

Preface and Acknowledgements

The unprecedented accumulation of greenhouse gases (GHG) in the atmosphere in the last two centuries is undeniably changing the climate, as consistently informed by the Intergovernmental Panel on Climate Change (IPCC) (see IPCC 2014a; Houghton 2015). This represents quite a serious threat for the survival of many vegetal and animal species and has the potential to generate considerable distortions in the lifestyles of human beings. Despite the fact that most citizens and governments are clearly aware of the problem, GHG concentrations are likely to exceed the 500 parts per million of CO₂ equivalent (ppm CO₂e) level. This represents a 50-50 chance that the average temperature would have been 2 °C above the average temperature in the mid-nineteenth century, i.e. in the preindustrial period, when the GHG concentrations were estimated at 280 ppm CO₂e. In volume terms, this means that the 50 billion tonnes of CO₂e emitted in 2013 should go down to 35 billion tonnes in 2030 and 20 billion tonnes in 2050. If emissions remain at this level in 2030, concentrations could be above 650 ppm CO₂e, consistent with temperature increases of around 3.5 °C with a 50-50 chance (Sachs et al. 2014: 8–10; Stern 2015: 14–15, 37). It should be taken into account that the current concentration of around 450 ppm is unprecedented in our planet, and it could have only happened between 800 thousand and 3 million years ago. If this concentration exceeded 750 ppm by the end of this century, the average temperature would likely be above 4 °C with respect to the preindustrial era. Both ecosystems and humans would suddenly be within an environment which has been the common one in our planet in the last 35 million years (Stern 2015: 9–10).¹

The anthropogenic origin of climate change can no longer be doubted since average temperature changes in the Holocene have remained within a narrow ± 1.5 °C range. This means that a wait-and-see attitude is not an option, even given the unavoidable uncertainty of the specific impacts of human-induced climate change. Delaying mitigation actions has two serious implications: on the one hand,

¹Since those increases are average values, the different regions can experience different rates of change according to the season of the year.

it would mean that those actions should become more drastic in later years, which would increase the costs of reaching a given concentration target (Edenhofer et al. 2009). On the other hand, there would be an increasing risk of a positive feedback of emissions (uncontrolled release of the methane contained in the permafrost), which would involve severe and irreversible changes in the biosphere (Houghton 2015). It should not be forgotten that GHG remain in the atmosphere for centuries, depending on their oxidation rate.

In spite of the arguments of the climate skeptics, the connection between human activities and climate change has a solid empirical base. The rejection of convincing evidence of the existence of climate changes due to GHG emissions leads the skeptics to conclude that such effects are non-existent. Or, in other words, from the absence of evidence they conclude an evidence of absence of such a relationship. Furthermore, the “deniers” use the inaccuracies that are unavoidably part of any long-term prediction of a complex system (such as climate) to their advantage. They attribute them to a lack of scientific rigour, although the underlying problem is one of inexactitude rather than the fact that it cannot be verified.

The real debate today is the degree of implementation of the climate mitigation measures. The experts stress the role of the energy sector in this issue. Electricity and heat generation represent 31 % of emissions, whereas the burning of fossil fuels by industry, transport and others adds a further 36 %. Energy provision is, thus, the main cause of human-induced climate change (Sachs et al. 2014: 13–14; Stern 2015: 41).

A package of mitigation measures has been implemented in many countries around the world in order to limit GHG emissions, aiming to change the nature of the energy sector. Several technologies are available to achieve this goal (Socolow et al. 2004). The effort made so far is non-negligible, but should accelerate and be stronger in the next decades.² This structural change should not necessarily involve a reduction of the welfare level in the developed countries, whereas it could also encourage the development of emerging and less developed economies (Stern 2009). The electricity sector and electricity generation from renewable energy sources (RES-E) have a prominent role to play in this challenge. And, within the different alternatives for RES-E, Solar Photovoltaic (PV) generation has raised huge expectations. This technology already generated great expectations when it was first developed around six decades ago.³ Then there was a period of skepticism about its performance, which was followed by a rapid evolution in recent times and

²For example, in 2011, the public promotion of renewable energy sources reached \$88 billion (73 % for electricity generation and the rest for agro-fuels). This figure, however, pales in comparison with the \$523 billion (according to IEA) or \$480 billion (according to IMF) of subsidies for the consumption and exploration of fossil-fuel sources (Stern 2015: 116–117). In fact, RES-E support reached only a 13 % of subsidies for oil, gas and coal (and the electricity generated with these fuels) in 2011. Another report, using a different estimation method, concludes that this figure reaches \$200 billion for OECD and BRIICS countries and that these subsidies have been reduced since 2012, although they still reached \$160 billion two years later (OECD 2015: 42–47).

³Its roots, however, can be found in the nineteenth century.

a widespread diffusion. Photovoltaic generation has been a key element of the structural and technological change in the electricity sector. This is due to two main advantages: the huge solar irradiation of our planet (approximately 6800 times the world annual energy consumption) and the fact that it is not an exhaustible resource at a human scale. Notwithstanding, having a colossal energy source is one thing, but quite another is to be able to exploit it in a convenient and efficient manner.

Since decades ago, humanity has been able to exploit the solar energy received by the Earth but only in recent times it has been able to develop technologies to convert such radiation into electricity. Those technologies, basically solar PV and concentrating solar power, are characterized by attractive environmental properties compared to conventional power technologies (Lechón et al. 2013). Even though the lower emission levels of pollutants achieved by solar PV generation are not a superfluous attribute with respect to its economic feasibility, this later variable has raised serious doubts. Unfortunately, it is difficult to measure and compare both aspects. In this book, the focus has been put on the economic and policy dimensions of solar PV generation, with a very scarce reference to other renewable energy technologies, each of them deserving a wide treatment in a handbook.

Therefore, a description of the goals achieved by solar PV generation as well as an assessment of its expected costs and performance is carried out. Those goals are intermingled with the vicissitudes of the promotion policies. The resulting economic analysis has always the same underlying backdrop: the environmental advantages of solar PV generation. It should also be taken into account that the final diagnosis is necessarily provisional, since many technical alternatives compete between each other and more drastic measures may be needed in order to mitigate human-induced climate change.

No one knows what the future will bring. Although we cannot rule out that radical innovations will appear, it is an undisputed fact today that the cost of solar PV generation has come close to the cost of other conventional and renewable energy technologies. This trend was unimaginable a few years ago. It all seems to indicate that the different policy measures to support solar PV generation (being gradually implemented since the end of the past century) and, thus, the other renewable energy sources have played a crucial role in this context. Two categories of measures have been adopted in this context: support for research, development and demonstration of the technical feasibility of solar PV and policies aimed to provide favourable economic conditions for the exploitation of solar PV (commercialization). The result has been a considerable reduction in the costs of solar PV equipments and thus, the electricity produced, employment creation (both direct and indirect) and CO₂ emissions reductions. However, reaching its full competitiveness in the electricity market requires even cheaper components and a better exploitation of the solar irradiation. Achieving a longer operational life is also quite relevant in this context. All in all, the solar PV sector deems the pending task a feasible one, even in the current policy context characterized by the modulation and, in many cases, the slowdown in the implementation of support policies.

The trajectory of the solar PV sector will be definitively drawn in the next years. This trajectory will be determined by two aspects: what design (of the cell and the module) becomes hegemonic (a robust condition, which evolves over time) and which is the comparative cost level of the electricity being generated. If its competitiveness consolidates, particularly in the terms set by the electricity market, there is a widespread consensus that solar PV generation will become a crucial energy source already in the second quarter of this century and beyond. This expectation will not be curbed by grid integration aspects, an issue currently being discussed. In this case, human beings in the future may regard currently common electricity generation systems such as coal, nuclear, combined cycle gas plants or wind installations in a similar manner as we regard steam-based machines or the linotype machines, i.e. as old technical gadgets of a distant past. This expectation will be conditional upon the absence of a technique which scores better in terms of cost, environmental impact, integration in the electric power system and regulatory simplicity. However, if solar PV generation is not able to be clearly competitive in the following years, future generations will consider it as a promising alternative which, unfortunately, did not live to its expectations.

Most experts envisage a considerable weight of solar PV in future electricity generation, although a few have doubts that this will be so (GEA 2012; IPCC 2012, 2014b; IEA 2014; IRENA 2014; MIT 2015). Nevertheless, there is a wide consensus that solar PV generation as well as other renewable sources of electricity generation is undergoing a decisive moment. This is due to the perception of what is at stake, i.e. whether this and the future generations are able to reconcile growing levels of economic welfare and environmental protection.

This book provides a contribution to the economic analysis of solar PV generation, which involves the design of an appropriate analytical framework and the development of a thematic repertoire. The scrutiny includes the following wide sections:

1. An overview of the main technical features of solar PV generation, together with the facts of its development in the last decades (Chaps. 2 and 3).
2. A description of the value chain of the solar PV sector, together with a debate about the impacts of solar PV integration in the electricity system (Chap. 4).
3. An analysis of the public promotion policies which can and have been implemented, both regarding the RD&D stages as well as the deployment stage, considering also self-production (Chaps. 5–8).
4. Chapter 9 provides a set of concluding remarks and provides some relevant insights on the future expectations of solar PV generation.

Given its handbook character, the aim of this book is to provide the basis for the economic analysis of solar PV generation and, to some extent, of other renewable energy sources. Therefore, the reader is encouraged to deepen its knowledge by consulting other books, journals and specialized electronic sources. This will allow

him/her to capture the complexity involved in a simultaneous analysis of the protection of the interests of the consumers, a sufficient profitability for investors in new sources of electricity generation and the promotion of environmentally friendly technologies.

The authors acknowledge the general or specific comments provided by Joan Batalla (Foundation for Energy and Environmental Sustainability), Natàlia Caldés (CIEMAT), Emilio Cerdá (Complutense University of Madrid), Félix Hernández (CSIC), Margarita Ortega (University of Burgos), Cristina Peñasco (CSIC), Desiderio Romero (University Rey Juan Carlos) and Elisa Trujillo (Energy Sustainability Research Group, University of Barcelona). This book has also benefited from the discussions with individuals related in one way or another, with solar PV generation. Obviously, the authors are the only ones responsible for any mistakes or omissions that the final text could contain.

References

- Edenhofer O et al (2009) The economics of decarbonization. Report on energy and climate policy in Europe (RECIPE). Potsdam Institute for Climate Impact Research (PIK)/CMCC/CIRED/EPRG. Available at <http://www.pik-potsdam.de/recipe>. Accessed Jan 2014
- GEA (2012) Global energy assessment. Toward a sustainable future. Cambridge University Press/International Institute for Applied System Analysis, Cambridge (UK)/Laxenburg (A)
- Houghton J (2015) Global warming. The complete briefing, 5th edn. Cambridge University Press, Cambridge
- IEA (2014) Technology roadmap. Solar photovoltaic energy. OECD/IEA, Paris. Available at <http://www.iea.org>. Accessed Sept 2014
- IPCC (2012) Direct solar energy. In: Edenhofer O et al (eds) IPCC special report on renewable energy sources and climate change mitigation (chapter 3), pp 333–400. Cambridge University Press, Cambridge
- IPCC (2014a) Climate change 2014. Synthesis report. Longer report. IPCC fifth assessment synthesis report. Available at <http://www.ipcc.ch>. Accessed Feb 2015
- IPCC (2014b) Energy systems. IPCC working group III-mitigation of climate change (chapter 7). Available at <http://www.ipcc.ch>. Accessed Feb 2015
- IRENA (2014) Rethinking energy 2014: Toward a new power system. International Renewable Energy Agency. Available at <http://www.irena.org/publications>. Accessed Oct 2014
- Lechón Y, Caldés N, Linares P (2013) Environmental implications of energy production. In: Dyer H, Trombetta MJ (eds) International handbook of energy security, pp 345–384. Edward Elgar, Cheltenham
- MIT (2015) The future of solar energy. An interdisciplinary MIT study. Energy Initiative Massachusetts Institute of Technology, Cambridge. Available at <http://mitei.mit.edu>. Accessed May 2015
- OECD (2015) OECD companion to the inventory of support measures for fossil fuels 2015. OECD Publishing, Paris. Readable at <http://oecd-ilibrary.org>. Accessed Sept 2015
- Sachs J et al (2014) Pathways to deep decarbonization-2014 report. Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations. Available at <http://deepdecarbonization.org>. Accessed April 2015
- Socolow R et al (2004) Solving the climate problem. Technologies available to curb CO₂ emissions. *Environment* 46(10):8–19

- Stern N (2009) Connecting climate change and economic recovery. Interview to economist Nicholas Stern. Available at <http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights>. Accessed Jan 2016
- Stern N (2015) Why are we waiting? The logic, urgency, and promise of tackling climate change. The MIT Press, Cambridge

The Economics and Policy of Solar Photovoltaic
Generation

Mir-Artigues, P.; del Rio, P.

2016, XX, 346 p. 56 illus. in color., Hardcover

ISBN: 978-3-319-29651-7