IRENA
International Renewable Energy Agency

FUTURE OF SOLAR PHOTOVOLTAIC

Deployment, investment, technology, grid integration and socio-economic aspects

Executive Summary

A Global Energy Transformation paper

NOVEMBER 2019

EXECUTIVE SUMMARY

THE DECARBONISATION OF THE ENERGY SECTOR AND THE REDUCTION OF CARBON EMISSIONS TO LIMIT CLIMATE CHANGE ARE AT THE HEART OF THE INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA) ENERGY TRANSFORMATION ROADMAPS. These roadmaps examine and provide an ambitious, yet technically and economically feasible, pathway for the deployment of low-carbon technology towards a sustainable and clean energy future.

IRENA HAS EXPLORED TWO ENERGY DEVELOPMENT OPTIONS TO THE YEAR 2050 AS PART OF THE 2019 EDITION OF ITS GLOBAL ENERGY TRANSFORMATION REPORT. The first is an energy pathway set by current and planned policies (Reference Case). The second is a cleaner climate-resilient pathway based largely on more ambitious, yet achievable, uptake of renewable energy and energy efficiency measures (REmap Case), which limits the rise in global temperature to well below 2 degrees and closer to 1.5 degrees, aligned within the envelope of scenarios presented in the 2018 report of the Intergovernmental Panel on Climate Change (IPCC).

THE PRESENT REPORT OUTLINES THE ROLE OF SOLAR PHOTOVOLTAIC (PV) POWER IN THE TRANSFORMATION OF THE GLOBAL ENERGY SYSTEM BASED ON IRENA'S CLIMATE-RESILIENT PATHWAY (REMAP CASE), specifically the growth in solar PV power deployment that would be needed in the next three decades to achieve the Paris climate goals.

This report's findings are summarised as follows:

- **ACCELERATED DEPLOYMENT OF RENEWABLES, COMBINED WITH DEEP ELECTRIFICATION AND INCREASED ENERGY EFFICIENCY, CAN ACHIEVE OVER 90% OF THE ENERGY-RELATED CARBON DIOXIDE (CO_2) EMISSION REDUCTIONS NEEDED BY 2050 TO SET THE WORLD ON AN ENERGY PATHWAY TOWARDS MEETING THE PARIS CLIMATE TARGETS**. Among all low-carbon technology options, accelerated deployment of solar PV alone can lead to significant emission reductions of 4.9 gigatonnes of carbon dioxide (Gt CO_2) in 2050, representing 21% of the total emission mitigation potential in the energy sector.

- **ACHIEVING THE PARIS CLIMATE GOALS WOULD REQUIRE SIGNIFICANT ACCELERATION ACROSS A RANGE OF SECTORS AND TECHNOLOGIES.** By 2050 solar PV would represent the second-largest power generation source, just behind wind power and lead the way for the transformation of the global electricity sector. Solar PV would generate a quarter (25%) of total electricity needs globally, becoming one of prominent generations source by 2050.

- **SUCH A TRANSFORMATION IS ONLY POSSIBLE BY SIGNIFICANTLY SCALING UP SOLAR PV CAPACITY IN NEXT THREE DECADES.** This entails increasing total solar PV capacity almost sixfold over the next ten years, from a global total of 480 GW in 2018 to 2 840 GW by 2030, and to 8 519 GW by 2050 – an increase of almost eighteen times 2018 levels.

- **THE SOLAR PV INDUSTRY WOULD NEED TO BE PREPARED FOR SUCH A SIGNIFICANT GROWTH IN THE MARKET OVER THE NEXT THREE DECADES.** In annual growth terms, an almost threefold rise in yearly solar PV capacity additions is needed by 2030 (to 270 GW per year) and a fourfold rise by 2050 (to 372 GW per year), compared to current levels (94 GW added in 2018).

  Thanks to its modular and distributed nature, solar PV technology is being adapted to a wide range of off-grid applications and to local conditions. In the last decade (2008–18), the globally installed capacity of off-grid solar PV has grown more than tenfold, from roughly 0.25 GW in 2008, to almost 3 GW in 2018. Off-grid solar PV is a key technology for achieving full energy access and achieving the Sustainable Development Goals.

- **AT A REGIONAL LEVEL, ASIA IS EXPECTED TO DRIVE THE WAVE OF SOLAR PV CAPACITY INSTALLATIONS, BEING THE WORLD LEADERS IN SOLAR PV ENERGY.** Asia (mostly China) would continue to dominate solar PV power in terms of total installed capacity, with a share of more than 50% by 2050, followed by North America (20%) and Europe (10%).

- **SCALING UP SOLAR PV ENERGY INVESTMENT IS CRITICAL TO ACCELERATING THE GROWTH OF INSTALLATIONS OVER THE COMING DECADES.** Globally this would imply a 68% increase in average annual solar PV investment from now until 2050 (to USD 192 billion/yr). Solar PV investment stood at USD 114 billion/yr in 2018.

- **INCREASING ECONOMIES OF SCALE AND FURTHER TECHNOLOGICAL IMPROVEMENTS WILL CONTINUE TO REDUCE THE COSTS OF SOLAR PV.** Globally, the total installation cost of solar PV projects would continue to decline in the next three decades. This would make solar PV highly competitive in many markets, with the average cost falling in the range of USD 340 to 834 per kilowatt (kW) by 2030 and USD 165 to 481/kW by 2050, compared to the average of USD 1 210/kW in 2018.

The levelised cost of electricity (LCOE) for solar PV is already competitive compared to all fossil fuel generation sources and is set to decline further as installed costs and performance continue to improve. Globally, the LCOE for solar PV will continue to fall from an average of USD 0.085 per kilowatt-hour (kWh) in 2018 to between USD 0.02 to 0.08/kWh by 2030 and between USD 0.014 to 0.05/kWh by 2050.

- **THE SOLAR PV INDUSTRY IS A FAST-EVOLVING INDUSTRY, CHANGING RAPIDLY THANKS TO INNOVATIONS ALONG THE ENTIRE VALUE CHAIN AND FURTHER RAPID COSTS REDUCTIONS ARE FORESEEN.** First-generation technologies remain the principal driver of solar industry development and still hold the majority of the market value. Tandem and perovskite technologies also offer interesting perspectives, albeit in the longer term several barriers still need to be overcome. The emergence of new cell architectures has enabled higher efficiency levels. In particular, the most important market shift in cell architecture has resulted from bifacial cells and modules, driven by the increased adoption of advanced cell architecture, such as passive emitter and rear cell (PERC), and by its compatibility with other emerging innovations, such as half-cut cells and others.

- **TAKING ADVANTAGE OF FAST-GROWING SOLAR PV CAPACITY ACROSS THE GLOBE, SEVERAL RESEARCH PROJECTS AND PROTOTYPES ARE ONGOING TO STIMULATE FUTURE MARKET GROWTH BY EXPLORING INNOVATIVE SOLAR TECHNOLOGIES AT THE APPLICATION LEVEL.** One example is building-integrated photovoltaic (BIPV) solar panels. BIPV solutions offer several advantages, such as multifunctionality (they can be adapted to a variety of surfaces), cost-efficiency (savings on roofing material, labour/construction, refurbishment and renovation costs), versatility and design flexibility in size, shape and colour.

  Solar panels have improved substantially in their efficiency and power output over the last few decades. In 2018, the efficiency of multi-crystalline PV reached 17%, while that of mono-crystalline reached 18%. This positive trend is expected to continue through to 2030. Yet, as the global PV market increases, so will the need to prevent the degradation of panels and manage the volume of decommissioned PV panels leading to circular economy practises. This includes innovative and alternative ways to reduce material use and module degradation, and opportunities to reuse and recycle PV panels at the end of their lifetime.

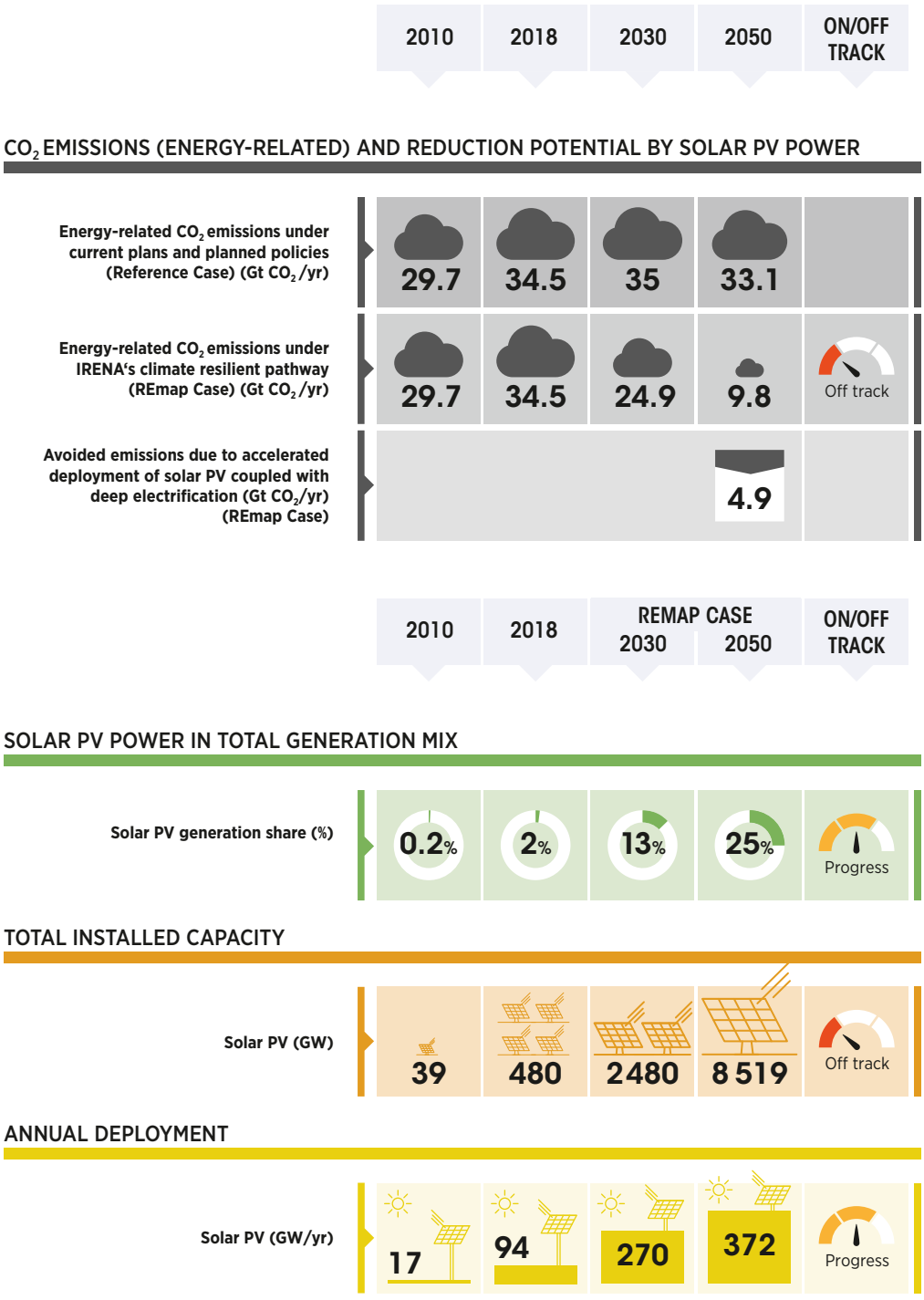
- **TECHNOLOGICAL SOLUTIONS AS WELL AS ENABLING MARKET CONDITIONS ARE ESSENTIAL TO PREPARE FUTURE POWER GRIDS TO INTEGRATE RISING SHARES OF SOLAR PV.** To effectively manage large-scale variable renewable energy sources, flexibility must be harnessed in all sectors of the energy system, from power generation to transmission and distribution systems, storage (both electrical and thermal) and, increasingly, flexible demand (demand-side management and sector coupling). Some countries, particularly in Europe, have achieved much higher shares in 2017: the VRE share in Denmark reached 53%, in South Australia 48%, and in Lithuania, Ireland, Spain and Germany over 20%. Globally, to integrate 60% variable renewable generation (of which 25% from solar PV) by 2050, average annual investments in grids, generation adequacy and some flexibility measures (storage) would need to rise by more than one-quarter to USD 374 billion/year, compared to investments made in electricity networks and battery storage in 2018 (USD 297 billion/year).

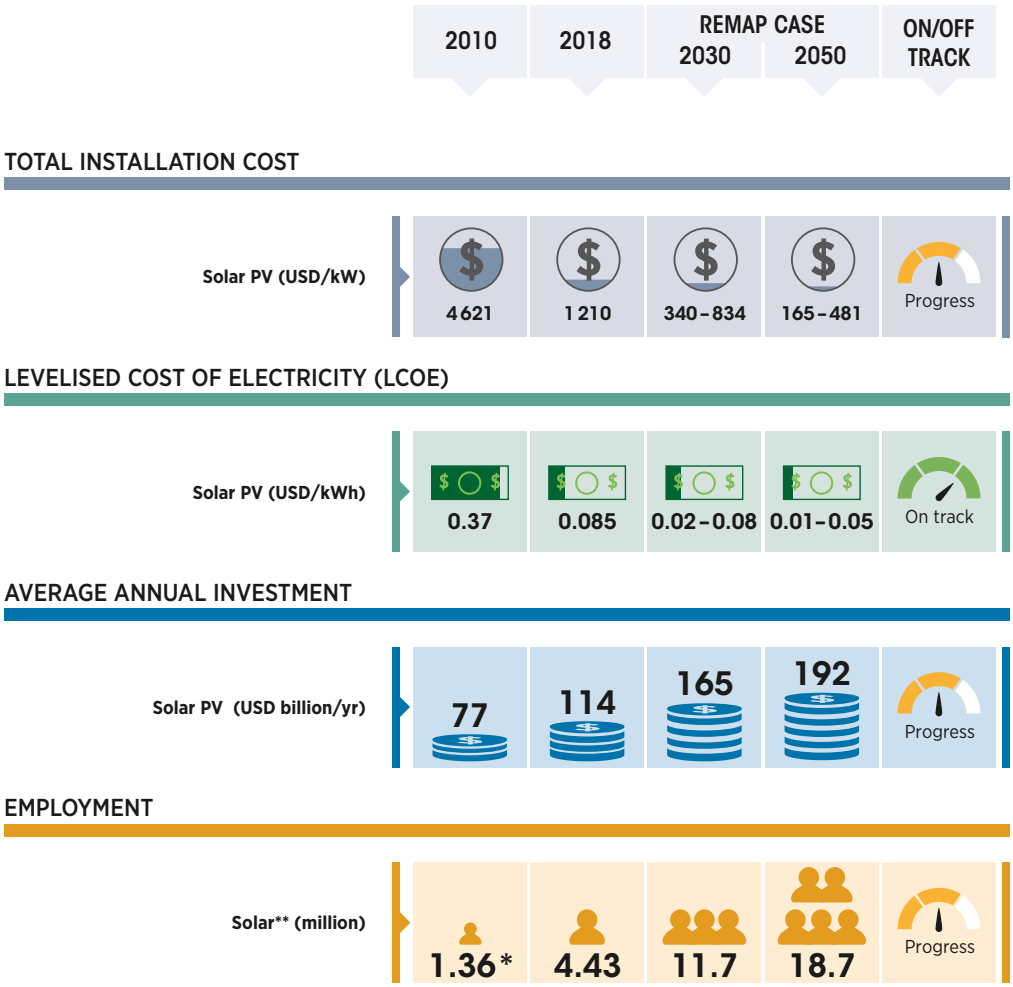
- **INNOVATIVE BUSINESS MODELS AND COST COMPETITIVENESS OF SOLAR PV ARE DRIVING THE REDUCTIONS IN SYSTEM PRICES.** The deployment of rooftop solar PV systems has increased significantly in recent years, in great measure thanks to supporting policies, such as net metering and fiscal incentives- which in some markets make PV more attractive from an economic point of view than buying electricity from the grid- PV-hybrid minigrid, virtual power plants and utility PPA. The competitiveness of distributed solar power is clearly evident amid rising deployment in large markets, such as Brazil, China, Germany and Mexico, however important differences remain between countries, which highlight the further improvement potential.

- **IF ACCOMPANIED BY SOUND POLICIES, THE TRANSFORMATION CAN BRING SOCIO-ECONOMIC BENEFITS.** The solar industry would employ more than 18 million people by 2050 (of which 14 million would be employed by solar PV) four times more than the 2018 jobs total of 4.4 million (3.6 million – solar PV). To maximise outcomes of the energy transition, however, a holistic policy framework is needed. Deployment policies will need to co-ordinate and harmonise with integration and enabling policies. Under the enabling policy umbrella, particular focus is needed on industrial, financial, education and skills policies to maximise the transition benefits. Education and skills policies can help equip the workforce with adequate skills and would increase opportunities for local employment. Similarly, sound industrial policies that build upon domestic supply chains can enable income and employment growth by leveraging existing economic activities in support of solar PV industry development.

- **UNLEASHING THE MASSIVE POTENTIAL OF SOLAR PV IS CRUCIAL TO ACHIEVE CLIMATE TARGETS.** This is only possible by mitigating the current barriers at different scales (policy; market and economic; technology; regulatory, political and social). Grid integration and grid flexibility, economies of scale, access to finance, lack of standards and quality measures, consumer awareness are among the key barriers that could hinder the deployment of solar PV capacities in the next three decades. Mitigating the existing barriers immediately, through a range of supportive policies and implementation measures including innovative business models, financial instruments is vital to boost future deployment of solar PV capacities to enable the transition to a low-carbon, sustainable energy future.

Figure ES 1. Status and future of solar photovoltaics (PV) - Tracking progress to accelerate solar PV deployment to achieve Paris Climate targets





* The data denoted solar PV sector jobs by 2012

**The data includes solar PV, CSP and solar heating and cooling jobs.

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