149 GW

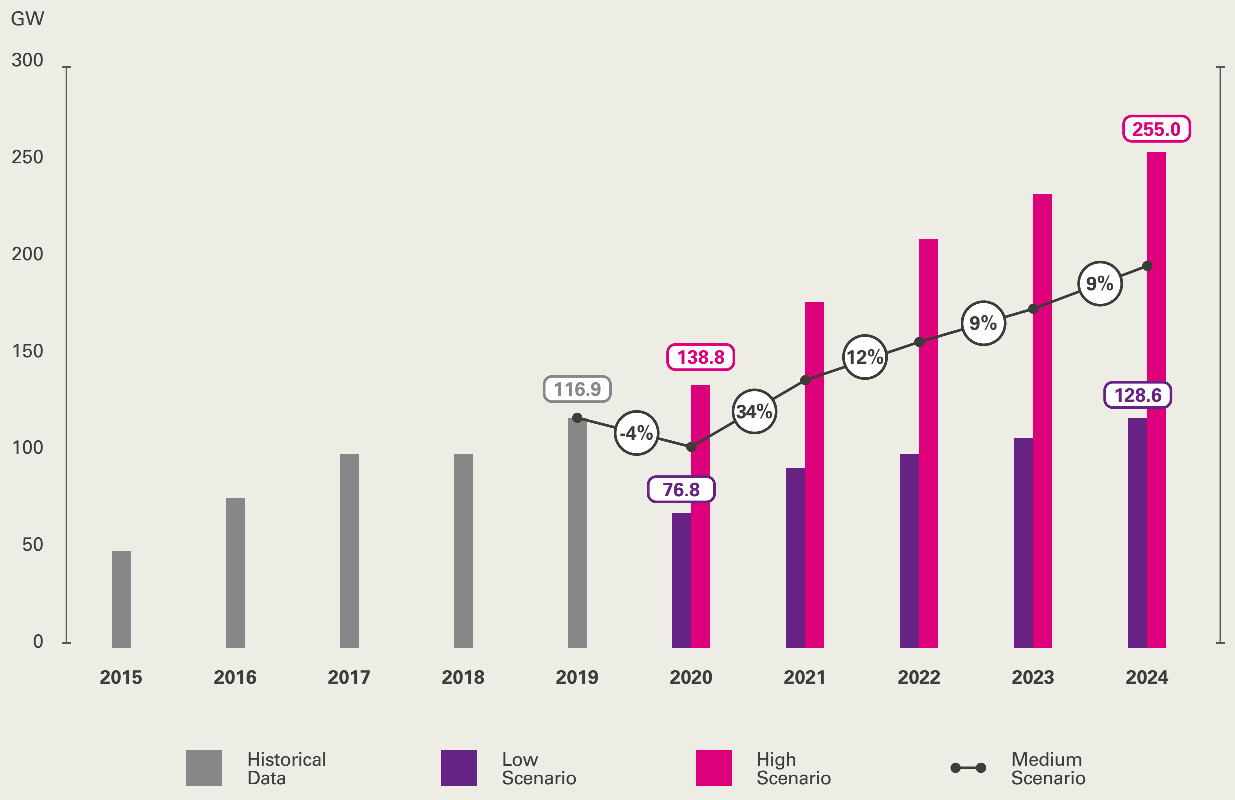


1.2.1 Forecast 2020-24 and Covid-19 impact

All leading solar market analysts have significantly decreased their 2020 forecast during the first half of this year to account for the impact of COVID-19 on their market, from more 140 GW to a range of 90-115 GW.
No expected the virus to pose a big risk in the medium-term for utility-scale solar, while Commercial/industrial and residential sectors might see negative impacts for some time as businesses and consumers will not necessarily invest in solar if they are struggling from a longer economic downturn. Here, the economic stimulus package will have a very important role, indirectly to boost national economies to enable a healthy business environment, but also directly, offering financial incentives for solar investments, which some countries and regions have already announced. About this the European Commission's Green Deal calling for carbon neutrality by 2050 and a much more ambitious reduction target for CO2 emissions of 50-55% instead of today's 40% by 2030, will have to make use of low-cost and versatile solar to succeed. As the Green Deal will be core to the EU's COVID-19 economic stimulus package, solar is expected to access funds from a number of incentive tools, such as InvestEU, which will support renovation of buildings.

Fig. 1.2

Global Annual PV Capacity Scenarios 2020- 24 (GW)

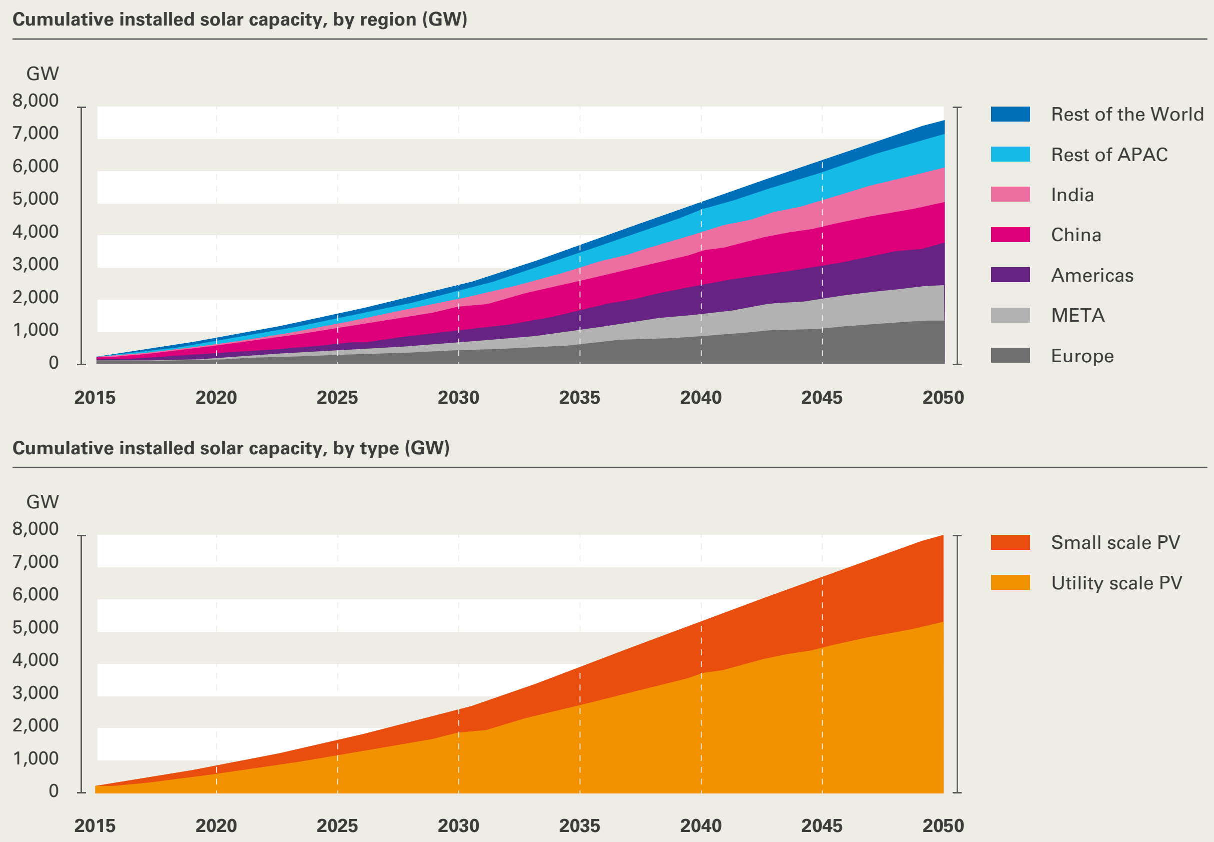


1.3 Medium and long-term market trend

Global solar capacity is expected to increase to 2.4 TW by 2030 and to 7.6TW by 2050. About 27% of the 2050 total is expected to be small-scale or rooftop PV and 73% utility-scale PV with a capacity greater than 1 MW. The market for solar new build grows fairly steadily at a rate of 5% year-on-year from 2018 to 2040. Then it slows when Europe, in particular, reduces the rate of new build as, by that point, 86% of generation in Europe has been already coming from renewable energy. The global PV market exceeds 200GW per year for the first time in 2029, although active government policy in multiple markets may bring this point forward.

Fig. 1.3

Cumulative installed solar capacity



1.4

LCOE trend

PV and onshore wind are now the cheapest sources of new bulk power generation in Countries that make up two-thirds of world population, 72% of global GDP and 85% of electricity demand.

In China, PV's largest market, LCOE sits at 38 $/MWh, following a rapid uptake in better performing monocrystalline modules. This is now almost as low as running China's coal-fired power plants at around 35 $/MWh. Globally, some of the cheapest PV projects financed in the last six months will be able to achieve an LCOE of 23-29 $/MWh, thus taking over competitive returns to their equity investors. Those can be found in Chile, U.A.E., Australia and China where solar segment will increasingly undercut existing fossil fuel power plants. Coal remains cheaper in Japan and Southeast Asia, but we expect a tipping point to be reached by 2025.

Benchmark LCOE for solar PV, onshore and offshore wind is expected to drop by 61%, 45% and 50%, respectively, between 2019 and 2050. In the near term, the biggest share of these average cost reductions is driven by the convergence of costs in emerging markets to more mature ones.

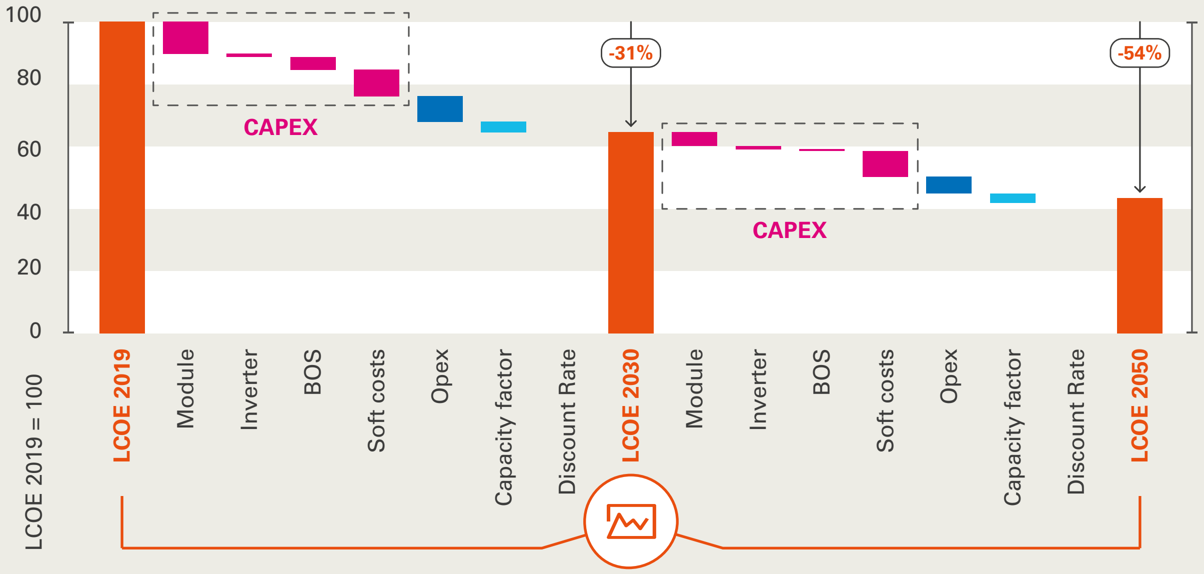
Technology continues to play a role as cheaper, so more efficient PV modules and larger turbines are able to extract higher capacity factors and continue to enter the market. No breakthrough in technology is needed to attain these cost reductions. They are based on incremental improvements to existing technologies. Over the next 30 years, the total cumulative capacity additions including replacements and repowering for solar PV, onshore and offshore wind will be 8 times, 4 times and 21 times than today's level, respectively. In the long term, improvements to technology, driven by continuous learning as more capacity is deployed, are expected to continue driving reductions across the entire value chain.

Solar PV LCOE reductions driven by:

- **Turnkey system.** On a system level, projects will be increasingly designed to optimize the value of the electricity produced rather than minimizing the cost. Increased module warrantees mean that a project lifetime of 30 years and beyond will become the standard.
- **PV module.** The near-term cost reductions are driven by continuing efforts to reduce the use of expensive raw materials, the shift to higher-efficiency monocrystalline wafers. Bifacial modules will quickly join the mainstream, thus resulting in a surge in efficiency at very little extra cost. Half-cell technology and large modules also offer potential cost reductions on a per-watt basis without requiring expensive capex upgrades. After 2023, the share of monocrystalline wafer n-type technologies is expected to increase, with heterojunction technology offering a path to continuing efficiency increases.
- **Inverter.** Cost reduction is driven by the switch to higher voltage and power densities for utility-scale inverters, commoditization and competitive pressure with the presence of Asian manufacturers, particularly, from mainland China. As the "brain" of the PV system, they can perform diagnosis on the PV system, thus allowing a reduction in opex. Inverters are also becoming increasingly digital and can perform grid services such as reactive power, frequency, and voltage regulation. Integration with the battery component of hybrid PV systems will offer opportunities for further cost reductions.
- **BOS (other hardware).** Mounting system, DC wiring, grid connection, site arrangement and other hardware cost reductions are primarily driven by standardization, scale (average plant size increase) and increased module efficiency. Depending on geography and site specifications, single-axis trackers (SATs) are being used increasingly in conjunction with bifacial technology, which is greatly improving the LCOE of utility-scale plants.
- **Capacity factors.** Product differentiation is expected to enable developers to match modules with site conditions to optimize low light performance, temperature coefficients and system degradation and to extract the best site-specific yield. Improvements in module topology, higher-voltage modules, more efficient inverters and more widespread use of module-level power electronics will contribute to increased average yields.
- **Operating costs.** There is a strong potential for cost reduction thanks to the ever-increasing penetration of digitalization and automation in the management of plant operations.

Fig. 1.4

Solar PV LCOE cost reductions, by component, 2019–50



Note: BOS = System Balance, Soft cost = installation and development.
Discount rate is assumed to be constant over the forecasting horizon.

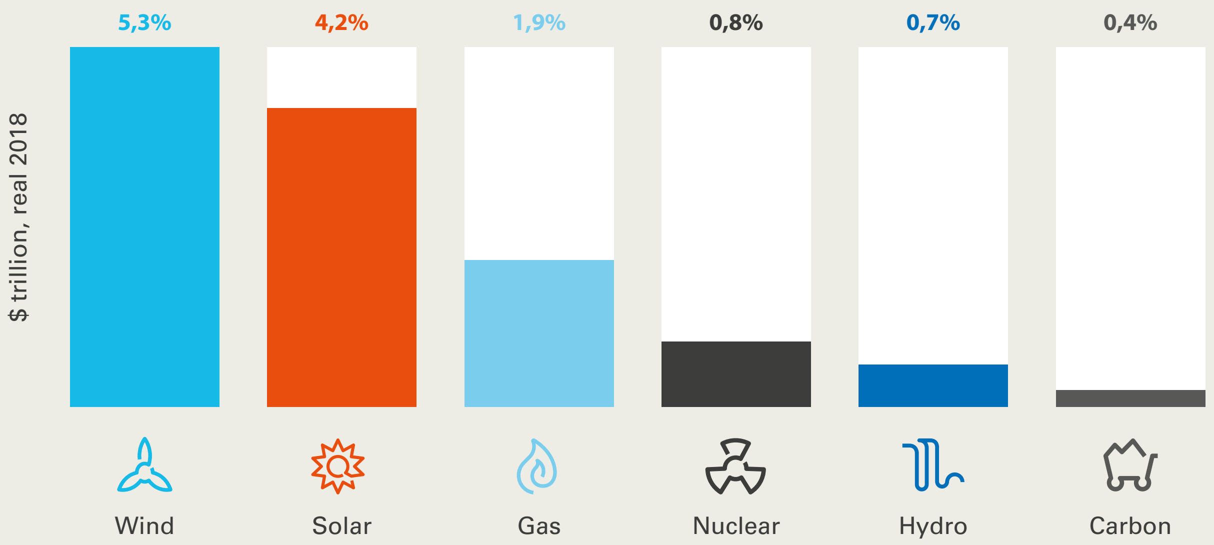
1.5

Investment trend

Investments in renewables outpaced all the other investments in the energy sector during the last five years. Solar and wind technologies, in particular, were the ones with the highest concentration of expenditures.
In 2020, the COVID-19 pandemic has involved the largest drop in global energy investment in history, but clean energy investment, especially for utility scale renewables projects, has been relatively resilient.
Looking at the future, major analysts' firms agree that approximately 10 $ trillion will be invested in renewables until 2050. New investments on solar technology accounts for 40% of the above-mentioned value (4 USD trillion). Asia-Pacific area will be the top runner region with approximately 4 $ trillion of expected new investment, second will be Europe with almost 2.5 $ trillion and third USA with 1.5 $ trillion. Focusing on the end uses, utility-scale PV plants outweigh distributed small-scale systems by a factor of five.

Fig. 1.5

Investment by technology, 2019-50



It is worth to note that among the conditions to make those investments happen, significant economic resources shall be dedicated to networks and storage, during the next 30 years. Distribution and transmission grids investments (approximately 11 $ trillions), from one hand, will be the key to increase the acceptance of unpredictable generation systems, while the storage system investments (almost 1 $ trillion is expected) will enhance the PV's ability to dispatch the generated electricity.

1.6

PV off-taking

There are several ways to commercialize renewable power produced by utility scale PV plants globally. Historically, the vast majority of projects would be built after receiving the certification that the project could benefit a Feed in Tariff scheme or other incentive created by government-owned entities. As the cost of PV panels fell and power produced from PV segment became competitive with thermal power production sources, government incentives started to disappear and were transformed into auction-based systems where only developers offering the lowest price would be selected to enter into a long-term sales agreement with the government-owned entity running the auction.
As in other industries, the private sector has then gradually been replacing governments in the support of renewables. As the global consciousness of global warming and the need to support the renewable sector have spread into the public, large companies started using renewables as a marketing tool to differentiate themselves from their competitors. Today most of the world's large companies have made sustainability pledges with the engagement to consume all their power from renewable sources by a certain date in the future.
In the USA mainly, companies started doing this through the signing of long-term power purchase agreements (PPA) directly with the developers of the projects. The main channel of sales for renewable power is today in the USA. At a global level, PPAs are executed also in Mexico, UK, Australia, India, South Africa, Morocco and many Countries in Europe and South America.
These contracts usually last at least ten years even though the trend is to reduce tenors to 7 or even 5 years as the buyers are reluctant to engage into such long-term deals at a fixed price when they see that historically prices have been falling continuously.
For this reason, we are looking at new types of price structures in the PPAs such as market following (price is indexed to the spot price). These structures can have a discount to the spot price, a floor price and a cap price. In some cases, the price can be indexed to another commodity price like Natural Gas or Metals. Almost all requests from buyers now include market following structures and we expect this to grow in the future.
Apart from the price, we are also assisting to an evolution in the volume structure of the contracts. Historically, buyers would buy the "as generated" power from the plant with associated variability and risk. Today most buyers refuse to take this risk and prefer to receive a fixed pre-set amount of energy, either baseload or peak. We are assisting to more and more requests for "as consumed" structures where the buyer only purchases the power profile it consumes, thus leaving the balancing risk to the developer. We expect "as consumed" structures to be the standard in the future.
This is particularly true for PV power as the cannibalization effect due to high penetration in certain areas is expected to gradually reduce the price of power during daytime. It is one of the main reasons why PV is perceived today as less attractive than wind segment for which buyers are ready to pay more.
Apart from direct PPAs with C&Is, there are other selling channels emerging today, mainly, involving financial players; some of which have created trading platforms where "standard PPAs" are exchanged amongst producers, consumers and traders. As in other markets, we expect this to grow in the future and be the main channel to sell renewable power.
To conclude, selling PV power is becoming more and more challenging mainly because of the cannibalization effect whose damage can already be ascertained in some areas of the world. We believe that the future of selling PV will depend on the ability from producers to associate it with another means of power production to "flatten" the produced profile. These can be short term flexibility solutions like batteries, hybrid PV/wind plants or blends PV/existing Hydro or PV/portfolio and traded energy.

1.7

Industrial solar strategy

When solar PV systems were first recognized as a promising renewable energy technology, subsidy programs, such as feed-in tariffs, were implemented by a number of governments in order to provide economic incentives for investments. For several years, growth was mainly driven by Japan and pioneering European Countries. As a consequence, cost of solar declined significantly due to experience curve effects like improvements in technology and economies of scale. Several national programs were instrumental in increasing PV deployment, such as the Energiewende in Germany, the Million Solar Roofs project in the United States and China's 2011 five-year-plan for energy production. Since then, deployment of photovoltaics has gained momentum on a worldwide scale, thus increasingly competing with conventional energy sources. In the early 21st century, a market for utility-scale plants emerged to complement rooftop and other distributed applications. By 2015, about 30 Countries had reached grid parity. Due to its rapid economic development, China started facing pressure towards energy and environment related to fossil energy shortage and emission issues. Consequently, since 2000, the Chinese government launched national policies that promoted the development of renewable energy sources, such as PV industry. Many other factors influenced the solar industry development, such as the policy-oriented market, subsidies, feed-in-tariff and sustainable policies.

The market growth also promoted the key technologies related to the PV industry chain, such as crystalline silicon manufacturing, wafer production, cell manufacturing, packaging and system integration. Chinese PV cell technology developed fast towards becoming highly efficient and low cost.

The rise of China's PV industry resulted in the reduction of solar energy utilization's cost.

Solar segment is booming in the EU, with [a more than] 100% market increase in 2019 and projections showing record-breaking installations in the coming years. This is a golden opportunity to implement an industrial strategy for the solar industry that can ensure the security of [energy] supply, the creation of highly-skilled and local jobs and to maintain

Europe's world-leading R&D in solar.

The organization has long called for favourable treatment for solar segment in terms of taxation, thus reducing red tape, accessing finance and easing land acquisition for project development, arguing the EU needs to do more to help the industry. Europe should aim for 30 million more PV rooftops by 2030 and could play a key role in decarbonizing polluting industries such as steel and chemical manufacturing.

It is crucial that no European regions or communities are left behind in the upcoming climate transition and solar segment, as the most cost-effective, scalable and popular energy source can play a significant role in order to ensure a beneficial transition for all.

For solar segment, the European Commission has committed to mobilise at least 1 € trillion of investments over the next decade in order to support a just and green transition, and the European Investment Bank will increase the share of climate-dedicated financing from the current 25% up to 50% in the next five years. This is cause for celebration, as the redirected funds will help continuing the EU's upward trajectory of solar deployments.

Following this trend, new sectors are becoming important part for solar segment like digitalisation. Many companies have a long history of using digital technologies to improve safety and increase production. Further cost-effective energy savings can be achieved through advanced process checks and by coupling smart sensors and data analytics to predict equipment failure. Digital technologies have also had an impact on the way products are manufactured. Technologies such as industrial robots and 3D printing are becoming standard procedures in solar applications. These technologies can help increasing accuracy and reducing industrial scrap.

Ultimately, Europe can still rely on robust pillars given by technology competence and industrial knowledge and it can reconquer its market share to become a primary player in the energy transition. Through technology innovation, there is the opportunity to rebuild a leading PV industry in Europe, able to compete with mainstream technology, thus proposing a new business model oriented to greater sustainability of photovoltaics and, above all, to a circular management model.

Chapter

2 Technology overview

2.1 PV module value chain

2.1.1 Introduction

Due to the remarkable cost reduction, PV segment is well positioned as an important player in the race for global warming control. Today, PV technology provides one of the most economically convenient solutions for generating electricity and it continues its growth with more emphasis on efficiency increase, which turns out to have the biggest impact on cost reduction. Research activities results show that there are perspectives to further increase solar cells efficiency, thus resulting in cost reduction at levels unconceivable few years ago. These module cost reductions have contributed to an even more significant reduction in the levelized cost of photovoltaic generated electricity, as documented by the lowest price bids for international PPAs for the long-term supply of electricity.
A major driver for the industry has been the push to even higher efficiency; this impulse arises because cell processing costs are subject to the same downward price pressure as in microelectronics, through increased manufacturing volume and processing sophistication. However, other costs, such as those of glass and polymer encapsulants, aluminium frames, junction boxes and cell interconnectors, do not benefit to the same extent. Improved cell efficiency directly decreases all these less tractable costs, by reducing quantities required for a given output.
Likely, this will imply the opening towards new markets development, such as building integrated PV segment and usage in the transportation sector, because the efficiency increase will involve the PV modules area and weight reduction.

2.1.2 Polysilicon

Raw polycrystalline silicon, commonly referred to as polysilicon, is a high-purity form of silicon, which is used as an essential material component in the solar PV manufacturing industry. It is the primary feedstock material used for the manufacture of solar cells today. Polysilicon feedstock generally consists of large rods, which are broken into chunks or chips of various size, then casted into multicrystalline ingots. The ingot materials are subsequently sliced into silicon wafers suitable for solar cell manufacture.
With about 15% price share, poly-Si remains the most expensive material of a c-Si solar cell. PV demand reached record levels, with global installations surpassing in 2017 100 GW for the first time ever.

Technology trend

The purity of silicon used to manufacture solar wafers can be considerably lower than electronic grade silicon used to produce semiconductors for microprocessors, thus allowing for the use of lower manufacturing cost technologies such as Siemens reactors, Fluidized Bed Reactors (FBR) and directional solidification furnaces.
Siemens and FBR processes remain the main technologies to produce poly-Si. Polysilicon producers are succeeding in lowering cost by reducing energy consumption, thus ramping up new factories to huge scales and optimizing the manufacturing processes. Nearly all polysilicon is produced using the modified Siemens process, the most mature technology. Today FBR processing has a share of <5% and the expectation is that this figure will not increase significantly against the mature and further optimized Siemens process (the share is around 95%). Other technologies will remain available in the market but they are not expected to yield significant cost advantages.
Looking at the polysilicon process developments, it seems that no revolutionary technology improvements or major rival purification methods will be available at industrial level in the short term. There is no likelihood of a disruptive technology emerging within the next 10 years to significantly reduce polysilicon production costs due to inherent chemical process limitations, especially taking into account the increasing purity requirements for high efficiency cells.
High purity polysilicon will continue to be produced using the three principal technologies employed over the past 50 years with constant improvements that use trichlorosilane or monosilane as precursor gases, and deposition in a Chemical Vapor Deposition (CVD) or FBR reactor:

1. **Siemens process produces chunk polysilicon.**
2. **Union Carbide (UCC) process produces granular polysilicon (FBR process).**
3. **Ethyl Corporation process produces granular polysilicon (FBR process).**

In recent years, the traditional Siemens process has been modified by new entrants to employ a hydrochlorination reactor, to both produce trichlorosilane (TCS) and to convert silicon tetrachloride (STC) back to TCS rather than the conversion of STC into TCS through a separate converter process, thus simplifying the overall loop and reducing CAPEX and OPEX.
The granular polysilicon technologies will grow in importance due to their inherent advantage and granular (bead) polysilicon, so it is perfectly suited to continues mono-crystal growth technologies (Continuous Czochralski process) that is likely the dominant technology for growing mono-crystal rods.

Market share

In the last 10 years, there has been a strong growth in production capacity passing from about 175 kTons of 2010 to around 500 kTons of 2019. The short-term forecast is to overcome 600 kTons of production in 2024.
The Chinese companies cover about 40% of the market (Tongwei, GCL, DAQO, Xinte) and the remaining 60% is covered by companies from the rest of the world.

Production cost and price trend

In the last 15 years, it has passed from almost 500 \$/kg to about 7-8 \$/kg today, so it is clear that by 2020 we will have achieved most of the feasible and significant gains in terms of cost reduction.
Market prices for solar grade polysilicon are not expected to deviate significantly from 2020 prices. Lowest cost producers are expected to reduce costs further by up to 2 \$/kg over the 2020-2024 period; subsequently, a further decline to less than 6.5 \$/Kg is expected in 2024.
Prices of polysilicon depend on supply and demand but also on volume, quality (purity, morphology), spot pricing and the contract market price. Considering that PV silicon crystalline will remain the dominant technology for the near future (>90%), polysilicon pricing is highly dependent on the evolution of downstream demand for PV panels.
A longer-term risk for polysilicon prices stems from new wafer manufacturing technologies that can produce wafers directly from chlorosilanes. At sufficient scale, they may affect the market for wafers and, hence, polysilicon demand and prices. It is too early to state whether these processes will be successful and, in any case, this is more likely to have a material impact on polysilicon prices only after 2024.

Fig. 2.1
Polysilicon manufacturing process overview from quartz

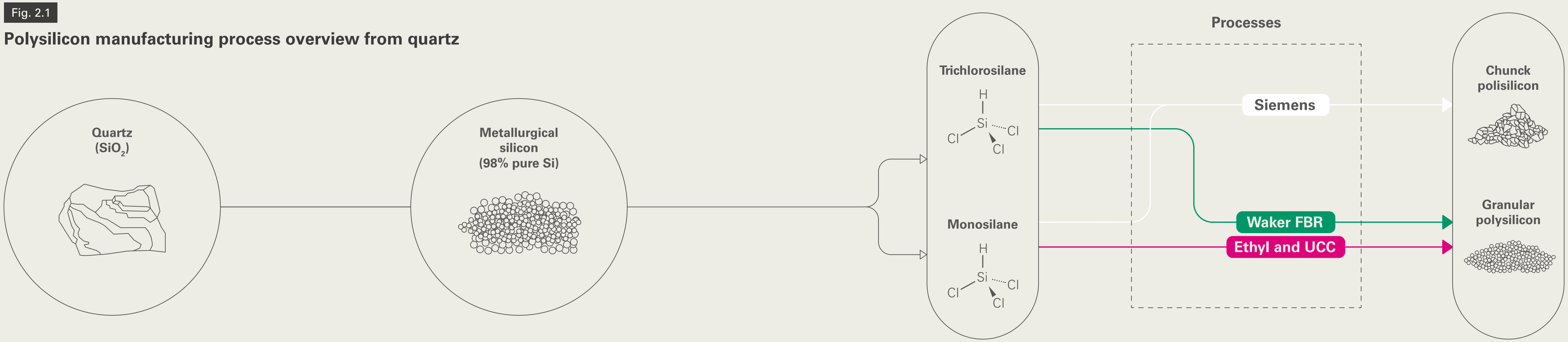
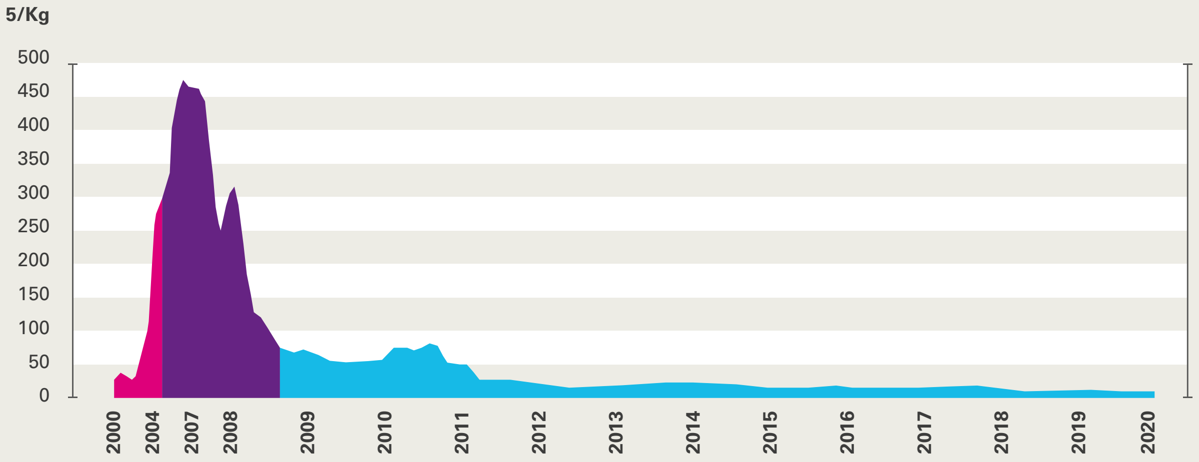


Fig. 2.2

Polysilicon historical price trend from 2000 to 2020



2.1.3 Solar Wafers

A Solar Wafer or PV Silicon Wafer is a thin slice of a crystalline silicon (semiconductor), which works as a substrate for solar cells manufacture. These wafers are the core of the PV cells wherein the electrical energy is generated by the conversion of the sunlight energy.

During last 60 years of its life, the solar wafer is characterized by its faster evolution in the lasts 10 years. The drivers for its evolution are the PV technology evolution, thus searching the continuous improvement of the Power Conversion Efficiency (PCE) to reach the silicon physical limit, and the costs impact of the material in the finished PV modules, thus guaranteeing an always-lower cost of energy for energy producer and good saving for top roof plants.

For costs reason, the mainstream production for PV purpose was represented by the multi crystalline wafers. With the market and technologic development, the mono crystalline wafer has become more competitive, thanks to the better performance of finished product and the increased amount of production.

Technology Trend

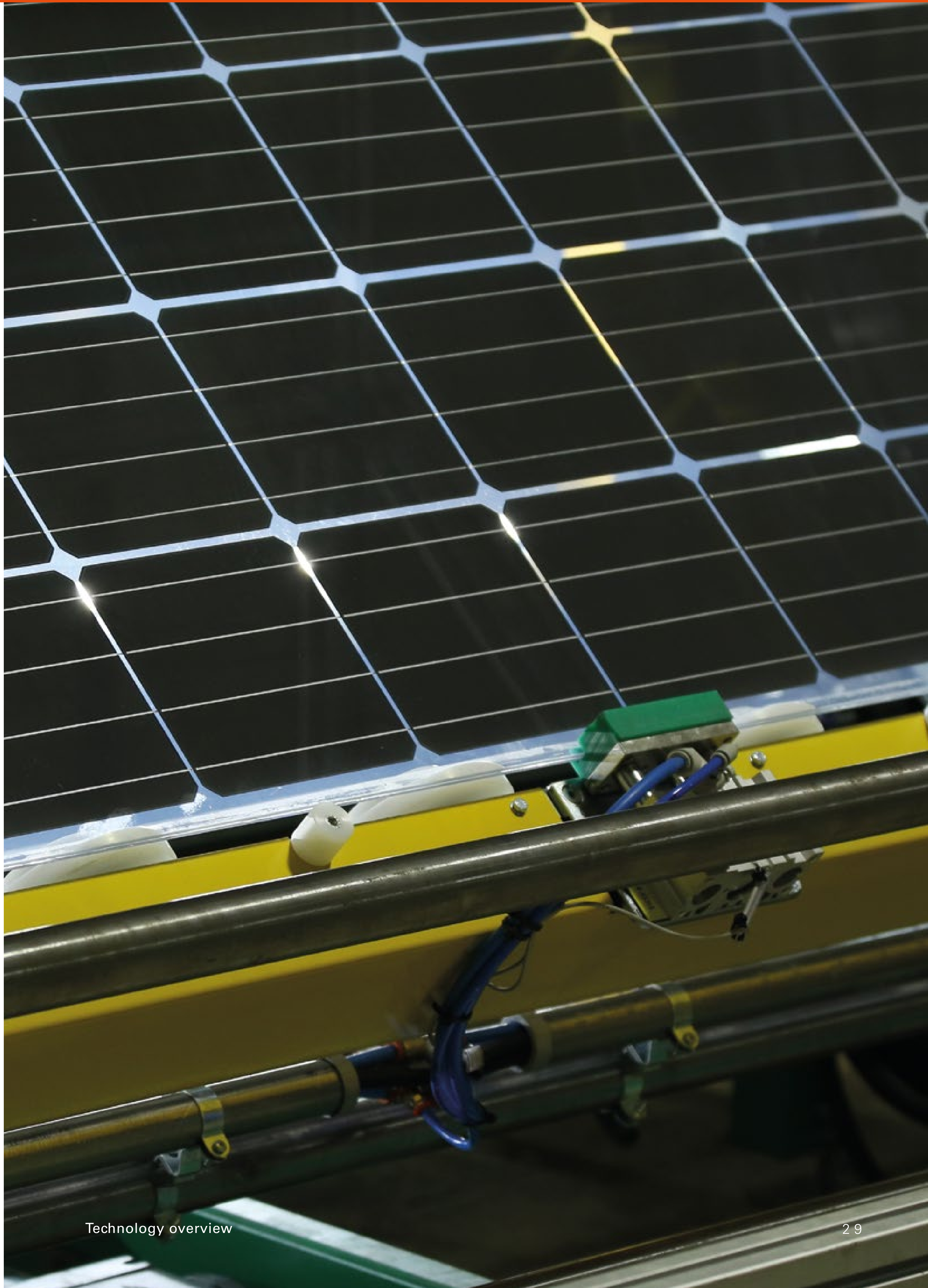
Ingot and rods manufacture

In this scenario, the mainstream technologies for the manufacture of solar wafers are the Directional Solidification Casting (DSC) and Czochralski (Cz) processes.

- DSC processes have been dominant for multi-crystalline (mc-Si) wafers (currently about 63% of c-Si PV market).
- Cz batch processes dominate the mono-crystalline (mono-Si) market (currently about 24% of the market) for the manufacture of mono-Si wafers -both of the p-type and n-type. With Cz, we bundle both standard Cz process and more modern Magnetic Cz (MCz) process, wherein the application of a magnetic field improves the impurity segregation in the melt and lower oxygen diffusion into the crystal.

With these two methods, the final product is represented by the multi-crystalline and crystalline ingots or rods of Silicon that shall be sliced to manufacture wafers as shown in the picture below.

In the last years, these two manufacture technologies have been developed, thus consolidating benefits from improved high yields, productivity and quality.



Alternative Ingot manufacture: casted Silicon

An alternative solution to manufacture Silicon ingots comes from the new technology launched from some wafer producer that, already in 2019, shipped 800 MW of mono-like wafer. The technique consists of melting, in a big crucible, a certain amount of polysilicon. The crucible floor is covered by crystalline Silicon seed tiles that drive that solidification of polysilicon in crystalline Silicon. The advantage is the cheapest final cost of wafers, 9-10$c/pcs less than standard mono-crystalline wafers, but, on the other hand, that final efficiency is 0.2-0.3% lower (that means around 5 W for a PV module of 72 cells).

Wafering processes

After their manufacture by the above-mentioned technologies, ingots (multi-crystals) and rods (single crystals) are sliced into wafers by wire saws of two types:

- Silicon carbide slurry-based wire saws: used mainly for multi-crystalline wafers. It is in continuous decline, due to the fact that it does not allow recovering much of the lost kerf silicon (contaminated the glycol used in the sawing process that makes silicon recovery too expensive).
- Diamond wire saws (DWS): they are rapidly gaining wider adoption especially for mono wafers (forecast >75% in 2020 for mono) thanks to: the ability to slice thinner wafers (currently down to 120 microns), better wafer surface quality and productivity, lower operating costs and energy use, a longer wire life and the ability to recycle the kerf loss (the cutting fluid is a simple aqueous surfactant solution).

The introduction of the DWS, completed in 2018 both for mono-Si and mc-Si wafering, involved a significant improvement in terms of process stability and cost reduction. It enables a significant reduction of kerf width and a lower wafer Total Thickness Variation (TTV).

A kerf width is today about 75µm and is predicted to decline to 50 µm within the next ten years. Further reduction of the TTV (20 µm today) is expected (10 µm in 2030).

Wafer size

A key parameter that has a positive effect on the production costs and, finally, on the cost of produced energy is the wafer size. Both from wafer and cell producers, the effect of increased area of wafer has a positive effect on production costs. The firsts, with same throughput, can produce a bigger silicon surface. The seconds will produce more energy. In both cases, the gap of increased costs is lower than the gap of increased surface and energy gains.

156.75mm (M2) wafers have become standard in the industry since 2017. However, the improvement of cell efficiency appeared to hit a bottleneck in the subsequent year, thus making wafer size again a hot topic among manufacturers. In the second half of 2018, 158.75mm (G1) mono wafers were introduced to the market successfully. It is certain that G1 format will be the mainstream in 2020 to 2021, thus having gained momentum. To differentiate products and reduce costs associated with crystal pulling, wafer manufacturers launched 166mm (M6), 182 mm (M10) and 210mm (M12) wafers. With more variables in the market, most manufacturers are now in a wait-and-see mode on wafer size.

The path to run across to use bigger wafer, with standard or improved qualities for the cell makers, is driven by technological and economic reasons. For that, it is expected a transition that will bring to have in 2023 the 70% of M6, G1 and M4, few percent of remaining M2, the 3-4% of M12 and 20-25% of other formats (such as M10). Of course, each cell and module manufacturer will handle its evaluation, thus considering the final LCOE, because the bigger size can result in higher scrap rate.

Jumping from one wafer size to the bigger one can introduce the need to modify the PV module size. To maintain their share in the utility and commercial scale markets, each manufacturer explores if its product will be compatible with the other components of the PV site (such as clamps, tracker, structures, etc.). If compatibility will be not observed, the conclusion is a more expensive PV segment, due to the higher prices of non-standardized components.

Wafer thickness

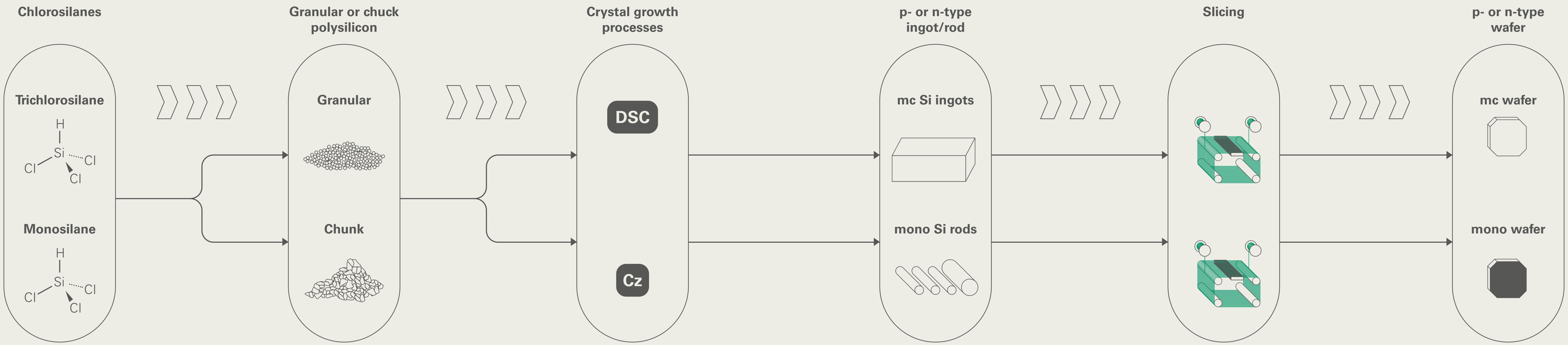
In recent years, the thickness of the wafer has been around 180 µm and in 2019 several wafer manufacturers planned to deliver thinner wafers, with a reduction of the thickness of 2% for mc-Si and 5% for mono-Si. Some big wafer manufacturers have already started the mass production of 160 µm pieces by the end of 2019.

Reduction of the thickness has a direct impact on the material cost, thus leaving to wafer manufacturers a tangible improvement in terms of price in the market of cells producers and, of course, higher profits.

The wafer thickness has a strong influence on the final cash

Fig. 2.3

Production chain for multi crystalline andcrystalline silicon wafer



production cost; obviously, the thinner wafers are more convenient from the material point of view, but technological considerations should be done:

- The thickness of multi-crystalline wafer is supposed to remain unchanged, because the wafer thickness needs adjustment in cell processing and module assembly to avoid breakage and companies lacked the motivation to perform this adjustment, as there were easier ways to increased efficiency and reduce costs.
- For HJT technology, the mono wafers can be used in mass production with reduced thickness (80-100 µm) for the low temperature production processes and this can induce an advantage in cost production reduction.

In this scenario that pushes the reduction mainly for the mono wafers, it is necessary to mention that bigger wafers are more challenge to make them very thin, because of their increased breakage rate. Therefore, it is likely that, due to the upcoming wafer size changes (M6, M10, M12, etc.), the thickness reduction will come to a halt.

Future technologies

Thinking about costs and quality, the developing technologies are trying to cut down on process steps. Indeed, these technologies were originally conceived in an era of high cost polysilicon, when eliminating kerf losses was an important cost reduction goal. These technologies, however, have other potential benefits: fewer process steps (lower costs), lower capex, thinner wafers and customized surface finish.

We are referring to technologies such as:

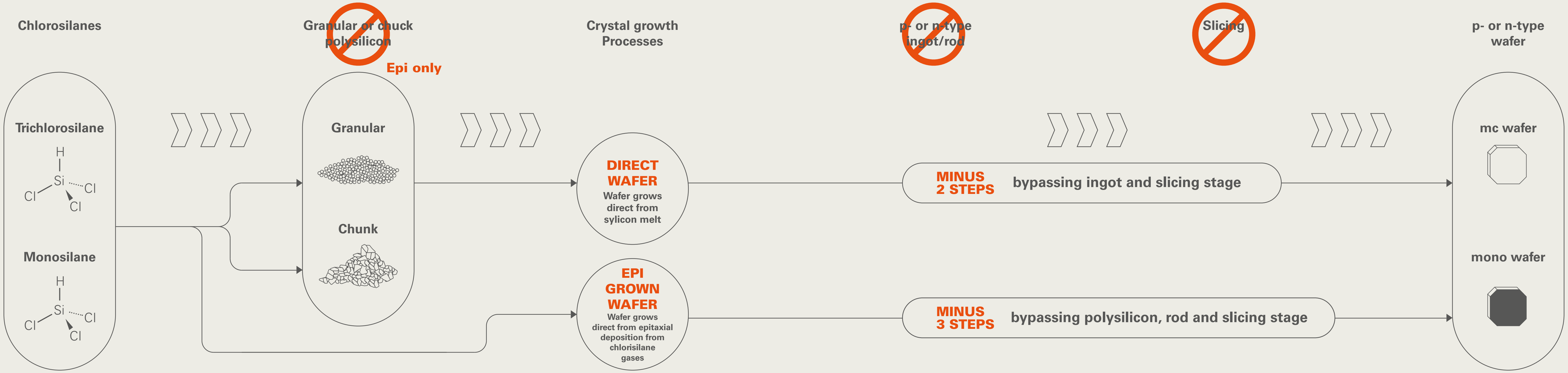
- **Direct Wafer**, based on polysilicon melt and substrate dip processes that actually are covering less than 0.01% of the mc-Si wafer market.
- **Epi-grown wafer technologies**, based on the chlorosilanes that can produce thin wafers (20-40 microns), thus allowing production of high efficiency cells with lower cost and that actually are covering less than 0.01% of the mono-Si wafers market.

These technologies give the opportunity to cut down both the Si ingots and rods manufacture and their slicing for the final wafer production.

The very promising epitaxial technology is very promising in terms of cost reduction (50%-80% lower compare to the current ones).

Fig. 2.4

Novel technologies to manufacture mc-Si and mono-Si wafers bypassing the ingot production and slicing processes



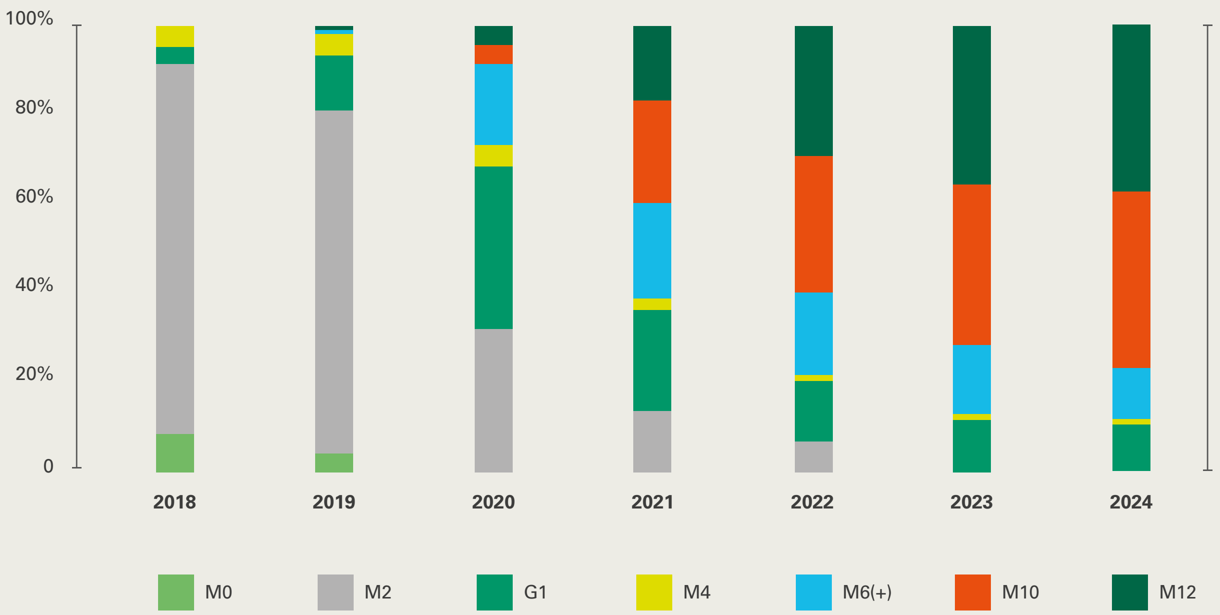
Market share

The mono-Si (of the n-type and p-type) by Cz process is dominating the market; in 2019 it had a market share of about 70% vs. about 30% for mc-Si materials and it is expected to gain further market share over casted materials of up to 80% in 2030. The market share of mc-Si material is expected to continuously shrink below 10% in 2030. Finally, the n-type mono-Si (suitable for high efficiency PV technology) material is expected to gain more than 40% in 2030.

As already mentioned above, in 2019 the evolution of wafer size moved from M2 (156.75x156.75 mm2) to new formats: M6 ((166x166mm2), M10 format (166x166 mm2) and M12 (210x210 mm2) so it is expected that in the next 3 years M2 format will be completely replaced.

Fig. 2.5

Expected trends for wafers in mass production



Production cost and price trend

The massive demand of the last years and the increase of the wafers manufacturers have generated both the reduction of production costs – thank to the massive production and technological production process innovation - and the reduction of the gross margin due to the competition between wafers manufacturers, thus involving a continuous lower price for the cells manufacturers.

In the last 10 years the cost and the price have decreased more than an order of magnitude:

- → **Cost passed from about 0.51 $/W in 2010 to about 0.049 $/W in 2020.**
- → **Price passed from about 0.94 $/W in 2010 to about 0.052 $/W in 2020.**

A further reduction is expected for the next years:

- → **Cost: 0.04 $/W in 2024.**
- → **Price: 0.05 $/W in 2024.**

2.1.4 Cell

PV technology for terrestrial applications is mainly based on crystalline and polycrystalline silicon. Mainstream technologies are based on cell architectures and processes proposed in the 80's and optimized to achieve maximum performance and lower costs in the last years.

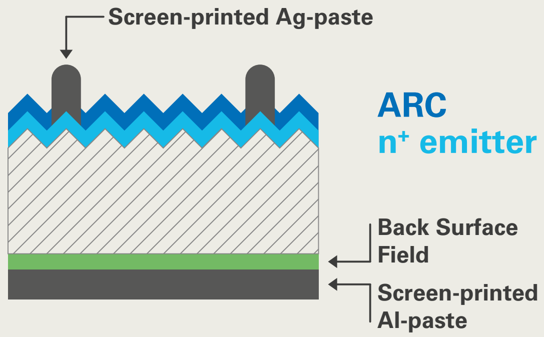
Technology trend

The most diffused technology since few years ago is known as **Aluminium Back Surface Field (Al-BSF)**, which uses a continuous layer of aluminium as backside contact. In such a cell, the contact process is performed through screen printing, by using metallic pastes that are printed as a grid on the front side of the cell and as continuous metal layers on the cell back side.

Fig. 2.6

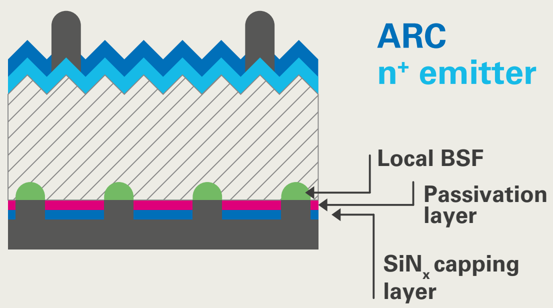
Aluminium Back Surface Field (Al-BSF)

Al-BSF Technology



Al-BSF solar cell structure. In the front side of the cell, there are the narrow metal stripes (fingers), with a width of about 40-60 μm, obtained with screen printing. In the rear side of the cell, there is the continuous layer of aluminium. The high temperature firing process forms an aluminium silicon alloy, which gives rise to the back-surface field.

PERC Technology



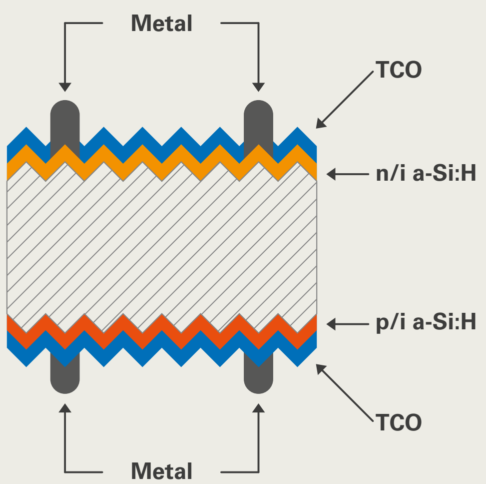
PERC cell architecture. One can note in the rear side of the cell the local openings made in the passivation layer, which consists of a stack of Al2O3 and Si3N4. In the contact opening regions, the BSF is formed.

As previously discussed, the monocrystalline silicon ingot manufacture technology has evolved in terms of cost reduction, thus making even more convenient, in terms of cost/watt, the employ of high performing monocrystalline silicon.
To further increase the efficiency and obtain more benefit from the use of monocrystalline, the architecture of the solar cell has been improved by introducing the concept of **Passivated Emitter Rear Contact (PERC)** solar cell. The new architecture allows a more effective passivation of the surface in order to increase the efficiency. Though from one side, more technology steps are necessary to manufacture the cell, so the increased performances allow a significant lowering of costs per watt. For the PERC cell, the passivation of the front side is extended also to the rear side of the cell, by depositing a stack of dielectric layers on the backside of the wafer.

Since the 80's, using the same cell architectures, there has been a significant development in the materials performances as in the case of the silver pastes that have led to a remarkable improvement of the grids with better aspect ratios, very thin fingers and excellent antireflection materials. It has taken about 30 years in order to obtain commercial solar cells with the efficiency levels originally obtained in the research laboratories.
A further technology step is represented by the silicon Hetero-Junction Technology (HJT) that combines the advantages of monocrystalline solar cells with the good light absorption and excellent passivation of hydrogenated amorphous silicon. With respect to most common approaches (Al-BSF and PERC), the passivation of HJT solar cell is a very efficient solution, which is achieved by passivating non-metallic contacts, i.e. they act as a contact and passivating layer at the same time.

Fig. 2.7

Schematic representation of a silicon heterojunction solar cell (HJT)



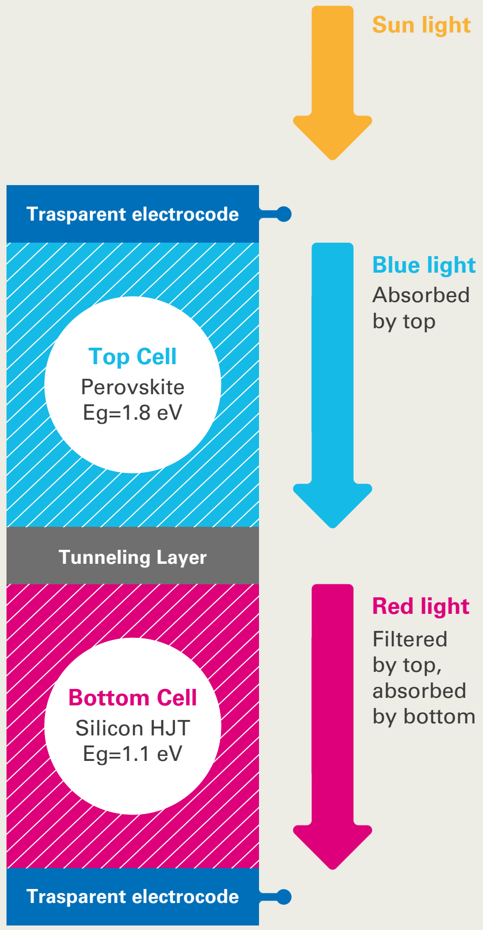
Structure of a Si-HJT solar cell consisting of thin intrinsic and n or p doped hydrogenated amorphous silicon layers (few nanometers) deposited on the front and on the back surfaces of a n-type silicon wafer.

The HJT cell achieves higher efficiencies than conventional crystalline silicon technologies, with typical efficiency between 23% and 24%, and have more margins to approach the maximum theoretically achievable efficiency (Shockley-Queisser limit) of silicon solar cells.
Though the technology processes that are quite sophisticated, HJT technology is characterized by a simple process flow with a small number of steps (7 steps), significantly lower than those of conventional technologies like PERC (11 steps).
HJT solar cell has a very symmetric structure and the passivation is obtained with the deposition of thin layers of similar thickness both on the front and on the backside; for this reason, it shows the highest bifacial ratio. Typically, HJT cell **bifacial ratio** exceeds 90% and can reach 95%.
Beside superior performances in terms of efficiency and bifacial factor, HJT cells show other advantages that are mainly observed in the average electricity produced by a PV plant. The better surface passivation enables a higher control of the solar cell performances at high temperature operation, due to a reduced thermal degradation factor compared with conventional crystalline cells. The behaviour of HJT solar modules is even better over time because of a type of regeneration effect increasing the performances after exposition to the light. HJT resilience is related to the winning combination of high-quality n-type wafer silicon, passivation effects of amorphous silicon on both surfaces and the barrier behaviour of the transparent conductive oxide (TCO). In particular, TCO acts as Na blocking layer, thus improving the robustness against potential-induced degradation (PID). Moreover, the use of the n-type wafer for HJT cells avoid the drawback of Light Induced Degradation (LID) and Light and Elevated Temperature Induced Degradation (LeTID).

The maximum conversion efficiency of silicon solar cell in ideal conditions is given by Shockley-Queisser limit, that is of about 29%. To overcome this limit, an interesting technology approach is given by the **Tandem Structure**, wherein two or more cells with different band gaps are overlapped. Solar cells with different band gaps are piled each other. The top cell absorbs the high frequency photons (blue light). Lower energy photons pass through the top cell and are absorbed by the other cells. The intermediate cell with intermediate band gap absorbs the green light and bottom cell absorbs the lowest energy photons (red light). In this way, almost all the visible spectrum is used in an efficient way.

Fig. 2.8

Tandem solar cell

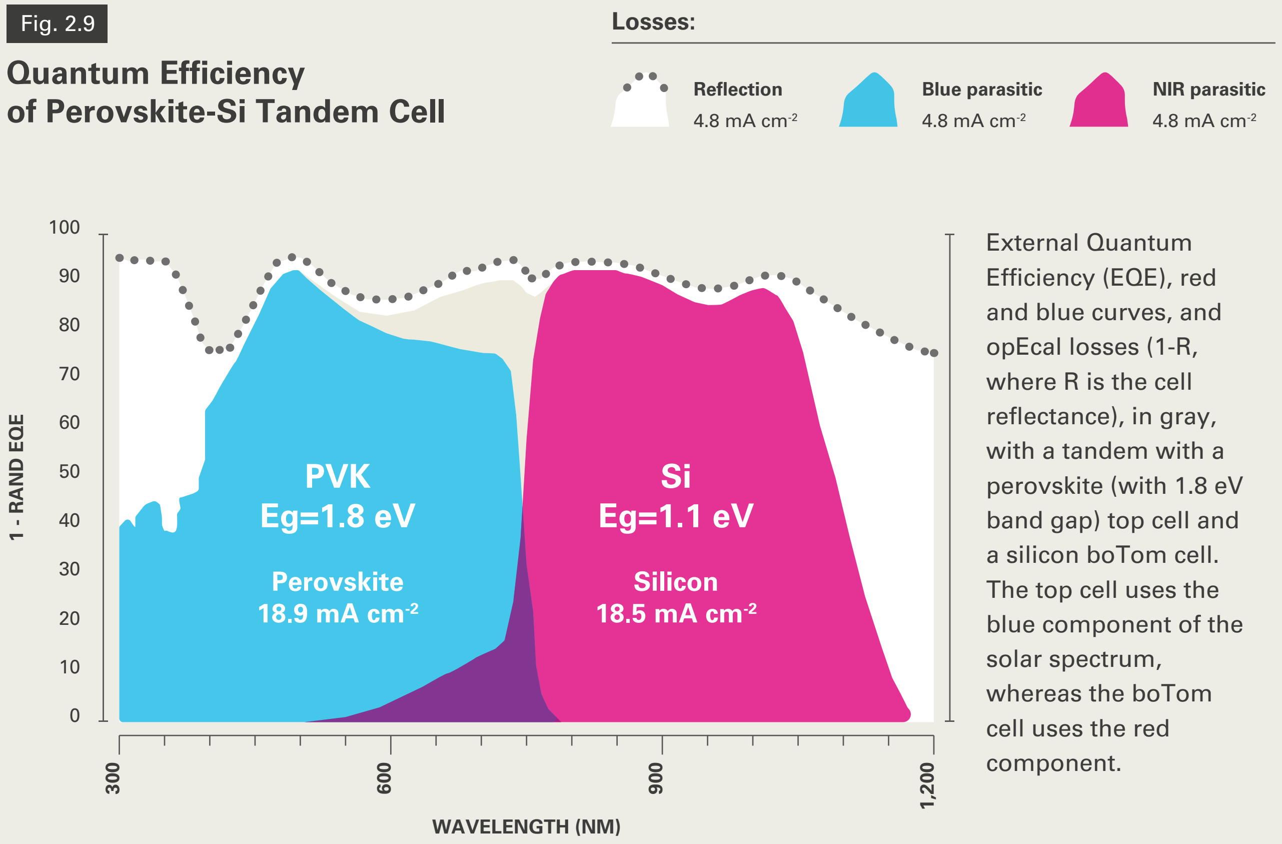


Solar cells with different band gaps are piled each other. The top cell has a higher Eg and absorbs the high frequency photons (blue light). Lower energy photons pass through the top cell and are absorbed by the other cells. The intermediate cell with intermediate band gap absorbs the green light and the bottom cell absorbs the lowest energy photons (red light). In this way, almost all the visible spectrum is used in an efficient way.
From an ideal standpoint, this approach can allow obtaining solar cell with very high efficiency. However, from a thermodynamic viewpoint, the entropy related to the number of solar cells with the p-n junctions increases. In order to extract current from the three cells tandem system, it is necessary that the cells are connected in series or in parallel. In the former case, the current of the system is determined by the lowest current that is generated by the less performing cell, typically the last one in the sequence that receives less light. In case of parallel connection, it is necessary to handle a voltage matching. Essentially, though for an ideal case, the use of many stacked cells can lead to the maximum theoretical efficiency; in practice, the most effective approach is the one that uses two cells because is the best trade-off between light absorption and losses reduction.

An interesting approach to industrial tandem application can come from the exploitation of **perovskite** solar cells. Perovskite solar cells can be useful as top cells in a tandem system in series with a crystalline silicon-based bottom solar cell. External Quantum efficiency (EQE) of a tandem with a perovskite (with 1.8 eV band gap) top cell and a silicon bottom cell is showed in the picture below.

Fig. 2.9

Quantum Efficiency of Perovskite-Si Tandem Cell



External Quantum Efficiency (EQE), red and blue curves, and opEcal losses (1-R, where R is the cell reflectance), in gray, with a tandem with a perovskite (with 1.8 eV band gap) top cell and a silicon boTom cell. The top cell uses the blue component of the solar spectrum, whereas the boTom cell uses the red component.

The top cell uses the blue component of the solar spectrum, whereas the bottom cell uses the red component. The name Perovskite is related to the name of the Russian mineralogist Lev Perovskite, who was the first to identify the crystalline structure (ABX3).

Perovskite cells can be manufactured in several ways. Such methods include either deposition techniques based on solution process, as spin-coating and slot-die coating or vacuum deposition processes such as thermal evaporation and chemical vapour deposition. It is important to point out that those processes can be potentially scaled-up to industrial applications. It is also noteworthy that so far most of the good performances and stability are obtained only in the laboratory under controlled conditions.

To transfer the perovskite technology to consolidated industrial manufacturing processes, it is mandatory the development of more robust and reproducible manufacture processes. Therefore, it is essential that the material used for the perovskite cell is well protected against environmental agents, including moisture, and it must be robust towards light and voltage induced degradation.

Despite the remarkable progresses from a scientific viewpoint, perovskites are still in a too experimental stage and exhibit several drawbacks for scaling up the processes (the high performances are achieved on cells of few cm^2).

Another limiting aspect for the widespread diffusion of perovskites on commercial scale involves the fact that lead (Pb) is an important component of the perovskite structure and Pb introduces serious issues of toxicity.

In order to allow perovskite solar cells to be used in an industrial tandem structure, it is necessary to solve the drawbacks related to scalability, non-toxicity and reliability. The scientific community is enthusiastically concentrated to find the solution to the above-mentioned drawbacks and, every few months, there is a significant result in that direction.

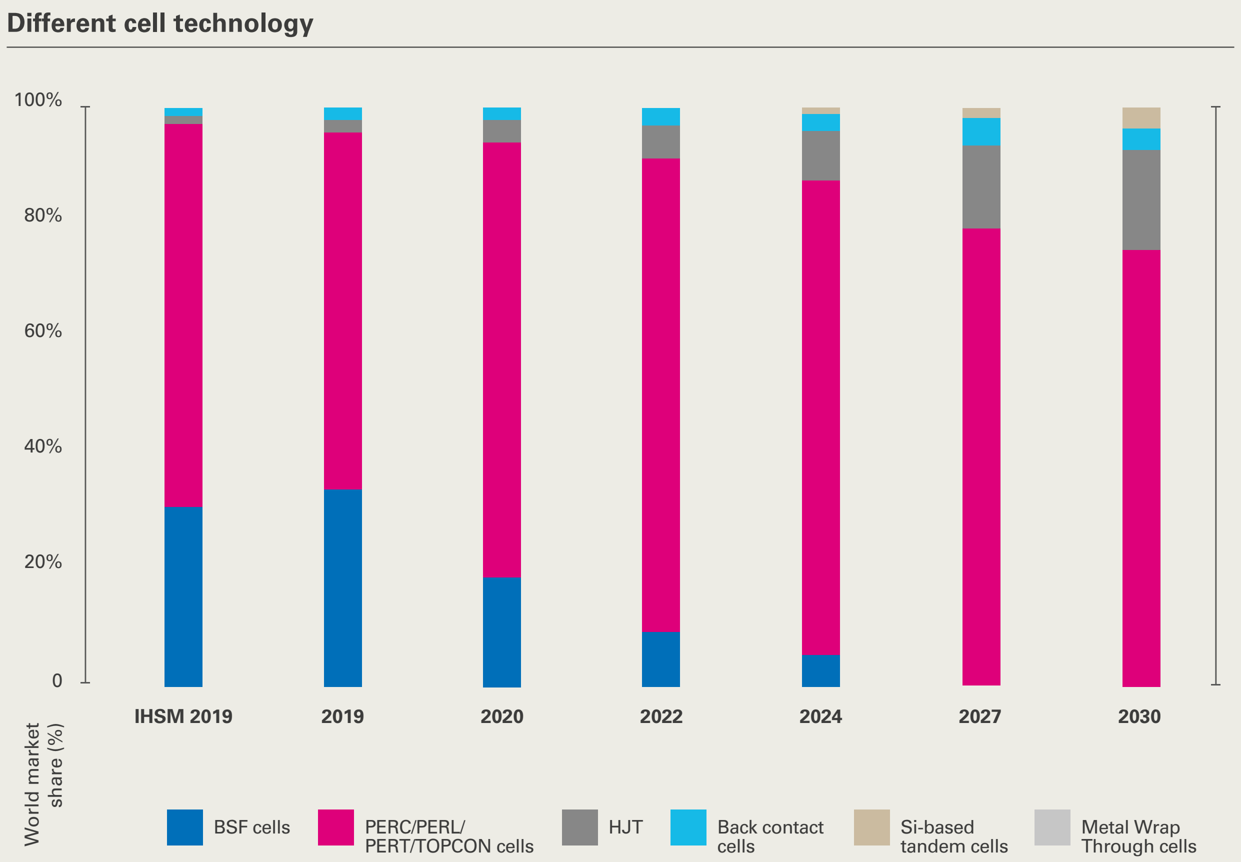
Market share

Chinese manufacturers, for more than 90%, dominate the terrestrial PV market. Some recent solutions, as bifacial modules can even improve performances in terms of energy production. Moreover, they shall be taken into account the advantages of an innovative silicon-based technology, known as heterojunction technology (HJT), which is ramping nowadays, and that could place the PV European manufacturers in leading positions.

The below picture shows the market share trends of the main technologies that are based on the usage of silicon, both crystalline or polycrystalline.

Fig. 2.10

Market trend for crystalline silicon technologies (mono e multi-crystalline)



Cell with diffused and passivated pn-junction and passivated rear side (PERC/PERL/PERT/TOPCON) will continue dominating the market over the next years starting from a market share of about 60% in 2019. BSF cells will rapidly decrease market shares in the next years (starting from about 30% in 2019), while HJT is expected to gain a market share of about 10% in 2024 and 17% in 2030 and Si-based tandem cell will start in 2024.

The cell technology that will dominate the market over the next years have bifacial features, so the market share for the bifacial cell of about 20% is expected to increase significantly to 70% in the next 10 years.

Production cost and price trend

In the last 10 years the cost and the price have decreased more than an order of magnitude:

- → **Cost passed from about 1.03 $/W in 2010 to about 0.09 $/W in 2020.**
- → **Price passed from about 1.22 $/W in 2010 to about 0.10 $/W in 2020.**

A further reduction is expected for the next years:

- → **Cost: 0.08 $/W in 2024.**
- → **Price: 0.09 $/W in 2024.**

2.1.5 Module

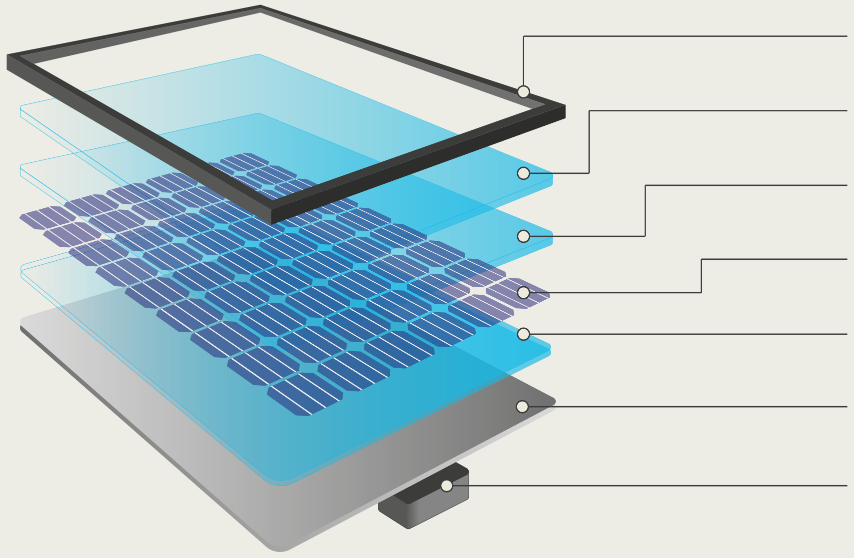
The module is the end product of the PV technology chain and, compared to wafers and cells, it is the component that has underwent the least changes in the last 30 years. It has only been for a few years that several innovations have been introduced allowing the tend to improve the impact on the performance and reliability.
In the cost share for PV module products, the module-related production cost share contributes with more a less 50% to the total module cost. Optimization of module performance and material cost are key factors to lower module cost. Approaches for reducing material cost include reducing material volume, as material thickness, replacing expensive materials and reducing waste of materials.

Technology trend

The power produced by a PV module is not only the sum of the powers of its cells. Typically, the output power of the module is different from the total sum of individual cells. This difference is referred to as **cell-to-module (CTM)**, defined as module power divided by cell power multiplied by the number of cells (module power / (cell power x number of cells)). CTM is influenced by different factors as the module format, border area and cell spacing, optical losses due to light reflection and absorption of glass and encapsulant, cell interconnection shadowing, electrical losses due cell and string interconnection. CTM is getting more and more attention as improvements in cell efficiency are becoming harder to achieve.
Until few years ago, about 98% of the c-Si solar panels were encapsulated/packaged using the traditional glass-encapsulant-backsheet sandwich (or relevant close derivations). In typical process, the CTM power loss can be greater than 3%.
PV module packaging is very important as it affects both costs in terms of $/W and, more importantly, the LCOE as it affects module performance and reliability (packaging is the predominant cause of failure in modules).
In the last few years, there have been revolutionary changes in the architecture of the crystalline silicon modules, with the introduction of more sophisticated assembly schemes, to reduce the losses from cell to module related to dead areas and resistive loss and to take advantage from bifacial cell architectures.
To improve the cell to module ratio, some manufacturers have introduced the concepts of half-cut cell assembly and of shingling.
The **half-cut cell** approach consists of cutting in two parts the solar cell and assembling them in the module. In other words, the module is obtained with 144 half cells from a structure made of 72 cells. The advantage is given by the reduction of resistive losses because the cell area is divided by two (thus halving the output current). Moreover, there is a better management of the captured light by increasing the fraction of silicon absorber area in the module (the dead areas are reduced). The improvement involves an increase of 3-4% in the output power of the module. The cell cutting process is obtained by laser cut and mechanical cleaving of the two half pieces. This process is critical because it can induce damaging of the devices by deteriorating the electronic properties as well as the mechanical robustness of the solar cell, with consequent reliability issues.

Fig. 2.11

Traditional glass-encapsulant-backsheet sandwich for c-Si solar panels



Currently with regard to the characteristics of the modules, there is in a transition phase, with the introduction of the new types of larger wafers (from M2 to M6, M10 and M12), the concept of cell division is taken to extremes, which is divided into 2, 3 even 4 sections. This makes it possible to manufacture modules of ever greater size and power, passing from about 400 Wp to 500 Wp to 600 Wp up to 800 Wp, while maintaining the same level of efficiency. This is happening because the major companies in the market, which are vertically integrated into the value chain, have reached the limit of cell efficiency with the PERC technology, and before making huge investments to change technology, they have focused on methods (half- cell, shingling, multi-busbars, multi-wire, etc.) to increase the power of the module without acting on the cell; this is feasible in a shorter time and with limited investments. At the same time, they acted on the manufacture of wafers by increasing the size and, therefore, the power of the cells.

The first effects of downstream are certainly a reduction in investment (BOS cost, land cost, installation cost) for the manufacture of PV systems. However, some questions still remain (impact on logistics, mechanical resistance and operation issues, reliability, etc.) that do not allow clarifying now which configuration of the module will become the reference.

In general, the reliability of PV modules is very important to establish their lifetime in a PV solar plant. Although the quality of materials and manufacturing processes have improved a lot, poor reliability can be an important issue in modern PV technologies. In particular, PV modules suffer from several reliability issues arising from the exposure to the light and to environment agents, such a moisture, wind mechanical stress, migration of mobile ions from the glass into the silicon, etc.

Crystalline silicon PV modules are affected by deleterious light-induced degradation (LID). The LID phenomenon was observed for the first time in crystalline silicon solar cells in the 70's. When the silicon solar cells started to be widely used, LID triggered some warnings due to the impact on long-term stability of solar plants. LID degradation is related to the boron-oxygen complexes, defects formed by a substitutional boron atom and two oxygen atoms. These complexes are typically present in the p-type doped silicon and the creation and annihilation of such metastable complexes are thermally activated, although they also depend on light intensity. Therefore, LID strongly affects the p-type silicon solar cells (typically used for the PERC technology) and it does not occur in the n-type wafers (typically used for HJT technology). This phenomenon is faced at industrial level and is mitigated with a light soaking process added to the solar cell process flow. Recently, a new phenomenon of degradation in the p-type silicon has been observed; it is induced by the light and is strongly activated by the temperature. This phenomenon is known as Light and Elevated Temperature Induced Degradation (LeTID) and can result in significant power reduction (from 5% to 10%).

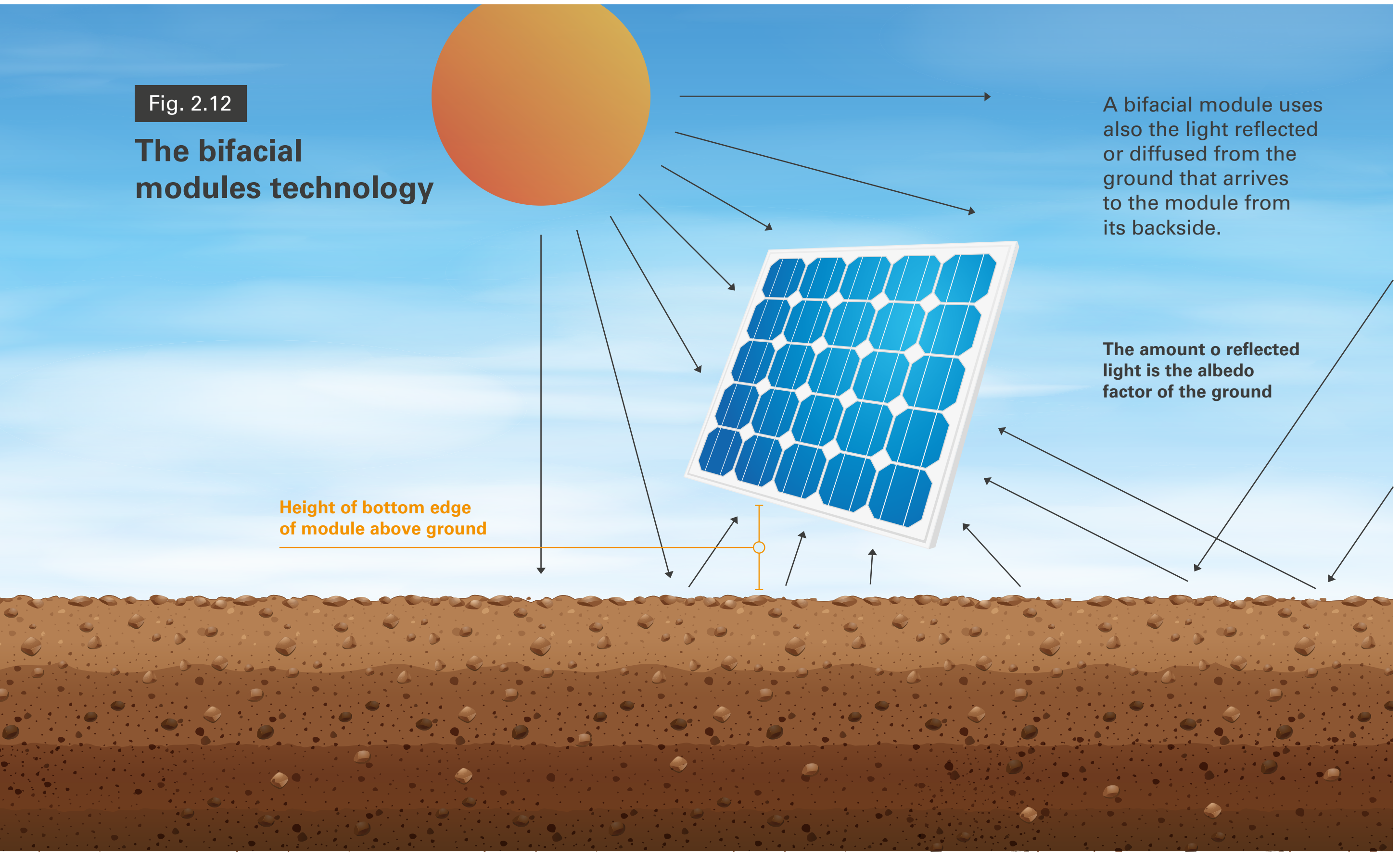


Fig. 2.12
The bifacial modules technology

Another important degradation phenomenon is known as Potential Induced Degradation (PID) and it is related to the migration of sodium ions or other mobile impurities from the glass into the silicon, thus causing current losses that result in a drastic degradation of the PV module.

The PID degradation can be reduced or controlled with barrier layers, which block the migration of the impurities. It is essential the polymeric encapsulant material, which acts as blocking layer against sodium and moisture. The most diffused encapsulant is based on ethyl vinyl acetate (EVA) or on polyolefin (POE), which are laminated with the front glass and the module tedlar based backsheet.

The bifacial modules technology has recently consolidated on the market. Bifacial modules can use both front and rear faces to capture the sunlight. The front face will capture the direct light impinging on the cell and the backside face of the cell can capture the light reflected or diffused from the ground. The bifacial option can offer an average increase of energy from 5% to 20%, and even more, depending on the reflectivity of the ground or albedo. Therefore, such an approach can significantly increase the performances of the modules without a significant augment of the costs, though the architecture of the module has to be changed by replacing the opaque tedlar backsheet with another glass or a transparent backsheet. Bifacial modules market share has remarkably grown in few years and it is expected that will grow in the next years.

Market share

Currently the global production capacity of PV modules is around 190 GW, of which more than 60% is covered by Chinese producers (the largest: Trina Solar, Jinko, JA Solar, Risen, Longi, Canadian Solar).

There are a significative number of manufacturing factories which exceeds 5 GWp and 10 GWp of annual production capacity, and for the next years the average production capacity of individual companies is growing together with greater vertical integration on the value chain.

Production cost and price trend

In the last 10 years the cost and the price have decreased more than an order of magnitude:

- **→ Cost passed from about 1.43 $/W in 2010 to about 0.18 $/W in 2020.**
- **→ Price passed from about 1.85 $/W in 2010 to about 0.20 $/W in 2020.**

A further reduction is expected for the next years:

- **→ Cost: 0.13 $/W in 2024.**
- **→ Price: 0.15 $/W in 2024.**

2.2

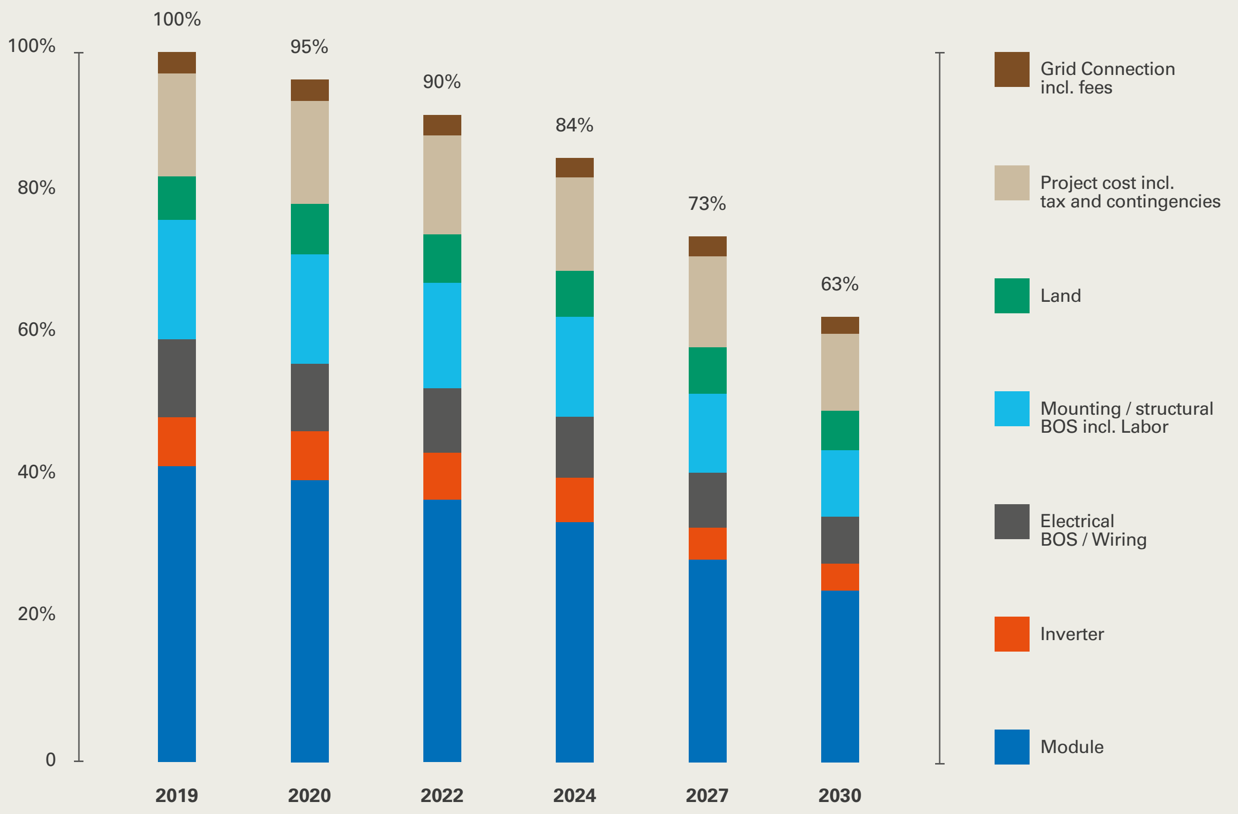
PV balance of plant

2.2.1 Introduction

Due to the significant reduction of PV modules prices over the last few years, BOS costs have become a crucial factor in overall system costs and thus the LCOE as well. Given the warranties for the product and the product performances as well as the degradation of the modules during the operation lifetime, an increase in system voltage and the trend to install more 1-axis tracking systems are important parameters to reduce LCOE. For instance, the increase in system voltage is an important measure for lowering resistive losses and BOS costs by reducing the required diameter of the connection cables within a PV system.

Fig. 2.13

Cost elements of PV System Worldwide (for system >100kW)



The below chapter describes the main equipment that must be built in the PV module of a PV power plant.
Inverter, structure and BOS will be listed with main features and products trend, including the market trend with the forecast of their main development for the next years. The evolution of the PV plant with the most innovative digital solution will also described.

2.2.2 Inverter

Over the past two decades, inverters have advanced from cumbersome and heavy pieces of equipment with limited functionality to highly advanced power electronic devices. Modern inverters balance demands for significant power density and operational efficiency while performing under an ever-evolving set of grid and safety mandates. Within an operating PV plant, inverters are responsible for more operational functions than any other PV system component. PV inverters ensure that the entire ecosystem of a PV system works continuously. Their functions span management of the direct current (DC) side of the system where the PV modules works interact with the alternating current (AC) side where the electrical grid works, while reporting all of this information continuously.
Complex functions involving efficiency, safety, availability and communications are all required to perform consistently and reliably for decades, despite harsh environments with unpredictable and sometimes non-ideal behaviour on both the AC and DC sides. With the rapid development of emerging ICT technologies, such as the AI, cloud, big data, and 5G, and in full consideration of the latest trends in power electronics technology, some emerging technical trends have released for smart PV in 2025. These trends aim at driving the inverter industry toward lower levelized cost of electricity (LCOE), power grid friendliness, intelligent convergence and security and trustworthiness.

Technology trend

Artificial Intelligence

Key point:
Over 70% PV plants will apply AI techniques

The in-depth integration of AI and PV will facilitate mutual sensing and interconnection between devices and will improve power generation and O&M efficiency through collaborative optimization. AI techniques can offer promising new avenues for PV systems, including: proactive identification and protection of PV module and device faults with AI diagnosis algorithms, tracker algorithm optimization with massive plant data and self-learning for higher yields and AI-aided solar-storage synergy to automatically optimize PV-storage plant revenue. As LCOE continues decreasing and O&M complexity increases, AI techniques will be highly likely to widely apply in PV plants.

Digitalization

Key point:
More than 90% of global PV plants will be digitalized

Despite the booming global PV market, there are still many dumb devices in PV plants, from power generation to communications. These devices cannot be effectively monitored, nor can they provide fault alarm. With the rapid development of digital technologies such as the 5G and cloud, it is expected that more than 90% of PV plants will be fully digitalized by 2025, thus making it possible for PV plants to be simple, intelligent and efficiently managed.

Proactive support for power grids

Key point:
PV plants will shift from grid-adapting to grid-supporting

The increasing penetration level of power-electronic-interfaced energy will undermine power grid strength, thus hindering the broader application of PV systems. Over the next five years, PV plants must gradually evolve from adapting to the power grid, to supporting the power grid. To this end, inverters should have capabilities such as wide short-circuit ratio (SCR) adaptability, capability to control harmonic current within 1%, consecutive high/low voltage ride-through and fast frequency adjustment, which are necessary for grid connection.

Solar + Storage

Key point:

The proportion of PV systems coupled with energy storage will exceed 30% by 2025

With the greater penetration of new energy sources, power grids will have increasingly stringent requirements for frequency adjustment and peak shaving. In the meantime, battery costs are decreasing with technology advancement. It is projected that energy storage will work in tandem with PV systems and become a critical component. Projections indicate that by 2025, the proportion of PV systems with energy storage will exceed 30%.

Modular design

Key point:

Core components such as inverters, PCS and energy storage devices will adopt modular design

Inverters, PCSs, and energy storage devices are key components in a PV plant, which greatly affect the availability of the entire PV plant system. As the capacity and complexity of PV plants increase, the traditional, expert-driven approach for onsite maintenance will be too costly. Modular design will become mainstream, as it enables flexible deployment, smooth expansion and expert-free maintenance, thus greatly reducing O&M costs and improving system availability.

Higher power density

Key point:

Inverter power density will increase by more than 50% in the next 5 years

With the trend of lower LCOE of the solar segment, higher requirements are required in higher power of a single module and easy inverter maintenance. To achieve the above, higher power density is required. With breakthroughs in research of wide-bandgap semiconductors, such as SiC and GaN, as well as advanced control algorithms, inverter power density is expected to increase by more than 50% in the next 5 years. Research has shown that SiC can be smaller, faster, tougher, more efficient and more cost-effective. SiC withstands higher temperatures and voltages than silicon, thus making it a more reliable and versatile inverter component. The benefits are listed herein:

- **Higher temperatures.** SiC-based power electronic devices can theoretically endure temperatures of up to 300°C, while silicon devices are generally limited to 150°C.
- **Higher voltage.** Compared with silicon devices, SiC devices can tolerate nearly 10 times the voltage, take on more current and move more heat away from the energy system.
- **Faster switching.** A power electronic device needs a switch that turns on to convert low voltage to higher voltage. SiC can switch on and off quickly and, although some energy is lost during switching, faster switching that limits loss and improves device efficiency.

Less-costly equipment: SiC translates to lower system costs because it allows for smaller and more affordable equipment. For example, the heat sink, which protects the other components by taking on excess heat, can be smaller because of less energy loss and less heat produced.

Market share

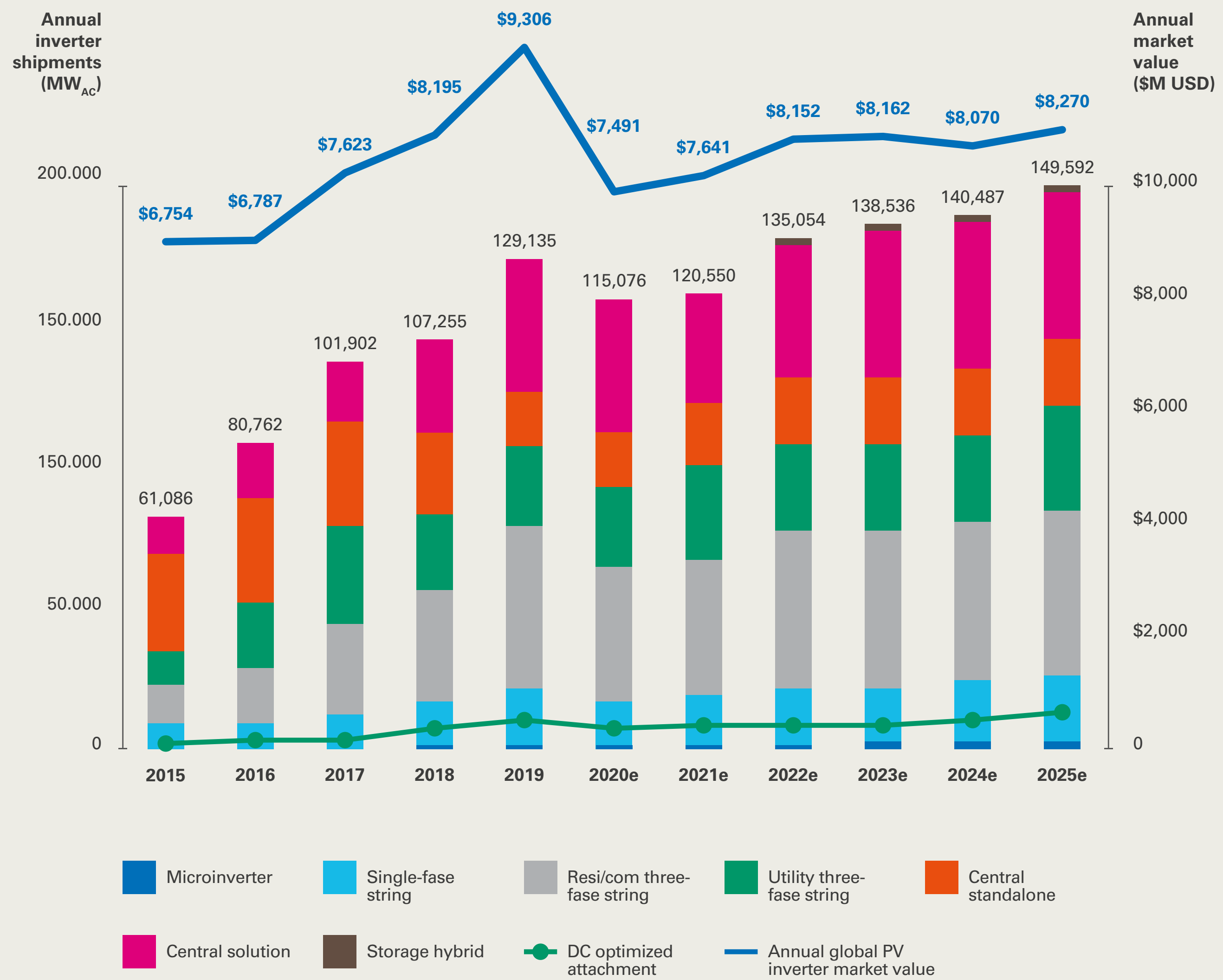
Central PV inverter was the dominant product segment for the global market. These equipment are mainly designed for large arrays of the PV module installed on industrial facilities, buildings and onsite installations.

String inverters are the second most widely used product and can be used in a wide range of applications. They are used primarily in residential and commercial sectors. However, in the past few years they have gained immense significance on account of rapid technological advancements. These inverters are easier to install and offer lower initial cost per peak watt price.

About the vendors, the top three maintain the same position from the 2015: Huawei (China), Sungrow (China) and SMA (Germany). The Chinese manufacturer Huawei led the field with the top three manufacturers unchanged for five years. The big five surrendered only 1% of their stranglehold on the global market to claim 56% of business. The 10 biggest inverters manufacturers accounted for 76% of global trade.

Fig. 2.14

Global Annual PV Inverter Shipments and market value forecast

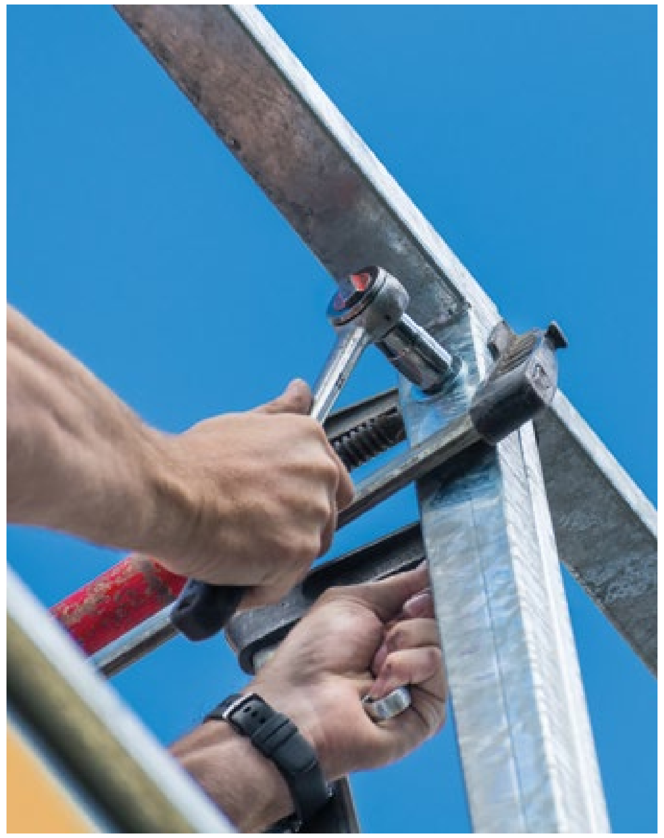


2.2.3 Mounting Structure

The Mounting Structures are one of the main equipment for the utility scale PV plants. Their goal is to support the PV modules sail and orient it properly towards the sun.
On the one hand, they have to be reliable from the structural point of view. Their design shall ensure the robustness to withstand the loads which the structure may be subjected to, like wind loads, and the durability through all the PV plant lifetime. The latter would apply both for the electronics used for the controls and communication and for the steel parts that shall be protected against corrosion with proper coatings. On the other hand, the mounting structures shall be designed to maximize the energy production of the strings of modules installed on it.
In addition, the differences in the shape of the PV module sail results in different PV structures configurations, mainly divided into vertical or portrait (P) ones and horizontal or landscape (L) ones.
The variety of PV structures has resulted in a widespread of different technical solutions that have evolved over the last 20 years of the PV industry.

Technology trend

At the beginning of the PV industry for utility scale projects, PV structures were most fixed ones, namely, with a fixed annual tilt depending on the site latitude, facing north or south depending on the hemisphere.
The configuration of the PV module sail can be tailored project by project, being the fixed structures adaptable to high-sloped terrains. They have intrinsic lower costs for the structures and for its maintenance over the PV lifetime, although the energy production can be highly boosted in order to reduce the LCOE.
To catch this extra-energy, tracking structures started to evolve, mainly as horizontal single-axis trackers, with a single tube oriented north to south, parallel to the ground and able to make the PV modules sail able to rotate from east to west during the day, thus tracking the sun and increasing the yield from 20% to 30%, depending on site locations.
Tracker configurations are typically 1P, that is to say one module in portrait with the sail that is almost 2 meters width, or 2P, with two modules in portrait and a 4 meters width sail.
The convenience of the structure installation between fixed and tracker are affected by several key parameters such as: solar radiation intensity, fraction of diffuse radiation with respect to the global radiation, ratio between the available land with respect to the available power grid interconnection capability, the weight of the fixed cost with respect to the overall costs and the orography of the terrain. Trackers solutions result in a different LCOE depending on the innovation related to the change of structure calculation, elements used to secure the module profile section, design of the main elements and improvements in the tracking algorithm. However, each of such innovative new solutions have to be validated by an on-site measurement.
For tracker with 2P configuration, the evolution goes in the direction of longer trackers, with more strings on it to reduce the CAPEX associated with the installation of the structure. This involves some issues with the wind load design that is tackled



by using different locking points along the structure length with different approaches. In this context, wind design is becoming more and more important, with many actors try to optimize the design with the implementation of slender sections based on a deep knowledge of the structural behaviour with wind tunnel testing.
Bifacial modules also are an opportunity to innovate the PV structure concept. On the one hand, the structural design has evolved to avoid rear shading of the modules by spacing them in the 2P configuration or by increasing the space between the torque-tube and the module rear side. The height of the structure is also important in the assessment of the potential production. In case of single-row configuration, the lower height is partially compensated by the lower structure width with respect to the double-row configuration. In any case, the presence of the torque-tube provides the 1P solution a negative impact in the production.
Innovation for PV structures aimed also at optimizing their components without compromising the reliability of the tracker. Unconventional-innovative materials and coatings have been used in PV plants.
The market is currently moving forward also in the direction of installation costs reduction, by improving the module securing on top of the PV structures, structural material (Corten), reducing coating of the structure, etc.
At the end, in the last period, high-strength plastic materials have been used for components such as rotational joint in order to allow both a reduction in the cost of the component and saving due to its maintenance free feature.

Market share

From the market point of view, fixed structures are used when they are more suitable for the installation due to land constraints or when the market prices for the produced energy do not add much value to the extra-energy that could be produced. Up to date, fixed structures currently hold the maximum market share.
As result of utility scale market segment growth, the market share of new installation of tracker will continue growing in the next year, thus reaching 40% in the 2024 compared to the fixed structure.
Tracker price is expected to decline in the next year, thus reaching 0,07 $/Wp, mainly due to the increase of the power of solar modules.

2.2.4 Balance of System

The Balance of system (BOS) includes the electric and civil activities required to connect the PV main equipment each other. In terms of PV plant CAPEX, BOS impact means 16% of the total amount. Main activities included in the BOS are the ones shown below.

Civil activity – BOS

- Site Area arrangement works.
- Earth Movements.
- Roads.
- Fences (including strip foundation and gates).

Electric activity – BOS

- Lightning protection system.
- Earthing (grounding) system.
- Video surveillance, intrusion detection and other security system.
- Solar cables & DC, connectors included.
- LV cables, including connectors.
- MV cable, including connectors.
- Data cables.
- Installation and test of all the electromechanical equipment.

Other activities – BOS

- Permit preparation, Back up materials, modules cleaning, cableways.
- Site needs (machinery, surveillance, signals, personnel, etc.).

Technology trend

Over the last five years, for utility scale projects, DC voltage has passed from 1000Vdc to 1500Vdc. Increase DC voltage to 1500Vdc has allowed, thus maintaining the PV design in the range of low voltage, thus reducing civil and electric BOS for longer strings.
PV modules are connected each other in one string, depending on the Voc (open circuit voltage) and temperature coefficients of the modules. Strings are wired with DC cable to the string box. String boxes can be placed and distributed in the PV field or in corridor and each one can house up to 24 strings. From the LCOE point of view, the optimal configuration is designing with string boxes distributed with 24 inputs. Depending on the modules type and site conditions, it could be necessary that the number of inputs per string box is lower than 24, but the optimal configuration is the figure nearest to 24.
Combiner boxes are provided with touch-safe DC fuse-holders, lightning induced DC surge arresters of the type II and a manual DC isolating switch. They are IP65 rated and designed for outdoor installations.
At the beginning, string boxes were active, thus collecting information of the string current. For that, string boxes included measurement and electronics. Nowadays, string boxes are passive and the information is gathered by the inverter.
Connection between the string boxes and inverter takes place with a 400 mm² LV cable.
Additionally, it is required power supply cabling to trackers actuator if self-powered trackers are not used and data cables to communicate the tracker with its control system if wireless technology is not available.
Optimal PV design based on optimal DC/AC ratio and ground coverage ratio is achieved combining the CAPEX of the main equipment, BOS and production to get the minimum LCOE.

Innovation Impact

The innovation on BOS is focused on improvement of the competitiveness through LCOE reduction. Optimizations related to BOS, while reducing time and cost of the construction of the PV plant, contribute to achieve this goal.
Under this scope, solar aerial cabling and harness are two possible solutions to reduce BOS LCOE, while simplifying labour works.
Another area on which to introduce new solutions is the PV module securing system with the aim of reducing the man-hours needed for the PV module installation, which corresponds to a reduction in installation cost per watt, but which could lead also to a reduction of the PV plant manufacture timing.
Another interesting innovative solution is focused on the replacement of manual activities on site by automatic equipment and promoting the reduction with the aim of improving the H&S and quality and reducing LCOE. In this sense, GPS bulldozer for earth movements, automatic trench-digger are a must.

2.2.5 Digital and control technologies

The digitalisation of the PV value chain supports the era of energy transition towards a low-carbon economy. It focuses on modules and components manufacturing, E&C design and O&M asset management. These are examples of the steps that have either already highly digitalised or have the potential to reduce costs further with new technologies.

Most of the digital solutions embraces nowadays a **data-driven approach**, thus trying to get the most from the huge quantity of data coming from the power plants. Anyway, the data-driven nature of the solar energy sector transformation requires understanding the interdependence with the Digital Market, to ensure access to online activities for individuals and businesses. The relevant areas include: **Interoperability** and related standards; **Horizontal standards on data**; **General Data Protection Regulation (GDPR)** and **Cybersecurity**.
The main clusters on the digitalization evolution of the energy sector could be listed as follow:

- Data Access and Interoperability;
- Digital Platforms;
- Infrastructure for Digital Solution.

Data Access and interoperability

Data Access refers to the rules ensuring that data should be sourced easily. In order to facilitate a successful energy transition, it is crucial that data for customers and market participants is accessible in an easy, transparent and non-discriminatory way, while ensuring that the consumer's personal data is fully protected. Access to non-sensitive energy data may be improved through the establishment of data hub with leverage specific Application Programming Interfaces (APIs) to enable data exchange in a transparent and secure manner and user-friendly for end users.
Interoperability is the ability of multiple systems with different hardware and software platforms, data structures, and interfaces to exchange information with minimal loss of content and operation. Standardization of data format could be a key for interoperability and it may apply to data that are required to develop the basic energy services, not all data involved in the process.

Digital platforms

Digital platforms deliver data-driven solutions that have the potential to create new markets and business models throughout the whole energy chain. As data-driven service models are still at the beginning and the sector is very fast and dynamic, it is hard to define the future models. However, we can see big solutions trends emerging. from a solar perspective; the key technologies are:

- Big data analytics and artificial intelligence (AI).
- Internet of Things (IoT) and connected smart objects.
- Robotics and drones.
- Blockchain.
- Mobile, 5G and wireless connectivity.
- 3D printing.
- Cloud and low-cost computing.

Infrastructure for digital solution and cybersecurity

Digital infrastructure enables decarbonization and further decentralization, which can result in more flexibility in the energy sector. Moreover, it allows a more cost-effective integration of decentralized renewable energy (better planning and system balancing), for example, through the integration of distributed grid sensors and advanced algorithms.
The development of energy infrastructures should go hand in hand with digital and telecommunication infrastructures, as new digital & energy services usually go hand in hand.
Given that energy services are essential to the economy and that these services are progressively subject to data-driven transformation, their cybersecurity should be ensured, hence stressing the interaction and interdependence between energy and digital infrastructure.

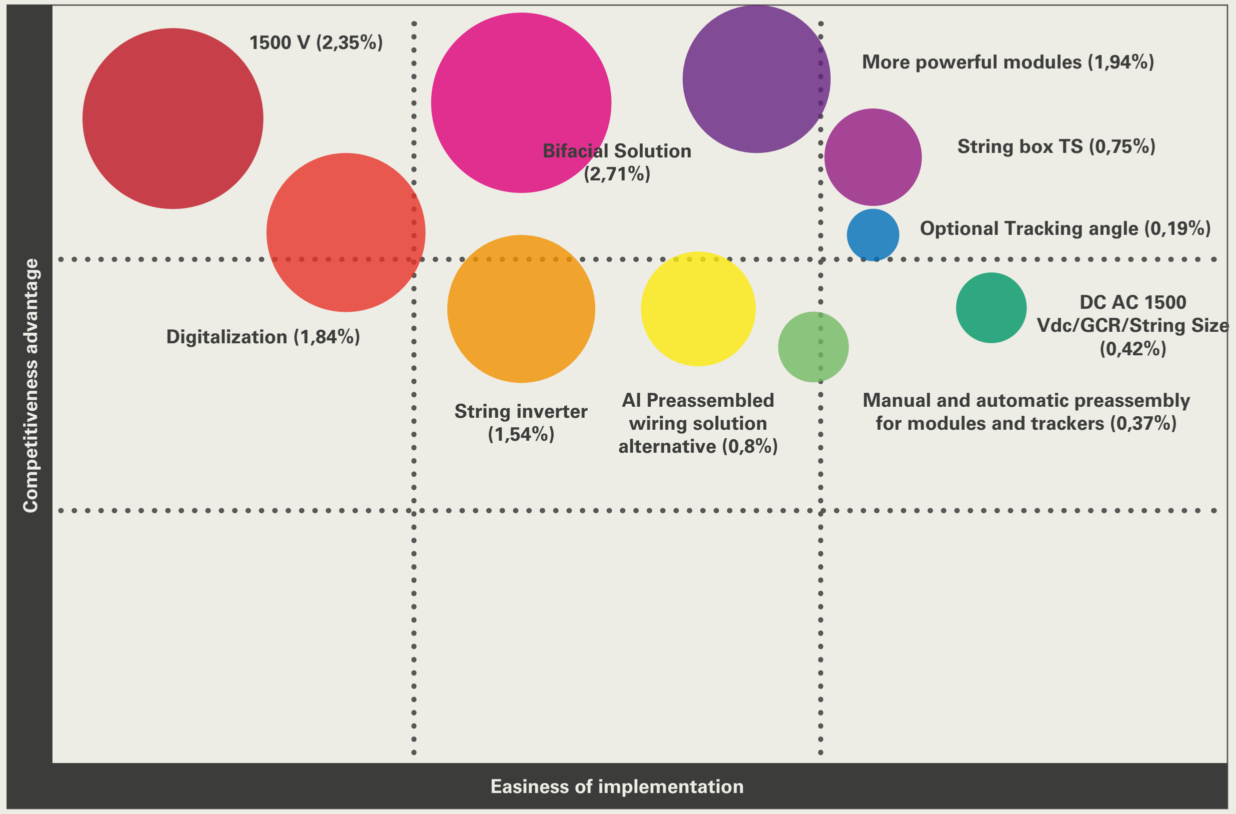
2.3

LCOE: overview and evolution of PV plant

LCOE estimates the revenue required to build and operate a generator over a specified cost recovery period.
Key inputs to calculate LCOE include capital, fixed and variable Operation and Maintenance (O&M), financing costs and an assumed utilization rate for each plant.
The rapid decline in total installed costs, increasing capacity factors and falling O&M costs have contributed to the remarkable reduction in the cost of electricity from solar PV sector and the improvement of its economic competitiveness.
The total installed cost reductions are related to various factors. Over time, cost structures have continued maturing in an increased number of markets. Lower module costs are driven by an improved manufacturing processes, reduced labour costs and enhanced module efficiency (new technologies). In addition, BOS costs declined because of project developers have gained more experience and supply chain structures continue developing in more and more markets.
Bigger impacts are due to PV plants at 1500Vdc, economy of scale, site specific designs, bifacial modules, self-power and wireless trackers, more powerful modules as well as digitalization.
The O&M costs of utility-scale solar PV plants have declined in recent years. Improvements in the reliability of the technology have resulted in system designs optimized to reduce O&M costs. In addition, improved O&M strategies that take advantage of a range of optimizations – from robotic cleaning to "big data" analysis of performance data to identify issues and preventative interventions ahead of failures – have collaborated to drive down O&M costs and reduce downtime.
In terms of OPEX, passive string boxes, string inverters, wireless, economy of scale have contributed in the reduction of LCOE.
Higher capacity factors in recent years have been driven by the shift in deployment to regions with higher irradiation, improvements in modules efficiency, bifacial modules, the increased use of tracking devices in the utility-scale segment in large markets.
The below picture shows the impact of the main optimizations on the PV plants LCOE in recent years. Each optimization is valued in terms of LCOE impact, competitiveness contribution and easiness of the implementation. The competitiveness is measured from 0 to 9 and is the improvement in the competitiveness due to the application of the optimization. On the other hand, easiness of the implementation means how difficult might be the application of the optimization. It is measured from 0 (more difficult) to 9 (easy). At the end, the size of each ball represents LCOE value.

Fig. 2.15

PV plant optimizations. Impact on LCOE



Chapter

3

Engineering and construction of PV plant

3.1

Design

The era of digitization has also affected the PV market and the changes are very significant, starting from the design in the development phase. The main changes are mainly related to the assessment of the different technical and economic parameters, which can affect the preliminary selection of the project. For example, it is now possible to evaluate the solar resource, geological and topographical information, permitting and interconnection info by querying different databases automatically in order to receive a score that represent the feasibility and the economic competitiveness of the project.

Furthermore, the other main digital transformation in the design phase is about the transformation of the processes related to the Conceptual Design, in terms of sizing the configuration, energy assessment, and final selection of best main equipment combination in terms of minimum LCOE. This has been achieved through the digitalization of the old process and the integration of many different tools into a unique integrated web-based platform. This platform is able to analyse a huge number of different combinations in terms of configuration parameters in order to find the best solution for each site condition. This allows also avoiding most of the manual labour needed to generate a layout and the related bill of quantities, which can be directly provided by the digital system starting from the optimum parameters selected and using the general references defined within the technical specifications that have been coded in the software.

The conceptual design allows the project team members focusing on the collection and supervision of all data needed to perform the analysis, thus leaving the computation to the software, increasing the productivity and the quality of the results and so improving the overall competitiveness of the project.

BIM (Building Information Model) method combined with GIS (Geographic Information System) framework is expected to play an essential role also in the solar plant design, construction and operation. Digital objects with their information database give the opportunity to rethink, optimize and automate design, construction and operation processes turning them into industrial processes. Digital objects will be the key factor to collect in a single, interoperable and always available format all plant 's critical information from the manufacturing to the dismantling.

3.1.1 Sustainable design

Understanding the limits of design. No human creation lasts forever and design doesn't solve all the issues. Whoever creates and designs must practice humility in the face of nature. Consider nature as a model and a mentor, not an inconvenience to evade or control. The Hanover principles are a model of design principles necessary for sustainability.

Hanover principles *"Bill of Rights for the Planet"* EXPO 2000 - Arch. William McDonough

Over the last few years, in the field of engineering and construction (E&C) of solar systems, EGP has interpreted and developed studies and methods for an increasingly sustainable engineering that integrates technical and technological innovations with the different and specific characteristics of each context and territory where it works for the construction of the plants.
Sustainable Design Model designs and manufactures infrastructures, thus avoiding and limiting environmental impacts and integrating the improvement of the quality of life in the project aims and meeting at best to local needs.
Already in the embryonic stage, it takes into account climatic rhythms and natural resources such as water and soil, without causing damage and discomfort to the host territory, thus harmoniously fitting into the landscape and providing for the total reuse of both the space occupied and the materials used.
Future challenges involve the need to design systems that take into account: climate changes and their influences on the planet, high modularity and flexibility, resiliency, design to be decomposable into materials/components easily recovered and reused and disposed of without causing further pollution with full or global recycling.
Sustainability in E&C is not only synonymous with energy savings or reduced consumption.
Sustainable engineering concerns an essential and intrinsic intersection of factors that affect our existence on the planet in its fullness and integrity. It is a cultural approach that exceeds the traditional vision by pushing the designer to design and manufacture, thus considering that the excellence of a project is increasingly measured in the degree of respect for human health and the environment in all its forms, through a limited consumption of non-renewable resources and the use of non-harmful and recyclable materials over time and, especially, in the degree of local development that induces and produces with its presence.

3.2 Construction

3.2.1 The trend of safety in photovoltaic sites

Building new plants, generating renewable energy, bringing experience and creating value in Countries are the main objectives of EGP; the value that surpasses, by priority and importance, this purpose, is to ensure that work, health and safety are combined in a single and indissoluble concept.
Being able to collect data from construction sites remotely is now possible thanks to the continuous monitoring of the processes, the presence of trained people and the technological progress that allows exploring the collected data in an evolutionary way. The construction sites thus become part of a virtuous network capable of highlighting, therefore anticipating, the effects of any operational critical issues.
The real difference with the past lies in a new approach to safety that is the passage from a reactive to a proactive role on which the concept of intrinsic safety in the projects is based.
A new approach to projects that allows us working taking into account prevention requirements, improving the safety conditions and simulating them before starting the construction already during the design phase.
In the past, remedies were put in place to avoid the recurrence of an accident; today it is possible to gather elements to predict, anticipate and therefore avoid it.

The active involvement of contractors, new technology providers, research and increasingly sophisticated, eco-sustainable operating systems and redundant safety systems capable of working remotely, under the direction of Enel, has made it possible to implement technologies capable of guaranteeing:

- Immediate help to the operator on-site consisting of a number of signals that can immediately call his/her attention towards an event that could represent a danger for him/herself or for third parties.
- A historicization of the data of each event that occurred in each phase of the work with the relevant geo-location of the work areas; this allows the analysis of the actions of personnel on site and identifies corrective safety measures in the design phase of subsequent projects.
- The ability to continuously structure and refine the analysis and processing of data making the survey system more reliable and punctual.

- Remote supervision of on-site activities with the possibility of intervening in real time with preventive actions.

Today, an active and functioning reality in our construction sites is represented by:

- Advanced monitoring tools such as advanced software for the intelligent acknowledgment of critical issues.
- IT platforms for data collection and aggregation.
- Control structures of areas with limited access to the possession of specific requirements.
- Check of the correct use of PPE (Personal protective equipment).
- Last generation of Smart PPEs used on site, the most advanced on market, with intelligent sensors that adapt to situations and that interact with the surrounding ambient and with the worker and that are able to detect the risk by warning and stopping the worker.

Therefore, in the sites managed by Enel, the possibility of anticipating the accident events has been added by introducing advanced control tools capable of promptly showing the signs to act and take the appropriate corrective measures. Technology is a proven and available area to guarantee a decisive increase in safety margins on photovoltaic sites.

3.2.2 Remote monitoring

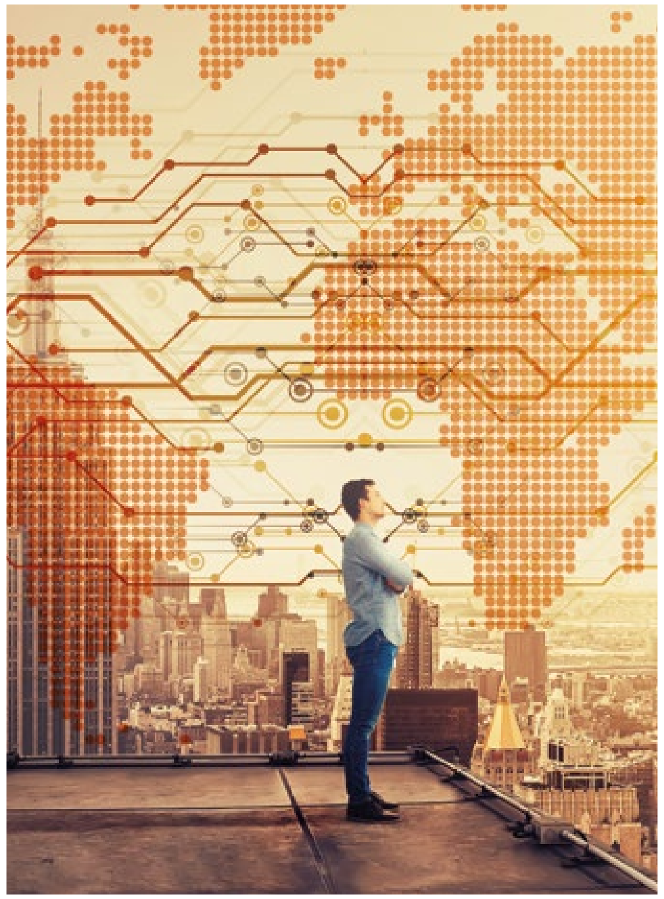
In the manufacture process of the EGP plants, GPS (Global Position System) controlled earthmoving and automated machines for mechanized cable laying have been introduced. These types of machines, while improving the quality, allow reducing the processing times so as to increase the productivity per machine and per worker present on site. Moreover, the working and safety conditions of the workers on site will be improved by limiting the workers' stay outside the vehicles and near machines at workplace.

The GPS solutions market for earth moving machines offers two main classes of solutions:

- → **GPS-guidance.** The operator's activity is facilitated by the presence in the cockpit of a monitor that views the position of the bucket/blade with respect to the target surface of the project. The control of the vehicle, in this case, is totally entrusted to the operator as in a traditional machine.
- → **GPS-control.** Automatic systems integrate the information from the GPS sensors and the target surface of the project so as independently operate the part of the mechanics of the earth moving machines (i.e. the level and inclination of the dozer blade, the movement bucket for excavators). The activity of the driver of the machine is in this case reduced compared to what is required with a traditional machine and involves a significant improvement in the quality of the work carried out.

The market solutions can also be divided into two categories based on the level of integration with the earthmoving machine:

- → **Aftermarket solutions.** They are created by the main suppliers of services and tools for topography and allow the conversion of a traditional machine into a GPS-guidance (for dozers also GPS-control).
- → **Integrated solutions.** Supplied by the main OEMs (Original Equipment Manufacturers) in collaboration with the aftermarket solution suppliers, they are available only in selected markets and enable both higher performance and the use of more advanced services for monitoring and managing the vehicle fleet. In the excavator sector, a single commercial GPS-control solution is currently available in this category.



3.2.3 Sustainable construction site

Construction is the phase when the presence of a large-scale solar project is most apparent and is usually the most delicate phase, as the impact on the environment and on people's lives becomes perceptible and evident to the community.

Since several years, the E&C Department of EGP make efforts to solve any environmental issue and to reduce the impacts on local communities related to construction of its own power plants.

According to this goal and applying the Created Shared Value (CSV) approach, E&C have developed the "Sustainable Construction Site" model with the aim of:

- Preserving natural resources.
- Keeping the site clean by avoiding any kind of pollution.
- Fostering the growth of the territory which the plant will belong to.

This is pursued by implementing all the possible mitigation actions that can operate mainly on the below aspects:

- Recycle/reuse of construction/demolition material and excavation soil.
- Reduction of construction energy consumption.
- Replacement of potable water consumption during construction with recycled and storm water.
- Minimization of temporary inconveniences associated with construction phase defining a Construction management plan to address impacts on environment and on the surrounding community.

In order to plan and arrange the above-mentioned actions, E&C have issued the Sustainable Construction Site Catalogue, including several procedures to be applied by EGP and its Contractors. Below are some examples.

ENERGY/EMISSIONS

Generation of electrical energy needed at site by using renewable sources:

- Stand-alone PV plants auxiliary to energy generation for the construction site.
- Prefabricated building/containers powered by the PV modules.
- Streetlamps powered by the PV modules.
- Hybrid solar thermal and PV modules.

WATER

The aim is to reduce potable water consumption and use recycled water:

- Rainwater collection at construction trailers .
- Collection and re-use of air conditioning water.
- Production of potable water by atmospheric water generator.

WASTE

A dedicated waste management plan reduces environmental impacts by maximizing the recovery of those materials that can be recycled or even reused with the final goal of saving natural resources:

- Packaging to be re-used by suppliers.
- Recycle/reuse of excavation and construction material.

COMMUNITY

Reduction of negative impacts on the territory related to construction activities (dirty roads, transportation) and fostering of local training about safety and environmental issues:

- Optimizing the construction site transportation.
- Vehicles washing equipment.
- Safety training courses.

Furthermore, Environmental Performances of Contractors are constantly monitored through the Sustainability Key Performance Indicators (KPI's) that are evaluated every three months, thanks to a monthly-based environmental and social data collection.

3.2.4 Future is being born now

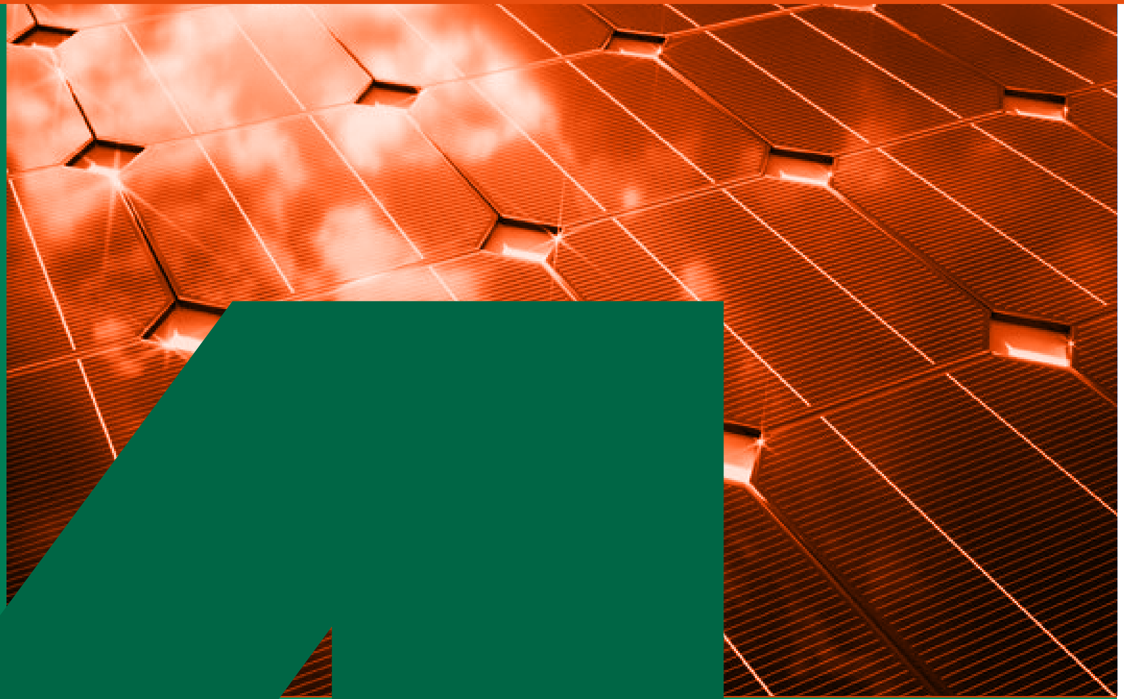
Considering the sequence of activities required for the assembling of a photovoltaic string, starting from piles installation up to PV modules connection, the most time-spending tasks are ramming, module supports installation and PV modules securing. Furthermore, due to the dimensions of the utility-scale PV plants, the above-mentioned works are repeated thousands and thousands of times in a single site with high time effort but low added value from human activity. Then, the assembly of a solar power plant can be simplified and summarized as the replication of a limited number of no-complex works.

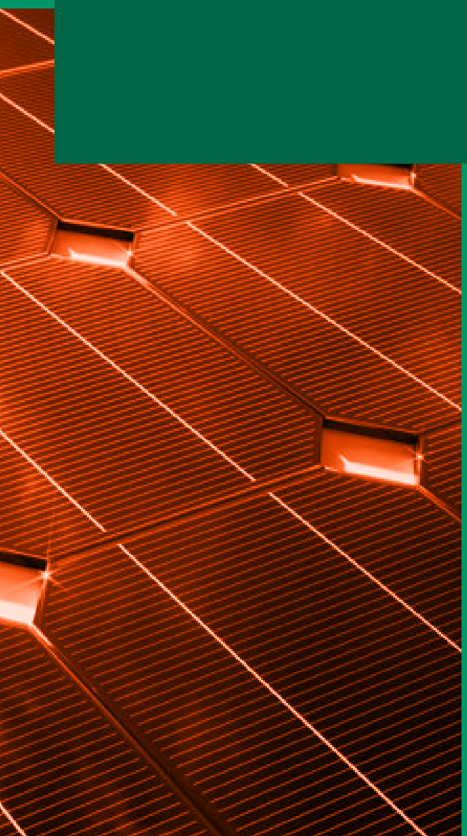
All these considerations lead to investigate on optimization of the current construction processes, by re-shaping and involving automation, robotics and innovative tools in order to take advantages in low level tasks and improving the contribution given by human labour.

Perspective on future manufacture aims at integrating different digital solution for productivity, quality and safety enhancement, not only from mechanical operation point of view but also for data gathering and processing, in order to exploit the power of the innovation for further and iterative optimization.

The revolution for the future construction site has already begun. To make it sustainable, each single task is studied and new technologies are introduced as new pieces of a puzzle that will be combined at next steps, with a top-down approach. For example, in EGP sites, case studies could be innovative machine to safely ram the tracker piles, new securing systems to speed up the modules installation, thus bringing robotics arms on a PV plant for materials handling, capture and processing of images of the sites to be built and extrapolating the related information and providing wearable devices to the operators to support them in tiring task.

All the above is the starting point to change the way to build a PV plant, thus allowing to find new solutions for the identified needs but also to establish a channel between two pillars of the current century, the renewable energies and digital revolution, thus enabling the merging and their maximum valorisation.





Chapter

4

Operation and Maintenance of PV plant

Operation and Maintenance is the longest segment of the life cycle of a PV power plant and a crucial point for good performances of the plant: a high-quality O&M service may mitigate potential failures and unavailability, improve the energy availability and, then, reduce the LCOE.
The O&M phase could last 25 - 30 years, following the evolution of the plant, solving faults and issues, but also looking at the trend of the available technology to reduce the faults frequency, impact and duration, and improve the performances of the installed machines.
The O&M consists of three parts, with different scopes, roles and people involved:

- **Operation.** It is the way to operate the PV plants, control the machines to follow the indication of external stakeholders (Transmission System Operator, suppliers of the components, etc.) and supervise the plant to avoid unauthorized access and manage the accesses; furthermore, the Operation measures the performances of the plant, using the installed sensors.
- **Maintenance.** It is the set of actions performed to keep the plant operation, thus solving failures, implementing planned preventive actions and systems to predict any failures, avoiding unavailability, solving issues before a fault and improving the life cycle of any components.
- **Decommissioning.** It is the final phase of the life cycle of the PV plant, when the useful life of the components has expired and the materials shall be recycled; a proper decommissioning may return the used material to a status that allows reusing those materials.

All the companies that deal with O&M need to collect and archive all the information and documents related to the PV plants fleet. EGP group manages the entire PV fleet of its 120 plants over 4 continents and a big grow (in 2024 there will be 23 GW of total PV power installed) is expected to begin in order to digitalize all the activities, such as the technical information and plant description, available in a dedicated Master Data Portal.

4.1

Operation

Operation is related to the below activities:

- **Remote monitoring and supervision.** It is the surveillance of the PV plant operation through an internet connection properly protected by external/cyber-attacks; this activity may also include the video surveillance control.
- **Control of the PV power plant.** It involves the operation complex to be followed in order to keep the PV plant working. It also involves liaising with or co-ordinating the maintenance activities, ordered shut-downs, power stops and frequent adjustment of settings such as power factor (source reactive power), frequency and voltage tolerances.

The Operation of the plant shall integrate a proper plant documentation management system; this should include, at least, the as-built documentation set (such as the PV modules' datasheets), updated to the last version available.

Through the remote monitoring, several data are collected and stored in the servers, to analyse and detect technical issues. Based on these data and analyses, the O&M Contractor should always strive to improve the PV power plant performance.

For the PV plants, the structure for the operation is a connection to a Control Room, usually with a 24/7/365 surveillance, to control, supervise and, eventually, apply the requests by external actors (i.e. the local TSO – transmission system operator - and DSO – distribution system operator). The data collected by the Monitoring Room are archived in a Cloud system through a Real Time Monitoring software.

The data collected through the Monitoring Systems are used to analyse the plant performances and detect any inefficiencies; those analyses are handled through an analytics software, which uses procedures and programs written directly in the workspace to automatize the performance indicators calculation.

The monitoring of the PV plants performances may also involve other software specifically developed for specific needs, for example, developed by the Inverter manufacturers and also by EGP; it is the Zone Monitoring software, which allows determining if there are string that are not producing, usually due to string box fuses intervention.

Other specific software that will be implemented by EGP, is an automatically alarm and underperformances software recognition that allows to notify inefficiencies/shut-downs directly to supervisors or contractors people that have in charge the maintenance. This software is able to detect and separate the different kind of faults, through the analysis of the data coming from the plant.

Another tool under development and tested in EGP workspace and, particularly, in the Roboost program, is the "Automatic Solar Log-Book", an automated diagnostic system, using Artificial Intelligence and Robotic Process Automation (RPA) that does the daily operational assessment with information from data monitoring system. In this way, all the daily inefficiency points (an average of 600 points/day) will be automatically classified, thus avoiding the intervention of manual labour of the Operational Efficiency employees.

4.1.1 Plant Management System

To support the activities of operation, particularly, the remote monitoring, several tools are available. For the EGP case, the tool used is the Plant Management Tool that consists of a digital platform that receives operational data by plants, evaluates any issues and presents them in interactive and user-friendly lists; it gives O&M people the opportunity to manage these issues, with an automatic connection with Management Software environments.

A mobile interface will provide O&M people a quicker management also outdoor.

4.2

Maintenance

Maintenance is usually carried out on-site by specialised technicians or subcontractors, all with proper training, according to the Operations team's analyses or remotely through a protected internet connection to the components that support this function, such as trackers, inverters and SCADA.

The maintenance activities can be credited to:

- **Scheduled (or Preventive) Maintenance.** It involves regular visual and physical inspections, check activities, necessary to comply with the device operating manuals, warranty requirements and tests to verify performances of the components of the PV plant, such as I-V curves etc. The scheduled activities shall follow an Annual Maintenance Plan.
- **Corrective Maintenance.** They are the activities necessary to restore a fault in the PV plant; the Corrective activities follow the levels division, according to the device categories, such as 1st, 2nd and 3rd level for Inverters.
- **Extraordinary Maintenance.** It includes all the activities necessary to restore the PV plant after events that exceed the design limit, such as flooding, storm that requires substantial repair works. The annual maintenance fee usually does not cover this kind of maintenance.
- **Predictive maintenance.** This type of maintenance has to identify any faults before that a failure takes place. This type of maintenance may require additional sensors, monitoring points, tests and dataloggers, particularly, in case of predictive work with smart SW, to monitor the status of the components involved in this activity. This maintenance is divided in:
  - **Condition-based.** It is carried out following the identification of parameters that are measured and processed using appropriate mathematical models in order to identify the time remaining before the fault, thus allowing to predict the time of failure.
  - **Predictive work with smart software.** A particular type of preventive maintenance, that uses instrumental measurements and smart software to identify the current status of components, to perform maintenance action only when that equipment may fail or need repair. This software may also include a self-machine learning process to adjust the calculation algorithm and the related results. In the EGP world, the predictive maintenance through software is under development applying a neural network with machine learning, so it is possible to monitor the plant components up to inverter level with daily alerts, to identify inefficiency periods and keep all the warnings under control.

4.2.1 Workforce Management

It is an integrated system that offers a complete support during the entire maintenance process, starting from planning/scheduling activities and continuing from resourcing and work's optimization and ending with works execution. Furthermore, the system will be available even through a mobile app.

4.2.2 Additional activities

Additional maintenance services include tasks such as module cleaning and vegetation control.
For the maintenance activities, there are some applications of robots for the automated grass cutting and for the automated panel washing. These machines are able to carry out the cleaning and cutting automatically or semi-automatically, thus reducing the OPEX, improving the performances of the plant and keeping the plant in the best possible conditions with a sustainable look about people on added value activities.

4.2.3 RoBoost Program

Under the RoBoost Program, in the last two years there was a deployment of other solutions to support operation and monitoring activities of solar power plants through Augmented Reality that boost interactivity and communication between personnel and remote specialistic support. Some example devices normally used are Smart Glasses with related platform and tools (i.e. digital workflow for standardized process) and APPs installed on smartphones, always with Augmented Reality included.
The smart glasses technology allows the on-site operators or one-to-one groups calling (also with the suppliers) supplying documents in real time (manuals, logbooks, etc), protocol activation, meetings support and remote assistance tool, to guide the operators in their maintenance activities.
Another kind of activity, already deployed worldwide through the RoBoost Program, are drones combined with Artificial Intelligence that are able to faster inspection on modules increasing dramatically the quality and the standardization of postprocessed data that represent a strong basis for Maintenance activities described deeply in the paragraph below.
Drones are commonly used in the PV plants to execute aerial IR thermographic surveys in order to detect thermal anomalies like hotspots, diode of by pass, PIDs, disconnections of strings, tracker misalignment and the outcomes are ordered and evaluated in order to prioritize interventions of the Maintenance Plan.
The detection of the faults is fully automated through the neural networks that leverage on anomaly detection to find differences within thermographies; everything is based on Artificial Intelligence and Machine Learning.
In order to improve this robotized value chain, we developed a dedicated infrastructure that is the ROMAP platform, where each Country can upload the IR and RGB (Red Green Blue standard) images; the data flow is flexible and in continuous evolution but ensures always the capability to process the data through an AI software for image recognition and prepares a report with the indication of the faults. The reports can be access worldwide.
In the future, a particular look will be dedicated to robotized value-chain in order to enhance each single task of the process both about on-site activities and about data flow, thus taking into account that we are strongly leveraging on Geographic Information System that ensures not only a common 'vocabulary' but also the management of a great amount of data accessible and performable by everyone.

4.2.4 Sustainability in O&M activities

As monitored before within the Sustainable Plant model, the improvement of O&M activities for solar technology concerns: water consumption reduction, multipurpose use of land and a sustainable soil management, PV panel end-of-life and robotization.

Water consumption reduction

The use of water in the operation of solar power plants is characterized by the greater use of water for cleaning panels, compared to other types of water use (human and administrative consumption), due to the high level of soiling on the panels, depending on the geographical area where the plant is installed.
In scares water supply region, the actions to reduce the water consumption for industrial use as well as to find new water sources are different.

1. Cleaning panel optimization

In Chilean solar power plants, a software has been developed to optimize the number and types of solar panel cleaning, as panel soiling can affect negatively their production and lifespan. It lies in the decreasing of water consumption, particularly important in water stressed areas. The implementation of the procedure can be divided into different phases:

- **Calculation of the Soiling Ratio.** Using a specific measuring equipment that measures the irradiance and the electrical parameters (short-circuit current and maximum power) of two reference panels (one always kept clean and one cleaned with the others panels), it is possible to calculate the performance differences.
- **Creation of the Soiling curve.** Using different parameters, a regression model allows calculating the soiling curve of the specific plant starting from the historic data measured.

Entering the initial soiling of the plant, possible types of cleaning, cost/MW of each cleaning type, hourly expected production, hourly energy sale price, the software returns the optimized date for the next cleaning, an annual cleaning plan, the type of cleaning recommended and any MWh and losses due to soiling under different scenarios.
This method allows increasing the production, reducing OPEX due to optimized cleaning frequency, avoiding any failures as deposited particles that tend to reheat (hotspots), decreasing the water consumption needed for cleaning panels, which benefits both the environment and the local community.

2. Water free cleaning panel strategy

A lot of suppliers and technical solutions are going to be tested for a **water-free cleaning strategy**, which actually is a ready-to-market technology and could be the best solution for stressed water regions: tractors with mechanical arm and brushes (not fully automatic). Laboratory tests (spectroscopy, calorimetry, traction, abrasion, resistance) confirmed the reliability of the system, with excellent level of cleaning and no abrasion on PV panels. The feasibility analysis must take into account some assumptions:

- Water supply cost to be compared with brushes wear.
- Perimeter of applicability: desert area with no humidity at all.

Warning to the supplier selection, point on which to pay attention are:

- Abrasion on PV panels.
- Brushes wear and cost (could be not competitive to the cost of water).

3. Reduction of water supply

The reduction of water supply is the way to reduce the needs to buy and supply water to the PV plants. This could be achieved collecting rainwater, particularly in regions where the rain is present, or generation of water from the humidity present in the air, that could be handled with a dedicated machine or through the air conditioning systems, already present in the O&M of the plant.

- **Rainwater collection system.** In regions where it is possible to collect rainwater for industrial use, there is the possibility to collect water though a watertight roof with drainage system that drives the rainwater in several tanks.
- **Water generation machine.** It is a water generation machine that generates water condensing from the humidity in the air. It is a useful solution for solar power plants wherein the access to water is often a challenge or the water supply for civil use is not allowed. This is a way to reduce water needs in regions with lack of water.
- **Recycling of water from air conditioning.** It is the collection and reuse of water for non-drinking use from the condensation of air conditioning systems installed in the plant buildings. The initiative starts from critical issues such as high con-

sumption of water, transport of water resources through hydrocarbon consumption vehicles and, particularly, hot and humid climate. The implementation requires the installation of PVC tubes connected to the water containment with filtration system in order to remove solid particles and chemicals.

Multipurpose use of land

Agrivoltaics (agriculture + photovoltaic) investigates the potential for reintroducing vegetation into the typical PV power plant installation in drylands. This new approach may result in increased renewable energy production, increased food production and reduced water use.

According to this approach, farming under solar panels generates a number of benefits, including: some plants do not need full sunlight and the presence of shade from panels can be positive for certain species; the presence of shade can be favourable for workers, because working in the full sunlight can pose health risk and hazardous working conditions; the presence of vegetation beneath panels reduces the heat island effect, which has negative consequences on the efficiency of panels.

Sustainable soil management

Grass management with vehicles piloted by remote control: This method reduces significantly the risk of accidents because the pilot is far from the movable and sharp parts of the equipment. Moreover, it reduces the risk of venomous animal's attacks. It also reduces the physical distress of the operator compared with the manual equipment use. The waste produced is crushed and left on the ground, without the necessity to dispose of it.

4.3

End of life and recycling

Solar farm decommissioning is defined as the final phase of the PV plant and can be considered as a reverse of the installation process, when the plant has to be dismantled to return the site to its original status and to recover and recycle the materials used in the construction phase; the recycle process may involve, at least, the PV modules, tracker and PV modules structures, inverters, MV cabins as well as aboveground and underground electrical connections.

Depending on the permits, the terms of the lease and the pre-construction land use, the project owner may be required to reinstate the site to its original conditions.

In particular, EGP in some project has adopted a decommissioning and site restoration plan where it is planned the removal of all equipment, holes or gaps created by poles, concrete pads and other equipment will be filled in with soil to the surrounding grade and seeded with previously approved seed mix.

This may include re-vegetation as native prairie, thus returning the site to agriculture or re-developing the land for other beneficial uses.

On a global level, many photovoltaic plants will reach the end of their life in the next few years, with the need to manage

large volumes of waste.

EGP is already taking steps to implement a number of initiatives that will allow, when necessary, recycling and reusing the components of the plant that have reached the end of their life.

The recycling phase involves, at least, the recycling of the PV panels, the recovery of the raw material and the removal and disposal of the site components. EGP is looking and implementing projects to cover all these activities.

4.3.1 Raw material recovery of PV panels at their end of life

In order to create a circular economy, several companies are working to implement projects and pilot plants aimed at increasing the quality and, consequently, the economic value of the materials recovered from the disposal of the panels.

Up to date, the recovery percentage of the panels is around 90% of the weight; the recycling processes differ according to the technology of photovoltaic modules but, currently, integrated mechanical recycling processes with chemical and thermal processes dominate the market.

Recently joint initiatives of European companies and research institutes have taken place, aiming at enhancing the recovery and recycling of the materials that make up the remaining 10% of the panel weight.

EGP in a consortium of European companies will develop a project focused on the develozpment and validation of innovative recycling processes for the recovery of secondary raw materials from end-of-life (including early failed) PV modules, aiming at demonstrating innovative solutions for PV End-of-Life (EoL) products recycling, thus minimizing material waste and achieving high recovery rates of Secondary Raw Materials (SRM).

Proposals and new ideas are coming to re-industrialize sites and power plants no longer working, in possible logistic centres or recovery plants where handling the material decommissioned from other plants.

Several providers of PV panel have developed an advanced recycling technique, for example, EGP in Romanian plants is recycling the glass in scrapped PV panels to high purity glass grain at 99.99%, which further is used as raw material for glass manufacturing. Other investigations on the suppliers that include recycling in their business are ongoing at global level in order to improve and invest in these solutions for the next future where PV panels will become more and more disposal waste.

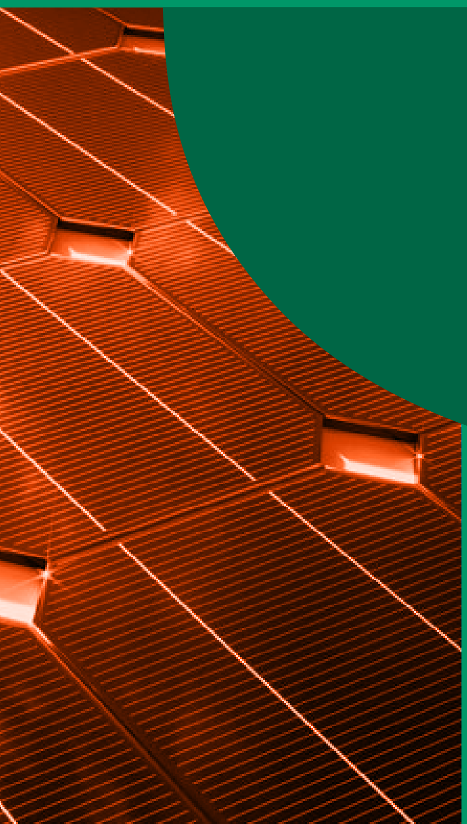
4.3.2 Removal and disposal of site components

This part of the decommissioning phase concerns the removal, the recycling of the recyclable materials and the disposal of the non-recyclable materials. EGP is strictly involved in this process, whose parts and actions are listed herein:

- **Modules.** They will be packed, palletized and shipped to the manufacturer or a third party for recycling purposes.
- **Trackers.** The trackers and related components will be uninstalled and removed from the steel foundation posts, sorted and sent to a metal recycling facility.
- **Steel foundation posts and beams.** All structural foundation steel posts and beams will be excavated and cut at a subsurface depth of four (4) feet, removed and shipped to a recycling facility.
- **Overhead and Underground Cables and Lines.** As part of the decommissioning of the project, these items will be removed up to a depth of 48 inches and shipped to a recycling facility.
- **Inverters, transformers, electronic devices and other components.** All electrical equipment will be disconnected and disassembled; all parts will be removed from the site, reconditioned and reused, sold as scrap, recycled, or disposed of appropriately with applicable regulations and industry standards.
- **Ancillary Foundations and Fence.** All parts will be removed from the site and reconditioned and reused, sold as scrap, recycled or disposed of appropriately with applicable regulations and industry standards.

Chapter

5 Innovation challenges approach from utility perspective



EGP is a world leader in the renewable energy industry and, to maintain this role, it is important to always be competitive from a technical, economic and sustainability point of view. EGP is able to give this thanks to a strong vocation for innovation in all aspects of the activities it carries out, allowing it to always be at the forefront of both the technologies it uses and the sustainability of what it handles.

With reference to the photovoltaic sector, EGP, thanks to its strong vocation for innovation, implements continuously a whole number of new solutions that cover all photovoltaic sectors, from the development and production of technologies with the highest efficiency and productivity to the development of various innovative concepts regarding the development, construction and O&M of the plant, end of life of the plant and, in order to guarantee the reliability, the life time and, consequently, performance and environmental and economic sustainability of the PV systems.

EGP leverages its internal skills to develop innovative solutions and implements an open approach towards the outside through the research and collection of innovative proposals and solutions (one of the most channels it uses is its global network of Innovation Hubs).

With reference to the solar segment, EGP has developed a technological hub that includes the research of the 3SUN factory and the Innovation Hub & Lab through which it develops and studies innovative solutions in the Photovoltaic scenario.

5.1 3SUN Factory

EGP is boosting the development of cutting-edge PV technologies in its 3SUN industrial technology development centre with the main purpose of becoming the undisputed leader of the PV module technology. The emphasis for the PV module is on increasing average energy generation, by exploiting HJT superior bifacial characteristics and thermal stability, thus reducing the overall cost of energy utility scale installations.

3SUN is a 200MW/year capacity manufacturing development centre, able to manufacture 100000 high efficiency silicon solar cells per day and to assemble more than 1000 PV modules/day. The centre has about 300 employees and there are about 300 people working as local subcontractors; the manufacturing area occupies 50000 m2.

The area can be expanded by implementing new equipment and facilities up to more than 2GW/capacity.

3SUN was established in 2011 as a joint venture of three important companies (Enel Green Power, Sharp and STMicroelectronics) from which the name 3SUN is derived. From 2012 to 2017, the factory has produced about 7 million of modules in silicon thin film technology and has pushed the amorphous silicon technology to its practical limits. In 2017, EGP decided to convert the thin film manufacturing lines, from thin film to crystalline silicon, thus still maintaining the use of amorphous silicon as innovative passivating layer in the solar cell architecture.

Today, 3SUN is an innovative manufacturing centre, which develops new PV technologies at industrial scale, thus accelerating their industrialization and marketing. The solar cells developed in 3SUN are based on silicon heterojunction and tandem solar cell technology. The centre has unique characteristics in Europe with high focus on PV tech competence, including materials, costs, industrial process, reliability and equipment.

Moreover, it is focused on consolidating know-how for EGP to maintain its leadership on the PV value chain as well as to anticipate leading edge technology solutions on the PV modules. As PV technology excellence in Europe, at the forefront of the industrial PV technology, 3SUN is actively driving the European research programs by collaborating with the most important research centres in Europe and in the world.

5.1.1 Innovative automation and digital

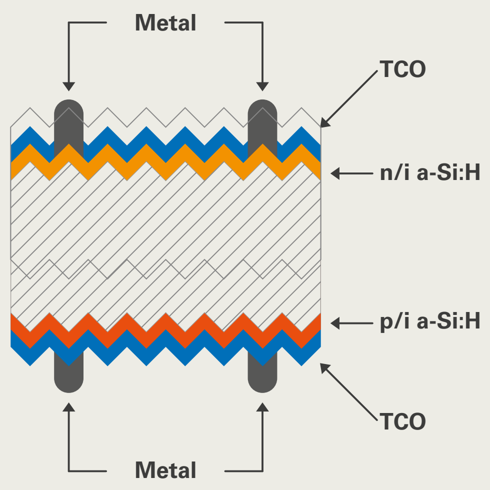
Enel's Strategy for competitiveness is centred on 3SUN HJT bifacial PV Cell and Module fully digitalized and automatized factory fully aligned with the Industry 4.0 approach. This characteristic leads to implement sustainable manufacturing using the ubiquitous information and communication technology (ICT) infrastructure. The approach follows three main guidelines: (1) horizontal integration across the entire value creation network, (2) end-to-end engineering across the entire product life cycle as well as (3) vertical integration and networked manufacturing systems. The manufacturing lines apply cyber-physical systems working in a self-organized and decentralized manner. Such systems are based on embedded mechatronic components such as applied sensor systems for collecting data and actuator systems to influence physical processes. The systems are intelligently linked with each other and are continuously interchanging data by virtual networks. Moreover, systems use human machine-interfaces for interacting with the operators.
The systems handle a big amount of data collected from the processes, machines and products. The data require extensive analytics that leads from the 'raw' data to the useful information and, finally, to the concrete actions that support an adaptive and continuously self-optimizing industrial production process.
Compared with the state-of-the-art in PV, the 3SUN factory automation and artificial intelligence systems are leading edge and comparable with the most advanced semiconductor manufacturing companies in the "Silicon Valley".

5.1.2 HJT technology

Bifacial HJT combines the advantages of crystalline silicon technology with those of amorphous silicon, thus allowing solar cells to increase significantly the power conversion efficiency and output stability with temperature. The process is based on few innovative technological steps that have the characteristics of preserving the perfect electrical properties of the crystalline silicon, used as generator of light producing charge carriers after absorbing the sun light. Actually, contrary to conventional technologies based on dopant diffusion techniques at temperatures exceeding 800°C, the advanced HJT process steps do not exceed 200°C and involve only few nanometers at the surface of the silicon wafer. The reduced number of HJT process steps compared to conventional processes enables an easier automation integration, thus implying a more accurate handling of silicon wafers and a reduced defectiveness.
With respect to most common approaches (Al-BSF and PERC), HJT cell passivation is achieved with non-metallic contacts that act as contact and passivating layer at the same time. Recently, Enel, in collaboration with the CEA-INES Technology Centre, has obtained a record efficiency of 24.6%, achieved on commercial solar cells manufactured with high throughput industrial equipment.

Fig. 5.1

Schematic representation of a silicon heterojunction solar cell (HJT)

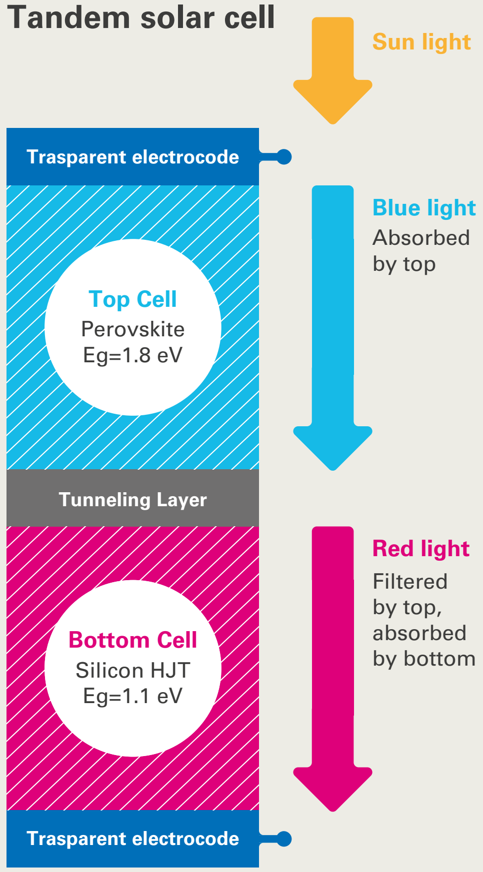


5.1.3 A look to the future of the PV segment

Though amorphous silicon used in HJT is a good selective contact, recombination losses can be further reduced by developing contact structures that improve surface passivation at the same time, extracts more carriers in a selective way with the aim of approaching the theoretical limit efficiency as much as possible; this is under development by EGP-R&D in 3SUN technology line.
The manufacturing process of HJT is easy and makes it the most performing technology based on silicon, thus relying on its compatibility with several advances that will allow the solar cell overcoming the theoretical limits of silicon, aiming at achieving more than 30% cell efficiency. In particular, multi-junction solar cells are the most promising path to increase PV module performances, so several approaches are explored in our technology centre in Catania (Italy) to find a double junction tandem structure, which can be industrialized. Coupling with an HJT bottom cell can be a viable path to obtain an industrial application.

Fig. 5.2

Tandem solar cell

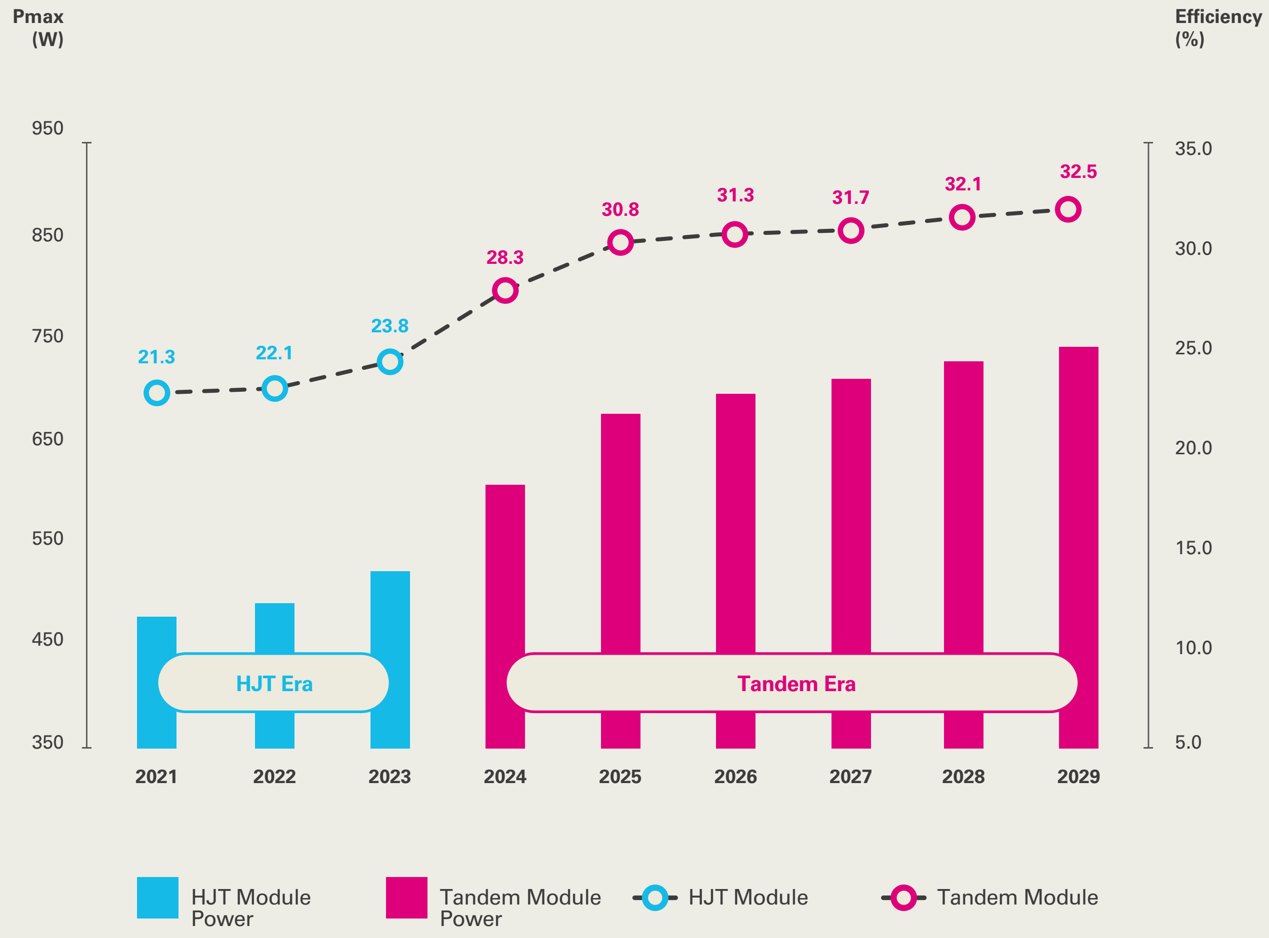


5.1.4 EGP technology roadmap

The EGP technology roadmap is based on the development of the silicon-based technology until the maximum practical or industrial limit. Considering that the theoretical limit is of 29%, it was evaluated a practical limit of around 27% using the Si-HJT technology. At our EGP-R&D Dept., we are developing solar cells that can overcome the silicon limitation related to its band gap. As mentioned before, the new solar cell architecture is a double junction where the top cell is a perovskite solar cell that uses more the blue component of the solar spectrum and a bottom Si-HJT cell that uses in the most efficient way the red component of the solar spectrum. To allow a monolithic tandem solar cell to work in an effective way, it is necessary to enable the current flowing across the entire device. For this reason, it is important to develop an adequate charge transport layer between the stacked cells. The transport layer is a very crucial item for the correct operation of the solar cell and some "smart" materials such as nanostructured materials and graphene. Graphene is an interesting material that we are studying for applications on both solar cells and module assembly. In addition, to the interesting properties as smart electronic material, graphene is very attractive for replacing the high cost silver in the metallization. In the future cell configuration, the device will be characterized by very thin thickness allowing for a significant reduction of costs.
The chart below shows the expected trend of the PV EGP technology in the next years, with the transition from the silicon HJT era to the double junction tandem era, with the development of the new solar cell able to reach even more than 30% efficiency. The future of module assembly is challenging too; the main development directions are the decrease of weight using new materials (thus maintaining the reliability) and the optimization of the optical and electrical losses that determine the cell to module ratio. Using segmented cells assembly (from half-cells to shingling) will improve the fill factor and enable use of more active area.

Fig. 5.3

Technology roadmap of solar cell and PV modules



Technology roadmap of solar cell and PV modules (that will exceed 2 square meters) evoluEon of PV EGP technology in the next years, with the transiEon from the silicon HJT era to the double juncEon tandem era, with the development of the new solar cell able to reach even more than 30% efficiency.
Cell and modules areas are growing. Silicon wafers are moving to larger size from a side of 156.75mm (M2) to 166mm (M6) to 210mm (G12). Using large wafers and segmenEng the cell leads to larger area modules.

5.2

Innovation Solar Lab

The Lab hosts several testing activities as well technology transfer projects, involving industrial large-scale private partners, small scale partners like start-ups and Italian and European research centres and organizations to demonstrate innovative solutions and concepts on the filed intermediate scale before deploying the most interesting solution to large scale solar plants. The facility offers more than 100.000 m2 available as outdoor testing area and 3000 m2 as indoor labs specialized in PV module advanced aging testing and performances assessment.

A solar power plant is a complex system that has several aspects that can be analysed, evaluated and improved in order to reach a higher overall energy production efficiency through the PV plant lifetime. From this point of view, the challenges include all the aspect of E&C and O&M: PV modules, mounting structures (single axis tracker, fixed structures, dual axis trackers), inverters, electronic on board and optimizators, data monitoring, module cleaning, energy production monitoring, degradation analysis and automation for mounting and cleaning.

5.2.1 Photovoltaic modules

Photovoltaic technology is fast moving towards innovative products and solutions: bifacial modules, larger wafers, half-cell and thirds of cell, new interconnect methods like shingled cells or smart wire and new high efficiency solar cell like HJT. Beside that also incremental innovation like light harvesting systems (reflecting ribbons and partially white backsheet) or thinner glasses together with new frame design, sometimes only addressed to the reduction of production costs.

This continuous improvement requires an equal fast response to evaluate the innovations and to verify if the quality and the reliability levels have not been sacrificed in front of a more economical solution even if apparently more efficient.

Often the simple IEC or UL certification is not enough to guarantee a long lifetime of the system since sometimes the PV modules seem to be designed only to overcome a basic testing stress.

The Innovation Lab is the EGP answer to this fast-changing market leading reliability and performance testing activity, following the standard protocols and developing innovative methods to evaluate the PV modules with innovative characteristics.

To follow this mission, the testing protocol has been developed behind the simple standard CEI EN 61215 to reach a deeper knowledge on the technology. Actually, the extended protocols campaign allows making a direct comparison of the performances in terms of reliability and energy production with the possibility to identify and measure the specific failure modes of different suppliers, thus leading to an internal ranking in terms of quality.

The objective is to make a more realistic evaluation of the levelized cost of electricity (LCOE), for example, evidencing and analysing the PV module failure modes and accurately evaluating their degradation.

5.2.2 Mounting structures and automation

One of the core parts of a PV power plant is the definition of the mounting strategy in order to minimize the LCOE. It is important to define case by case depending on the plant dimensions in terms of Pmax and in terms of area, which is the best compromise also according to the geographical area. The maximization of energy production could not be the only approach to obtain results.

The EGP approach is to always look for innovative solutions to create new opportunities. By studying and comparing fixed amounting structure, single axis trackers and dual axis with various approach to the geometries in order to simplify architectures and to be more competitive are taken into account. These solutions can allow the automatic on-site mounting or the automatic cleaning since the next future will make available new robotics solutions and we are working to be always on the line to be ready to this change. AI approaches to the PV plant design and self-guided robotics to mount and clean PV modules are also under evaluation. Also, more advanced approaches are under scouting like the design of trackers by using an AI approach to the geometry's definition.

At Innovation Lab, we on-site test new solutions on a relevant industrial scale and, in this way, we can handle a pre-industrial screening of technologies that afterwards can be deployed and tested on solar fields, thus selecting only the most promising ones and addressing the efforts towards the state of art.

5.2.3 Digitalization

Digital devices and approaches for utility scale application will more and more fill the future and will be more and more present on the market. Actually, this type of solutions needs to achieve a very high level of reliability and intrinsic robustness to be used for stressing application like the PV power plants. Manufacturing a device able to resist to 30 years in a harsh environment is a quite challenging Innovation activity. This kind of devices could allow a full remote control of the PV power plants starting from the single panel performance monitoring up to the general live energy yield of the whole plant.

Such a distributed and complex control requires the development of solutions starting from the single monitoring devices up to the low energy data sending leading to a whole new world to be explored and addressed to specific needs.

EGP is on the line to follow all the evolution in this field by participating in different kind of project and by scouting specific solutions in power and control electronics.

5.2.4 Innovation Lab testing facility

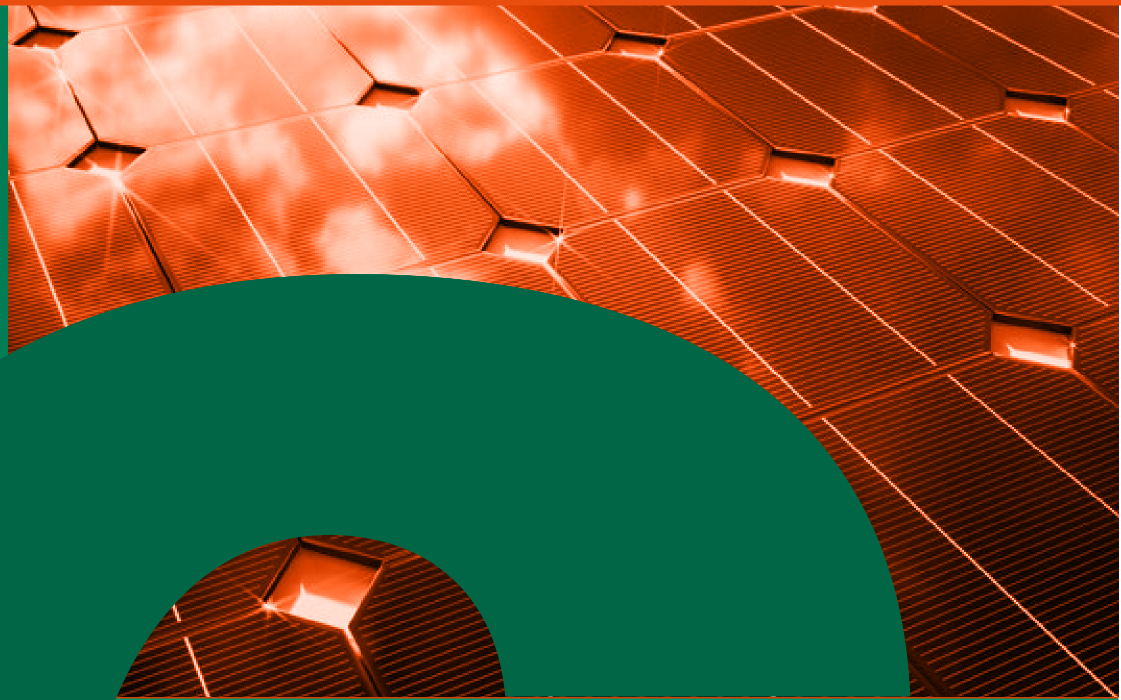
To follow all the above-mentioned innovation initiatives, EGP created an advanced testing lab able to give a fast and clear feedback to the proposed solution. The IEC 61215 and IEC 61730 standards for module certification can be performed and extended and modified testing protocols have been developed to evidence more clearly degradation aspects of the PV modules.

In the last years, the Innovation lab is evolving towards the new challenges of the PV module testing with the aim of introducing new characterization techniques to evidence the behaviour of the PV modules under stress condition. The main new efforts will be the installation of the new climatic chamber with the integration of a solar simulator to test the not well-known phenomena like the Light and Thermal Induced Degradation (LeTID).

Complementary to the Indoor Activities, the Innovation Lab has also an extended Outdoor testing area. There are, for example, installed several different modules to compare energy production under the same conditions giving a direct feedback on which to base the best technology also from this point of view.

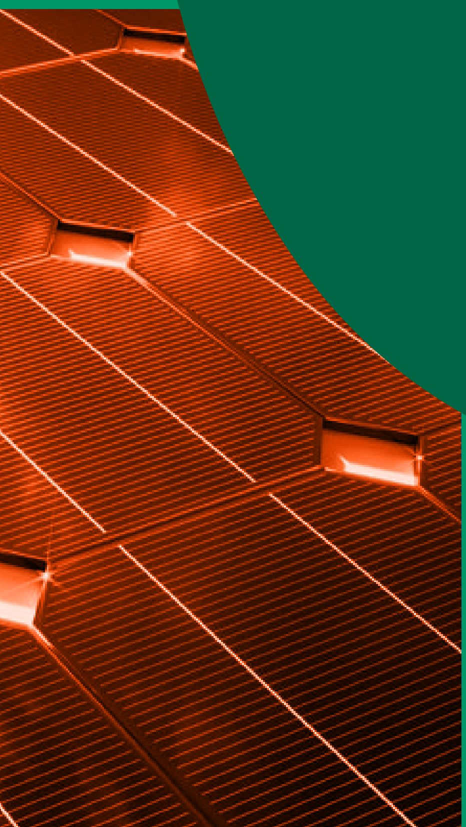
The outdoor testing facility allows making different types of test on the PV modules and structures. It is possible to perform the stabilization required by IEC standards for the certification and the energy yield comparing, for example, different albedo due to different backgrounds in the bifacial module case. It also possible to use the fixed benches or the trackers to test the automated PV cleaning or to test the automated mounting solutions.

The Innovation Lab is able to put in place several different experimental scenarios to give a feedback on the main issue related to the PV module lifetime and the PV systems efficiency.



Chapter

6 Sustainable impact in PV industry



In the last decade, sustainability awareness has been increasing in many ways, but one of the most remarkable shifts has been the growing focus on sustainability by citizens, thus pushing public and private sector in accelerating the transition towards a sustainable world.
Sustainability integration in the business of private sector companies is an ongoing unstoppable process in this period.
Environmental sustainability is one of the focus, considering the attention that climate change has reached and the importance of GHG emissions reduction in order to avoid the planet temperature increase.
Nevertheless, also social sustainability has been gaining more and more attention, especially for topics such as respect of Human Rights, as rejection of forced or compulsory labour and child labour guaranteeing just and favourable working conditions, considering the rights of communities and people.
Moreover, to speed up the transition to a sustainable world, the actual way of manufacturing goods is going to be rethought, thus passing from a linear to a Circular Economy model, based on the principles of redesign, avoiding waste and pollution, keeping products and materials in use and regenerating natural systems.

6.1 Social and economic impact

Sustainability has been at the centre of our business model and our way of working for years.
In 2015, we started to integrate the 17 UN SDGs (United Nations Sustainable Development Goals) into EGP company policies, thus defining specific targets.
In the autumn of 2019, we launched the world's first general purpose SDG-linked bonds – inviting the market to invest in our achievements, measured based on four specific goals. The success of these bonds has shown that we are on the right track. However, more importantly, it has shown the rest of the world that investing in sustainability is now also synonymous with economic value.
Searching for shared value for the Company and its stakeholders provides an opportunity to combine competitiveness with the long-term social value creation.
With approximately 1,600 projects in the various Countries where EGP works, we actively contribute to the development and social and economic growth of regions, including the expansion of infrastructure, education and training programs, initiatives aimed at social inclusion, and projects supporting cultural and economic life in line with the SDGs. Partnerships with organizations operating at the local level that promote regional development through innovative and tailored interventions are an essential tool for these projects.
EGP has devised a development strategy that constantly implements sustainable actions and procedures. Our proactive approach is structured to pinpoint opportunities to create shared value between the company and the territories where we work. EGP activities are focused on a constant dialogue with stakeholders and are integrated with careful studies of the social and economic context, in order to define effective measures that comply with the needs of local stakeholders, while remaining on track with corporate targets. The end result is creating energy that's not only renewable but, above all, sustainable.
Environmental conservation and caring for people's health start out from our workplaces like construction sites, power plants and administrative facilities. We are engaged in reusing, recycling and recouping all materials used in the manufacture process of a power plant. Furthermore, emissions from manufacture are lowered by harnessing energy efficiency systems. We implement cutting-edge technology and circular economy solutions to curtail the environmental impact of O&M activities, thus streamlining the operational efficiency of power plants and a conscious use of resources. Our buildings comply with the world's highest standards in energy and water consumption, safety and comfort for the workforce, accessibility and biodiversity.

The Nova Olinda solar power plant in Brazil is a case: the surrounding "quilombos" are the subject of a number of projects designed to create shared value. "Quilombos" are the hinterland settlements that were established centuries ago by Brazilian slaves who escaped from the plantations. Our Nova Olinda solar plant is located in the State of Piauí, surrounded by several quilombos. For this reason, when we started working on the design project for a plant, we asked ourselves what we could do to minimize its impact on the local population. We, therefore, decided to meet with its representatives. We listened to their stories and learnt about their traditions and this enabled us appreciating the importance of the land for the quilombolas. This dialogue meant that we were able to identify their priorities and requirements. These went on to provide the basis of a number of projects for Creating Shared Value (CSV) and ensuring sustainable development. Indeed, in many ways, the plant is a tribute to the 1700 workers who built it. We believe that the training that EGP offered them helped unleashing their energy and their spirit of initiative, both of which are evident in the final result, the plant itself. In addition to the training courses, EGP also promoted a number of educational programmers. The subject matter didn't only include solar energy, but also respect for the environment, as well as the Quilombolas' culture and rights. As part of the EGP CSV project, a new square was built in leftover wood that had originally been supplied for the construction of the plant. Some 150 volunteers from EGP and partner companies chipped in, thus helping to transform pallets and coils into fences, benches and playground equipment. In this way, they created a meeting point for members of the two communities, a place where children can play and adults can chat.

6.1.1 CSV projects

In this paragraph, we would like to describe other three cases, in which EGP successfully adopted a CSV approach in order to create value for the company and for its stakeholders.
An example of the application of the CSV approach to EGP solar plant is the project that was implemented in Mexico, in our Villanueva Solar Plant.
The project involved the donation of 80 PV Panels to the "ejidatarios" that are Mexican local people that live in the land near our plant and that had received the usufruct rights by the Mexican State to land the area. These people received from EGP some PV Panels that reached their end of life on the site but that were still working. These panels allowed the local people to produce electricity for agricultural use and to put the excess into the national grid.
This donation allowed the support to main economic activity of the 60 "ejidatarios" who could cultivate melons and watermelons without energy costs. Moreover, the project had a benefit for Enel that saved the costs of the solar panel disposal.
A second example, where EGP successfully adopted a CSV approach in a solar plant is the "Sheep grass management" case. This project was implemented in Greece, in 15 different solar plants across the Country, and it consisted of using a flock of sheep grazing around the plants areas to carry out the periodic maintenance and cut the excess of vegetation. In fact, the weeds need to be periodically removed in order to avoid shading, which inevitably affects the efficiency and yield of the solar plants.
In this way, EGP contributed to the development of the local communities by supporting the entrepreneurial activities of the local shepherds. At the same time, the company reduced the maintenance costs for cutting the excess of vegetation. This project contributed to define an operating model, in support of the EGP's approach for the development of low-impact solar systems, thus also improving the overall performance of energy generation.
A third case of application of the CSV approach to EGP solar plants is the "Pollinator-Friendly Solar Site Management" project that was implemented in the United States, in three of the sixteen sites that are part of Aurora solar project in Minnesota. The project consisted of a three-year cutting-edge research, carried out by EGP North America and the National Renewable Energy Laboratory (NREL), which assessed how careful vegetation management at solar sites can benefit the environment, biodiversity, cultivation and electricity generation. The research studied vegetation selection and management best procedures underneath utility-scale solar infrastructure. Furthermore, microclimate conditions, soil characteristics, soil carbon cycling and the impacts of vegetation on the project's energy output were assessed.
The project proved how native vegetation management programs at solar sites could deliver long-term environmental and soil quality benefits.
In particular, this project created value for the local communities in several ways. Firstly, it has to be considered the economic value of the research study and test phase for vegetation monitoring and pollinator insect health. In addition, the project contributed to increase the pollinator plants habitat to address the honeybee population decline. The subsequent rise of honeybee population produced a growth of productivity yield of the neighbouring crops (please note: over 75% of global crops that humans consume depend at least in part on pollinating insects). Another benefit produced for the local communities is the preservation of the soil from erosion, which will allow using the land for agricultural purposes at the time of decommissioning of the plant. In this way, the landowners avoid the costs of restoration of the land, which maintains its relative market value. At the end, the project created value also concerning education. In fact, a grant was addressed to five schools in order to involve students on experimental and practical projects for the redevelopment of the habitats of the farms and other rural lands.
On the other hand, the project generated practical benefits, insights, and data that contributed to Enel's approach to low impact solar development, thus also improving the overall energy generation performance. In particular, there has been an Increased PV efficiency, which resulted in an increased production. Moreover, the company achieved both a reduction in mechanical mowing expenses and in herbicide application expenses for noxious and invasive weeds. More generally, there has been also a decreased cost due to safety risks and damage.

6.1.2 Sustainability ecosystem in PV plant development

In the previous chapter we described how sustainability is integrated into the internal EGP Value chain.
In order to create shared value, EGP sustainability integration is not limited to the corporate internal value chain, but also includes both the supply chain and the commercial offer to our C&I clients.
The CSV full sustainability integration in procurement processes is not a top down activity that impacts suppliers, but it is a path where Enel supports its suppliers and potential ones in increasing their sustainability performance.
The sustainability integration covers all the main supply chain process, as:

- **Qualification.** Potential suppliers are admitted to participate in EGP tenders also considering their sustainability approach especially on environmental performances and Human Right respects.
- **Tender requirement.** During tender, EGP chooses its suppliers not only considering their technical performance and economical bids, but also their sustainability performance through the application of:
  - Sustainability requirements in technical specifications, as a mandatory requirement.
  - Sustainability K Factor, as incentive methods to push sustainability performance above the minimum requirement.

  Requirement and Sustainability K factor cover different topic as: social and local development, environmental footprint, circular economy and safety.
- **Supplier performance management.** Suppliers' performances are measured on various topics, one of which is sustainability, focusing on environment and Human Rights. Low performances can lead to penalties, cancelled contracts or exclusion from future tenders.

Moreover, EGP is committed to develop its supply chain and, in this framework, it considers its supplier as partners with which it is possible to develop together sustainability projects connected to the specific tenders in order to make synergy with the EGP sustainability activities in place and have greater impact on local community and the environment.
One concrete example on how EGP integrates sustainability in its procurement process and activities, also involving its suppliers, is the "CIRCULAR ECONOMY INITIATIVE FOR ENEL SUPPLIERS ENGAGEMENT", a project that is based on the adoption of the Environmental Product Declaration (EPD) for main equipment used in EGP as PV module and wind turbine.
The EPD is a certification where environmental indicators, using the LCA (Life Cycle Assessment) method, are calculated to quantify, interpret and evaluate the environmental impacts of a product or a service considering its entire life cycle.
The project started in 2018 with a first voluntary adhesion, in which EGP asks its suppliers to share, on an internal platform, the data related to environmental footprint of their equipment.
In 2020, EPD certification has been linked to a SUS K factor applied to tenders, so EGP can acknowledge an advantage to the suppliers with EPD certified equipment, such as a PV Panel.
Starting from 2021, the EPD certification will be linked to qualification requirement, so it is going to be mandatory to have equipment certified in order to participate in EGP tenders.
Moreover, EGP will use the K factor linked to the EPD data in order to push the use of equipment with lower environmental footprint.
This, in the near future, making synergy with all the activities normally handled by EGP during construction and O&M phase, will allow developing new plants more and more sustainable, thus reducing the supply chain environmental impact while maximizing its social and local benefit.
To complete the integration of sustainability into the entire extended value chain, EGP offers its C&I clients the opportunity to develop sustainability projects for and with their customers, in order to maximize the positive impacts created by working synergistically and achieving common goals related to the SDGs, thus leveraging on Enel's unique expertise in this field, CSV knowledge, different project portfolio and connection with primary stakeholders.

Moreover, involving its major PV and wind suppliers, EGP is launching a Global Alliance, involving key players in the renewable energy value chain (material suppliers, equipment manufacturers, OEMs, project developers and builders, utilities) and others (NGOs and associations, energy associations, large consumers companies, technical and technological partners, external auditors) to promote a renewable energy industry that is truly sustainable. The mission of the Alliance is to set Sustainability targets on Environmental, Social, Governance Pillars and circular economy, in order to:

- Define standards and KPIs for new design, business models, and End of Life in line with UN SDGs.
- Disseminate and activate funding/collaboration frameworks.
- Promote a supportive regulation.
- Launch tailored initiatives featuring alliance members.

Furthermore, EGP will promote the alliance that is going to be independent and not overlapping other current initiatives and associations of the REN sector given its alliance nature, its global reach and targeted stakeholders.

6.1.3 Sustainable product policy tools

An energy source is no longer sufficient, so it is the case of renewables, which must also be sustainable. More and more Countries are becoming sensitive to the environmental footprint of the energy sources they supply with, in fact, in many Countries, the environmental footprint is becoming part of the criteria with which to select renewable energies in tenders for the sale of energy, therefore, it is expected that it will become an increasingly decisive aspect in the future on the energy markets.

In particular, Europe, from this point of view, is very forward. In fact, through the Ecodesign Working Plan 2016-2019, the EU is currently exploring the possibility of applying policy tools such as Ecodesign, Energy Label, Ecolabel and Green Public Procurement to solar modules, inverters and systems. The scopes of this policy are as follows: cutting out least sustainable products, incentivising choice of higher sustainability products and encouraging development of new and more sustainable products. The Ecodesign and Energy Label Directives are the two pillars of the European policy for energy-efficient products. Products covered by the Ecodesign Directive will be mandatory and they can only be put on the European market if they meet minimum requirements related to energy efficiency and circular economy. The EU Ecolabel will be a voluntary label promoting environmental excellence by identifying products and services with reduced environmental impact. In a year and a half and two and a half, these new sustainability tools will be issued on the European market.

6.2

Circular economy

For an energy transition that is based on the two pillars of energy efficiency and renewable energy, a circular approach is needed to invert the human historical inclination to take advantage of its temporary control over the earth's resources and to use them only for its own benefit, without paying attention to what it leaves to children and descendants. This concerns also how renewable plant components are manufactured and managed and how their end-of-life is addressed. At the same time, renewable energy is a key component to manufacture circular products and assets.

Circular economy in the energy system consists of designs, processes and solutions that decouple resource consumption from energy production, without limiting to the fuel used but also addressing all the other dimensions. It can be represented in terms of five pillars to be implemented along the value chain.

Circular design

1. **Renewable input (material and energy).** To replace current materials with new ones from renewable sources or from recycling.
2. **Extended life.** To design assets and projects in a way that their useful life can be extended as far as possible (i.e., design for disassembly, modularity, repair, flexibility or biodegradability, as well as for enabling reuse, remanufacturing, refurbishment or regeneration).

Maximizing the load factor

3. Sharing. Increasing the load factor through assets and/or resources sharing.
4. Product as a service. Selling the use, not the ownership.

New life cycles

5. Designing the end of life according to these priorities, i.e. first reuse, than remanufacturing and as last option recycle.

Among the key enabler of circular economy, there are metrics and cross sectorial sinergies:

- Metrics are fundamental to set targets, measure performances and assess among alternative approaches. On this regard, EGP has developed a circularity model that coherently implements the five pillars and is now one of the reference model worldwide.
- Cross sectorial sinergies because circular economy is very often about creating innovative solutions throughout value chain collaboration. It is worth mentioning that EGP has launched variuos initiatives involving companies from other business industries.

It is important to remember that circular economy is not about adding a recycling phase to a linear model as it is about innovating the whole value chain phases in order to drive to zero the resource impact. This has to be done in an economically competitive way, because these applications have to affect the whole economic model and not only the niche applications.

In the last years, EGP has included circular economy in its strategic driver and GPG is implanting it within its activities, including the solar technology.

Besides all the circular initiatives implemented in the Sustainable Construction Site and Sustainable Plant, EGP is carrying out several projects to increase the circularity of solar technology in all extended value chain ranging from the design to the repurposing:

- Optimization of PV modules' packaging material in order to identify innovative techniques of solar panel packaging to reduce waste and disposal cost and increase material reuse.
- Identification of alternative scenarios for PV modules end of life management, thus significantly improving the opportunity to recover and re-use materials and, especially, limited resources.
- Evaluation of the possibility to introduce eco-friendly materials increasing lightness, easier production and recycling processes and decreasing environmental impact.

An important example is the PHOTORAMA Project, aiming at developing and demonstrating innovative solutions dedicated to Raw Materials recycling from complex multi-layers End-of-Life PV products (including PV manufacturing scrap) in order to minimize waste and achieve high recovery rates. The project is fully aligned with the new European Circular Economy Action Plan that promotes new initiatives along the entire life cycle of electric and electronics equipment in order to modernise and transform our economy while protecting the environment. Europe is highly dependent on metal imports such as critical raw materials and precious metals. The goal of the European Innovation Partnership (EIP) formulated in the Strategic Implementation Plan (SIP) is to reduce the import dependency on Raw Materials (RM) of the European economy, which is the overall target of PHOTORAMA. The implementation of a full-management PILOT LINE in PHOTORAMA Project will address low-carbon recycling of the PV modules (crystalline Silicon (c-Si), Thin Film CIGS-CIS) to recover the critical and precious metals: Si, In, Ga, Ag. This novel approach will allow reaching huge benefits in terms of materials recovery, thus in terms of revenues, which could be brought by the innovative solutions listed below. Innovative layer separation will enable the access to the valuable secondary RM encapsulated in the component's layers and new green metal extraction technologies will lead to efficient recovery of precious and critical metals from solar cells. Manual work will be replaced by automation in the PV recycling plant, thus making the whole scheme profitable and safer compared to the current procedures.

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Acronyms

ASP - Averaging Selling Price
BIM - Building Information Model
BoP - Balance of Plant
BOS – Balance of System
C&I - Industries and commercial
CSV - Creating Shared Value
CTM - Cell-to-module
DSO – Distribution system operator
E&C – Engineering and Construction
EPD - Environmental Product Declaration
FIT - Feed in tariff
GIS - Geographic Information System
HLT - Hetero Junction Technology
LCOE - Levelized cost of energy
LeTID - Light and elevated temperature induced degradation
O&M – Operation and Maintenance
PCE - Power Conversion Efficiency
PID - Potential-induced degradation
PPA - Power purchase agreement
PV - Photovoltaic
SCADA - Supervisory Control and Data Acquisition
SDG - Sustainable Development Goals
STC - Tetrachloride
TCS - Trichlorosilane
TSO – Transmission system operator
Voc - Voltage open circuit
YoY - Year-over-year

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