PHILOSOPHICAL
TRANSACTIONS
OF
THE ROYAL
SOCIETY A

rsta.royalsocietypublishing.org

Realizing solar power's potential in the European Union

G. De Santi, A. Jaeger Waldau, N. Taylor and H. Ossenbrink

European Commission, Joint Research Centre, Via E. Fermi 2749, 21027 Ispra(VA), Italy

Research

Cite this article: De Santi G, Waldau AJ, Taylor N, Ossenbrink H. 2013 Realizing solar power's potential in the European Union. Phil Trans R Soc A 371: 20120391.
http://dx.doi.org/10.1098/rsta.2012.0391

One contribution of 15 to a Discussion Meeting Issue 'Can solar power deliver?'.

Subject Areas:
energy

Keywords:
renewable energy, photovoltaic, concentrated solar thermal

Author for correspondence:
G. De Santi
e-mail: giovanni.de-santi@ec.europa.eu

The European Union aims at largely decarbonizing its energy system by 2050. In this context, this paper reviews the status of the solar electricity technologies that can exploit our largest renewable energy resource. Although substantial progress is being made, the possibility, for instance, to more than double the efficiency of photovoltaic systems underlines the continued need for coordinated R&D efforts, aimed also at promoting European expertise and industrial competiveness. In parallel, it is important to expand the market by developing integrated building products and by demonstrating the viability of very large scale systems for both technologies.

1. Introduction

Energy has become one of the grand challenges of the twenty-first century, from a political, economic and societal point of view. Without affordable, more efficient and reliable low-carbon energy technologies, Europe will not achieve a sustainable energy system by the middle of the century. An accelerated decrease in energy intensity is a crucial ingredient to solving our supply problem, but it cannot do the job alone as our energy consumption structure, mainly of electricity and for transport, reflects our lifestyle. This is moving towards increased electrification, and more electricity production with less energy imports can be realized only by using our own renewable energy resources more efficiently and on a larger scale.

At European level, efforts to increase the role of renewable energy have started already with the 1997

Royal Society Publishing
Informing the science of the future

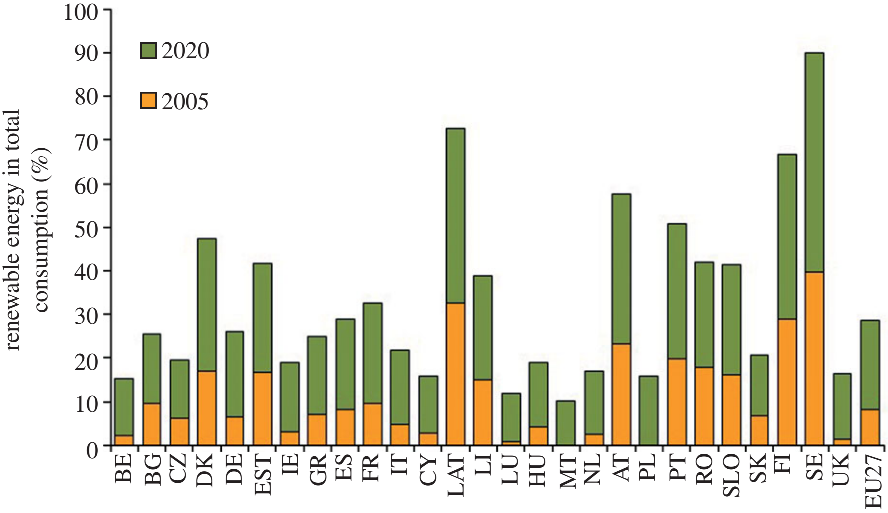

Figure 1. Renewable energy share in European Union Member States in 2005 and mandatory targets for 2010. BE, Belgium; BG, Bulgaria; CZ, Czech Republic; DK, Denmark; DE, Germany; EST, Estonia; IE, Ireland, GR, Greece; ES, Spain, FR, France; IT, Italy; CY, Cyprus; LAT, Latvia; LI, Lithuania; LU, Luxembourg; HU, Hungary; MT, Malta; NL, Netherlands; AT, Austria; PL, Poland; PT, Portugal; RO, Romania; SLO, Slovenia; SK, Slovakia; FI, Finland; SE, Sweden; UK, United Kingdom; EU27, European Union with 27 Member States. (Online version in colour.)

White Paper [1]. In June 2009, the European Directive on the promotion of the use of energy from renewable sources [2] came into force. This sets mandatory targets for the Member States to achieve by 2020 (figure 1), to support the worldwide stabilization of the atmospheric greenhouse gases in the 450–550 ppm range.

At the end of 2011, the Commission published its energy roadmap 2050 [3], in which a range of scenarios are analysed. A common feature of all of these is that renewables should provide the biggest share of all energy supply technologies by 2050; indeed, the ‘high renewables scenario’ would result in 97 per cent of renewable electricity. The split between the different sources and technologies is open, and the discussion about new renewable energy targets for 2030 is heating up. The Commission’s most recent communication on renewable energy policy [3] looks to the post-2020 period and proposes to start the process of preparing policy options and milestones for 2030.

Solar energy is a key technology option to realize this shift to a decarbonized energy supply. The solar resources in Europe and worldwide are abundant—indeed the current target in European Union (EU) Member State National Renewable Energy Action Plans of 89 GW by 2020 substantially underutilizes the available resources [4]. Solar energy can be used by a family of technologies capable of being integrated among themselves, as well as with other renewable energy technologies. These can deliver heat, cooling, electricity, lighting and fuels for a host of applications.

In the medium term, photovoltaic (PV) systems will be introduced as integral parts of new and re-fitted buildings, a market that will also be driven by legal requirements for energy efficiency in buildings. Directive 2010/31/EU [5] requires Member States to ensure that by 2021, all new buildings are so-called ‘nearly zero-energy buildings’. Building-integrated PVs provide an important energy supply component to balance consumption.

In the following, we look at the status of the two primary routes to exploiting solar energy to produce electricity, PVs and solar thermal electricity, before considering the research needs and policies to realize their potential as competitive energy providers.

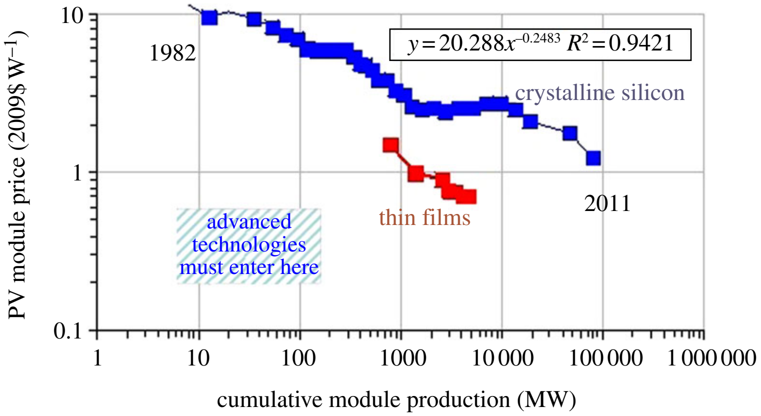

Figure 2. Learning curve for photovoltaic modules. (Online version in colour.)

2. Current perspectives

(a) Photovoltaics

The PV sector has expanded rapidly annually in Europe with high annual growth rates, of the order of 40 per cent per year since 2000 [6]. With a cumulative installed capacity of about 51 GW, the European Union is leading in PV installations, with more than 70 per cent of the total worldwide 69 GW of solar PV electricity generation capacity at the end of 2011. The industry itself claims to now provide more than 300 000 jobs in Europe, with the potential to increase to over 2 million by 2020.

Crystalline silicon-based systems are (and are set to remain) the dominant PV technology in the short to medium term. Production data for the global cell production in 2011 vary between 28 and 37 GW. The significant uncertainty in the data for 2011 is because of the highly competitive market environment, as well as the fact that some companies report shipment figures and others report sales or production figures.

However, the cell production is only a limited part of the whole PV value chain. In order to judge the developments in the PV industry correctly, it is necessary to look at the whole upstream industry (e.g. materials, polysilicon production, equipment manufacturing), as well as the downstream industry (e.g. inverters, balance of system components, system development, installations). It is worth noting that although more than two-thirds of the solar modules installed in Germany were not produced there, more than 60 per cent of the added value remains within the German economy.

Concentrating PVs (CPVs) is an emerging technology that is growing at a very high pace, although from a low starting point. Within CPVs, there is a differentiation according to the concentration factors and whether the system uses a dish (dish CPV) or lenses (lens CPV). The main parts of a CPV system are the cells, the optical elements and the tracking devices. The recent growth in CPVs is based on significant improvements in all of these areas, as well as the system integration. However, it should be pointed out that CPVs is just at the beginning of an industry learning curve, with a considerable potential for technical and cost improvements.

The change of the market from a supply-restricted to a demand-driven market and the resulting overcapacity for solar modules has resulted in a dramatic price reduction of PV systems of more than 50 per cent over the last 4 years. This has allowed the technology to maintain its learning curve in terms of module price per kWp (figure 2). This has been mirrored by reductions at system level: at the beginning of January 2012 for Europe, the average prices were €1850 (kWp)$^{-1}$ for residential and €1685 (kWp)$^{-1}$ for commercial systems.

(b) Concentrated solar thermal power

Within just a few years, the concentrated solar power (CSP) industry has grown from negligible activity to over 4 GWe, either commissioned or under construction. At the end of January 2012, CSP plants with a cumulative capacity of about 1.7 GW were in commercial operation in Spain (about 71% of the worldwide capacity of 2.4 GW). Capital investment for solar-only reference systems of 50 MWe without storage were estimated to be approximately €4800 $(\mathrm{kWe})^{-1}$. With storage, these costs can go up significantly. Depending on the direct normal insolation (DNI), the cost of electricity production for parabolic trough systems is currently of the order of €0.18–0.20 kWh^{-1} (southern Europe, DNI: 2000 $\mathrm{kWh\,m^2\,a^{-1}}$) [7]. The Solar Europe Industrial Initiative indicates the potential to reduce costs by 35 per cent by 2020.

More than 10 different companies are now active in building or preparing for commercial-scale plants, compared with perhaps only two or three who were in a position to develop and build a commercial-scale plant a few years ago. These companies range from large organizations with international construction and project management expertise who have acquired rights to specific technologies, to start-ups based on their own technology developed in house. The supply chain is not limited by raw materials because the majority are glass, steel/aluminium and concrete. At present, evacuated tubes for trough plants can be produced at a sufficient rate to service several hundred MW per year. The National Renewable Energy Action Plan (NREAP) forecasts an increase in capacity to 7 GW by 2020, mostly located in Spain. The CSP industry association European Solar Thermal Electricity Association is more optimistic, predicting 30 GW by 2020 and 60 GW by 2030 [8].

3. Future directions

(a) Strategic energy technology plan

Since 2007, the EU has, with the strategic energy technology plan (SET-Plan) [9], set out a long-term energy research agenda to address the key innovation bottlenecks that energy technologies are currently facing: in frontier research, at the R&D/proof of concept stages and for the demonstration and commercialization process when companies seek capital to finance major projects.

Implementation of the SET-Plan started with the establishment of the European Industrial Initiatives that bring together industry, the research community, the Member States and the Commission in risk-sharing, public–private partnerships aimed at the rapid development of key energy technologies at European level. In parallel, the European Energy Research Alliance has been working since 2008 to align the R&D activities of individual research organizations to the needs of the SET-Plan priorities, and to establish a joint programming framework at the EU level.

The SET-Plan has two major timelines.

— For 2020, the SET-Plan provides a framework to accelerate the development and deployment of cost-effective low-carbon technologies. With such comprehensive strategies, the EU is on track to reach its 20–20–20 goals.
— For 2050, the SET-Plan is targeted at limiting climate change to a global temperature rise of no more than 2°C, in particular, by matching the vision to reduce EU greenhouse gas emissions by 80–95%. The SET-Plan objective in this regard is to further lower the cost of low-carbon energy and put the EU's energy industry at the forefront of the rapidly growing low-carbon energy technology sector.

The development of PV together with CSP is being addressed by the European Solar Industry Initiative. The Commission itself is closely involved, both with an enabling role and to independently monitor progress been made in reaching the targets agreed with all stakeholders. At a very practical level, the Joint Research Centre (JRC) European Solar Test Installation (ESTI) laboratory provides a European reference laboratory to validate electrical performance and lifetime of PV devices based on emerging technologies. ESTI provides a unique, independent reference function at a European level. In tandem, it performs pre-normative research to develop and improve traceable, accurate measurement techniques with reduced uncertainty levels, benefiting both manufacturers and investors.

(b) Technology road maps

SETIS, the SET-Plan information system, is operated by the JRC and has been supporting SET-Plan from its onset, providing referenced, timely, validated and unbiased information on low-carbon energy technologies. Its 2011 technology map report [10] offers an assessment for medium to long-term development of solar energy technologies.

(i) Photovoltaics

A broad variety of PV technological routes will continue to characterize the sector after 2020 depending on the specific requirements and economics of the various applications. Typical commercial flat-plate module efficiencies are expected to increase to 25 per cent in 2030, with the potential of increasing up to 40 per cent in 2050 due notably to wafer equivalent technologies and new device structures with novel concepts. The operational lifetime of PV modules is expected to increase from 25 to 40 years.

The use of energy and materials in the manufacturing process will become significantly more efficient, leading to considerably shortened PV system energy payback times. At the same time, affordable materials will replace the expensive ones currently used (e.g. copper instead of silver). Increased R&D is required to bring thin-film technologies to maturity and long-term reliability and to create the necessary experience in industrial manufacturing. Beyond 2020, the efficiency of commercial modules could reach more than 20 per cent for copper indium gallium di-selenide (14% max module efficiency today), 16 per cent for a-Si, and 15 per cent for CdTe, with new and improved device structures and substrates, large area, non-vacuum deposition techniques, interconnection, roll-to-roll manufacturing and packaging.

Concentrated PV technology is presently moving to commercial-scale applications. Further R&D efforts are required in optical systems, module assembly, tracking systems, high-efficiency devices with the potential of reaching module efficiencies higher than 23 per cent/45 per cent (low/high concentrating PVs).

Emerging PV technologies, such as advanced inorganic thin-film technologies, organic solar cells (organic PVs and dye sensitized solar cells), also based on novel concepts such as quantum and excitonic structures with their potential for cost reduction and performance improvement will represent an increasing share of the PV deployment after 2020. Significant R&D is necessary to capture this potential. For instance, it is necessary to work on the long-term stabilization of the performances of the organic solar cells and improve their lifetime.

(ii) Solar thermal electricity (concentrated solar power)

The mainstream approach to CSP (oil circulating in trough receivers) appears to have a limited potential for cost reduction. When that approach is used, dispatchability analysed as CSP future promise does not seem sufficient, together with mass production, to assure competitiveness. More research on advanced concepts (molten salts/solar trough, direct steam/Fresnel, molten salts/solar tower) that is able to create technology innovations is necessary.

Beyond 2020, substantial increases (above 600°C) in the operating temperature of the heat transfer fluids are to be expected compared with the current mainstream technology. This will be achieved by studying materials and components that are reliable at very high temperatures, developing new heat transfer fluids, more efficient cycles and new system architectures, and optimizing the plant control system. Gains in efficiency will be considerable—more than 20 per cent compared with the current state of the art.

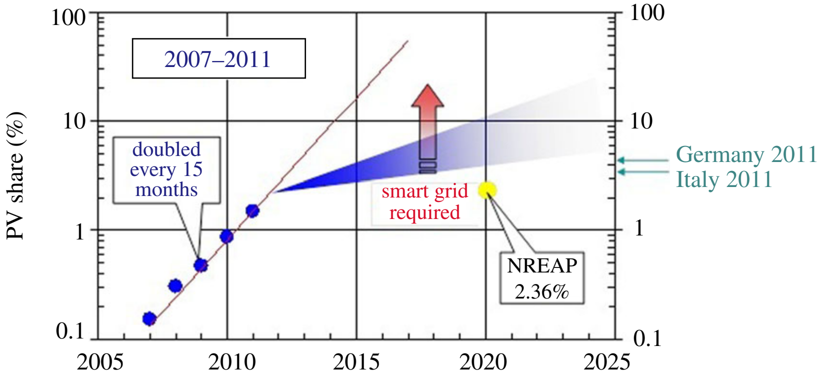

Figure 3. Share of photovoltaic generated electricity in the European Union. (Online version in colour.)

In terms of dispatchability, the storage capacity will be improved (above 250 kWh m^{-3}) owing, in particular, to the implementation of ad hoc thermochemical processes. This will make storage systems much more cost effective. With regard to the environmental profile, beyond 2020, a significant reduction of water consumption (below 0.25 l kWh^{-1}) can be obtained (in particular, through the use of dry cooling systems), while at the same time, maintaining the overall efficiency of the plant. For multi-purpose plants and hybridization, beyond 2020, it should be possible to optimize the hybridization of CSP plants with other renewable energy sources and to efficiently couple the production of electricity with other uses (e.g. desalination). CSP plants—exploiting possible efficiencies, cost reduction, performance improvements from innovative combined production of electricity and fresh water—are strategically and symbolically relevant for exploitation in the Middle East and North Africa region.

(c) Cross-sector themes

Regardless of the type of renewable energy source, there are also non-technical aspects that profoundly influence the development and deployment of renewables.

- *Electricity grids*. The current European system is based on centralized conventional sources of energy (coal, oil, natural gas and nuclear energy) and their respective distribution systems with a one-directional flow of the energy carrier. On the other hand, renewable energy sources can either be used in centralized or decentralized installations. More effort is required, not only to install PV electricity generation systems, but also to facilitate grid access and enable the electricity infrastructure to absorb and distribute the solar electricity (figure 3). To this end, it is essential that the solar energy technology community collaborates and contributes to the development of smartgrids.
- *Serving the customer*. A challenge to all renewable energy technologies and solar in particular is that becoming a significant electricity provider also means developing the ability to manage the supply and demand. Effective integration of PVs with economic storage technologies is likely to be a key challenge in this respect.
- *Markets, targets and support mechanisms*. The Commission's 2012 communication on renewable energy policy calls for a more coordinated European approach in the establishment and reform of support schemes and an increased use of renewable energy trading among Member States. For the time beyond 2020, it identifies three options beyond business as usual. (i) New goals for greenhouse gas (GHG) emissions, but no goals for renewable energy. The energy trading scheme would be the main instrument to cut down on CO_2 emissions. (ii) National targets for renewable energy, energy efficiency and GHGs. (iii) EU wide targets: renewable energy, energy efficiency and GHG goals.

— *Standards to support innovation*. The internationalization of common standards to further promote innovation and ensure market access worldwide for European industries is an issue for all low-carbon technologies, including solar. The Commission's communication in June 2011 on a 'Strategy for European Standardization' stresses that science has a crucial role to play in the field of standardization.

4. Conclusions

Solar energy is our largest potential source of renewable energy, and, as such, the further development of both PV processes and of solar thermal will continue to be a strategic priority. PV technology has seen rapid growth and price reductions in the last few years, and its contribution to the electricity supply look set to comfortably exceed the albeit modest targets set by the EU Member States for 2020. Both technologies have the potential to make a substantial contribution to achieving a low-carbon energy system in the long term. However, issues to address include:

— effective R&D investment to exploit the potential to more than double the efficiency of PV systems, to achieve increasing cost competitiveness and to maintain European expertise and industrial competiveness in these areas;
— development of integrated building products and their widespread deployment; and
— development of very large scale systems for both PV and concentrated solar thermal, exploiting suitable land or sea areas.

Optimized exploitation is intimately linked to the development of appropriate grid and storage systems, with advanced demand/supply management based on active forecasting.

References

1. Energy for the future: renewable sources of energy—white paper for a community strategy and action plan, COM(97)599 final (26 November 1997). See http://europa.eu.int/comm/energy/library/599fi_en.pdf.
2. Directive 2009/28/EC (23 April 2009) Promotion of the use of energy from renewable sources.
3. Communication from the Commission, Energy roadmap 2050, COM(2011) 885, 15 December 2011.
4. Communication from the Commission of 6 June 2012 on renewable energy: a major player in the European energy market, COM(2012) 271.
5. Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings.
6. PV Status Report 2012, European Commission Joint Research Centre, EUR 25749 EN.
7. Marquesz Salazaar C. 2008 An overview of CSP in Europe, North Africa and the Middle East, CSP Today, October 2008. See http://www.csptoday.com/reports/CSPinEU&MENA.pdf.
8. European Solar Thermal Electricity Association. 2009, A European solar industry initiative contributing to the European Commission 'strategic energy technology plan'. See http://www.estelasolar.eu/.
9. Communication from the Commission. Investing in the development of low carbon technologies (SET-Plan), COM(2009) 519.
10. 2011 Technology map of the European strategic energy technology plan (SET-Plan) technology descriptions EUR 24979 EN.