

---

# 1. Introduction to the *Handbook on the Economics of Renewable Energy*\*

*Pablo del Río and Mario Ragwitz*

---

The decarbonisation of energy systems represents a key element of the energy transition which is needed to meet the targets of the Paris Agreement, which was adopted by 196 countries in 2015. Governments agreed to limit global warming to 2 degrees, and preferably 1.5 degrees, above preindustrial levels.

Low carbon investments are essential for transforming the energy system into a renewable one aligned with the pledges of the Paris Agreement and more globally with the sustainable development goals. According to the International Energy Agency (IEA 2021), around \$5 trillion per year of additional capital investments by 2030 and around \$4.5 trillion per year by 2050 are needed only in energy and energy-related infrastructures to achieve net-zero CO<sub>2</sub> emissions globally by 2050.

Therefore, meeting such a target is contingent upon a large transformation of our global energy production and consumption systems. Renewable energy technologies (RETs), and more specifically technologies which generate electricity from renewable energy sources, are a main pillar of this decarbonised energy transition, together with energy efficiency. “Energy from renewable sources” or “renewable energy” means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogas (EU Parliament and Council of the European Union 2018). According to the International Renewable Energy Agency (IRENA) (2022a), 25% of the reductions of 37 gigatonnes of annual CO<sub>2</sub> emissions by 2050, which will be required in order to meet the 1.5 degree target, will be achieved cost efficiently through renewables.<sup>1</sup>

Currently, the share of renewables in energy production and consumption is modest. In 2020, “modern renewables” only accounted for 12.6% of final energy consumption worldwide (REN21 2022).<sup>2</sup> This global average for renewables masks important differences in the penetration levels per region and final use sectors. According to the IEA (2021), world energy supply from renewables amounted to 68.5 exajoules (EJ) in 2020. Three-quarters of this supply came from three regions: Asia Pacific (25.8 EJ), with China accounting for 12.9 of this last figure, North America (12.8 EJ) and Europe (14.3). The contributions from the other regions were: Africa (4.6 EJ), Central and South America (9.5 EJ), Middle East (0.2 EJ) and Eurasia (1.3 EJ).

Broadly speaking, renewables can be used in three different sectors: heating and cooling, transport and electricity. They have a different share in the three energy consuming sectors: 11.2% in heating and cooling, 3.7% in transport and 28% in electricity. The focus of this book is on this final energy use sector, i.e., electricity, although the other sectors are also taken into account.

In order to meet the Paris Agreement targets, those percentages should increase considerably. According to IRENA, the share of renewables in final energy consumption should

increase from the current 16% to 79% in 2050 (IRENA 2022a). Focusing on the electricity sector, according to IRENA, the share of renewables in electricity generation should skyrocket from 25% in 2018 to 57% in 2030 and 86% in 2050 (IRENA 2019). A more recent estimation by IRENA shows that the share of renewables in electricity generation should grow even faster from the current 26% to 90% in 2050 (IRENA 2022a). There is a wide consensus that solar photovoltaics (PV) and wind will be the RETs with the greatest diffusion potential worldwide (see, e.g., IEA 2021; IPCC 2022). These two technologies are expected to make the largest contribution to renewable energy penetration in 2030/2050, given their relatively low costs with respect to other electricity generation technologies, whether renewable or not. According to IRENA (2019), annual additions of wind electricity generation capacity should increase three-fold in the next decade (from 109 GW in 2018 to 300 GW in 2030 and 360 GW in 2050) and annual additions of PV capacity should increase four-fold (from 54 GW in 2018 to 200 GW in 2030 and 240 GW in 2050) in order to meet the Paris Agreement targets. Annual solar PV should increase more than three-fold from the current 126 GW/year to 444 GW/year in 2050, whereas annual wind additions should more than double from 115 GW/year today to 248 GW/year in 2050 (IRENA 2022a).

Apart from their application in different final energy use sectors, there are other policy-relevant distinctions between different types of renewables in electricity generation: maturity and dispatchability. An analogy between RETs and a human life can be made. Technologies in general and RETs in particular are initially immature: they are imperfect and have high costs. Due to research on those technologies, but also as they diffuse, improvements and cost reductions take place, and they become fully mature. Mature RETs include onshore wind and solar PV. Less mature technologies have a high potential for improvements and cost reductions, whereas this potential is modest for technologies that have already reached a high maturity level.

On the other hand, all RETs in the power sector depend on renewable energy resources to produce electricity. In some cases, electricity generation can only take place when the resource is available at the moment when electricity is produced, i.e., when the wind blows or when there are sufficient solar irradiation levels. In case such resources are not available instantaneously, no generation can occur. This is the case with non-dispatchable (also called variable or intermittent) RETs, such as wind and PV. Of course, the electricity generated with those RETs can also be stored in batteries, but large-scale storage is still costly. In contrast, other RETs have an inherent storage feature, i.e., the renewable resource can be stored and used at will. This is the case with biomass (i.e., crops or forest residues) and hydro (water), although the availability of the resource is contingent upon the absence of droughts. It is also the case in concentrated solar power (also called solar thermal electricity) in which a fluid (water, oil and sands) is heated with the sun impacting mirrors and the thermal inertia allows such fluid to be available in order to move a turbine and produce electricity even hours after the sun has set. These dispatchable RETs allow power to be produced “on demand”.

Renewable electricity technologies are, thus, a *sine qua non* in achieving climate change mitigation targets, i.e., to reduce the emissions of greenhouse gases (GHG). However, they provide more benefits beyond decarbonising energy (electricity) sectors. They also reduce the emissions of other local pollutants. Apart from the environmental benefits, renewable electricity provides other socioeconomic advantages such as economic development, employment and investment opportunities. Finally, by having renewable energy projects in their territory, countries can also reduce their fossil fuel dependency and mitigate the risks related to the

security of energy supply, which is certainly a major policy concern nowadays, particularly in those countries without fossil fuel resources.

In addition to those benefits, there are costs. In general, the decarbonised energy transition will not be achieved without significant investment and costs. And also the huge penetration of renewables which will be needed will come at higher generation and system costs, at least temporarily. This is a major concern for policy makers everywhere in the world. Traditionally, RETs have been more costly than their fossil fuel counterparts. However, given the aforementioned dynamic nature of the cost reductions taking place in RETs, some of these have been able to achieve cost-competitiveness with their fossil fuel competitors. According to data from IRENA (2022b), solar PV, onshore wind and hydro are already cost-competitive technologies in terms of direct costs (LCOE) with respect to other renewable and non-renewable electricity generation technologies. However, for some technologies, a high cost gap remains, although the question is whether these technologies will be needed then if such a high cost gap remains. Furthermore, a characteristic of all RETs is their capital intensity. This means that the required investments in these technologies need to be made up-front, and then, when they start to produce electricity, only small variable costs are incurred (operation and maintenance costs, but not fuel costs). The economic implications of this feature are considerable, since those investments need to be financed and this means that those funds need to be available, which might be difficult in some regions of the world and may not be possible in most countries in the absence of public policies which ensure some return on those investments.

In fact, the aforementioned required increase in the uptake of RETs would need to accelerate the growth in deployment and penetration of renewable electricity experienced in recent years, which has been substantial, but slower than needed to meet the aforementioned requirements. Renewables generated 28.3% of global electricity in 2021, up from 20.4% in 2011 (REN21 2022). The diffusion of RETs has been driven by demand-pull policies, with administratively set feed-in tariffs and feed-in premiums (ASFITs/FIPs) being the most popular instrument in this regard (see Chapter 16). ASFITs/FIPs have been superseded in recent years by auctions as the dominant scheme for RET deployment worldwide (REN21 2022). However, given their alleged advantages in terms of cost-effectiveness and lower support costs, auctions are the most rapidly expanding form of support for renewable energy project deployment and are becoming the preferred policy tool for supporting the deployment of large-scale projects. The adoption of RET auctions has increased linearly in the last decades, from 6 countries holding auctions in 2005 (IRENA 2017) to 131 countries holding auctions in 2021 (REN21 2022). This compares to 92 countries with ASFITs/FIPs in 2021 (REN21 2022).

The above paragraphs shape the background context for this book, which, as the title states, is about “the Economics of Renewable Energy”. The aim of this book is to provide a comprehensive vision on this topic. It applies economic analysis techniques to identify the costs and benefits of renewable electricity development and deployment, inferring policy implications for the future. It does so by adopting a systemic and dynamic perspective on costs: all the costs of renewable energy deployment (i.e., not only the project-level ones, but their impacts at the electricity-system/energy-system level) and factors that affect their evolution over time, with a main focus on deployment policies. In short, the coverage of the book is also broad: it addresses theoretical, methodological and empirical aspects of RET deployment with a clear policy-oriented philosophy.

It is also broad in the economics perspectives adopted, since it encompasses different economic approaches and disciplines, with a main basis in environmental economics and

innovation economics. Although some economic disciplines are based on different assumptions about human behaviour (i.e., rationality) and, thus, sometimes lead to contradictory results, our vision is integrative, i.e., we believe that different approaches have a role to play, since they capture different aspects of a problem or issue.

Such broad coverage and a holistic and comprehensive approach are also reflected in addressing the many sides of the economics of renewable energy: it focuses on both efficiency and distributional issues, on static and dynamic perspectives, on the short-term and the long-term implications, on different levels (macro and micro) and on different renewable electricity deployment scales (including utility-scale, self-generation and community initiatives). Although it is not exhaustive in the treatment of each and every possible topic in renewable electricity deployment (since they are many), we hope that the sufficiently broad coverage of topics and perspectives remains useful for different actors, including researchers, policy makers and practitioners.

Written by experts in the field, the book has 19 chapters and is structured into 6 parts. The first part covers the main theoretical and methodological aspects and provides a “framing” for the rest of the book. In Chapter 2, Breitschopf et al. outline a comprehensive approach for assessing costs and benefits for the past and future development of the energy transition in the EU. The chapter briefly outlines the analytical framework to assess the impacts of the energy transition and describes the framework by using the RET deployment in general as well as based on examples. It describes different types of costs and benefits, applies a unified and consistent terminology for costs and benefits of the energy transition and provides guidance for their assessment. It identifies which types of effects arise in line with the energy transition in general, in different economic sectors, regions or technology fields, how they can be assessed on a regular basis, e.g., life cycle or annual, what the system boundaries of impact assessments are, which impacts can be quantified, expressed in terms of indicators and their potential monetarisation, which information and methodological approach is most suitable to get an appropriate picture of costs and benefits of the system that are the focus of the analysis and how to critically assess results in terms of indicators and be aware of limitations.

In Chapter 3, Resch et al. assess past developments in energy system modelling of renewable energy and related energy infrastructure prerequisites. Illustrative snapshots are provided, offering a chronological survey of energy system models with a focus on renewable energy and related main thematic fields. Illustrated topics of interest as well as approaches used in corresponding model-based assessments are provided, with a geographical focus on Europe. The chapter provides fruitful insights on how the energy policy debate has emerged as well as how energy system modelling has advanced to provide substance and support decision making in accordance with emerging policy needs.

Quintana-Rojo et al. argue that analysing the factors that determine the development and deployment of renewable energy sources (RES) is a valuable academic effort, since it will allow the elaboration of strategies based on the drivers that stimulate investment in installed capacity, as well as the elimination of barriers that hinder the diffusion of renewable technologies. Chapter 4 focuses on one of the analytical approaches that can be applied to analyse this topic, i.e., econometric modelling. Econometric techniques have the benefit that they represent, in an objective and replicable manner, the system of relations that characterises the development of RES. This technique identifies the main variables that have an impact on this development and allows an analysis of the impact on this system of the relations of various technical, economic, political and social scenarios. Thus, the authors provide a critical

perspective on what econometrics has to offer with respect to other methods, an insightful discussion of some of the problems that may be encountered when using econometric modelling to analyse the drivers of renewable energy deployment and review the state of the art of studies on this topic.

Input-output analysis is another technique which has been used in the past to analyse the benefits of renewable energy deployment. In Chapter 5 (Banaclache et al.), the use of input-output (IO) to conduct gross or net assessments of the socioeconomic implications of renewable energy deployment is considered. The use of IO methodology extended with environmental and socioeconomic vectors has been proposed as a framework for analysing the sustainability of energy investments, as it is able to capture the total, direct and indirect, impacts of energy investments, considering the global value chains phenomenon both in environmental and socioeconomic terms. This chapter describes the IO methodology and its extensions and discusses the scope of its applications to renewable energy investments. Chapter 6 extends this discussion with the results of several case studies.

The second part of the book is, indeed, devoted to the empirical analysis of the benefits of renewable energy deployment. In Chapter 6, Gamarra et al. provide a review and also some concrete examples of case studies of renewable energy investments and policies using multi-regional input-output models (MRIO). In addition, a section dedicated to the assessment of external costs of RES technologies is included. The authors show the relevance and wealth of information derived from this type of study with four examples. The objective of the first study was to assess the sustainability impacts of specific renewable energy innovations. The second aimed to evaluate the employment impacts of alternative renewable technologies. The third study conducted a comparative assessment of national programmes of RES investments and the fourth aimed to assess the socioeconomic impact at the regional level in Europe. Besides, the socioeconomic benefits of air pollution mitigation associated with RES penetration in the transport sector were also presented in a final example. One of the conclusions of this chapter is that, when time and resources allow for it, sound and scientific-based quantitative socioeconomic assessments are required to fully understand the magnitude and causality of such impacts in order to inform and guide investment decisions, design policies, implement measures to minimise adverse effects, boost positive impacts and raise awareness.

Chapter 7 (Tomás et al.) focuses on one of those benefits from RES deployment, i.e., employment creation. They use a socially extended MRIO to quantify the employment impacts of a decarbonised energy transition in Spain. The authors consider alternative installation cost vectors and analyse the job creation in green investments under different assumptions for two technologies: onshore wind and solar photovoltaic. Their results show that Spain could create between 6.13 and 12.75 jobs for every million euros invested in renewables, depending on the assumptions and scenarios considered. Most of the jobs created in Spain and the rest of the European Union would be direct, while the indirect effects would be stronger in the rest of the world. Finally, we observe that solar energy generates more jobs overall, but wind energy leads to more jobs in Spain (8.89 vs. 8.65, respectively).

Apart from benefits, another key element in the economic analysis of renewable energy deployment is costs. Therefore, Part III of this book focuses on this topic. In Chapter 8, Batalla-Bejerano and colleagues start from the assumption that, in order to make decarbonised electricity generation a reality, it is necessary to improve the exploitation of energy resources and the connection of renewable generation systems to the grid. This chapter shows that a successful deployment of power generation coming from variable renewable sources,

such as wind and solar photovoltaic, highly depends on the economic cost of system integration. This chapter seeks to look beyond the impact of renewable generation and aims to present the relevance of transmission and distribution networks and the economic fundamentals of power system operation. The chapter highlights the need to redefine the role of electricity networks to be adapted to the future challenges related to energy transition characterised by a large penetration of renewable electricity generation.

In the context of the analysis of the costs inflicted by renewable energy deployment and generation on the overall functioning of current electricity markets and their design, Chapter 9 (Gerres et al.) argues that market design revisions are possibly inevitable to meet the three main objectives of electricity systems (trilemma): capacity adequacy, emission avoidance and affordability. Their results from a Spanish case study demonstrate how changing policy scenarios require additional market mechanisms with significant interdependencies among each other. They show how a market mechanism that is not perfectly aligned with the main system objectives, such as renewable payments, is suboptimal to comply with the main objectives. Furthermore, the authors challenge the premise of cheap green electricity for everyone since the remuneration of additional services increases the total system cost.

The previous chapters mostly focused on the macro and system level and on utility-scale deployment. Part IV of this book is devoted to the analysis of more micro-level, small-actor initiatives. This includes self-generation and community initiatives. In Chapter 10, Mir-Artigues addresses the socioeconomic dimension of residential micro-generation, with an empirical focus on Spain. This is a possibility which was created by the enormous reduction of the prices of photovoltaic equipment which started in 2008. The chapter provides a general classification of PV plants, identifies the six factors that influence the design and management of a residential plant (illustrated with a real case) and defines and discusses the three criteria used for the economic evaluation of micro-generation, namely, the rate of return, the avoided cost and the influence of some heuristics (such as social imitation and sufficient satisfaction) that trigger it.

In Chapter 11, Kanellou et al. argue that, to successfully mitigate energy poverty (at least in the European Union) while putting citizens at the heart of the energy transition and fostering energy democracy, bottom-up approaches, including renewable energy ones, need to be pursued at a policy level. Collective energy actions can pave the way towards the uptake of renewable energy enabling and incentivising consumers to become prosumers. Due to their nature, collective energy actions can contribute to empowering citizens to participate in the energy market, especially when combined with innovative financing schemes that can secure the necessary funds needed to invest in renewable energy projects. In this chapter, the notion of employing collective energy actions to support citizens to tackle energy poverty leveraging joint energy initiatives is investigated. The principles of collective innovative actions are presented, followed by the notion of community finance and crowdfunding. Then the reasoning for how this approach can be especially beneficial in mitigating energy poverty is given. Finally, the case of Greece is presented. The status of energy poverty in Greece and the legal framework of collective energy actions such as energy communities is given along with the challenges that need to be addressed to foster citizen participation and enhance energy democracy for the case of Greece.

Part V broadens the focus and looks into relevant issues for the future of the energy transition in general and for renewable energy in particular, all of them with considerable policy implications: geopolitical aspects, innovation aspects and risk/financing aspects. In Chapter 12,

Escribano and Lázaro-Touza observe that the transition towards a renewable regime implies a shift in geopolitical and geo-economic balances. Therefore, this chapter seeks to analyse the international implications of renewables, as well as their linkages with climate geopolitics and the role of the main renewable powerhouses (China, the US and the EU). It also explores the new geographies of renewables and reviews the literature on their geopolitics. The chapter focuses on the bi-directionality linking geopolitics and renewables, which is key to assessing the geo-economic benefits of the latter. Geopolitics has an economic impact because it might make cross-border renewable cooperation economically prohibitive between rivals. However, the renewable regime is thought to be less conflict-prone and more cooperative, offering new opportunities for economic and political cooperation. The chapter concludes that this requires clear and transparent governance mechanisms to avoid replicating the governance and market failures of the fossil regime.

In Chapter 13, del Río and Kiefer not only provide an analysis of an important topic (innovation), but they also do so using a relatively new theoretical/methodological framework from innovation studies which has been applied to renewable energy. The authors observe that barriers to the development and diffusion of RETs need to be removed to achieve a high penetration of renewables and the potential drivers of this high share should be activated in order to accelerate their uptake. Therefore, insights on those drivers and barriers are required in order to implement policies which encourage the diffusion of RETs. The analysis of those drivers/barriers can greatly benefit from the literature on technological innovation systems (TIS) which, indeed, has been applied extensively to analyse the drivers/barriers to RETs. Although some reviews on barriers to RETs are available in the literature, none has focused on the insights provided by the TIS approach. The aim of this chapter is to review the literature on the drivers and barriers to RETs using a TIS approach and to identify relevant insights from this literature. However, some weaknesses of the TIS approach when analysing the determinants of RETs have also been identified, which suggest that it should be complemented with other streams of the literature and that some missing aspects should be integrated into the TIS approach in order to provide a more complete framework for the analysis of drivers and barriers to RETs.

In Chapter 14, de Llano Paz et al. provide a forward-looking perspective, combining energy planning, risk and financial analysis. The authors propose that the assessment of investment projects linked to energy planning be carried out from the perspective of a long-term investment selection problem. They use modern portfolio theory (MPT) methodology, which is based on maximising the yield-risk dichotomy (or its alternative, minimising the cost-risk) of the asset portfolio for this task. The energy planning problem over the medium to long term for a company, region or territory can thus be conceived as based on an electricity-generating (power plant) energy asset portfolio optimisation model. The intent is to define the efficient management of a portfolio or group of assets with a long service life over time and characterised by the previously indicated uncertainties (technological, economic, regulatory and environmental). In their empirical study of Spain and Germany, the authors show how to apply the methodology to energy planning. Potential trends in investments in specific energy sources can be identified over the upcoming years for a given territory. Their application leads to useful and policy-relevant insights. They show that, if the aim is to achieve an affordable mix, the investments will flow towards onshore wind in Germany and in Spain over the medium term, and towards solar in both countries, over just the medium term for Germany, and over the short, medium and long term in Spain. Risk-effective technologies, such as large-scale

hydro, mini-hydro (only in Germany) and biofuels over the short and long term in Spain, are expected to thrive if a risk-averse portfolio is followed. Moreover, regardless of the type of approach chosen, some technologies are expected to be or to remain important, such as coal and gas (over the short run) in both countries and mini-hydro in Spain (over both the short and long run). Some technologies, such as onshore wind in Germany and solar in Spain, have enormous importance in all scenarios, especially in low-cost portfolios, where they reach shares of up to 65%.

In Chapter 15, Sporleder et al. pay attention to the integration of renewables in district heating system (DHS) with a case study for a German grid. The research has shown that large-scale heat pumps combined with waste heat are competitive with heat generation costs of 12 ct (kW h)<sup>-1</sup> (including the pricing for waste heat) compared to CHP plants with generation costs of 10.9 ct (kW h)<sup>-1</sup> (the gas price of 2021) and 33.7 ct (kW h)<sup>-1</sup> (the gas price of 2022). Biomass will also be an economical option in renewable DHS with an estimated price of 15.7 ct (kW h)<sup>-1</sup>, especially because biomass has the lowest emissions. In 2022, gas-fired CHP plants are no longer competitive due to the rising gas prices. Biogas-fired CHP plants were more expensive than the other two renewable technologies, at 22.1 ct (kW h)<sup>-1</sup>. However, it might be an option if no heat source at a high temperature level is available and a renewable share of the heat is obligatory. However, shifting to renewable energy systems will require multivalent and sector-coupled systems.

The final part of this book (Part VI) is about policy, covering the more general aspects (Chapter 16), discussing key aspects related to the dominant renewable electricity deployment instrument (auctions, Chapter 17), policy mixes in renewable energy deployment, with a main focus on the design of instruments (Chapter 18) and a key international dimension in renewable energy support, with special attention to official development aid (ODA) (Chapter 19).

Renewable energy has been supported for decades now, using different instruments and even different policy approaches. In Chapter 16, Kiefer et al. provide a critical, historical overview of the evolution of public policy support for renewable energy technologies, with an emphasis on the last two decades, deployment support and the solar and wind technologies. An overall framework for the analysis of renewable electricity policy, which includes framework conditions (i.e., targets and policy stability), instruments and their design elements, is provided. The instruments to support renewable electricity deployment are described, and their pros and cons are discussed. The authors also identify the patterns and trends in the adoption of those instruments in the last decades, with a focus on the European Union. Finally, a discussion of the alternatives for the design of different instruments is provided.

In Chapter 17, Anatolitis and Winkler provide insights on the application of renewable energy auctions. The authors analyse the history of renewable energy auctions and describe how renewable energy auctions work, their main advantages (e.g., efficient control of renewable energy deployment and lower support expenditures) and their drawbacks (e.g., potentially low realisation rates of projects). Then, the authors present several policy objectives that can be pursued with auctions, among others, supporting cost efficiency and effectiveness, providing an exhaustive overview of auction design elements and their effects on these policy objectives. They discuss the emergence of zero-price bids in offshore wind auctions and approaches to effectively select winners. The chapter concludes with an outlook on the future of renewable auctions and the role of auctions in related sectors, such as the support of green hydrogen.

In Chapter 18, Kwon and del Río start from the assumption that the success of instruments for the deployment of renewable electricity depends on how those instruments are designed

and combined. However, despite the importance of the choice of design elements and the widespread use of instrument mixes, the impact of such choices on the interactions between instruments has not received much attention. This chapter addresses this gap in the literature and illustrates how the choice of design elements for one instrument may affect the outcome of the instrument mix. It also examines the design elements of auctions in South Korea, where auctions, renewable portfolio standards and feed-in tariffs are combined. The case of South Korea shows that the choice of design elements in an auction may have considerable effects on the instrument mix. The results suggest that, although the need to coordinate instruments for improving the success of instrument mixes has often been proposed, this is not only an issue of coordinating instruments, but also of selecting the appropriate design elements of instruments.

Finally, in Chapter 19, Peñasco analyses the evolution and characteristics of climate-related development finance for the generation of electricity with renewable sources since the Copenhagen Accord in 2009, i.e. donors, recipients, technologies and instruments. Then, she revises the available policy instruments in the hands of governments to promote the transition to low carbon economies and the importance of policy mixes. Lastly, using a qualitative comparative analysis (QCA), she explores the simultaneous/complementary role played by those policy instruments and climate-related development finance for renewable energy projects in incentivising the transition to low carbon economies in countries receiving ODA. Her results confirm the importance of different strategies and policy mixes depending on the level of development of the countries analysed. Those strategies imply different combinations of ODA, energy auctions, tax credits, renewable standards and carbon pricing. Understanding these relationships is key to fostering a faster low carbon energy transition with a high share of renewables.

## NOTES

- \* Online appendices for chapters 4, 13 and 19 are available on the companion website at: <https://www.e-elgar.com/textbooks/del-rio>.
- 1. The rest would be accounted for by energy efficiency (25%), whereas electrification (20%), renewable energy-based CO<sub>2</sub> removals (BECCS, 14%), hydrogen (10%) and fossil fuel CO<sub>2</sub> capture and storage (CCS, 6%) should contribute the rest (IRENA 2022).
- 2. Within this percentage, renewable heat (biomass, geothermal and solar) accounts for 4.8%, hydro-power represents 3.9%, biofuels for transport account for 1% and the share of other renewables (biomass, geothermal, ocean, solar and wind power) is 2.8% (REN21 2022).

## REFERENCES

- EU Parliament and Council of the European Union. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).
- IEA. (2021). *Net Zero by 2050*. IEA, Paris. <https://www.iea.org/reports/net-zero-by-2050>.
- IPCC. (2022). *Climate Change 2022. Mitigation of Climate Change*. Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
- IRENA. (2017). *Renewable energy auctions. Analysing 2016*.
- IRENA. (2019). *Global Energy Transformation: A Roadmap to 2050* (2019 edition). International Renewable Energy Agency, Abu Dhabi.
- IRENA. (2022a). *World energy transitions Outlook 2022. 1.5°C pathway*.
- IRENA. (2022b). *Renewable Power Generation Costs in 2021*. <https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021>.
- REN21. (2022). *Renewables 2022. Global Status Report*.