23 The role of renewables in the pathway towards decarbonisation

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Renewable energy technologies represent an important low-carbon alternative to hydrocarbons in all applications, from transport to electricity generation and heating. In the shorter term, developments that lower the costs of renewable energy will help lower the cost of decarbonisation efforts. In the longer term, renewables could represent the main source of energy for a zero-carbon planet. Renewables can also bring about a whole set of important ancillary benefits, such as reductions in local pollution and increased access to energy. For all these reasons, policies that lower the barriers to adopting renewable energy and that spur innovation should play a key role in a future international climate agreement.

Introduction

Renewables represent the broad category of energy flows occurring in the natural environment that can be captured for use up to their rate of replenishment. Renewables include hydropower (although typically excluded from the group of 'new' renewables), wind and solar energy, tidal and wave energy, ocean and geothermal energy, and biomass energy (IPCC, 2011). Renewables are a key energy option for decarbonisation, but their use as a substitute for fossil fuel energy can also result in important co-benefits, such as improvements in 'energy security' by diversifying the set of energy sources, reductions in local pollution, the alleviation of energy poverty, and more broadly the promotion of 'green growth'. As renewables offer a variety of sources of energy, they are geographically distributed more widely than hydrocarbons. Thus, in principle, renewable energy provides new possibilities for development in most regions in the world.

In the short term, a shift towards renewables and improvements in these technologies have the potential to lower the cost of transitioning out of fossil fuels, thus making it more attractive for countries to adopt more ambitious INDCs. In the longer term, renewables provide the main technological means for reducing global emissions to zero, and so can help shape the ambition for setting long-term global temperature targets.

For all these reasons, policies related to renewables (either easing their adoption, lowering integration barriers, or promoting innovation in the next generation of technologies) should play a key role in future international climate negotiations.

This chapter provides an introduction to renewable energy technologies, describing their future technical potential (Section 1); reviewing their key role in addressing the GHG-mitigation challenge (Section 2); and, finally, discussing in Section 3 the main bottlenecks to the large-scale penetration of these technologies and the policies needed to help overcome these bottlenecks.

It is important to keep in mind that, following a period that has seen an unprecedented drop in the cost of new renewables (and solar modules in particular), a generalised trend change in the regulatory environment of several countries might result in a slowdown of future investments (IEA, 2014). As a result, renewables might run the risk of falling short of the levels required by deep decarbonisation scenarios. As argued here, international climate negotiations could counteract this trend by providing the predictable and long-term signals that will be needed to secure a sustained growth in these technologies.

1 Renewables today and their technical potential

In 2013, renewables represented about 22% of total electricity generation, with hydropower producing the lion's share, and roughly 13% of the world's total primary energy supply, the vast majority of which came from biomass alone. The deployment of renewables power capacity is expected to rise globally to 2550 GW in 2020 (a growth of 50%), with more than half of this new capacity expected to be installed in non-

OECD countries. The International Energy Agency projects that, thanks to this growth, by 2020 power supplied by renewables will grow from 22% to 25%. A further 50% growth by 2030 is shown in the projections presented in Table 1.

Table 1 Global installed capacity of renewables in 2000, 2010 and 2014, and projections for 2030 (GW)

Renewable technology	2000		2010		2014		2030 (IEA projections)	
Hydropower	781.73	(92.8%)	1027.60	(76.2%)	1172.00	(64.1%)	1670.00	(41.4%)
Wind energy	17.33	(2.1%)	196.33	(14.6%)	369.60	(20.2%)	1173.00	(29.1%)
Solar energy	1.23	(0.1%)	40.05	(3.0%)	179.64	(9.8%)	900.00	(22.3%)
Bioenergy	33.72	(4.0%)	72.54	(5.4%)	94.53	(5.2%)	245.00	(6.1%)
Geothermal energy	8.32	(1.0%)	10.98	(0.8%)	12.41	(0.7%)	42.00	(1.0%)
Tidal, wave, ocean energy	0.27	(0.0%)	0.27	(0.0%)	0.53	(0.0%)	6.00	(0.1%)

Notes: Relative share in parentheses.
Source: IRENA (http://resourceirena.irena.org/); 2030 projections from IEA (2015).

Table 1 gives estimates and projections for the cumulated installed capacity of different renewables technologies for various years. Wind and solar capacity have grown most rapidly, in response to the large reductions in the costs of solar PV modules, which fell by a half in several countries over the period. Most of this cost reduction was due to innovative changes in the production structure developed by Chinese manufacturers.

Roughly 50% of renewable installed capacity is currently located in the top five countries in terms of renewables deployment: China, the US, Brazil, Germany and Canada. However, most of the future instalment is expected to be concentrated in developing countries, where energy demand will grow the most in the next decades.

Underlying the projected numbers for 2030 presented in Table 1 is the assumption of an increase in investments in renewable energy technologies in the power sector from US$270 billion in 2014 to $400 billion in 2030, resulting in a more than threefold increase in the installed capacity for both wind and solar. Notwithstanding the current growth trend in renewables investments, renewables are projected to face a transition period in response to a change in the policy regime of most countries (IEA, 2014). Although it might be affected by international climate negotiations, new generation, capacity additions and investment in renewable power are all expected to level off through 2020. As far as biofuels are concerned, production and consumption in the US, the EU and Brazil are now slowing down after a period of very rapid expansion, mainly due to changes in policies in reaction to the peak in land demand and general equilibrium implications on crop prices that previous policies have caused. To meet the IEA's projections for 2030, a change in this recent policy trend would be required.

Renewable energy technologies can potentially cover the full spectrum of human energy needs; they can be used to produce electricity and heat, and provide energy for transportation. The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation concluded that the aggregated global technical potential for renewables as a whole is significantly higher than global energy demands although there is great uncertainty regarding assumptions on land use availability that have to account for issues like biodiversity, food security, water limitation, and soil degradation (IPCC 2011).[1]

2 The projected role of renewables in a decarbonised future

Simulations from global energy economy models suggest that renewables are fundamental both in the short to medium term as well as in the second half of the century (Clarke et al. 2014).

Those renewables options that are largely confined to the electricity sector (e.g. wind and solar) and to heat generation are projected to be especially important in the first part of the century. Each option contributes to keeping mitigation costs down and to facilitating decarbonisation by enriching the portfolio of technological alternatives and allowing a diversification of energy sources. In the short term, coupling renewables penetration with gas power generation is seen as the most promising solution, which would help maintain the flexibility of the power system.

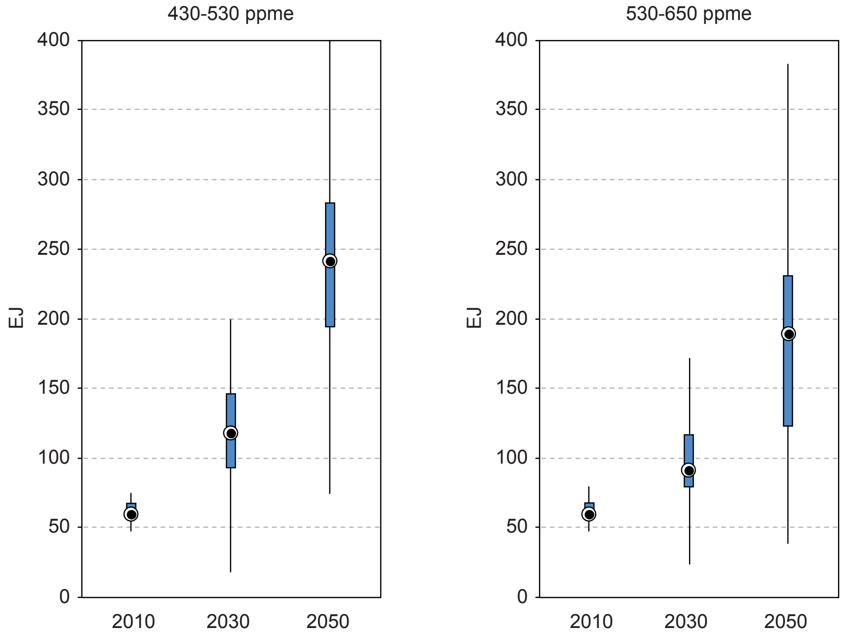
1 The complexity of such intricate interactions scales up the uncertainty surrounding the potential deployment levels of biomass for energy, which is estimated to be in the range of 100 to 300 EJ by 2050 (for the sake of comparison, 112 EJ is the primary energy consumption of North America in 2012 was 112 EJ).

Wind and solar technologies might have a less critical role in the longer run. Around 2050 and beyond, the effort to keep the average global temperature in line with a 2°C or 2.5°C target is such that 'negative emissions' technologies in moderating mitigation costs (Krey et al., 2013). Indeed, in the longer term, the technological option of combining biomass generated power with carbon capture and storage (CCS) gains a prominent role as it allows for the production of carbon-neutral power while, at the same time, generating 'negative' emissions. The idea is to generate power using carbon-neutral sustainable biomass and then capture CO2 at the plant level and store it underground in geological sites (see the chapters in this book by Tavoni and Barrett and Moreno-Cruz). Most projections that do not incorporate such a technological option either report costs of decarbonisation that are at the higher end of the scale, or fail to find a combination of technologies that would deliver stringent climate targets (i.e. scenarios leading to about 450 ppm CO2eq) (Azar et al., 2006; van Vliet et al., 2009, 2012; Krey et al., 2013).

Figure 1 summarises projections of renewables primary energy from multiple integrated assessment model (IAM) simulations for two representative future years (2030 and 2050) under two climate scenario classes (the left-hand panel reports the range of model results for 430-530 ppme, approximately in line with a 2°C temperature target, while the right-hand panel reports results for 530-650 ppme, or approximately 3°C).

Notwithstanding the huge uncertainties that characterise this range of IAM results, including over breakthroughs in renewables technologies, the average required expansion by mid-century in the more stringent climate scenarios (left-hand panel) is projected to be a threefold increase relative to today's levels. *This would represent a level of primary energy supplied by renewables in 2050 that is roughly half of today's total primary energy* (and a third for the more moderate climate stabilisation scenarios).

Figure 1 Model-based projections of primary energy from renewables



Notes: Average of estimates from integrated assessment models (IAMs). In each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend to the most extreme data points not considered outliers (corresponding to 99% if the data are normally distributed). Primary energy is the energy contained in raw fuels. Note that today's total primary energy global consumption (including fossils and nuclear) is 567 EJ, projected to grow to 612 and 643, by 2020 and 2030, respectively (IEA 2015).

Source: Author's elaboration of the IPCC AR5 Working Group III database (https://secure.iiasa.ac.at/web-apps/ene/AR5DB).

3 Limits to actual deployment

Below I review the uncertainties that could prevent the deployments of renewables.

Costs evolution

The major bottleneck slowing down the materialisation of the huge technical potential of renewables is, first and foremost, related to their transformation cost relative to the incumbent, fossil-fuelled technologies.[2] Although costs of both solar and wind power

2 Hydropower is the most mature of the renewables technologies and the only one for which costs are competitive. However, most of the hydropower potential, except for in Latin America and Africa, is already tapped and most projections are pessimistic with regards to the possible growth in the role of hydropower.

have decreased substantially in the last five years, grid parity[3] is still some way off, especially if fossil fuel prices were to remain low. Indeed notwithstanding regional variabilities due to resource availability, besides hydropower, it is only onshore wind that may be competitive with coal or gas power production. While in the case of wind technologies, the main source of cost reduction might come from improvements in assemblage and material costs as well as learning effects, solar, biomass-based and ocean technologies might still foresee drastic cost reductions due to major technological breakthroughs.

Three main (and not mutually exclusive) strategies could make renewables more competitive. The first is mainly based on directly funding public research and development (R&D) programmes or incentivising private R&D efforts in renewables technologies. The second is a set of strategies based on demand-side promotion schemes. Public policies directed to renewables deployment that include standards, energy certificates and feed-in tariffs not only promote the adoption of renewables, but also play a critical role in spurring additional innovation in these technologies (Johnstone et al., 2010). The third strategy would be to directly price carbon emissions, thus penalising the competitive, incumbent technology and again spurring adoption of and innovation in renewable technology. Though the debate over the relative merits of these strategies is far from being settled, it is increasingly evident that a combination of the three will likely be required. In addition, a key to success will be the adoption of a long-term policy strategy that will secure the commitment to the required investments.

Multiple recent studies have collected expert assessments of the probabilistic evolution of the cost of carbon-free technologies in response to R&D efforts – the first of the three strategies – by means of structured protocols and interviews (so-called 'expert elicitations'). These studies gather the probabilistic distributions of future costs of renewables technologies and how these distributions might be affected by R&D investments (Baker et al. 2008, 2009, Anadón et al. 2012; Bosetti et al. 2012, Fiorese et al. 2013, 2014).[4]

3 Grid parity occurs when an alternative energy source can generate power at a levelised cost of electricity (LCoE) that is less than or equal to the price of purchasing power from the electricity grid. The term is most commonly used when discussing renewable energy sources, notably solar power and wind power (en.wikipedia.org/wiki/Grid_parity).

4 Tidal and wave energy, ocean and geothermal energy technologies have not yet been covered by expert elicitation surveys.

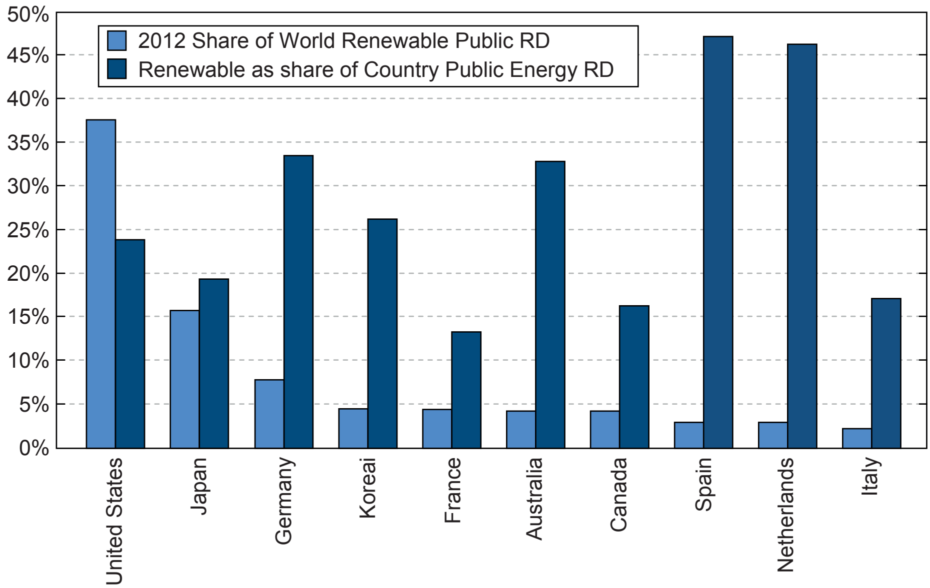
A summary of these studies (Bosetti et al. 2015) reports that overall renewable technologies costs are projected to decrease in the coming 15 years, and that experts expect these costs to be responsive to current levels of public R&D efforts. These elicitations also support the notion that R&D investments will often not reduce the uncertainty surrounding costs; rather, uncertainty is likely to stay the same or increase with larger investment in R&D as the range of technological possibilities expands (Bosetti et al. 2015). Solar PV technologies are to have the largest relative cost reductions, both under current public R&D funding as well as under increased R&D funding. Notwithstanding this expected trend, all reported median values for 2030 costs (and, in most cases, 10th percentile values) imply levelised costs of electricity still higher than coal- or gas-generated power (reported medians of solar PV LCoE cluster around $0.1 per kWh, in 2010 US dollars).

Elicitations for biofuels and biopower for 2030 also suggest that to become competitive with their fossil-fuelled competitors, public R&D efforts in renewables in OECD countries (see Figure 2) might not be enough, and policies that either internalise the external costs of carbon emissions or that work as demand-side promotion schemes will be necessary.

To get a sense of the magnitude of these investments, the dark blue bars in Figure 2 show each country's public contribution to renewables R&D as a share of its total public energy R&D (including fossils and nuclear). Contribution to R&D of renewables remains within the range of 13-20% for most countries, except for a few outliers (Australia, Germany, the Netherlands, Spain).

If we look at the private side of R&D investment, the Bloomberg New Energy Finance databases report, for the period 2004-2011, an average corporate R&D investment in renewables of around $3.5 billion, with solar receiving the largest share (around 60%) and wind following at just under 20% (Frankfurt School-UNEP Centre/BNEF, 2014). To put this number into perspective, in 2011 the R&D expenditure by Exxon Mobil alone was more than $1 billion. In addition, the energy sector is traditionally one of the sectors with the lowest levels of R&D expenditure as a ratio of net sales (less than 1%, while, for example, the R&D expenditure level in the drugs and medicine sector is in the order of 10%).

Figure 2 Share of renewables in public R&D expenditures of selected OECD countries, 2013



Source: Author's calculation from OECD Energy R&D dataset (2013 data).

Looking at patenting activities (see Popp et al., 2011), an indicator of the output of innovation, the US, Japan and Germany again emerge as the most innovative countries in renewables technologies.

On the second set of policy instruments (demand-side promotion schemes), evidence from multiple countries is becoming available. Supported by long-term policy frameworks, renewable investments have increased from multiple financing sources. Energy markets, in particular futures markets for electricity, span forward only a few years, whereas renewables are capital-intensive investments with a life-time of 20-30 years. This market failure, together with the lock-in of fossil fuels, has been the main motivation for these demand-side promotion schemes (Edenhofer et al., 2013) which have been fundamental for the adoption of solar PV and wind throughout Europe and that this has, in turn, been critical for the decrease in the cost of these technologies.

Several factors have contributed to the declining trend in demand-side promotion schemes throughout the developed world. In the case of biofuels, it is mainly related to the realisation of failures in the original policy schemes. In the EU and Japan, uncertainties remain over the evolution of the renewable policy framework, the feed-in tariffs schemes, and the prospected investments towards grid integration across countries. In the US, the EPA regulation on existing power plant emissions could help support renewables going forward, although renewable portfolio standards are debated in several states (see the chapter by Burtraw in this book).

In developing countries, most policy frameworks have traditionally emphasised electrification. Starting from Brazil and China (two major markets for renewables today), as well as India, policies to promote renewables adoption and to cope with barriers to their use have been increasingly important in accelerating deployment and attracting investment to this sector, while in Africa electrification remains a huge challenge (see the chapter by Mekkonen in this book).

System integration

Even if recent developments in the evolution of renewables costs were to be replicated in the near future, a second, major obstacle is becoming increasingly important – system integration. In the face of stable and growing demand, renewables are an energy source that is unpredictable and highly variable over timescales that might range from seconds to years (IPCC, 2011). System integration issues are important barriers to deployment and they will require investment in innovation (most notably, for storage technologies), investment in new infrastructures, and institutional changes to account for required changes in the energy markets. The larger the share of renewables in the system, the more pressing these issues will become.

In order to meet power demand at each moment in time, either complementary technologies supporting enough flexibility in dispatch or energy storage systems are required. Gas power plants, with their flexibility, are the best complement to increases in the share of renewables in the grid, at least in the short term. For storage technologies, the most prominently discussed technologies are either based on pumping water or air pressure, or on large batteries, including networks of smaller batteries, such as those employed in electric drive vehicles. Finally, renewables could also be better managed by using demand-side response practices.

Lack of predictability and lack of flexibility can also put pressure on energy markets, which are currently based on marginal cost pricing; hence, large penetration of renewables could lead to low and even negative pricing, which in turn could lead to reductions in overall sectorial investments (Edenhofer et al., 2013).

Environmental issues

Other environmental and social issues should be kept in the picture when designing policy that implies penetration of renewables technologies on a massive scale. This is particularly critical in the case of large-scale penetration of biomass usage, both for power production and for biofuels. Indeed, diffusion of energy crops exerts pressure on other land uses, ranging from food crops to forestry, and, in principle, threatens biodiversity. Land use is also one of the major potential issues associated with large-scale deployment of solar technologies (together with the issue of toxic waste and lifecycle GHGs emissions for solar), but it is overall much less of a concern than in the case of biomass.

The modest potential for hydroelectric energy still available, hydroelectric development will play only a minor role in the future of renewables.

Environmental risks from ocean energy technologies appear to be relatively low, although the technology is too immature for any definitive evaluation. Finally, in the case of wind, the environmental footprint of the technology is relatively low.

4 The way forward

Even though renewables will become more competitive, their future development is still closely linked to public policies aimed at stimulating innovation, actual deployment and carbon pricing. In particular, long-term and stable policy frameworks and market signals will be crucial for large-scale deployment of renewables. This is in contrast to the uncertainty recently affecting the renewables regulatory environment (in particular, in the EU, Japan and the US). This general trend in the policy environment could be reversed by an international climate agreement that establishes a long-term global commitment to internalising the costs of carbon emissions or that includes some form of commitment to renewables deployment.

Indeed, any international climate agreement implying a mid- to long-term commitment to fossil fuel emissions mitigation and an appropriate carbon price would help to provide this signal. In addition, policies and technologies aimed at increasing power system flexibility will be particularly important. In the longer term, policies fostering innovation and key technological breakthroughs in storage technologies, third generation PV, algae-based biodiesel or third generation biofuels, as well as other technologies still far from any commercial application, will play a more important role.

As discussed by Toman in his chapter in this book, an international agreement with the objective of coordinating national R&D programmes for renewables and sharing the resulting knowledge (for example, with special patent rights for open knowledge or facilitated licensing) could represent an important step forward in dealing with these longer-term innovation issues. This would be particularly relevant for high-risk technologies with large potential but that are still far from any commercial implementation.

However, as we have discussed, most experts believe that innovation policies alone would fall short in delivering the required price cuts in the short to medium term. Rather, demand-side promotion schemes could play a crucial role, as well as policies favouring international transfer of technologies. Since in the coming decades the largest share of the global energy demand growth will be located within fast-growing developing countries, technological transfers will play a key role. Indeed, notwithstanding China and Brazil, most of today's renewables installed capacity and know-how is located in developed countries. Similarly, the largest share of investments in R&D, as well as the largest effort in terms of complementary policies to spur the diffusion of renewables has, so far, mainly taken place in the developed world. As discussed in detail by de Coninck et al. in their chapter in this book, agreements and policies promoting the transfer of technology and know-how to developing countries will therefore be extremely valuable in the deployment of renewables.

In addition, as discussed by Buchner and Wilkinson in their chapter, specific programmes designed to reduce the risk-return ratio of renewables investments and explicitly targeting developing countries, whereby risk is shared with public (national or international) institutions, could nurture a thriving market for renewables in developing countries.

References

Anadón, L. D., V. Bosetti, M. Bunn, M. Catenacci and A. Lee (2012), "Expert Judgments about RD&D and the Future of Nuclear Energy", *Environmental Science & Technology* 46(21): 11497–504.

Azar, C., K. Lindgren, E. Larson and K. Möllersten (2006), "Carbon Capture and Storage From Fossil Fuels and Biomass – Costs and Potential Role in Stabilizing the Atmosphere", *Climatic Change* 74 (1-3): 47–79.

Baker, E. D., H. Chon and J. Keisler (2008), "Electricity from Biomass: Combining Economic Analysis with Expert Elicitations to Inform Climate Policy", Working Paper, University of Massachusetts, Amherst, MA.

Baker, E., H. Chon and J. Keisler (2009), "Advanced Solar R&D: Combining Economic Analysis with Expert Elicitations to Inform Climate Policy", *Energy Economics* 31: S37–S49.

Barrett, S. and J. Moreno-Cruz (2015), "The alternatives to unconstrained climate change: Emission reductions versus carbon and solar geoengineering", Chapter 25 in this book.

Bosetti, V., M. Catenacci, G. Fiorese and E. Verdolini (2012), "The Future Prospect of PV and CSP Solar Technologies: An Expert Elicitation Survey", *Energy Policy* 49: 308–317.

Bosetti, V. L. Diaz Anadon, E. Baker, L. Aleluia Reis and E. Verdolini (2015), "The Future of Energy Technologies: An Overview of Expert Elicitations", forthcoming OECD report, Paris.

Buchner, B. and J. Wilkinson (2015), "Pros and cons of alternative sources of climate change financing and prospects for 'unconventional' finance", Chapter 33 in this book.

Burtraw, D. (2015) "The regulatory approach in US climate mitigation policy", Chapter 17 in this book.

Clarke, L., K. Jiang et al. (2014), "Assessing transformation pathways", Chapter 6 in *Climate Change 2014: Mitigation of Climate Change* (see IPCC (2014b) in the introduction to this book for the report's full reference).

Edenhofer, O., L. Hirth, B. Knopf, M. Pahle, S. Schloemer et al. (2013), "On the Economics of Renewable Energy Sources", *Energy Economics* 40: S12–S23.

Fiorese, G., M. Catenacci, E. Verdolini and V. Bosetti (2013), "Advanced Biofuels: Future Perspectives from an Expert Elicitation Survey", *Energy Policy* 56: 293–311.

Fiorese, G., M. Catenacci, V. Bosetti and E. Verdolini (2014), "The Power of Biomass: Experts Disclose the Potential for Success of Bioenergy Technologies", *Energy Policy* 65: 94–114.

Frankfurt School-UNEP Centre/BNEF (2014), Global Trends in Renewable Energy Investment 2014 (available at http://www.unep.org/pdf/Green_energy_2013-Key_findings.pdf).

IEA (2014), *Medium-Term Renewable Energy Market Report*, Paris.

IEA (2015), *World Energy Outlook Special Report 2015: Energy and Climate Change*, Paris.

IPCC (2011), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, Cambridge, UK and New York: Cambridge University Press.

Johnstone, N., I. Haščič and D. Popp (2010), "Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts", *Environmental and Resource Economics* 45(1): 133–55.

Krey, V., G. Luderer, L. Clarke and E. Kriegler (2013), "Getting from Here to There – Energy Technology Transformation Pathways in the EMF27 Scenarios", *Climatic Change* 123(3-4): 369–82.

Mekkonen, A. (2015) "A view from Africa", Chapter 5 in this book.

Popp, D., I. Hascic and N. Medhi (2011), "Technology and the Diffusion of Renewable Energy", *Energy Economics* 33(4): 648–62.

Tavoni, M. (2015) "Carbon capture and storage: Promise or Delusion?", Chapter 24 in this book.

Toman, M. (2015) "International cooperation in advancing energy technologies for deep decarbonisation", Chapter 22 in this book.

van Vliet, J., M. den Elzen and D. van Vuuren (2009), "Meeting Radiative Forcing Targets under Delayed Participation", *Energy Economics* 31: S152–S162.

van Vliet, J., M. van den Berg, M. Schaeffer, D. P. van Vuuren, M. den Elzen et al. (2012), "Copenhagen Accord Pledges Imply Higher Costs for Staying below 2°C Warming", *Climatic Change* 113(2): 551–61.

Wang, X. and M. Murisic (2015) "Taxing carbon: Current state-of-play and prospects for future developments", Chapter 19 in this book.

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