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Opportunities to accelerate national energy transitions through advanced deployment of renewables

A report from the International Renewable Energy Agency (IRENA)
to the G20 Energy Transitions Working Group (ETWG)

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ABBREVIATIONS

CO_2	carbon dioxide
CSP	concentrated solar power
EJ/yr	exajoule per year
EV	electric vehicle
FiT	feed-in tariff
G20	Group of 20
GDP	gross domestic product
Gt	gigaton
GW	gigawatt
IPP	independent power producer
IRENA	International Renewable Energy Agency
km	kilometre
kW	kilowatt
kWh	kilowatt hour
LCOE	levelised cost of electricity
m3	cubic metre
MW	megawatt
MWh	megawatt hour
OTEC	ocean thermal energy conversion
PJ/yr	petajoule per year
PHES	pumped hydro energy storage
PPA	power purchase agreement
PTC	parabolic trough collector
PV	photovoltaic
R&D	research and development
TES	thermal energy storage
TW	terawatt
TWh	terawatt hour

PREFACE

This report was produced by the International Renewable Energy Agency (IRENA) at the request of Argentina's G20 Presidency, as a key input for the activities of the Energy Transitions Working Group (ETWG).

The G20 (Group of Twenty) Heads of State Summit was established in 2008 in response to a severe international financial crisis, and its members currently account for 85% of the global economy, 75% of world trade and two-thirds of the global population.

Argentina assumed the G20 Presidency on 1 December 2017, and its term ends on 30 November 2018. Taking as its motto **"Building consensus for fair and sustainable development"**, Argentina's G20 Presidency focuses on three key themes: the future of work, infrastructure for development, and a sustainable food future. (For an overview of the vision and priorities of Argentina's G20 Presidency, see https://g20.argentina.gob.ar/en/overview-argentinas-g20-presidency-2018.)

Within this framework, Argentina defined eight priority areas for G20 collaboration under its Presidency, one of which is **"Energy transitions towards cleaner, more flexible and transparent systems".** Under this motto, the ETWG developed most of its activities between December 2017 and June 2018, resulting in collective energy policy recommendations contained in the Bariloche Energy Ministers' Communiqué (see https://g20.org/sites/default/files/media/energy_communique.pdf).

Additionally, Argentina prepared five substantive technical documents, with the invaluable support of several international organisations. The present report is one of these outputs and should be considered an **Argentine Presidency deliverable**, given that its contents were discussed and enriched by the ETWG but not submitted for formal approval by the Energy Ministers, for which reason it does not necessarily reflect the G20 membership's national or collective views.

INTRODUCTION

The world is experiencing a global energy transformation driven by technological change and new policy priorities. This transformation is win-win: a strong economy and a healthy planet are mutually reinforcing. The global energy transformation is manifest in all members of the Group of 20 (G20),[1] but in each the transition to cleaner energy systems has specific features, reflecting specific circumstances and priorities; hence, reference is often made to energy transitions in the plural.

In the past three years, renewable energy has featured prominently on the G20 agenda, and a number of actions have been identified to accelerate renewables' deployment in G20 countries.

At the first G20 Energy Ministers Meeting, presided over by the Turkish G20 Presidency in October 2015, renewable energy, energy efficiency and energy access were among the key themes of discussion. Ministers adopted the G20 Toolkit of Voluntary Options for Renewable Energy Deployment (hereafter, the Toolkit), which presents a set of voluntary options for G20 countries to accelerate the scale-up of renewable energy. The International Renewable Energy Agency (IRENA) was tasked with being the central co-ordinator of the Toolkit's implementation, in co-operation with other international organisations, across five action areas:

- Analysis of renewable energy costs, cost reduction estimates and good practices;
- Exchange of good practices in the design of national policy frameworks and in the integration of larger shares of variable renewables into power systems;
- Development of a risk-mitigation facility dedicated to renewable energy;
- Assessment of the potential benefits of renewable energy technology at the country level, and the development of roadmaps; and
- Deployment of modern bioenergy.

At a 2016 meeting in Beijing, presided over by the Chinese G20 Presidency, energy ministers reviewed the progress made since the implementation of the Toolkit. They adopted the G20 Voluntary Action Plan on Renewable Energy with the aims of substantially increasing the share of renewable energy by 2030 and continuing to advance the Toolkit's implementation.

In 2017, in the context of its G20 Presidency, Germany requested IRENA and the International Energy Agency (IEA) to analyse options for decarbonising the energy sector to meet the objectives of the Paris Agreement, along with investment implications. At the same time, the Climate and Energy Action Plan for Growth attached to the 2017 G20 Leaders' Declaration called on IRENA to support the G20's efforts by providing a regular update of the energy sector's global transformation and further investment needs. The plan noted the progress represented by the creation of the Voluntary Action Plan on Renewable Energy and the Toolkit, and called for their continued implementation to further support the global scale-up of renewable energy.

Argentina, in the context of its G20 Presidency in 2018, has asked IRENA to elaborate opportunities for the accelerated deployment of renewables, using a systemic and holistic approach, and to present relevant lessons learnt from implementing policy and investment frameworks.

Renewable energy plays a key role in the ongoing energy transitions. Such a global energy transformation – as the culmination of energy transitions that are happening in many countries – can create a world that is more prosperous and inclusive. In September 2015, the 193 countries of the UN General Assembly adopted the 2030 Agenda for Sustainable Development which outlines the Sustainable Development Goals (SDGs), including Goal 7.2 to substantially increase the share of renewable energy in the global energy mix by 2030. Accelerated deployment of renewables promises multiple benefits, ranging

1 The members of the G20 include the European Union and 19 countries: Argentina, Australia, Brazil, Canada, China, Germany, France, India, Indonesia, Italy, Japan, Mexico, the Russian Federation, Saudi Arabia, South Africa, the Republic of Korea, Turkey, the United Kingdom and the United States.

from economic growth and job creation to the mitigation of climate change and the reduction of air pollution, which have severe health effects in many regions worldwide.

Renewable energy has grown rapidly in recent years, especially in the power sector, as associated costs have fallen, policy frameworks have matured and the field of applications has widened. Since 2012, more than half of the world's new power capacity additions have been based on renewable energy, and renewables' share is growing rapidly. Electricity from renewable sources represented about a quarter of the world's production in 2017. While end use sectors such as heating and cooling and transport are lagging behind, a few are starting to transition, for example, in the area of electromobility.

As countries' economic ambitions continue to grow, there is increasing recognition that the energy transformation offers significant economic opportunities. Those countries that resist change may fall behind. Innovation and industrialisation of the energy sector are turning out to be critical, as a better understanding emerges of the forces that will shape the transitions. IRENA's analyses have deepened the world's understanding of the key role accelerated renewables deployment can play in energy transitions and on the tools and instruments that have proven successful in those countries that are leading the global transformation.

The G20 members host around 81% of the world's installed renewable power generation capacity and hold 75% of its deployment potential, as estimated by IRENA for the period 2010 to 2030 (IRENA, 2016a). Even as national circumstances, priorities and needs vary, the G20 members are well positioned to lead the global energy transformation, with renewable energy as a key enabler in the transition to a cleaner global energy matrix. Many G20 countries are indeed leading in building the required policy frameworks, refocusing public finance to support the scale-up of renewable energy investment and driving innovative activities to increase research, development and deployment of renewable energy. All such efforts support a cleaner global energy matrix.

Renewable energy features prominently on the G20 agenda. Still, the transition to cleaner energy systems has specific features in each country.

1. THE POTENTIAL OF RENEWABLES

Key Findings

- The unfolding energy transformation promises to have a profound effect on global energy supply and demand. If current and planned policies are left in place, the share of renewable energy would rise from around 15% of primary energy supply in 2015 to 27% by 2050. IRENA's analysis, however, shows that to meet global development and climate objectives, this share must rise to at least two-thirds of primary energy supply by 2050 – and must coincide with significant advances in energy efficiency. To achieve this, the pace of renewable energy deployment must accelerate six-fold (IRENA, 2018a).
- Accelerating the deployment of renewable energy and energy efficiency is economically beneficial at system level – even as it requires 30% more investment in low-carbon technologies than is being currently planned. While this increase may seem significant, further drops in the cost of requisite technologies will play role in increasing investment.
- The significant socio-economic benefits of the global transformation include improved welfare, largely driven by reductions in the health effects of air pollution and climate change; a 1% increase in gross domestic product (GDP) and 11.6 million additional jobs in the energy sector by 2050.
- Energy transformation is the cornerstone of efforts to mitigate climate change: to achieve the objective of the Paris Agreement that the global average temperature increase should be kept, at minimum, to well below 2°C compared with pre-industrial levels, the carbon dioxide (CO2) emission intensity of the global economy needs to be reduced by at least 85% by 2050. Increasing both renewable energy and energy efficiency can achieve more than 90% of the energy-related emissions reductions required to set the world on that path.

Key Actions

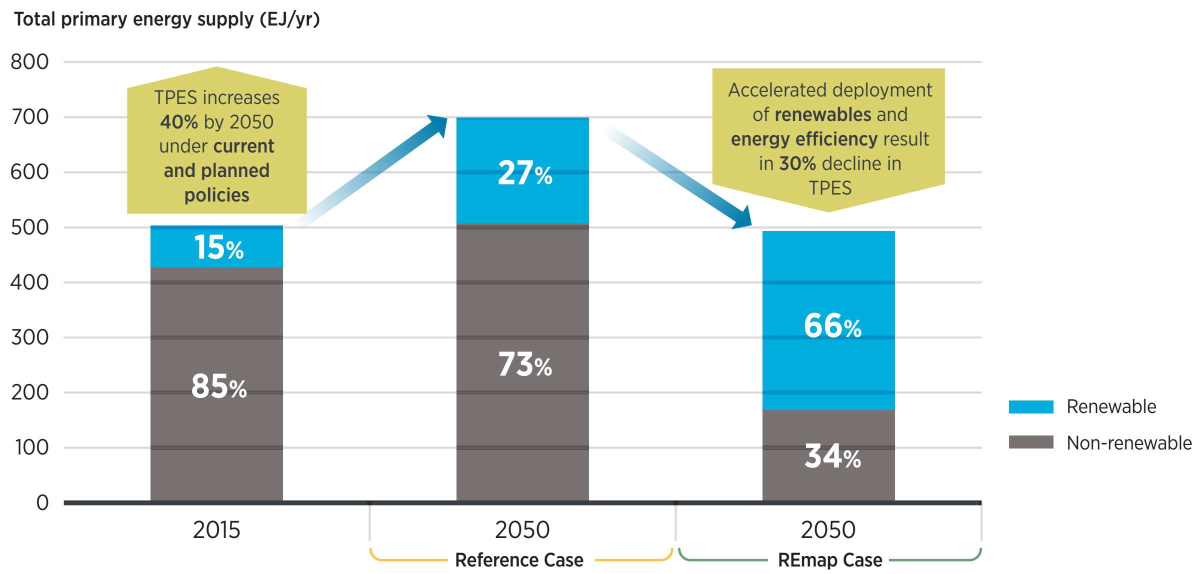
- Governments have a critical role to play in accelerating energy transitions. In accordance with national abilities and needs, governments have the responsibility to foster an enabling policy framework that provides long-term certainty for the private sector and ensures a positive environment for energy transitions. Market signals and financial incentives for low-carbon solutions are central to this. The G20 members, whose greenhouse gas emissions are among the highest in the world, have a key role to play in this regard.
- Early action is essential to limit a rise in the planet's temperature to well below 2°C and to maximise the benefits of the global energy transformation, while minimising the risk of stranded assets.

IRENA's recent report, *Global Energy Transformation: A Roadmap to 2050* (IRENA, 2018a), maps out a fundamental shift to energy systems that enhance efficiency and are based on higher levels of renewable energy. Such a transformation – seen as the culmination of energy transitions that are already happening in many countries – promises to make the world more prosperous and inclusive.

The study shows that the share of renewable energy could rise from around 15% of the primary energy supply in 2015 to around two-thirds in 2050 (Figure 1.1). This would require at least a six-fold increase in renewable energy growth in final energy terms. To reach this high renewable share, growth in renewables needs to take place across the spectrum of energy uses, from electricity to heating and cooling to transportation.

Intensive energy efficiency improvements reduce consumers' energy costs and could, in effect, ensure that energy demand in 2050 stays close to today's level. Such improvements would need to increase from a projected 1.8% (if current policies continue; in Figure 1.1, this is called the Reference Case) to 2.8% per year (in line with IRENA's roadmap, or the REmap Case) by 2050. Such a profound shift would, of course, require concerted government action.

Figure 1.1 Global energy supply (TPES) and the share of renewables and non-renewables: two scenarios



Source: IRENA, 2018a.
Note: EJ/yr = exajoule per year; REmap = IRENA's 2050 renewable energy roadmap; TPES = total primary energy supply. The Reference Case considers the results of current and planned policies.

To date, renewables account for a quarter of all power generated worldwide and also for more than half of global capacity additions made in the power sector since 2012. These figures reflect renewable power's strong economic performance as well as supportive government policies (IRENA and IEA, 2017). In locations with adequate natural resources, solar photovoltaic (PV), wind, hydropower, geothermal and biomass technologies can now provide electricity that is priced competitively with fossil-fuel-fired generation. Development is rapidly growing as technology improves and costs continue to fall at a rapid rate.

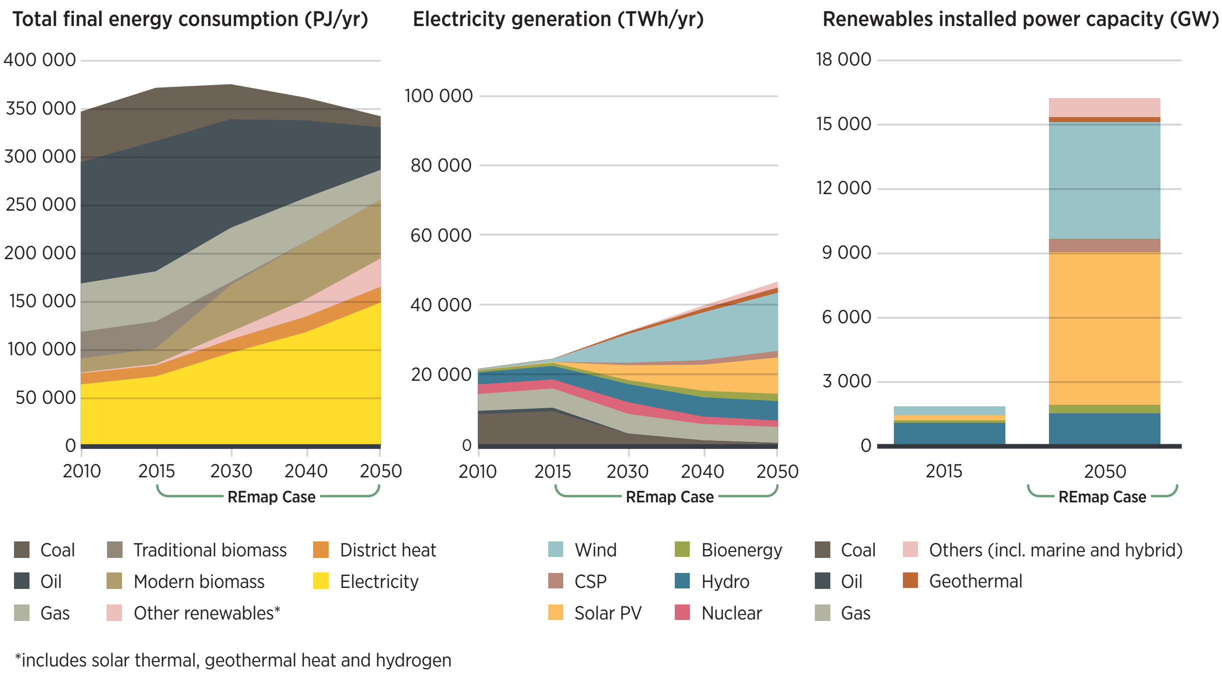
However, electricity itself accounts for only around 20% of the final energy delivered to consumers. The remaining 80% largely concerns energy in end-use sectors, namely heating and cooling in industry and buildings, as well as transport. These direct uses of energy are largely fossil-fuel based, with some sizable contributions of bioenergy, and smaller contributions of solar thermal and geothermal energy (IRENA, 2018a).

Overall, the main source of renewable energy today is bioenergy. In the REmap Case, bioenergy would continue to play an important role, accounting for about a third of renewable consumption by 2050, and, more specifically, for 22% of final energy use in transport, 14% in buildings, 19% in industry and 4% for power generation (IRENA, 2018a). That said, bioenergy's recent growth is insufficient. A more concerted effort to expand its reach is needed, particularly in sectors where it could provide key solutions, namely transportation (specifically shipping and aviation), and in various industrial applications. Bioenergy also has to be sourced from sustainable and affordable feedstocks.

While IRENA's 2050 roadmap focuses on significant electrification of end uses, which would boost the share of electricity in final energy from 20% to 40% by 2050, a large part of energy demand will still need to be met from non-electricity sources.

The share of renewables in transportation today is only 3%; it is higher in industry, at around 10%. It is highest in the buildings sector, at about a third, although much of that comes from traditional uses of bioenergy, which implies an inefficient use of biomass.

Figure 1.2 Energy consumption, electricity generation and renewable power capacity in IRENA's roadmap to 2050



Source: IRENA, 2018a.
Note: CSP = concentrated solar power; GW = gigawatts; PJ/yr = petajoule per year; PV = photovoltaic; REmap = IRENA's 2050 renewable energy roadmap; TWh = terawatt hours.

As noted, a quarter of the electricity consumed globally is supplied by renewable sources (Figure 1.2, first panel). But this share has been growing faster in the power sector than in end-use sectors. Accelerating the energy transformation will require not just dramatically ramping up the electrification of end uses and renewable power, but also applying renewable solutions beyond the power sector. There is a clear need to include end uses in planning, solutions and actions. IRENA's 2050 roadmap shows that the renewable energy share could grow to 77% in buildings, 63% in industry and 58% in transport (IRENA, 2018a).[2]

In the REmap Case, the share of renewable electricity generation in the power sector reaches 85%, and wind and solar in power generation would increase to 64% by 2050 (Figure 1.2, centre panel), requiring policy measures to ensure a reliable supply of electricity, including time-of-use electricity pricing, adaptation of market designs and new business models. Additional interconnectors, flexible fossil and renewable fuel generation,[3] and demand-side response can also increase flexibility, thus enabling higher shares of variable renewable energy.[4]

The combination of electrification with renewable power and direct renewables deployment, underpinned by high efficiency rates, could boost renewable energy's share to 65% of total final energy consumption by 2050 (Figure 1.2, first panel).

2 Including the use of electricity and district heat sourced from renewables.

3 Chapter 5 further discusses the role of hydropower and power generation from bioenergy resources in providing flexibility.

4 An often-discussed flexibility option is storage, which comes in many forms. As of mid-2017, the world had around 176 gigawatts (GW) of storage capacity providing 4 670 GWh of electricity storage potential, 96% of which came from pumped hydro (IRENA, 2017a). Under IRENA's 2050 roadmap (REmap), 11 900 15 300 GWh of stationary electricity storage is expected by 2030, with only 51% from pumped hydro. (For more details on pumped hydro storage, see Chapter 5.) Furthermore, important synergies can be achieved that allow much higher deployment of variable renewables if smart electromobility solutions are widely deployed (IRENA, 2018b).

BOX 1.1 FALLING COSTS OF RENEWABLE ENERGY POWER GENERATION TECHNOLOGIES

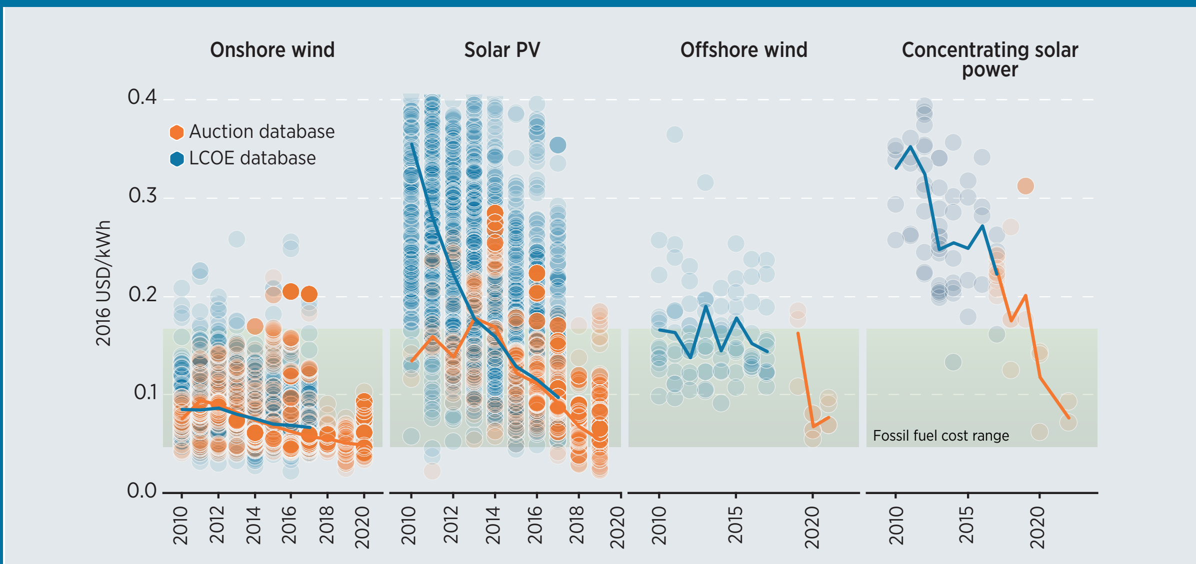
Between 2010 and 2017, solar photovoltaic (PV) module prices dropped by over 80%, and the global weighted average levelised cost of electricity (LCOE)[a] fell by 73% to USD 0.10/kilowatt hour (kWh). Onshore wind turbine prices fell 37-56% between 2007/2008 and 2016/2017, and the global weighted average cost of electricity from onshore wind fell 23% between 2010 and 2017 to USD 0.06/kWh. Utility-scale solar PV projects commissioned in 2017 had LCOEs as low as USD 0.05/kWh; onshore wind projects had them as low as USD 0.04/kWh (IRENA, 2018c), making them competitive with conventional power generation technologies.

Recent auction and tender results have signalled that costs for solar PV and onshore wind will continue to fall, with LCOEs between USD 0.03/kWh and USD 0.04/kWh, and even less by 2020.[b] Concentrated solar power (CSP) and offshore wind, both nascent technologies, had auction results (for future delivery) of USD 0.06/kWh to USD 0.10/kWh in 2016 and 2017.

These figures imply that, as innovation and economies of scale push costs lower and efficiencies higher, all commercially available renewable power generation technologies will be competitive with fossil fuels by 2020, with onshore wind and solar PV projects increasingly undercutting fossil fuels.

IRENA analysis indicates a learning rate for the LCOE (e.g., the percentage cost reduction for every doubling of cumulative installed capacity) could be 14% for offshore wind, 21% for onshore wind, 30% for CSP and 35% for solar PV (IRENA, 2018c) for the period 2010 to 2020.

Figure 1.3 Weighted average and project-specific global LCOE from utility-scale renewable power generation technologies, 2010-2017



Source: IRENA, 2018c.
Notes: Each circle represents an individual project or an auction result where there was a single clearing price at auction. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, the real WACC is 7.5% for OECD countries and China, and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range. LCOE = levelised cost of electricity; USD/kWh = US dollars per kilowatt hour; WACC = weighted average cost of capital.

a. All LCOE figures in this box exclude the impact of local or federal financial support policies. They are for the year of commissioning and are based on IRENA's Renewable Cost Database, which contains cost and performance details for 15 000 utility-scale power generation projects.

b. Headline auction prices below USD 0.03/kilowatt hour (kWh) for 2020 are not equivalent to LCOE calculations, as additional revenue streams are often not included (e.g., clean energy certificate values in Mexico).

Further, significant technology cost reductions will be a major driver for increased investments across the range of renewables and enabling technologies. Nevertheless, for the world to achieve a more renewables-based energy system by 2050 as envisioned in IRENA's 2050 roadmap, cumulative energy system investments in the period 2015 2050 would need to increase 30%, from USD 93 trillion (in the Reference Case) to USD 120 trillion (in the REmap Case). Early action is essential to capitalise on existing economic opportunities while minimising the substantial future costs of stranded assets.

The global energy transformation is economically beneficial. It would significantly improve global welfare, economic growth (measured in GDP) and employment. Across the world economy, GDP would increase by 1% by 2050; with cumulative gains from increased GDP through 2050 estimated at USD 52 trillion.[5] Additional welfare gains of 15% compared to the Reference Case would mainly stem from reduced health impacts from air pollution and a reduction of expected climate change impacts.

With holistic policies, energy transitions could also boost overall employment in the energy sector, as more jobs are created than are lost in the fossil fuel industry. The REmap Case would result in the loss of 7.4 million jobs in fossil fuels by 2050, but 19.0 million new jobs would be created in renewable energy, energy efficiency and grid enhancement, and energy flexibility, for a net gain of 11.6 million jobs (IRENA, 2018a).

5 For further discussion of the socio-economic impacts of the global energy transformation, see Chapter 2.

2. SUCCESS FACTORS FOR G20 COUNTRIES: THE POLICY DIMENSION AND SELECTED SOCIO-ECONOMIC IMPACTS

Key Findings

- G20 countries have adopted a variety of policy instruments to support renewable energy deployment. To advance the global energy transformation, support will have to be scaled up in all end-use sectors, taking account of domestic needs and priorities. Carbon taxes, along with other fiscal incentives, are effective tools when they provide a sufficiently strong signal.
- Renewable energy policies should be part of a holistic approach that allows for system integration, enables system efficiency and facilitates sector coupling.
- In the power sector, G20 countries have been innovating policy design to respond to changing market conditions and rising challenges. Assessing the impacts of policy choices is needed to evaluate their effectiveness in meeting country objectives – and to inform plans for policy adjustment, as needed.
- No single instrument can fulfil all countries' objectives, and the choice of policies should be context-specific and tailored to the particular country's objectives and circumstances. A mix of policies is needed to ensure an enabling environment for renewable energy development. The mix includes policies that facilitate access to finance, support training and build capable domestic supply chains, in addition to trade policies that support local products and services, among others.
- Effective policy making requires co-ordination among relevant government ministries and different stakeholders. This includes, for example, harmonising industrial and trade policies and extends to co-ordination with industry associations and the educational sector for the establishment of dedicated training programmes. To avoid skills gaps, G20 countries should draw on all available talent and support measures to overcome gender barriers and imbalances.
- Economic accounting systems need to be adapted to reflect the full array of socio-economic costs and benefits of renewable energy.

Key Actions

- Draw on lessons learned from the policy record to date and explore how successes can be replicated while being adapted to the local context of each country and the changing market dynamics of each sector.
- Focus policy making on all end- use sectors, following a systematic, integrated approach that combines policies for energy efficiency and sector coupling.
- In the power sector, provide adequate support for distributed generation as part of a wider energy system plan that ensures proper integration.
- Take appropriate measures to maximise the socio-economic benefits of renewable energy deployment, ensure fair energy transitions for communities affected by the move from conventional sources to renewable energy and provide strong signals in support of just energy transitions.

The energy transitions in the G20 countries initially focused on creating a market for renewables, but policy making has since moved to facilitating their cost-competitiveness. As the sector matures, policies must be continually adapted to changing market conditions while providing a steady framework for long-term transitions. So far, much of the attention has been devoted to the design of policies for the power sector. Innovative policies to transform end-use sectors, such as heating and cooling and transport, are required to ensure a comprehensive approach to energy transformation.

Policies will be most effective if they recognise and maximise the full range of benefits of renewable energy. Beyond climate-related benefits, the deployment of renewable energy has net positive effects on GDP and offers a wide range of socio-economic benefits. In the G20 countries and around the world, there is now a growing recognition of these benefits and of the need for appropriate policies to maximise the resulting welfare for individuals during the transformation. Key benefits include job creation, skill-building, opportunities for local economic value creation, reduced air and water pollution, improved health outcomes, and greater gender balance.

Renewable Energy Policy Landscape

This section discusses the latest developments in renewable energy policies among G20 members in all end-use sectors. It also highlights some good practices that have been seen to advance fair and just energy transitions while maximising socio-economic benefits.

G20 members have set different types of renewable energy targets, for power and for end uses, including those outlined in the Nationally Determined Contributions (NDCs). Targets range from those that are binding, technology neutral and covering all end uses (e.g., Argentina's legally binding target of 20% renewable energy in final energy consumption by 2025), to those that are aspirational and sector and technology specific (e.g., the Kingdom of Saudi Arabia's target of 9.5 gigawatts [GW] of installed solar and wind capacity by 2023).

To achieve these targets, various policies have been implemented in different sectors, at times complemented by policies for system integration (see Chapter 4) and energy efficiency.[6]

Policies supporting renewables in the power sector

As of 2017, all G20 countries have implemented some policies to support renewables-based power generation from large-scale and distributed installations, and some have adopted policies and measures to provide electricity to remote areas not connected to the grid.

Large-scale power generation installations are increasingly being supported by auctions with record breaking (low) prices and innovative policy design. In 2017, Germany's offshore wind auction ended with most bidders requesting no support on top of wholesale electricity prices,[7] while Saudi Arabia and the Russian Federation awarded solar and wind at low prices[8] (Figure 2.1).

Several G20 countries have used innovative policy design to address country specific objectives and difficult macroeconomic conditions. A Mexican auction in 2016, for example, tackled grid integration issues by providing local incentives/penalties, and auctioned tradable certificates along with capacity and energy to ensure renewable quotas would be met. In India, the government tried and tested different designs using contracts with and without escalation, as well as viability gap funding, to overcome risks related to offtake, inflation and currency exchange.

Brazil, a pioneer in auctions, has introduced further innovations to their design, beyond the initial bidding. In 2017, it offered relief to developers

6 Policies to advance energy efficiency in the G20 mostly draw on economic incentives to drive the market for more advanced energy-efficient equipment (reducing up-front investment costs through tax relief or subsidies, grants or loans), regulatory building codes, energy certification schemes and minimum energy performance standards (MEPS) for building components, among others.

7 Three out of four winning projects (1 380 MW out of the total 1 490 MW) bid a strike price of EUR 0/ MWh, while the rest bid a strike price of EUR 60/MWh. Analyses of these prices are presented in IRENA (2017b).

8 Note that auction prices may not represent an LCOE equivalent value given different boundary and contract conditions. Care should be also taken when comparing auction results between countries.

that had bid too aggressively by auctioning the penalties (the depreciation of local currency had been the main reason for their default) (IRENA, 2017b).

In the European Union, the European Commission's Guidelines on State Aid for Environmental Protection and Energy, adopted in 2015, require that EU Member States support renewable energy deployment through auctions. Several European countries, including France, Germany and Italy, have adopted auctions for large-scale projects and feed-in tariffs (FiTs) for small-scale installations.

Figure 2.1 Countries in the G20 that awarded renewables in auctions in 2016-2017: Technology, quantity and price

MW megawatts MWh megawatt-hours

The term "country" as used in this material also refers, as appropriate, to territories or areas.

~ Indicates average price resulting from auction

** Price undisclosed at time of auction*

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

FiTs have been successful in driving the solar PV and onshore wind sector in countries such as China, Indonesia, Germany and Japan. Some of the challenges faced, however, may lead to changes in policy. For instance, Japan offered an administratively set solar PV FiT (USD 119/megawatt hour [MWh]) irrespective of project size, resulting in the surcharge increasing from JPY 0.3 trillion to JPY 1.4 trillion between 2013 and 2016. The increased amount of electricity purchased under the FiT and the drop in the fuel price for thermal power led to a decrease in avoided costs linked to this charge[9] (Renewable Energy Institute, 2017).

China's FiT, set in 2011 using auctions, drove installed capacity in 2016 to the highest level globally – before a new record in additions was set in 2017. However, issues related to the structure of China's power market led to significant curtailment (IRENA, 2014a). Indonesia has already made the switch from a predetermined FiT to a new tariff for solar PV that is based on the cost of electricity generation, negotiated between the independent power producer (IPP) and the state-owned power utility.

Fiscal and financial incentives have also played a significant role in driving large-scale renewable deployment in several G20 countries. India has successfully relied on the accelerated depreciation scheme to develop its wind industry, while an investment tax credit and production tax credit have driven wind and solar deployment, along with state-level renewable portfolio standards, in the Republic of Korea and the United States. India, the Republic of Korea, the United Kingdom and the United States have also relied on renewable obligations,[10] though with different degrees of success in enforcing penalties (IRENA, IEA and REN21, 2018).

Indonesia's Geothermal Fund Facility, a risk-mitigation scheme aimed at reducing developers' up-front risk, together with fiscal incentives such as tax allowances and tax holidays and the simplification of licensing procedures, are expected to accelerate geothermal exploration and development in the country (IRENA, 2017c).

9 The surcharge is calculated by subtracting the avoided costs from thermal power and the expenses of adjusting cost burdens from the total purchasing cost.

10 Renewable portfolio standards in the United States and renewable purchase obligations in India.

Fiscal incentives and renewable obligations have also driven distributed generation in G20 countries along with net-metering schemes and voluntary programmes. In the United States, net metering is adopted in 41 states and several other jurisdictions and 99% of distributed solar installations across the country were under a net-metering scheme in the year 2014, representing 44% of total solar PV installed capacity (IRENA, 2017d). Other G20 members, such as Australia, Brazil, India, Italy, Mexico and the Republic of Korea, have also implemented policies for distributed solar PV, including tax exemptions and net metering. To better distribute the costs of grid operation, a number of amendments have been made to net metering in Brazil and other countries.

Policies to support stand-alone and mini-grid systems have been adopted with an eye toward energy-access objectives. While most countries in the G20 are 100% electrified, grid extension in some areas remains uneconomical. In India, mini-grid systems, for example, have been supported through public financing, including capital subsidies, and regulations for their development (IRENA, 2016b). An overarching approach that combines deployment policies with financing instruments and measures for capacity building has been instrumental in the development of renewables in all G20 countries.

Experience with renewable energy policies in the G20 countries highlights the importance of stability and continuity in instilling investor confidence and attracting investment. How abrupt changes to the investment tax credit and production tax credit in the United States affected the industry is a case in point. In Spain, retroactive changes made to the regulatory instruments supporting renewables increased uncertainty regarding existing projects and weakened the investment environment, significantly increasing policy, regulatory and legal risk. Also, policies need to ensure that deployment practices are effective and efficient. In India, for instance, although fiscal incentives were successful in encouraging wind energy projects, they were not performance based and did not lead to the most efficient installations possible (IRENA, IEA and REN21, 2018).

Policies driving renewables in heating and cooling

The use of renewable energy for heating and cooling has been driven mainly by renewable targets, mandates and incentives, as well as carbon taxes. This is the case for district heating and distributed heating for residential, commercial and industrial use. Other measures to promote cleaner cooking have been instrumental in several G20 countries.

A variety of policy instruments – including ambitious targets combined with various levels of financial support, fiscal measures and regulatory measures – have supported renewables for district and decentralised space heating and solar water heaters in G20 countries. In the EU, for example, such instruments supported Denmark's renewables in district heating. Municipalities were obligated to develop heat supply plans in heat-dense areas suitable for collective heat systems. Meanwhile, energy taxes were applied to fossil fuels, with some exemptions for biomass (IRENA, IEA and REN21, 2018). In this same manner, several European countries with above-average climate-related heat demand and extensive district heating networks have come to utilise high shares of renewables from biomass and geothermal energy.

Decentralised heating solutions are mostly driven by financial incentives. In the United Kingdom and the United States, where the capital cost of gas boilers is much lower than renewable heat alternatives, financial incentives have helped bridge the cost gap. Traditionally, these have been offered as grants or tax incentives to subsidise the higher capital costs of renewable heat options. In recent years, production-based incentives have been deployed in several countries (e.g., the Netherlands and the United Kingdom), similar to FiTs for renewable electricity.

For the residential sector, several countries have adopted policies to promote solar thermal energy in residential buildings, with the most successful countries using mandates for new construction. South Africa set targets for solar water heaters and has since updated these regularly: the country now aims to have 1.75 million systems installed by 2019 and 5 million by 2030. Its programme relies on rebates, and installations of solar water heaters are free for low-income households. But progress has been slow. In Brazil, both Sao Paulo and Rio de Janeiro require all new and refurbished public buildings to meet at least 40% of their water heating needs with solar energy. This approach seems to have been successful: solar thermal capacity doubled between 2010 and 2015.

In several emerging economies in the G20, policies are increasingly supporting renewable energy for industrial heating. A large proportion of heat demand in these economies is from industry, and this share is growing rapidly, driven by economic growth. Industrial heat demand in India, for example, grew by 30% between 2010 and 2015. Co-generation with biomass has been incentivised by policies in India and Brazil, both of which have a large sugar industry. Bagasse is frequently used in co-generation in both. In India, the Indian Renewable Energy Development Agency provides loans for setting up biomass power and bagasse co-generation projects and in Brazil subsidies are provided for bagasse co-generation. The projects can participate in auctions and pay less to access the grid (as is the case with wind and solar).

Carbon taxes can also be effective in driving the use of renewable energy in heating and cooling and increasing system efficiencies, and have been introduced in several G20 countries. Mexico introduced a tax on carbon from fossil-fuel use[11] in 2013, charging USD 3.50 per tonne of CO_2. India introduced a tax on coal in 2010 that is now equivalent to a carbon tax of USD 6 per tonne of CO_2, with some of the revenue going into a National Clean Environment Fund which has supported renewable energy projects. As yet, these taxes are at a low level but if increased over time they could play an important role in encouraging both renewable energy and energy efficiency.

Where people still rely on traditional biomass for cooking, the installation of clean cooking technologies is supported by policy. While some countries, such as China and Indonesia, have seen large reductions in the share of the population that relies on solid fuels for cooking, overall, the number of people without access to clean cooking technologies has stayed flat since 2000, as population growth has outpaced improvements in access (IEA, 2017). In India, the number of people without access has even increased and clean cookstove programmes have had a limited impact. Barriers to clean cooking include the high capital costs of cleaner stoves and cookers, highlighting the need for financial support to improve affordability. Clean cooking programmes have, in most cases, been funded by international or bilateral aid programmes, such as the Global Alliance for Clean Cookstoves, a public private partnership with the goal of getting 100 million households to adopt clean and efficient cookstoves and fuels by 2020.

Policies driving renewables in transport

Transport is the second-largest energy end user, accounting for 29% of final energy consumption in 2015 (IEA, 2017), and it remains heavily fossil-fuel based. Almost 93% of energy used for transport is from petroleum products, representing 65% of final global oil demand in 2014 (IRENA, 2016c). In response, many G20 countries have implemented policies to mandate the use of biofuels in transport and to promote electric vehicles (EVs) running on renewables.

Biofuel mandates exist in most G20 countries. The bulk of mandates have come from the EU-27, where the Renewable Energy Directive of 2009 specified a 10% renewable content by 2020, though this has since been scaled back to 5.0 7.5%. Major blending mandates have also been set in Brazil, China and the United States, with targets of 15 27% by 2020 2022. In some countries, complying with mandates has been costly. The Republic of Korea, for example, imports palm oil – and here the cost of compliance with blending mandates reached USD 77.5 million in 2014 and is estimated to reach USD 118.7 million in 2018 (Biofuels Digest, 2016). In Indonesia, mandatory biodiesel blending was increased from 10% to 18% in 2018, supported by subsidies, as biodiesel prices have been generally higher than those for petroleum fuels. In 2015, Indonesia started collecting a levy from exports of palm oil and palm oil derivatives, partly as a mechanism to support domestic palm biodiesel consumption. Indonesia has also implemented measures for fuel-economy standards or vehicle-efficiency incentives (IRENA, 2017c).

11 Natural gas has been zero rated.

Beyond biofuel mandates, some innovative policies are worth mentioning, such as the Brazilian RenovaBio, which tries to achieve CO_2 emissions targets based on life-cycle analysis, while promoting quality biofuels production chains and innovation.

Several countries, states and provinces in the G20 have set targets for electric vehicles. Examples include the zero-emission target set forth by the International Zero-Emission Vehicle Alliance, comprising several European countries and North American states and provinces, for all new cars by 2050. In the case of the United Kingdom, all new cars and vans should meet this target by 2040, and nearly all cars and vans by 2050. India aims to have 6 million electric vehicles (including hybrids) on the road by 2020; China's Technical Roadmap for Energy Saving Vehicles set a target for 7% EV sales by 2020 and 40% EV sales (an estimated 15 million units) by 2030. China also aims to install 12 000 charging stations to serve 5 million electric vehicles by 2020. In the United States, California and several other states require zero-emission vehicles to make up around 15% of new car sales by 2025. California also requires that the renewable energy share of hydrogen for vehicles increase to 33% by 2022.

Fiscal incentives are also being deployed to advance electric vehicle use in the G20. Japan offers subsidies for the purchase of electric vehicles. The Republic of Korea implemented a generous subsidy for such vehicles in 2013, at both national and local (province and city) levels, and has recently revised it to differentiate between high- and lower-mileage vehicles (Kim and Yang, 2016; Gijong, 2017). Germany launched an EV support scheme in 2016 that includes purchase grants and funding to expand charging infrastructure. In 2015 China spent USD 4.5 billion in subsidies for the purchase of electric vehicles, with plans to gradually phase these out by 2021. In addition, in Beijing electric vehicles are exempt from restrictions levied on vehicles with internal combustion engines (which are, for example, not permitted to drive one day per week and whose licencing is restricted and may be allocated by lottery).

Some cities are developing zero-emission (at the tailpipe) transport strategies. Taiyuan became China's first city to replace its entire taxi fleet with electric vehicles, and the city funded a network of 1800 charging stations.

Although EV mandates and incentives are in place in almost all G20 countries, they lead to renewable energy deployment only if they go hand in hand with renewables-based power generation. This can be done explicitly by, for instance, tying financial incentives for electric vehicles to the use of renewable electricity. Integrated planning of electric mobility and electricity production, transmission and distribution is crucial. The uptake of electric mobility will increase demand for electricity and may create new peak demands linked to EV charging, creating the need for a systemic approach to sector coupling.

Progressively increasing the share of renewables in the energy mix – in the power sector and across all end-use sectors – will require large-scale investments, ongoing technical innovation, far-reaching institutional reform and adaptation, and steady support policies. Far from constituting a drain on resources, however, renewable energy deployment can result in a multitude of socio-economic benefits.

Socio-Economic Impacts

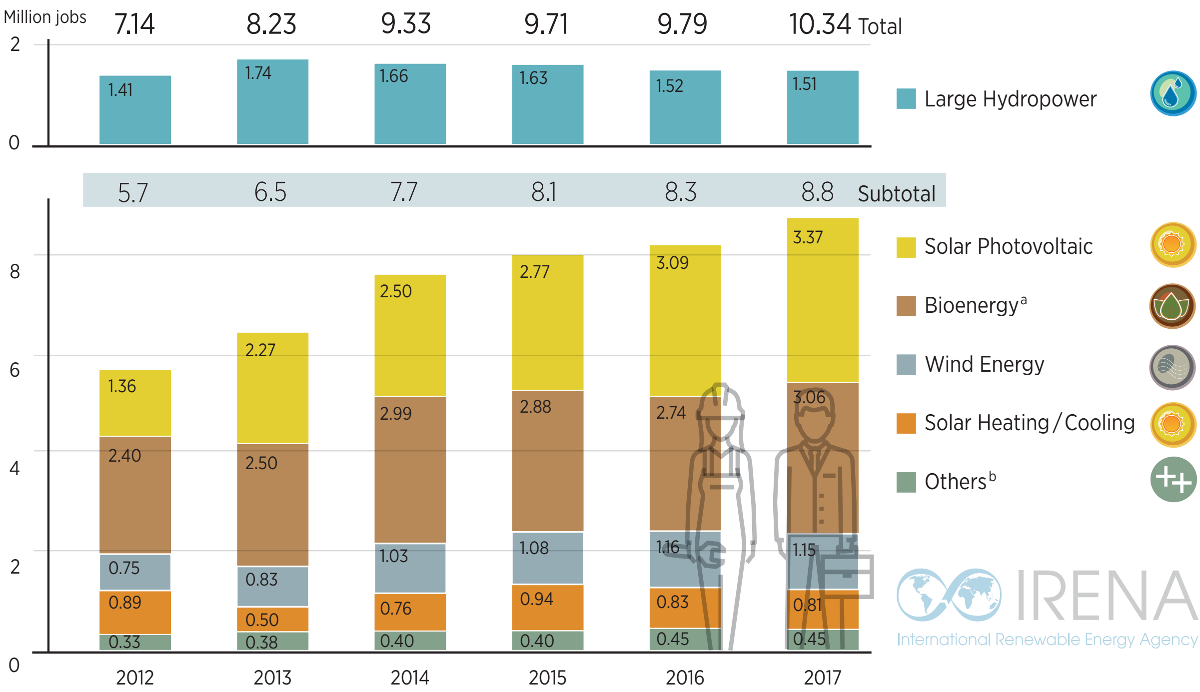
The deployment of renewable energy has positive effects on national GDP and enables a wide range of socio-economic benefits, including employment, local economic value creation and skill-building, and positive effects on health.

Relative to the status quo (the Reference Case identified in Chapter 1), IRENA analysis finds that reducing global emissions through renewables and energy efficiency would boost global GDP by 1.4% in 2030 and by 1.0% in 2050. The first of these two figures reflects the net investment stimulus of renewables, energy efficiency, grid improvements and energy flexibility. Changes in tax rates, mainly associated with carbon taxes and the phasing out of fossil fuels, also promise to boost GDP growth in the medium term. After some time, indirect and induced effects would become dominant – and these explain the 2050 figure. Global trade would have a minor effect throughout the transition, given the intrinsic requirement of export and import flows being balanced at the global level in nominal terms (IRENA, 2018a).

Specific impacts vary by country and region, primarily accounted for by differences in investment profiles, trade in fossil fuels and the extent to which domestic supply chains are able to respond to emerging economic opportunities. Globally, the sectors likely to gain the most from the energy transitions include those responsible for the construction, engineering and manufacturing of the goods required for the transitions (especially renewable energy equipment), as well as needed inputs such as basic metals and cement and related supply chains.

Employment impacts, too, are positive. IRENA estimates that the renewable energy sector had created 10.3 million direct and indirect jobs worldwide as of 2017 (Figure 2.2), and that this could rise to 29 million jobs by 2050 (IRENA, 2018a). G20 countries, as leading manufacturers of renewable energy equipment and preeminent deployment markets, account for the vast majority of these jobs. Worldwide, the energy sector as a whole is expected to gain employment during the transition. This is the case because per dollar of expenditure, renewable energy has been estimated to produce nearly 70% more jobs than spending on fossil fuels (Chen, 2017). Similarly, solar PV could create more than twice the number of jobs per unit of electricity generation than can coal or natural gas (UKERC, 2014).

Figure 2.2 Jobs in renewable energy, 2012-2017



Source: IRENA, 2018d.

a) Includes liquid biofuels, solid biomass and biogas

b) Other technologies include geothermal energy, hydropower (small), concentrated solar power (CSP), heat pumps (ground-based), municipal and industrial waste, and ocean energy.

Owing to the variety of generating technologies, the renewable energy sector spans a broad range of occupations and skills (IRENA, 2018d; IRENA and IEA, 2017). To avoid already-evident skills gaps from widening, better coordination between the industry and educational institutions is essential. Specialised training institutions also have a role to play. For example, the South African Renewable Energy Technology Centre offers accredited training, working closely with government, academic and industry stakeholders. In partnership with domestic education and research institutions, it is expected to make locally developed technologies more accessible to the renewable energy industry (SARETEC, n.d.).

The renewable energy sector needs to draw on all available talent. Gender-disaggregated data in the renewable energy sector are still relatively scarce. An online survey of nearly 90 companies from more than 40 countries (IRENA, 2017e) suggests that women account for 35% of the sector's labour force. This is higher than the 20-25% range typical in the conventional energy sector, but lower than the 40-50% economy-wide share in most countries of the Organisation for Economic Co-operation and Development (OECD). To overcome gender imbalances, dated perceptions of gender roles and structural obstacles such as pay discrimination and a persistent glass ceiling for managerial positions need to be tackled. Other solutions include offering greater workplace flexibility (flex-time, part time, etc.), and greater support for women through mentorship and training.

Socio-economic benefits can be maximised along two policy avenues. First, strong deployment policies facilitate dynamic domestic markets and help create jobs in project development, construction, installation, operations and maintenance. Second, industrial policies are needed to support the creation of competitive manufacturing facilities, viable supply chains and related infrastructure. Several countries have pursued policies to localise portions of the renewable energy value chain, requiring domestic sourcing of a specified portion of inputs to a renewable energy project. Outside manufacturing, more than half of the jobs in the value chain can be localised by leveraging existing industries and developing capable supplier firms (IRENA and CEM, 2014). Turkey, for example, has adopted strict local content rules for solar PV manufacturing in a bid for jobs and knowledge transfer (Hirtenstein and Ant, 2016; Hablemitoğlu, 2017). PV capacity installations were further boosted, to a 2017 total of 2.6 GW, by a year-end rush to install a large number of small PV plants before FiT rates were reduced at the beginning of 2018 (Bhambhani, 2018).

Economists and many decision makers in the government and the private sector use GDP as a shorthand measure for human well-being. Changes to the energy system, including policies and investments in support of renewable energy deployment, are assessed by how they affect economic growth. Studies indicate a positive effect emanating from transitions toward a clean energy system. The energy transitions can indeed trigger a powerful economic stimulus, provided a policy framework is adopted to give clear signals and long-term certainty.

However, GDP alone does not convey the full range of human welfare impacts – and often records negative welfare impacts as gains. Economic accounting systems need to better reflect the externalised costs of the energy system and thus reveal the advantages of a renewables-based energy economy.

IRENA's study, *Global Energy Transformation: A Roadmap to 2050*, suggests that welfare gains of 15% relative to the Reference Case are possible by 2050. This is mainly due to a reduction in the negative health effects of local air pollution (62%) and reductions in greenhouse gas emissions (24%, in cumulative terms). Importantly, all regions and countries across the world reap welfare gains, irrespective of varying GDP impacts (IRENA, 2018a). Other IRENA analyses have also indicated a broad range of socio-economic benefits for individuals, communities and countries resulting from the expansion of renewable energy.

3. ACCESS TO FINANCE FOR DEVELOPING COUNTRIES AND RISK MITIGATION INSTRUMENTS

Key Findings

- Where investors consider renewable energy investments in emerging markets to be relatively risky, the cost of capital tends to be relatively high, reflecting a risk premium added on top of other costs. Perceptions of risk may reflect real constraints or merely the lack of a track record in renewable energy.
- To overcome constraints that limit investor interest in renewable energy assets and to accelerate the scaling up of investment in renewables, worldwide experience points to several key actions, detailed below.[12]

Key Actions

- Create an enabling environment for renewable energy investments by reducing barriers to entry for investors, including large-scale, institutional investors. Encouraging institutional investors to invest more of their capital into long-term assets would mobilise a significant amount of the global capital needed to scale up renewables.
- Support the growth of new capital-market instruments, such as green bonds, through which investors can invest in renewables. Successful development entails collaboration among policy makers, security regulators, issuers and investors, using instruments whose issuance, reporting and use are guided by robust and clear rules.
- Help develop a pipeline of investment-ready renewable energy projects through the targeted use of public finance, initiatives and platforms supporting project preparation and connecting various stakeholders, and through the standardisation of project procedures and documentation, as well as the development and use of project aggregation mechanisms.
- Increase the ability of local financial institutions to invest in renewables through initiatives such as on-lending and co-lending (loan syndications). In this context, development finance institutions can use their high credit rating, access to markets and knowledge of project finance to draw in local investors.
- Allow for local-currency- denominated power purchase agreements (PPAs), or mixed- currency PPAs, to enable local investors, including local institutional investors, to engage in renewable projects.
- Foster successful community-based and innovative low-cost finance models to increase the affordability of new energy technologies in economically disadvantaged communities and to help reach energy-access goals.
- Foster the issuance and use of risk-mitigation instruments, such as guarantees and insurance products, for renewable energy investments. The use of public finance for such instruments, complementing privately offered risk-mitigation products, can rapidly build confidence among investors and accelerate the scale up of renewable energy finance.
- Support the creation of a global risk-mitigation platform dedicated to renewable energy to facilitate the issuance of standardised guarantee/insurance products for renewable energy projects, and mobilise international capital to back up these guarantees and accelerate investments.

12 Continuity and synergy should be maintained with existing initiatives in this area, such as the Investment and Infrastructure Working Group (IIWG), one of the G20's main working groups, mandated to recommend co-operative principles in global infrastructure investment, including with respect to financial engineering, risk allocation and mitigation.

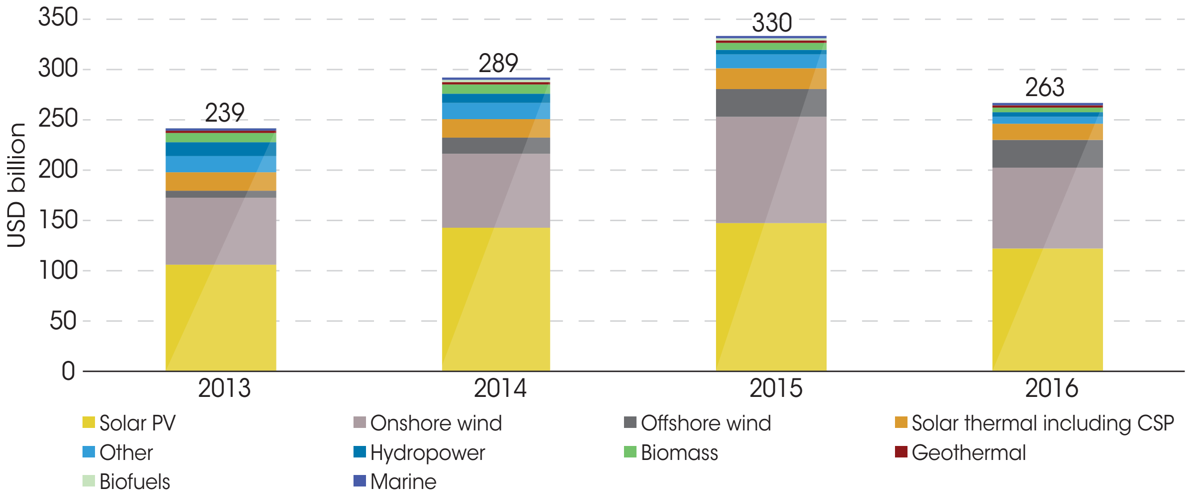
Renewable Energy Investment Landscape – Recent Trends

Global annual investment in renewable energy rose steadily in 2013-2015, peaking at USD 330 billion in 2015 before falling to USD 263 billion in 2016 (IRENA and CPI, 2018) (Figure 3.1). Preliminary estimates made by IRENA and the Climate Policy Initiative suggest that, compared to 2016, investment levels remained stable in 2017, at around USD 265 billion. While annual investment declined in 2016, annual capacity additions grew steadily. This was partially due to declining technology costs, as well as to the time lag between financial closure[13] and the completion of construction, after which an installation becomes operational.

Investment in solar power (both photovoltaic and thermal) and wind power (both onshore and offshore) dominated spending on new renewables projects globally, increasing from 82% of total renewable energy finance in 2013 to 93% in 2016. While investment in other technologies declined in absolute terms, offshore wind investment saw an almost fourfold increase in the same period, growing its share from 3% of total investment in renewables in 2013 to 11% in 2016. This reflects cost reductions and investors' preference for large-scale projects.

Capital flows into renewable energy in recent years have been characterised by a notable geographic shift (Figure 3.2). While initial investments occurred mostly in Europe and the United States, in the 2013-2016 period, the East Asia–Pacific region, dominated by investments in China, was the main destination for renewable energy investment, accounting for one-third of the 2016 total (USD 88 billion of USD 263 billion) (IRENA and CPI, 2018). Western Europe was in second place in 2016, with USD 53 billion, followed by the USD 51 billion invested in the OECD Americas[14] (IRENA and CPI, 2018). While Brazil and India hosted significant investments in renewables in 2016, other emerging economies in Africa, Asia and Latin America have much untapped potential for renewable energy investments.

Figure 3.1 Global renewable energy investment, by technology, 2013-2016

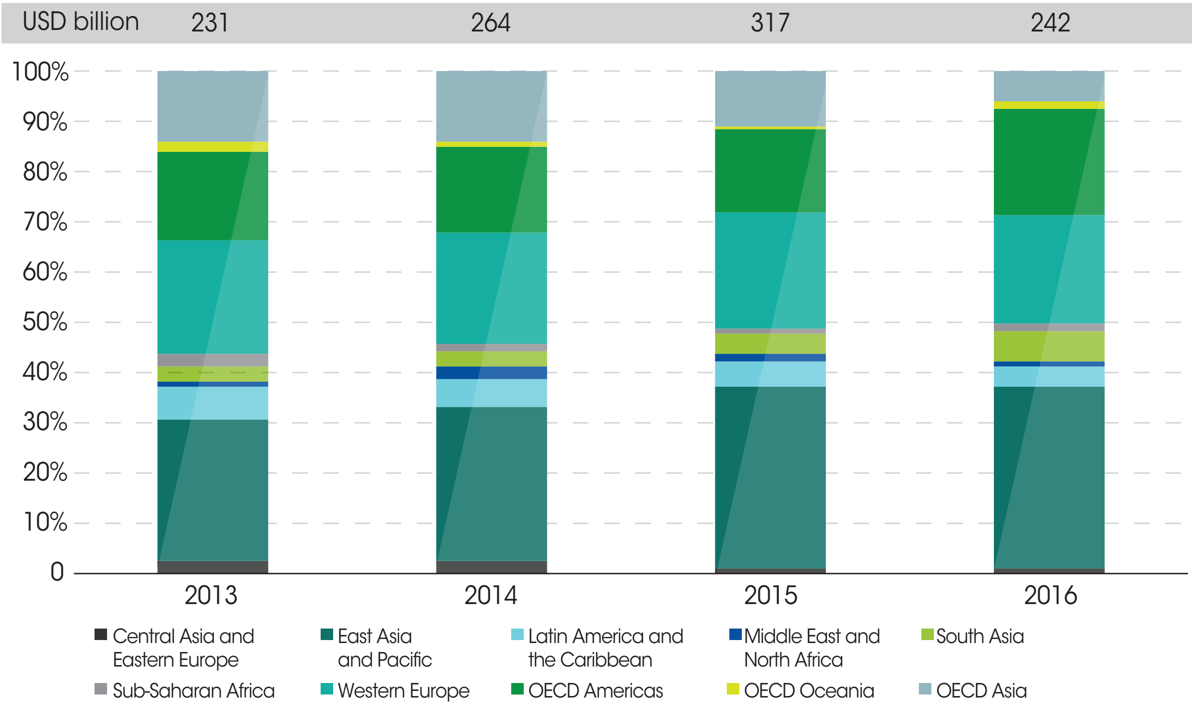


Source: IRENA and CPI, 2018.
Note: CSP = concentrated solar power; PV = photovoltaic.

13 That is, the time of investment.

14 Regional groupings follow definitions from IRENA and CPI (2018). "OECD Americas" includes Canada, Chile, Mexico and the United States.

Figure 3.2 Global renewable energy investment by region, 2013-2016



Source: IRENA and CPI, 2018.
Note: OECD = Organisation for Economic Co-operation and Development.

While the bulk of renewable energy investment globally is provided by private sources (over 90% of direct investment[15] in 2016), direct public finance can play a key enabling role, covering early-stage project risks and getting new markets to maturity. Significant additional public resources are allocated every year to the implementation of a wide variety of policies supporting the deployment of renewable energy, including regulatory instruments and fiscal incentives. Public spending on policy implementation was found to far outweigh direct public investments, for example, in the European Union and Japan (IRENA and CPI, 2018). In developing and emerging economies, public finance also provided substantial direct investments in renewable energy in 2013-2016: 49% in Latin America, 41% in Sub-Saharan Africa and 24% in South Asia (IRENA and CPI, 2018).

Early action is essential to achieve the global energy transformation outlined in Chapter 1 and reach global climate goals, maximising socio-economic opportunities while minimising the substantial risk of stranded assets.

Main Barriers to Financing Renewable Energy Transitions

The most important barriers to financing renewable energy projects identified in recent years were high up-front costs, project-specific characteristics and perceived high risks, many of them centred on variability and performance. However, as renewables become increasingly cost-competitive and related experience accumulates, many project developers are now better able to overcome such barriers to seize available opportunities.

As the industry further matures, the main challenges include setting appropriate policy frameworks, making risk-mitigation instruments available and scaling up renewable energy projects. Several common project risks, such as non-payment by the offtaker and currency fluctuations, are still perceived as high in certain markets, particularly emerging markets in developing countries. Financial risk-mitigation instruments, including political risk insurance, partial/credit risk guarantees and credit enhancements (e.g., loan-loss reserves), among others, would help

15 Excluding expenditures for feed-in tariffs (FiTs) and other policy support measures.

investors and developers cover their risks, thereby lowering financing costs and making renewable energy projects more attractive to investors. Focusing on such instruments, in turn, gives public finance institutions leverage to mobilise private investment, which can be an effective strategy to maximise the impact of scarce public resources. International financial institutions are well positioned to mitigate the investment risks of renewables, but until now they have dedicated only about 4% of the total issuance value of their infrastructure-risk-mitigation instruments to renewable energy (IRENA, 2016d).

Developing economies face significant additional challenges to their ability to attract capital into renewable energy projects. Most of these involve the real or perceived risks surrounding

1) policy, regulatory or institutional frameworks which some investors consider non transparent or unreliable;

2) undeveloped capital markets; and

3) the lack of local financial capital and capacity to develop investment-ready projects.

Lack of local capacity can involve inadequate transmission infrastructure, system design or inefficient permitting procedures. Where local financial institutions lack expertise and experience in renewable energy, or more generally in project finance, the project pipeline may be limited. Unfavourable national investment conditions and nascent capital markets are usually characterised by a lack of adequate investment instruments and financing terms, which ultimately translate into a higher cost of capital for renewable energy projects and higher energy prices for consumers.

Unlocking Investment for Deployment of Renewables

To unlock opportunities to invest in renewable energy in emerging markets, several major risks and barriers need to be addressed. Doing this requires a range of measures that improve both project and capital supply in the market. Such measures would necessarily be at the national level, but can be supported through co-ordinated and joint international action.

Enabling environment

Develop energy policies to create a stable, long-term and streamlined basis for renewable energy deployment. An enabling policy framework is the foundation for greater and more efficient deployment of financial capital. As described in Chapter 2, various policy instruments have been successful globally, including in the G20, in encouraging renewable energy deployment in the power and end-use sectors. These instruments create a level playing field for renewables while catering to local conditions and policy priorities. The falling costs of relevant technologies have reduced fiscal pressure on public budgets and thus boosted the long-term stability of policy frameworks, which is very important for investors.

Enable institutional investors to engage in renewable energy investments in the presence of financial regulations. Institutional investors, such as insurance companies and pension funds, hold the bulk of assets globally. If they could recognise renewable energy assets as an attractive addition to their portfolio, this would help to scale up the finance available for renewables. It would also diversify investors' portfolios away from conventional energy assets that could be stranded.

At the same time, institutional investors are subject to significant financial regulation to ensure their ongoing financial viability. Such regulations can come in the form of investment restrictions, such as the maximum portion of capital that can be invested in infrastructure (of which renewable energy is often seen as a subset). These regulations can severely restrict investors' ability to allocate a portion of their assets to renewables. For instance, new financial regulations, such as Basel III for banks and Solvency II for insurance companies, require institutions to hold more long-term capital reserves for their long-term and less-liquid assets, such as renewable energy assets (UNEP, 2014). As a result, insurers and banks may provide less long-term lending to renewable energy projects (UNEP, 2014). As part of an effort to increase "green financing", standardised procedures can be developed to facilitate a simplified review of renewable energy investments within financial regulations.

Adjust and develop policies and guidelines to increase green bonds. Green bonds are capital-market instruments that help scale up renewable energy and other "green" investments by allowing investors to allocate their capital into listed and professionally managed funds. Governments can support the issuance of green bonds by developing relevant policies and guidelines. Supportive policy frameworks for green-bond issuance can attract significant new investment, as seen in China and India. The first step is for key stakeholders to define a vision and identify opportunities. Government authorities, such as securities market regulators and central banks, then define the criteria by which projects are considered "green" and procedures for how green bonds will be certified and issued. Adhering to and helping to further develop internationally accepted frameworks and standards, such as the Green Bond Principles or Climate Bonds Standards, will further ensure transparency, consistency and a greater uptake of green bonds by final investors.

Before green bonds can be scaled up or even initiated, however, regulation and supervision need to be developed and strengthened in local or regional capital markets. This is well beyond the scope of energy ministries, but is critical to attract investment to a particular sector. While bonds are a source of debt finance, there are also important vehicles for green equity finance, such as YieldCo structures (for a discussion, see IRENA, 2016d).

Ensuring a viable project pipeline

Facilitate renewable energy projects from initiation to full investment maturity. A robust and continuous pipeline of new projects is a necessary precondition for the mobilisation of more investment in renewables, particularly for larger investors such as institutional investors, as it would justify the commitment of large capital resources and the efforts of risk-analysis teams (World Bank, 2015). Governments and development finance institutions can help build the pipeline through capacity building and dedicated grants. Grants and concessional finance (capital extended at lower than market rates) are often key financial instruments for early-stage project development in developing countries.

Several governments and development banks have attempted to enhance the pipeline of bankable projects via project preparation facilities that can perform feasibility studies and structure transactions to make them attractive to investors. These facilities represent a potentially promising area of development, and require more funding support. IRENA's Sustainable Energy Marketplace (https://www.irena.org/en/marketplace), an integrated and inclusive portal designed to mobilise private and public financing for projects and to enhance project development activities, can facilitate interaction between project developers and investors, and increase the transparency and liquidity of renewable energy markets.

Simplify, streamline and standardise project documentation to reduce transaction costs and speed up project development and financing processes. Standardised project documentation, with active uptake and use by project developers and financial institutions, can significantly reduce both transaction costs and the time required for project development and financing. Such efforts have started with solar energy, a commoditised technology that is widely disseminated, capital intensive and scalable. Significant standardisation efforts have also been made at the country level: examples include Argentina's RenovAr programme, Australia's auction programme, and South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) for solar tenders (Foerster, 2018). In addition to streamlining processes, standardisation also provides the basis for the aggregation of projects to achieve greater scale, as discussed further below.

Facilitate aggregation to scale up investment and increase asset liquidity. Some large-scale investors would not even consider some renewable energy projects, given their relatively small scale compared to conventional energy installations. By aggregating multiple smaller projects into a larger portfolio, investors can reduce the costs of due diligence and advisory services, given the larger investment pool. In addition, assembling a pool of multiple projects diversifies the risks of any single project's underperformance, thus lowering the overall risk for investors. Standardising project documentation and terms is a prerequisite for the aggregation of renewable energy assets. Once aggregated, renewable energy assets are easier to sell, for example, to large institutional investors or to energy utilities with renewable energy mandates. For example, seven solar projects in Jordan were aggregated into a larger portfolio by the IFC (International Finance Corporation) (IRENA, 2016d, Chapter 5.3).

Improving capital supply

Attract institutional investors such as pension funds, insurance companies, endowments and sovereign wealth funds. With over USD 100 trillion in total assets under management, their role will be crucial to scale up renewable energy investments (OECD, 2016). Some institutional investors are already aiming to capture the upside potential of climate change by investing in projects and companies involved in renewable energy and energy efficiency. Renewable energy investments can bring significant benefits to institutional investors, including fulfilment of fiduciary duties, diversification of assets and potentially high-yielding and long term returns to match institutional investors' long-term liabilities.

Institutional investors' commitments to invest directly in new European renewable energy projects have been growing, exceeding USD 2.8 billion and USD 1.7 billion in 2016 and 2017, respectively (IRENA and CPI, 2018). Their investment in refinancing renewable energy projects is estimated to be much higher. Institutional investors, such as Canadian and Australian pension plans, are also increasingly investing in renewable assets in emerging markets. Illustrating this trend, two of Canada's largest pension plans, the

Canada Pension Plan Investment Board (CPPIB) and Caisse de Dépôt et Placement du Québec (CDPQ), have announced commitments to India's growing renewable energy sector (Sharma, 2016). In addition, the Government Pension Fund of Norway, the world's largest sovereign wealth fund, with over USD 1 trillion in assets, has proposed gradually removing oil and gas companies from its benchmark index to reduce the national economy's vulnerability to falling oil prices (Fouche, 2017).

Engage local financial institutions in renewable energy finance and improve their access to capital. Many developing and emerging markets are still reliant on public finance for a significant portion of direct investments in renewable energy. Finding and replicating successful models to activate private and local sources of capital are therefore necessary. On-lending, also known as financial intermediary lending, can increase the availability of local debt, improve access to local financing and build local lending capacity (IRENA, 2016d). Public finance institutions can use their high credit ratings and market access to borrow debt at low rates and on-lend such funds via credit lines to a government or a local private institution, which can then draw on the credit lines to finance renewable energy projects locally. Public finance institutions can also co-lend senior debt with commercial banks and distribute the risks among a broader group of lenders (IRENA, 2016d). The participation of a development finance institution in loan syndication can bring in local banks, that can then benefit and learn from the development bank's experience in renewable energy project finance. Development banks can increase loan syndication either by increasing their overall loan syndication rates or by increasing the share dedicated to sustainable infrastructure.

Promote community-based finance and innovative low-cost financing mechanisms. Community-based finance is already an active component of energy finance, helping to raise capital for projects in power generation, energy storage and energy efficiency. While data on global volumes are lacking, citizens and co-operatives in Germany in 2012 were estimated to have funded about 47% of the 73 GW of installed renewable energy power capacity (Farrell, 2014). Further growth in community-based finance (which involves a broader range of considerations and can provide capital at lower cost than traditional investments) through initiatives such as Australia's National Community Energy Strategy (NCES, 2018), can help lower the overall cost of borrowing for renewable energy projects, especially the scale gap between utility- and household-scale projects.

Expansion of innovative low-cost financing models would increase the affordability of new energy technologies and accelerate progress toward energy-access goals. Off-grid solar and other renewables provide a very cost-effective way of rapidly bringing clean energy to communities that currently rely on traditional biomass and that will not be reached via power grids in the foreseeable future. Several initiatives are helping to decrease up-front costs of off-grid renewable systems through end-user financing schemes tailored to income profiles and demand. In Bangladesh, for example, microfinance services are extended to households to procure solar home systems, where up-front payments are typically 15% of the system costs followed by, generally, payments in 36 monthly instalments equivalent to monthly expenditures on kerosene. In East Africa, among other regions, the pay-as-you go model is increasingly common: households join a payment scheme, often via their mobile phone, to lease a product or receive a service, in some cases with the goal of eventual ownership (IRENA, 2017f).

Promote local-currency-denominated PPAs, or mixed currency PPAs, to enable local investors to invest in domestic renewable energy projects. Currency risk is particularly acute in emerging markets where macroeconomic conditions can be volatile. It arises from the mismatch between the currency in which the revenues are received and the currency in which loan payments need to be made. While this risk can be mitigated via hedging instruments, such as currency forward contracts and swaps, in emerging economies such instruments are not easily available or are potentially costly. Therefore, PPAs are often denominated in a hard currency (such as USD or EUR) to avoid the mismatch for foreign capital providers – but this merely shifts the currency risk to local actors, in some cases local utilities. The second implication of hard-currency PPAs is that local investors, such as local pension funds, are excluded. To avoid such effects, PPAs are increasingly being denominated in local currencies, or in a mix of local and hard currencies, to enable domestic and foreign investors to co-finance a project and share the risk. Such local- or mixed-currency PPAs can also be combined with hedging solutions and integrated into broader risk-mitigation approaches.

Create a risk-mitigation facility dedicated to renewable energy. A dedicated facility which issues or provides access to risk-mitigation instruments, and supports the design and implementation of structured finance mechanisms specifically targeted at renewables, would help greatly to attract private investments into renewables. It could also provide support for transaction costs, guarantee fees or make grants to fund technical assistance. Such a facility was supported and endorsed by G20 countries in the G20 Toolkit of Voluntary Options for Renewable Energy Deployment (see Introduction), which mandated IRENA to follow up on its development (IRENA, 2016a).

Thus, IRENA, in consultation with experts from the finance sector, has developed a conceptual framework for a global renewable energy guarantee platform, which allows for the integration of existing risk-mitigation instruments, pursues a standardised approach for renewable energy projects and streamlines the processes required. The concept builds on global experiences in the use of specialised risk-mitigation instruments covering various risks, such as counterparty, political and currency risks.

Taking a decentralised approach, national development finance agencies or regional development banks can take the lead in providing capital and administering funds for a dedicated guarantee facility. A good example of the use of a national financing entity for such goals is Argentina's guarantee scheme under the RenovAr programme, which provides energy payment and sovereign guarantees through a national Fund for the Development of Renewable Energy (FODER). To back up any risk of the offtaker's insolvency, a guarantee account was set up, funded at all times with an amount equivalent to 12 months' payment of all the PPAs subscribed.

FODER's termination payment guarantee (covering political risk, non-convertibility of national currency into US dollars and non transferability of funds abroad) allowed the investor to exercise a put option and enabled the payment of all non-depreciated capital expenditures of the project. This was implemented through a mechanism by which the project companies could terminate the PPA contract and sell the renewable energy to any third party, or they could exercise the put option, assign the project assets to FODER and receive a cash compensation for them at a price equivalent to the project's non-depreciated capital expenditures. The put option price was guaranteed by national bonds. The World Bank guaranteed and backstopped a government failure to fund FODER for the put option price (World Bank, 2017).

Another example is the Regional Liquidity Support Facility, developed by Kreditanstalt für Wiederaufbau and the African Trade Insurance Agency. This takes a regional approach and provides short-term credit lines with a guarantee to address the power offtaker risk for IPPs against short-term cash shortfalls (ATI, 2017).

Building on these experiences, a global renewable energy guarantee platform would accelerate the scale-up of renewable energy investment by helping to cover a range of core risk categories. A global approach would help to achieve economies of scale in risk assessment standards and increase the creditworthiness of renewable energy projects. In the end, investors and lenders could de-risk their exposure at an acceptable price, and reinsurers and guarantors could achieve a better spread of risk and accept exposures that match their risk appetite. This represents an efficient financial solution to unleash renewable energy potential on a global level and at the scale needed to address climate and sustainable development challenges.

4. INTEGRATING RENEWABLE ENERGY IN POWER SYSTEMS

Key Findings

- The power sector has thus far led the global energy transformation, incorporating increasing shares of renewables. Yet realising the full potential for transformation, as outlined in Chapter 1, requires a significant increase in renewables in the coming decades, along with growing electrification of the overall energy system. These aspects are necessary to achieve proper integration and efficient deployment, in accordance with national circumstances, priorities and needs.

- Variable renewable energy sources are expected to show the largest growth. Variable renewables, meaning solar and wind, can help enable the transition of the heat and transport sectors through renewables-based electrification. Limited dispatchability of output and the non-synchronous nature of variable renewables will require new ways of planning and operating power systems that maximise flexibility on both the demand and generation sides. System integration, through sector coupling, can provide further flexibility for the operation of a power system with high shares of renewables.

- The world's energy transitions feature the emergence of new actors and are redefining the roles of existing ones. Regulatory measures should facilitate relations among all stakeholders, including consumers, prosumers, aggregators, utilities, and distribution and transmission companies. In particular, consumers and prosumers have to be involved actively and effectively in the configuration and operation of the energy system.

- Policies and regulations are needed for effective electricity market design. Markets have to facilitate efficient deployment of resources, with adequate incentives to encourage flexible behaviour on both the supply and demand sides. Needed mechanisms include demand response, storage, smart aggregation of distributed resources and system integration.

- Policies and regulations are needed for distribution networks and distributed energy resources. With the growth of distributed energy resources, policy makers and regulators need to address issues related to the planning, operation and economic regulation of distribution companies. Distribution companies should be allowed to interact regularly with distributed energy resources or aggregators to efficiently manage network constraints, thereby facilitating the participation of distributed flexibility resources. The economic regulation of distribution companies should be based on performance and focused on total system costs.

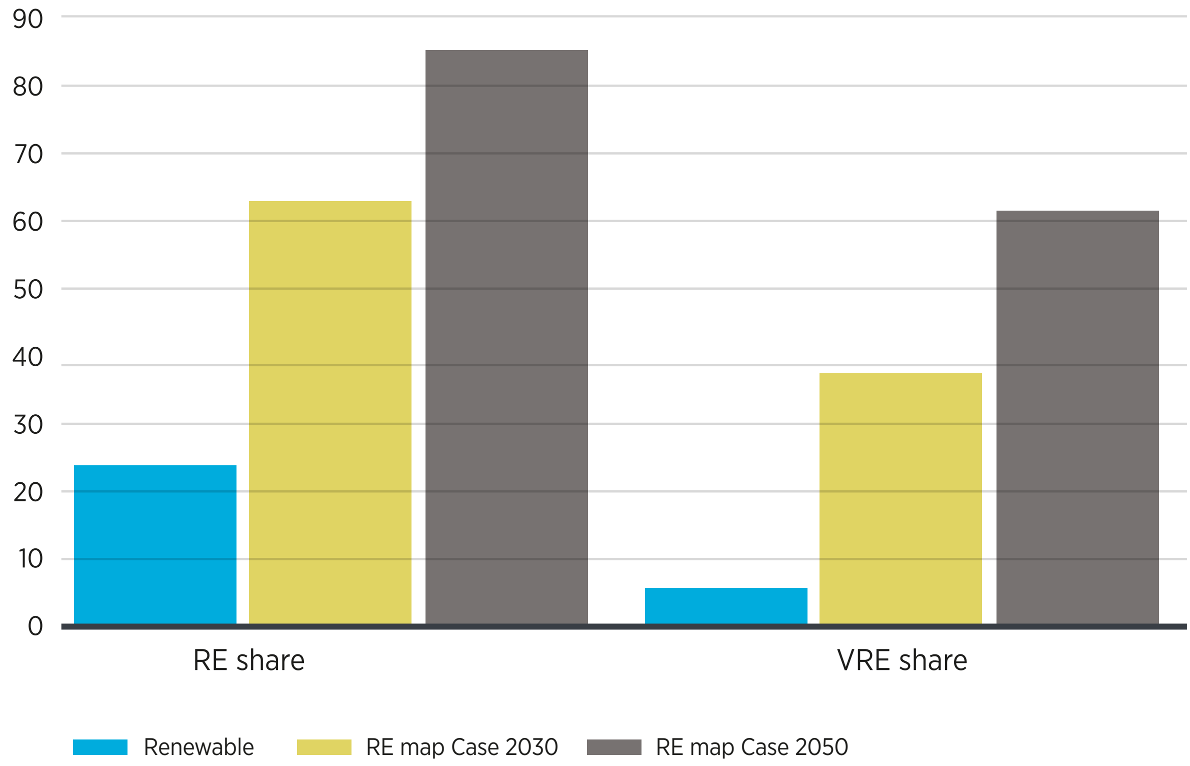
- Tariff design should keep prosumers in mind. Retail tariffs are among the main drivers of consumer and prosumer behaviour. Regulators should take advantage of this and actively promote self consumption and demand response by designing retail and flexibility services' compensation tariffs to reflect costs. Behind-the-meter generation and storage can yield benefits for both end users and the power system as a whole. An appropriate tariff structure must be established to reap all potential benefits.

- Efforts to promote energy efficiency have an important role to play in the transitions. This can be through directly mitigating emissions, accelerating the scale up of renewables and, in the context of an integrated energy system, limiting power sector growth and the requirements for renewable energy deployment. Policies and regulatory measures should leverage the synergies between energy efficiency and renewable energy deployment, while striking the right balance between energy efficiency and flexibility.

Key Actions

- Remove the barriers that prevent available energy flexibility mechanisms (demand response, storage and its aggregation) from participating in the market, so that the market can play its role of techno economic optimisation.
- Introduce policies and regulations for distribution network planning and operation that facilitate the participation of distributed resources in the energy market by focusing on performance based regulation and total system costs.
- Develop policies and regulations that establish the appropriate mechanisms for smooth interaction between existing and new stakeholders (e.g., consumers and prosumers), including appropriate retail tariffs. These will strengthen stakeholders' trust, critical to the long-term success of energy transitions.
- Develop a vision and a roadmap to support and guide the operation and configuration of power systems based on renewables.
- Encourage efforts to increase energy efficiency while ensuring the right balance between energy efficiency and energy flexibility in the context of an integrated energy system.
- Set higher targets, both collective and individual, for the G20 countries' energy transitions, and whenever possible, foster new regional or bilateral partnerships to jointly develop policies and market-based approaches that facilitate the integration of greater shares of renewables.

Figure 4.1 Forecasted shares of total renewable energy and variable renewable energy in total electricity generation: Two scenarios



Source: Based on IRENA, 2018a.
RE = renewable energy; REmap = IRENA's 2050 renewable energy roadmap; VRE = variable renewable energy.

Technology

The power sector's transition from fossil fuels to renewables is ongoing. The sector is leading the way in the global energy transformation. While each country is at a different stage of this process, many have successfully integrated a large share of renewables-based generation in their power sector, particularly by exploiting the vast potential of solar photovoltaic (PV) and wind resources. These sources, referred to as variable renewable energy sources, are expected to have the largest growth potential through 2030 to 2050 (Figure 4.1), and to support the electrification of heating and transport.

Enlarging the share of variable renewables in power systems will bring fundamental changes to their operations. Power systems have traditionally relied on dispatchable fossil-fuel plants or hydropower to meet supply and demand at all times, with synchronous generators ensuring system stability. Limited output-dispatchability and the non synchronous nature of variable renewables require that power systems find new ways of operating, and the magnitude of the challenges can increase alongside the share of variable renewables (IRENA, 2017g).

Where variable renewables' shares are low, investment needs may be limited and focused on reinforcement of transmission lines and minor retrofitting of power plants to increase their flexibility, in conjunction with the increased coordination of electricity markets and operations at the regional level. But where variable renewables are being deployed faster than transmission capacity can be expanded, electricity storage can play an important role (and this holds true even where renewables' shares are relatively low). For example, hydropower offers a large-scale and low-cost energy storage solution.

Notably, however, storage is only one possible source of flexibility, along with dispatchable generation (both renewable and fossil), interconnectors, demand-side management and sector coupling opportunities (e.g., thermal storage, electric vehicles, etc.). Where variable renewables' shares are larger, the role of storage may become crucial, initially to provide grid services, perform short-term arbitrage and complement reductions in firm capacity from the replacement of dispatchable generation with variable renewables. Where the shares of variable renewables are much larger (greater than 70-80%), seasonal storage could become necessary, and power-to-X may be a game changer (Hydrogen Council, 2017; IRENA, 2018e).

A wide range of technical and institutional solutions that support these changes are available, and many are cost-competitive. Meanwhile, several emerging solutions require further innovation. Policy makers should focus on creating appropriate regulatory and market environments to facilitate variable renewables' integration and minimise integration costs. Key solutions that exist today are discussed below.

Appropriate requirements for variable renewable energy have to be incorporated in national grid connection codes. In the past, power systems relied primarily on conventional generators to meet system stability requirements. As their share increases, variable renewables will have to take over a growing number of duties from the conventional generators they replace. A grid connection code defines the minimum technical and design requirements for variable renewable energy generators so that their behaviour is compatible with system stability and safety requirements. These requirements include, for example, provision of reactive power for voltage control, active power reduction during congestion or over-frequency events, and network support during faults. Technological innovation in parallel with the development of grid codes has allowed variable renewables to help stabilise the network. Many of the technical and design requirements are typically implemented with minimum costs (IRENA, 2016e).

Demand-side management and sector coupling can provide significant, potentially low-cost, flexibility. If the necessary information and communications technology (ICT) infrastructure and market frameworks are in place (RMI, 2015; Lampropoulos et al., 2017), electric vehicles provide an opportunity to absorb variable renewable electricity at times of high solar and wind output, and potentially provide some grid services to support generation adequacy. Benefits from electric vehicles and smart charging are evident even where shares of variable renewables are small; they become significant as these shares grow. Benefits range from the provision of grid services to energy arbitrage. However, the costs of providing such services need to be carefully assessed against the revenues that can be earned under existing market frameworks. Markets might need to be revised to ensure that monetisable revenue streams reflect the value provided to the system. Other opportunities for coupling end-use sectors – for example, through thermal energy storage (TES), district heating and cooling networks, and the aggregation of smart appliances – may also provide the flexibility needed.

The cost of storage continues to fall but uncertainty regarding its future role remains. In general, a limited amount of storage can provide significant benefits in most power systems, especially for ancillary services and to meet residual demand peaks (avoiding investments in peaking plants). Beyond this, storage requirements depend on the specificities of each system (IRENA, 2017a). In well-interconnected systems where renewable resources are complementary, flexibility markets exist and synergies with end-use sectors are exploited, the role of storage may be minimal, except where the share of variable renewables is very large. In transmission-constrained systems, or systems with a limited geographical footprint, storage may be an economical solution early on (e.g., on islands). An in depth analysis is needed to assess the value of storage for a specific system. IRENA is developing a storage valuation framework to support this.

Planning frameworks are needed to help determine the best path forward. Comprehensive planning can minimise the technical impacts of integrating variable renewables and the associated costs. A series of co-ordinated planning studies is essential in identifying techno economic bottlenecks, evaluating the cost-effectiveness of integration solutions and building political consensus on long-term goals. Crucially, while variable renewables can be deployed rapidly, transmission requires much more time, making planning essential for cost-effective deployment. Among other analytical tools, IRENA has developed a "FlexTool" to assess the optimal amount of investment in flexibility options to reliably operate power systems with high shares of variable renewables (IRENA, 2017g).

Fostering business model innovation. As innovations in business models and underlying technologies rapidly emerge, new opportunities for renewable energy integration are becoming available in the power and end-use sectors. For example, major ICT improvements and increased digitalisation can allow for greater engagement of power consumers through "smart" devices or networks. Such technology has enabled the emergence of aggregators and virtual power plants, while blockchain technology facilitates peer-to-peer exchanges. Such innovations are affecting, and will continue to affect, the sources, boundaries and dynamics of value in the power sector landscape.

Market Design

While, in principle, technological solutions can create value and enhance the flexibility and resilience of variable renewables, the incentive structure in which they operate is of critical importance. Sound market design is necessary, with incentives that encourage flexible behaviour on the supply and demand sides at appropriate times and locations, as well as regulations which do not preclude the participation of innovative options and participants. For example, market and regulatory frameworks may need to be adjusted to unlock flexibility not only on the supply side, but also on the demand side (i.e., industry, commercial, residential and electric vehicles).

As the electricity sector's transformation gathers momentum, the shares of variable renewables will rise significantly. Higher levels of penetration will, in turn, introduce challenges in the electricity system and market for which early responses will be needed. Effectively tackling these challenges requires the deployment of energy flexibility tools such as storage, demand response and an active role for renewable energy generation that will have to be facilitated by ever more efficient markets. These changes will require a rethinking of electricity markets to overcome the barriers that currently hinder the full range of flexibility options from fully participating, while providing the adequate economic and financial framework to support the deployment of capital intensive renewable generation capacity. (IRENA, 2014b, 2017d).

The electricity market should facilitate all available variable renewable energy resources and promote the required long-term investments that provide system flexibility, while ensuring high standards of efficiency, reliability and environmental performance. At the same time, the growth of decentralised power generation requires new approaches to network regulation and advanced grid management methods.

Drawing chiefly on IRENA's (2017d) report, *Adapting Market Design to High Shares of Variable Renewable Energy,* the next section highlights lessons learnt from pioneering countries with liberalised electricity markets, and discusses policy and regulatory measures relevant to different stakeholders, such as regulators, market operators, utilities and aggregators. It covers policies and regulations pertaining to the electricity market, distribution systems, prosumers and tariffs.

Policies and regulations for electricity market design

Characteristics of variable renewable energy technologies, if not coupled with appropriate energy flexibility resources and dispatchable renewables, may introduce challenges to the operation of electricity systems and markets, compromising the reliability of services.[16] The magnitude of these impacts depends on the dimension and characteristics of the power system itself (specifically, the generation mix and the degree of flexibility already available), as well as on electricity markets (specifically, time frames).

Various issues need to be addressed in several time frames: capacity expansion in the long term, electricity dispatch in the short term and real-time balancing in the very short term:

Increasing the shares of variable renewable energy, because of its relatively low marginal cost, leads to low energy prices in the current market structure. This effect, together with increased cycling requirements to procure flexibility from conventional fossil-fuel plants, complicates the recovery of conventional generators' investment costs (IRENA, 2017d). In a renewable-based electricity system without regulated support for renewable energy generation, low energy prices would not allow the required return on investment and therefore would not provide a sustainable framework for deploying the required renewable generation capacity. Options for revising the market structure in the interest of sustainability include the incorporation of transition-focused capacity mechanisms and/or premium tariffs to complement energy market revenues. Market modifications, when undertaken, must focus on supporting and facilitating the transition process, and avoid introducing barriers.

In the short-term market (i.e., day-ahead and intra-day), electricity is usually traded as a stable output for a certain period (i.e., a trading block), usually one hour. Market participants submit their bids and offers, and a clearing algorithm determines the cleared energy quantities and the market price for each settlement period (e.g., for each hour) of the following day. Increasing the time granularity of energy trading and reducing the minimum size of energy products will allow the effective participation of small, modular and aggregated variable renewable energy plants and a better representation of their generation, providing an improved characterisation of the flexibility required (IRENA, 2017d). Aggregating plants could facilitate their incorporation into the system and market.

In the very-short-term market (i.e., balancing market), which operates in close to real time, the system operator is responsible for ensuring overall security and stability. This requires an instantaneous (on the order of seconds) matching of electricity supply and demand. As volumes

16 The right policy design can avoid or help reduce technical curtailment. At low levels of penetration, curtailment is unlikely to be required. In systems with high shares of variable renewables, however, curtailment may become necessary and should be assessed at the investment stage to ensure investment recovery. Even some systems with low shares of variable renewables are experiencing high levels of curtailment, mainly due to insufficient grid capacity, inflexible generation and market distortions. The more flexibility the system has, the less need for curtailment and the right policies can help unlock flexibility.

of renewable energy generation increase, fast-responding energy flexibility is needed. Properly designing balancing markets is essential to offer accurate incentives for flexibility. The system can procure flexibility from energy storage and demand response, and the capacity of all renewable energy technologies to contribute to overall system regulation. In many power systems (Belgium, Denmark and Spain are examples), renewable energy producers and even variable renewable energy producers are considered responsible for their imbalances (IRENA, 2017d). But imposing penalties does not provide the required solutions. Technological innovation allows even variable renewable energy generation to provide some of the necessary ancillary services, ultimately contributing to system flexibility and reliability, as seen in the case of California (IRENA, 2017d). An appropriate market structure should lead to the optimum deployment and dispatch of the required flexibility.

Policies and regulations for distribution networks and distributed energy resources

Over the past decade, distribution networks have multiplied their connections to distributed energy resources. This is mainly driven by support policies and the decreasing costs of renewables, as well as the empowerment of small- and medium-size consumers, facilitated by innovative technologies and increased availability of information. In addition, electric vehicles and distributed storage (as seen in Germany and Australia) will soon have a significant presence in the system. With the growth of distributed energy resources, policy makers and regulators need to be prepared for the challenges that the system can face, including those related to operations and planning, economic regulation, changing roles and innovation (IRENA, 2017d), as detailed below.

Operations and planning: Current approaches to operating and planning distribution networks, as well as the regulation of distribution and retail activities, are not sufficient to facilitate the growth of distributed energy resources. Distribution companies and/or aggregators will have to bridge the gaps between flexibility providers, markets and system operators. Moreover, they will have to integrate the flexibility offered by distributed energy into their planning and operational practices. Comprehensive, holistic and inclusive planning of generation expansion, fully incorporating the potential of distributed generation, is required. Distribution companies should also interact more often with distributed energy resources or aggregators to efficiently manage network constraints by facilitating the participation of distributed flexibility resources into the energy market.

Economic regulation: Distributed energy resources increase the uncertainty around the volumes connected to a grid in the medium and long term. Without knowing how to estimate this impact, revenues linked to the current tariff structure could be insufficient to cover distribution costs. To prevent network operators from opposing or delaying the connection of distributed energy resources, regulators should focus on mitigating the negative impact that these may have on the recovery of network costs and on the revenues of distribution operators, while enabling new streams of revenue that allow network operators to play a more active role in the transitions. Regulators should update the way distribution companies are rewarded, moving toward regulation based on output, performance and total cost. The United Kingdom's Office of Gas and Electricity Markets, for example, launched a new regulatory model, called RIIO (Revenue Using Incentives to Deliver Innovation and Outputs). Before RIIO, capital and operational costs were kept separate; now, ex ante total expenditure revenue allowances are based on well-justified business plans to improve the cost efficiency of interventions. The number of incentives based on output factors (customer satisfaction, environmental impact or energy not injected by renewable energy sources due to network unavailability) has been increased, and automatic revenue has been adjusted within the regulatory period.

Changing roles: With the growing decentralisation of power systems, the flexibility resources connected to the distribution grid become increasingly necessary to balance generation and demand. Existing provisions constrain this process. To unlock the flexibility inherent in distributed energy resources, the participation of distribution companies in upstream system services is crucial.

To enable this, regulators should develop new grid codes that define the responsibility of utilities and distribution companies as facilitators of distributed energy resources' participation in upstream services and markets. Regulations should also be set for the data management and information exchange required between utilities or distribution companies, aggregators and system/market operators.

Innovation: Technology risks and the absence of economic incentives prevent the development of smarter, digitalised distribution grids. These challenges can be tackled through policies and regulations that promote and support the implementation of pilot projects. Joint public-private partnerships (PPPs) should be promoted to exchange lessons learnt. Examples of such collaboration networks at the regional level include the European Union Smart Grid Task Force, the U.S. GridWise Alliance and the Indian Smart Grid Forum (IRENA, 2017h).

Policies and regulations for prosumers and the design of tariffs

Retail tariffs are among the main drivers of consumers' and prosumers' behaviour. Regulation should take advantage of this and actively promote self-consumption and demand response by setting retail and flexibility services' compensation tariffs to reflect costs. Behind-the-meter generation and storage can yield benefits for both end users and the power system as a whole. However, an appropriate tariff structure needs to be in place to fully reap the potential benefits.

Self-consumption and net-metering may complicate cost recovery for grid services, prompting utilities to request that retail tariffs be restructured. However, a reformulation centred exclusively on this issue could lead to tariffs that penalise prosumers and, together with the availability of increasingly affordable distributed storage, might even encourage them to disconnect from the main grid (leading to the so-called utility death spiral).

Cost-reflective tariff structures should be deployed. This requires moving away from purely volumetric charges and introducing some kind of fixed charge (e.g., USD/meter-month) or demand charge (USD/kW), or readjusting the weight between these two components where they already exist but do not properly reflect the system's cost structure (IRENA, 2017d). Exposing consumers and prosumers to time-dependent pricing (time-of-use tariffs) would incentivise them to consume during those hours of the day and of the year when variable renewable energy resources are abundant, thereby contributing to system flexibility. To avoid additional barriers, this type of tariff structure needs to capture benefits from energy efficiency, flexibility and demand response, as well as manage the right rate of progression toward socket parity.

Integrating sharing-economy approaches into tariff reformulation would help soften the resistance of those stakeholders that may feel threatened by the process, and simultaneously engage stakeholders (e.g., prosumers) without an active role in the system yet.

Well-designed net-metering schemes that encourage self-consumption can encourage prosumers to shift toward more system-friendly behaviours. Regulations should consider the appropriate design elements, like the length and timing of the netting period and the actual value of net excess generation. There is a balance between pushing the prosumer to consume as much energy as it generates and providing the adequate economic signals to deploy distributed generation.

Smart metering enables both net-metering and cost-reflective tariffs, facilitating the incorporation and deployment of the policy and regulatory measures mentioned above. There are different ways to roll out smart meters, from those that rely on mandates to the distribution companies to those that centre on consumer choice. Brazil's experience offers a middle way. The regulator adopted a standard that mandated distribution companies to offer their customers the choice of installing a smart meter. The offer highlighted the potential benefits of access to enhanced information, more tariff options and remote connection management.

5. INNOVATIONS IN RENEWABLE ENERGY TECHNOLOGIES AND THEIR DEPLOYMENT

Key Findings

- Technologies that are not widely deployed today will play an important role in the transformation of the energy sector. IRENA's analysis indicates that more than 15% of global CO_2 abatement potential, or around 4.8 gigatons of carbon dioxide per year (Gt CO_2/yr), could come from a combination of the following technologies:

    - Concentrated solar power (CSP)
    - Ocean energy
    - Offshore wind
    - Geothermal energy
    - Bioenergy – advanced liquid biofuels
    - Hydropower – pumped hydroenergy storage (PHES)
    - Enabling electrification – batteries and electric vehicles
    - Heat and cold storage

- Additional investment needs for these technologies are estimated at USD 6 trillion for the 2015-2050 period. Policy makers need to act now to nurture innovation, supporting research and development (R&D) to improve performance, reduce costs, and find new approaches to the deployment and scale-up of the technologies needed to further the global energy transformation. While the private sector must ultimately bring innovations to the market, governments have a critical facilitating role. Innovation in renewable energy and energy efficiency technologies, stimulated by government-driven efforts, would bring major benefits beyond decarbonising the energy sector (IRENA and IEA, 2017), such as increasing wealth, promoting social inclusion and improving environmental quality an health.

Key Actions

- Support and encourage established platforms for the sharing of knowledge and establish more cross-border co-operation in the innovation of renewable energy and energy efficiency.
- Establish more bilateral and multilateral, public-private-funded, commercial- scale demonstration projects and "real-world" pilot programmes for innovative technologies and processes.
- Encourage the development of internationally harmonised technical standards and quality controls that will facilitate the cross-border trade of innovative technologies.
- Work with international organisations, such as IRENA, and engage existing international programmes and initiatives to define a joint agenda that identifies the critical innovation needs of developed, emerging and developing markets and designs collaborative strategies to address them. International collaborative efforts should consider approaches to foster technology and knowledge transfer for renewable energy.
- Encourage a systemic approach to innovation that considers not just innovation in technology but also in systems, processes, market design and business models to accelerate uptake.
- Foster the transfer of technology from industrialised to emerging economies.

Emerging technologies that are not widely deployed today will have an important role to play in the transformation of the energy sector, which is powered in part by new and innovative technologies. IRENA's analysis indicates that more than 15% of global CO_2 abatement potential, or 4.8 Gt CO_2 /year, will come from the emerging technologies discussed in this section (IRENA, 2017h). Additional investment needs for these technologies are estimated at USD 6 trillion between 2015 and 2050.

The emerging technologies profiled here differ in their stage of development. Some, like ocean energy, are in the R&D stage. Others are in early commercialisation, like advanced biofuels, CSP and offshore wind. Still others are more mature but just starting to be scaled up, like pumped hydro storage and geothermal energy. A comprehensive overview of emerging technologies, including many not touched on here, can be found in IRENA's report, *Accelerating the Energy Transition through Innovation* (IRENA, 2017h).

Concentrated Solar Power

Over the past two years, CSP has been gaining momentum in emerging markets with high solar resources, such as Morocco, the United Arab Emirates, South Africa and Chile. The technology is still in its infancy in terms of deployment, with total capacity close to 5 GW at the end of 2017 (IRENA, 2018f). However, over 25 CSP plants, representing an aggregated additional installed capacity of more than 1 GW, are under development (NREL, n.d.). IRENA's REmap analysis indicates that more than 600 GW of installed capacity in CSP technology will be needed by 2050 to decarbonise the global energy system.

The significant advantage of CSP over PV is that it can integrate low-cost thermal energy storage (TES) to provide intermediate and base-load electricity. This increases the capacity factor of CSP plants and allows dispatchability, thus improving grid integration and economic competitiveness (IRENA and IEA ETSAP, 2013).

CSP technologies are of two types, according to the way the solar collectors concentrate the sun's rays. Parabolic trough collector (PTC) systems concentrate the rays along a single focal line of heat receiver tubes, while solar towers use a ground-based field of mirrors (heliostats) to track the sun (along two axes) and focus it on a central receiver, mounted on a high tower. With over 50 utility-scale plants installed worldwide, PTCs are the dominant technology, accounting for about 85% of cumulative installed capacity at the end of 2015.

Recent CSP power purchase agreements in Australia and the United Arab Emirates indicate record low prices of USD 0.06/kWh to USD 0.07/kWh for plants that will be commissioned in 2020-2022 and onward. Moving forward, key improvements expected in PTC plants will significantly reduce installed costs, capital costs and LCOEs while also improving thermal storage performance. China is a key emerging market for this technology; here, costs are expected to be cut in half as the CSP market and technology mature. IRENA's analysis indicates that a reference PTC plant with 7.5 hours of storage could see total installed costs decline by 33% in ten years, from USD 5 550/kW in 2015 to USD 3 700/kW in 2025 (IRENA, 2016f). The costs of CSP plants may be further reduced by:

- Cost reductions in the solar field components (mirrors, collectors, piping, etc.) that make up about one-third of total installation costs;
- Learning effects and expected reductions in indirect costs (engineering and management) and owners' costs; and
- A decrease in the risk margins of suppliers and parties to energy performance contracts, along with increased commercial deployment of the technology.

These variables will be responsible for about half of the total reductions in the costs of PTC systems up to 2025. TES system cost reductions will account for about one fifth. At the same time, the overall efficiency of PTC plants is expected to increase from 15% to 17%.

Ocean Energy

The theoretical resource potential of ocean energy is more than sufficient to meet present and projected global electricity demand well into the future. Estimates for this potential range from 20 000 terawatt hours (TWh) to 80 000 TWh of electricity a year, which is 100% to 400% of the current global demand for electricity (IRENA, 2014c). At present, ocean energy technologies are still in their developmental stages, with most technologies in the prototype phase and some in the pre commercial stages. Substantial growth in deployment and installed capacity is expected in the coming years.

The current LCOE of ocean energy technologies is highly uncertain owing to their early stage of development. It has been observed that tidal stream demonstration plants may have an LCOE between EUR 0.320/kWh and EUR 0.371/kWh, while wave demonstration plants may have an LCOE between EUR 0.407/kWh and EUR 0.52/kWh (IRENA, 2014c).

Ocean energy technologies are commonly categorised based on the resource utilised to generate energy. The most common identified technologies include:

- Wave energy
- Tidal energy
- Ocean thermal energy conversion

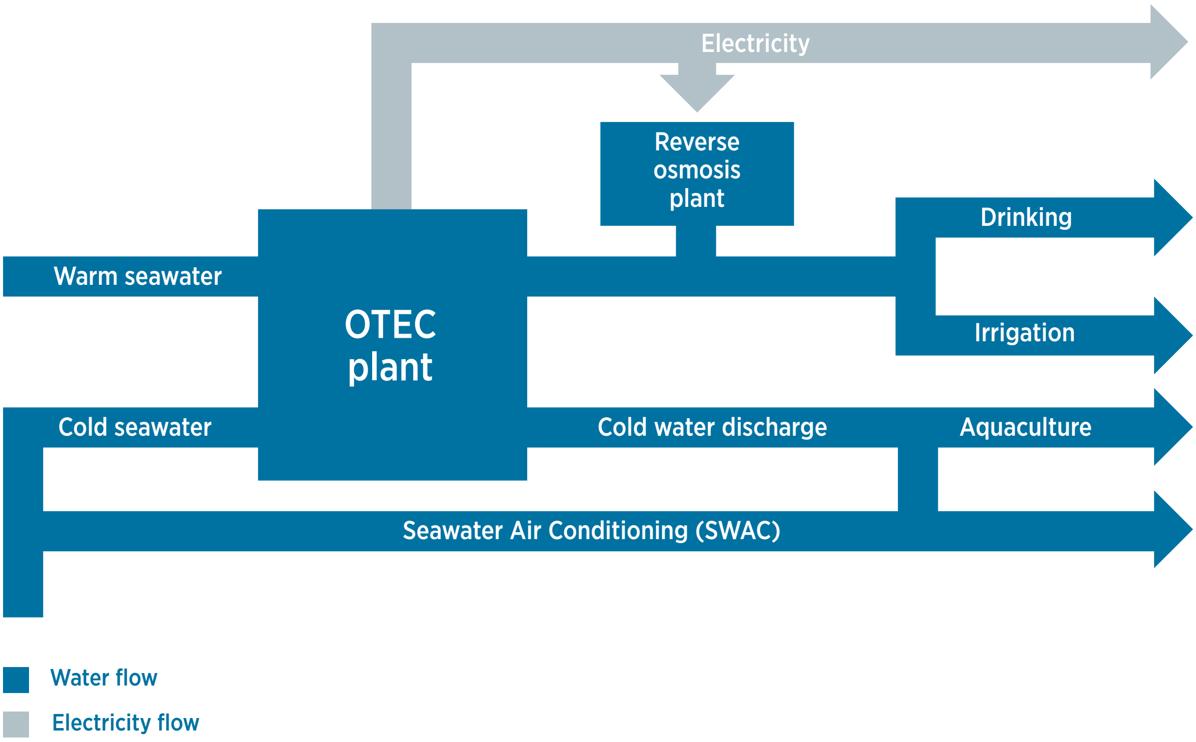
Tidal stream and wave energy converters are the technologies of greatest medium-term relevance. Except for tidal range, they are the most advanced ocean energy technologies available, albeit at a pre-commercial stage. Tidal range is a mature technology, but the very limited site availability, high capital investment and potential environmental impacts have until now ruled it out for large-scale utility projects in all but a couple of locations. Other ocean energy technologies may become increasingly relevant over longer time horizons.

Wave technology. The areas of the world with the greatest wave resources can be found in locations lying between 30^0 and 60^0 latitude and in deep water (> 40 metres); the southern latitudes have the most extreme power density, corresponding to the locations with the highest wind forces. Wave energy technologies have not seen a convergence toward one type of design, as has happened for wind energy or tidal energy. The types include oscillating water column, oscillating bodies and overtopping devices (IRENA, 2014d). The European Marine Energy Centre (EMEC, n.d.) presents an extended list of technology types, including the attenuator, point absorber, oscillating wave surge converter, oscillating water column, overtopping/terminator device, submerged pressure differential, bulge wave and rotating mass. In recent years, despite the absence of a clear technology convergence for wave technologies, most deployments are of the point absorber type. This design is based on a floating or submerged buoy. Energy is generated from the movement of this buoy caused by all wave directions relative to the base connection. By June 2017, a cumulative capacity of 30 MW had been installed globally. Projects currently in planning would result in a cumulative capacity of 165 MW by 2020.

Tidal technology. A theoretical tidal current energy potential of 150 TWh/yr is estimated globally, corresponding to an installed capacity of 90 GW. Countries with high tidal energy potential include Argentina, Canada, France, India, the Russian Federation, the Republic of Korea, the United Kingdom and the United States. A distinction is made between tidal range and tidal current technologies. The former makes use of tidal barrages, the latter extracts energy from tidal currents. The highest share (> 90%) of installed ocean energy capacity is tidal range energy. However, this capacity mainly corresponds to just two installations: a 240 MW plant in France from 1966 and a 254 MW plant in the Republic of Korea from 2011. More of this large-scale tidal range is unlikely to be installed in the near future because of high capital costs and environmental concerns. In coming years, a significant increase in the installed capacity of tidal current technologies may occur, based on information from projects planned at the moment, from a cumulative installed capacity of 30 MW as of June 2017 to 775 MW in 2020, demonstrating growth in commercial deployment.

Ocean thermal energy conversion (OTEC) technology. OTEC's generation is based on the temperature difference between the surface and deeper layers of the ocean. At locations where this difference is around 20^{0}C, energy can be produced using cycles with heat exchangers and turbines (IRENA, 2014e). The global technical potential of OTEC is the largest of all ocean energy sources at 30 TW (262 800 TWh/yr). Currently, the largest OTEC plant has an installed capacity of 210 kW; a plant with a net capacity of 10.7 MW is under construction (see Figure 5.1). An OTEC plant also provides the possibility of using the cold deep as well as the warm surface water flow for purposes other than energy generation, such as desalination, aquaculture and cooling.

Figure 5.1 Multifunctionality of an OTEC Plant



Source: IRENA (2014), Ocean Thermal Energy Conversion Technology Brief, Abu Dhabi

Challenges for ocean energy. The further development of ocean energy technologies faces numerous challenges related to technical, environmental, infrastructure and economic concerns. These challenges include difficulties in deployment and maintenance, as well as in ensuring reliable operations in harsh environmental conditions. As of now, there are no economies of scale to help costs fall to competitive levels (Table 5.1).

In the face of high barriers, tailored combinations of different policies will have to be implemented to encourage R&D and stakeholders' engagement in harnessing ocean energy at commercial scale.

Table 5.1 Challenges to ocean energy technologies

Type	Description
Environmental and social	Uncertainties regarding impact
	Political issues in "sharing" the ocean
Technology	Harsh environment (salinity, extreme forces)
	Lack of resource assessment
Infrastructure	Lack of grid connection
	Lack of supply-chain support
Economic	Lack of funding
	High LCOE

Source: IRENA, 2014c
Note: LCOE = levelised cost of electricity.

Offshore Wind

Offshore wind technology allows countries to exploit sites with high winds. Offshore wind farms can be built at gigawatt scale and close to densely populated coastal areas. This makes offshore wind an important addition to the portfolio of technologies used to decarbonise the energy sector. The first commercial-scale offshore wind plant was commissioned in 2002 in Denmark with an installed capacity of 160 MW. By the end of 2017, the world's installed offshore wind capacity exceeded 19 GW (IRENA, 2018f), mainly off the coasts of Europe.

According to IRENA's analysis, offshore wind capacity could reach 100 GW by 2030, as innovation continues and the industry evolves (IRENA, 2016g). In 2016, average installed costs for a European offshore wind farm were at USD 4 697/kW. From 2010 to 2016, the global weighted average LCOE of offshore wind decreased from USD 0.17/kWh to USD 0.14/kWh, while the prices awarded in auctions in 2016 and 2017 (for projects to be started up in 2020-2022) ranged from USD 0.06/kWh to USD 0.10/kWh (IRENA, 2018c).

Developments in wind turbine technologies as well as in foundations, installation, access, operation and system integration have permitted moves to sites with better wind resources, which are often in deeper water and farther from shore. Today, turbines are being routinely installed in water depths of up to 40 metres and as far as 80 kilometres (km) from shore. These turbines, rooted in the seabed by monopile or jacket foundations, are still restricted to waters less than 50 metres deep. This is a major limitation, as some of the largest potential markets for offshore wind, like Japan and the United States, have few shallow-water sites. Scaling up offshore wind markets undoubtedly requires offshore wind turbines to move into deeper waters (> 50 metres). Therefore, floating foundations are potentially a game-changing technology for offshore wind (Figure 5.2).

Figure 5.2 Examples of floating foundation designs

Figure 1: Offshore wind floating foundation concepts

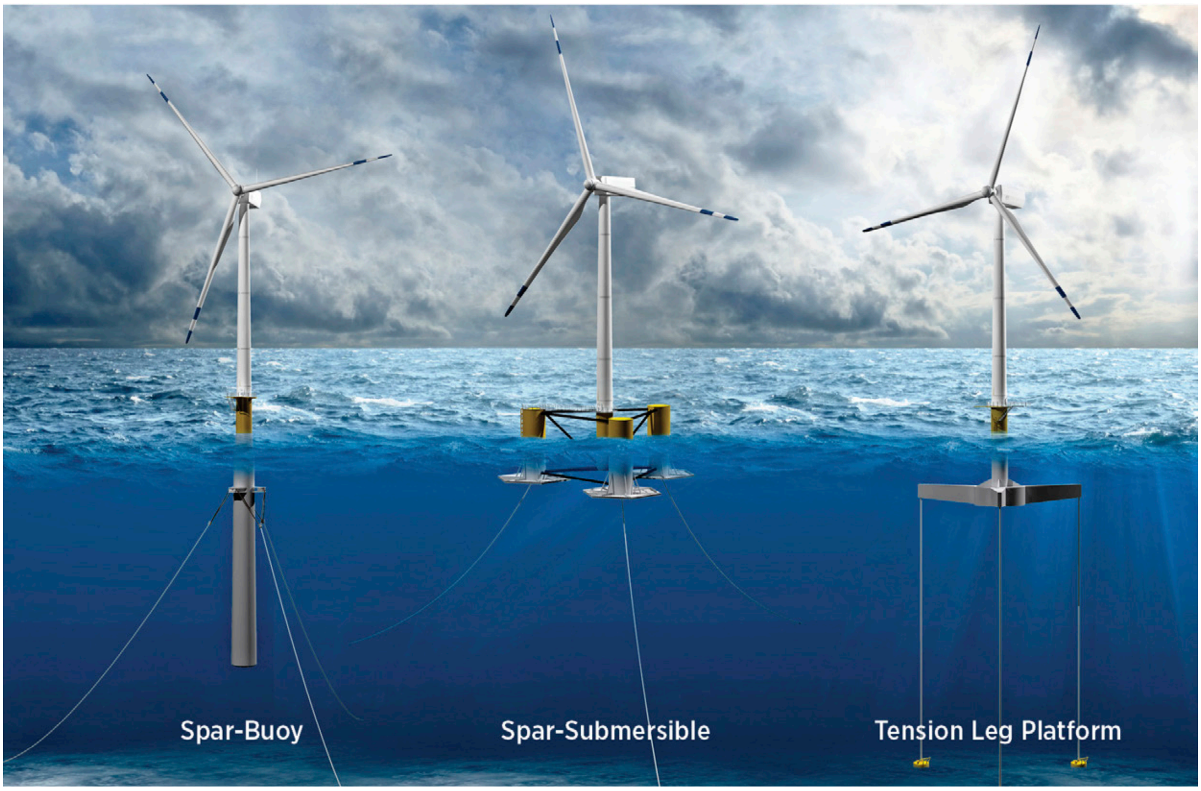


Illustration by Joshua Bauer, National Renewable Energy Laboratory, US Department of Energy.

Floating foundations offer the offshore wind industry two important opportunities: 1) they allow access to sites with water deeper than 50 metres; and 2) floating foundations ease turbine set-up, even for mid-depth conditions (30-50 metres), and may in time offer a lower-cost alternative to fixed foundations (IRENA, 2016h). The first full-scale prototypes for floating wind turbines have been in operation for several years with three main designs being tested (Figure 5.2): spar buoys, spar submersible and tension-leg platforms.

The year 2017 saw significant and encouraging developments in floating foundations. The first offshore wind farm to deploy them began operating off the coast of Scotland (UK), in October 2017. The Hywind Scotland Wind Farm has a nominal power capacity of 30 MW, consists of five turbines of 6 MW each and uses spar buoys (Hirtenstein, 2017). Based on progress seen in the market, three to five additional foundation designs are expected to be demonstrated at full scale by 2020, and the commercialisation of floating offshore wind could be anticipated between 2020 and 2025.

To accelerate the development of floating offshore wind projects, policy makers may facilitate private investment through, for example, proven mechanisms focused on pre-commercial technology, such as extending support to demonstration plants. This can bolster confidence and boost the visibility of future markets. At the same time, researchers should focus on cost and risk reduction across the entire offshore wind project cycle. This includes whole-system modelling and optimisation, taking well-characterised site conditions into account and learning from wind resource and power-output measurements from early projects.

Geothermal Energy

Geothermal energy is generated within the Earth. Geothermal heat can be directly used or transformed into electricity. An advantage of geothermal energy is that, once harvested, it is predictable, independent of weather conditions and can be found around the globe. Many of the power plants currently in operation utilise high-temperature resources, which are generally limited to volcanic or active tectonic areas. However, medium- and low-temperature resources are much more widespread across the globe. Several countries are therefore pursuing the development of medium-temperature resources through geothermal binary power plants and low-temperature resources for heating and cooling for industry, agriculture, and residential and non-residential sectors (IRENA, 2017i).

Global geothermal power capacity by the end of 2017 totalled 12.8 GW (IRENA, 2018f), with annual electricity generation reaching 80.9 TWh in 2015 (most recent data), approximately 0.3% of the global electricity generation. Geothermal electricity generation relies mainly on technologies that exploit conventional geothermal resources, such as dry steam plants, flash plants (single, double and triple), binary plants and combined-cycle or hybrid plants. The type of technology depends on the reservoir quality (notably the temperature). However, as high-quality conventional resources become harder to access, deeper resources may become accessible in the future through the development of enhanced geothermal systems.

Geothermal power project costs are highly site sensitive. Typical investment costs for geothermal plants range from USD 1 870/kW to USD 5 050/kW, and binary plants are normally more expensive than direct dry steam and flash plants. The LCOE of a geothermal power plant ranges from USD 0.04/kWh to USD 0.14/kWh.

There are three main technologies for heat applications: ground source heat pumps, direct-use geothermal and deep enhanced geothermal. A ground source heat pump takes advantage of the naturally occurring difference between the above-ground air temperature and the subsurface soil temperature to move heat in support of end uses, such as space heating, space cooling (air conditioning) and even water heating. Direct-use geothermal systems use groundwater that is heated, up to 93°C or higher, by natural geological processes below the Earth's surface. Deep geothermal systems use steam from 1.5 km or more below the Earth's surface for applications that require such high temperatures. These systems typically inject water into the ground through one well and bring water or steam to the surface through another. Other variations can capture steam directly from underground ("dry steam").

Geothermal heat is increasingly used for district heating systems but also for industrial, commercial and agricultural purposes. These so-called direct-use applications can contribute to local economic development and help share the benefits of geothermal deployment with local communities. Scaling up geothermal deployment requires clear, transparent and tailored policies and regulations which take into consideration, among other factors, the size of the economy, market design and geographical location, as well as targeted applications (electricity, district heating and cooling, etc.).

A peculiarity of geothermal projects, especially those on greenfield sites, is the high resource risk during the exploration phase. Significant up-front costs for test drilling are required to confirm the presence of resources, and before project profitability can be determined. This uncertainty during the early phase of a geothermal project makes it difficult to mobilise capital to the higher-risk project exploration phase, especially through the private sector. Innovative risk-mitigation mechanisms, together with efficient exploration practices, can play a vital role in reducing this risk or spreading it across multiple parties, thereby attracting private finance. To support enabling frameworks for investments in geothermal power generation and direct use, governments and key organisations have joined forces in the Global Geothermal Alliance. The initiative, co-ordinated by IRENA, was launched at the twenty-first session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) in December 2015 with the aim to enhance dialogue, co-operation and co-ordinated action toward tapping geothermal energy among public, private, intergovernmental and non-governmental actors.

Bioenergy – Advanced Liquid Biofuels

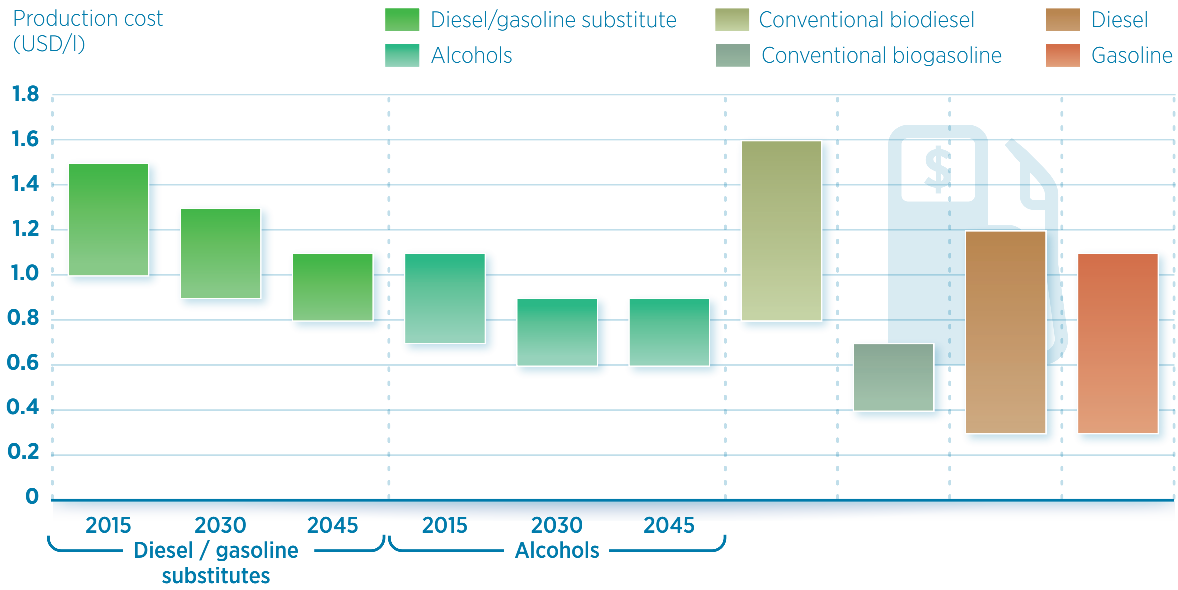
Bioenergy promises to play a vital role in achieving a low-carbon energy system by the second half of the 21st century. A great advantage of bioenergy is its versatility as an energy resource, as it can be converted into final energy for heat, power and transport fuels. IRENA analysis indicates that bioenergy could account for about half of total global modern renewable energy use by 2030, with demand equally distributed across the buildings, industry, transport and power sectors. To achieve this, total primary bioenergy supply would need to increase substantially (by up to 70%) in coming years.

Today, around 4% of transport energy comes from liquid biofuels (137 billion litres in 2016). Liquid fuel demand is expected to increase globally, with most of the growth in Asia, especially China and India. IRENA projections for the REmap Case (described in Chapter 1) suggest that 500 billion litres per year should come from liquid biofuels by 2030. In recent years, the growth has been around 2% per year, whereas growth of up to 10% per year is needed. Today, ethanol from corn and sugarcane dominate, as well as various oil plant crops for diesel-type products (conventional biofuels). In the coming decades, growth will be needed in conventional and advanced biofuels alike. Given the recent investment trends, meeting this demand will be a challenge. Scaling up cellulosic bio-gasoline production to commercial levels will be particularly challenging.

Advanced biofuels, using lignocellulosic feedstocks, waste and algae, can vastly expand the range of resources for fuelling light and heavy transport alike. IRENA estimates that 124 billion litres per year of advanced biofuels will be needed by 2030. This equates to about a quarter of total biofuel production in energy terms.

The potential is large, but so are the challenges. A competitive advanced biofuels industry will rely on innovative technology and supply chains, market development and policy support. IRENA's innovation outlook for advanced biofuels indicates that, by 2045, advanced biofuels would likely cost between USD 0.60 and USD 1.10 per litre to produce. At oil prices below USD 80 per barrel, they would have difficulty competing with fossil-based gasoline and diesel. But at oil prices above USD 100, most advanced biofuels should be able to compete effectively (Figure 5.3).

Figure 5.3 Current and projected fossil-fuel and biofuel production costs



Source: IRENA, 2016i .
Note: GJ = gigajoules.

In most advanced biofuel production pathways, feedstock costs are the greatest contributor to production costs. The feedstock cost share is currently 40% to 70%, and could grow over time as capital costs decline, with technology development making conversion cheaper and more efficient. Establishing sustainable, affordable and reliable feedstock supply chains, therefore, have to be established at scale.

Demonstration and commercial plants in 2016 added 1 billion litres of advanced biofuel production capacity per year, which would meet 0.04% of current demand for liquid transport fuel. Plants planned or under construction would add another 2 billion litres of capacity per year. These include plants producing ethanol, methanol, mixed alcohols, and diesel and jet fuel, mostly located in Brazil, Europe and North America. Clearly, the pace will have to pick up exponentially, and projects be developed in a wider range of locations, if advanced liquid biofuels are to realise their practical and economic potential.

Many technologies and production pathways can convert lignocellulosic feedstocks into liquid transport fuels. The fact that residues can be used as feedstock represents a major advantage that opens up a wide field of applications. Lignocellulosic ethanol plants using agricultural residues or energy crops have reached an early commercial phase. Located in Brazil, the GranBio lignocellulosic ethanol plants started operation in September of 2014 with a capacity to produce 82 million litres per year using sugarcane straw and bagasse as feedstock. In October 2015, DuPont opened the largest such plant in the world in the U.S. state of Nevada, with a capacity of 114 million litres per year. Other commercial lignocellulosic ethanol plants are, for example, Abengoa and POET-DSM in the United States, Raizen in Brazil, Beta Renewables in Italy and Shandong Longlive in China. Other production pathways, like gasification and fast pyrolysis, have reached a commercial-scale demonstration phase, but more efforts are needed to push these technologies to commercialisation.

Accelerating deployment of advanced liquid biofuels requires a range of policy support interventions in energy markets, technology development and enterprise formation.

Technology development: For promising technology pathways, investment support for early plants is essential to achieve technology learning and cost-competitiveness. First-of-a-kind commercial scale pilot plants are crucial to the progress of advanced biofuels technologies, since laboratory conditions do not replicate real-world factors such as feedstock impurities, logistical requirements and the need for offtake arrangements. But commercial-scale pilot plants have a high risk profile and will typically not be built unless support is provided.

Market formation: Policy incentives, targets or mandates are often needed to address barriers, such as insufficient operational experience, immature supply chains and uncertain market size. The internalisation of carbon costs in the market would encourage production and conversion of lignocellulosic feedstocks. Public procurement initiatives can encourage demand for biofuels in aviation, marine shipping and trucking. Co-production of fuel additives, chemicals, plastics and cosmetics can make biofuel production profitable.

Enterprise formation: Advanced biofuel projects can be stimulated through more equity investments in start-ups. Strategic partnerships and joint ventures could allow companies to share expertise and financial risk. Effective business models can be documented and shared to help advanced biofuel markets expand.

International collaboration: Even as technology development benefits from international collaboration between research institutes and industry, globalised biofuel markets also require internationally harmonised requirements. Several collaboration platforms focused on bioenergy can be utilised to advance technology development and deployment. These platforms include those housed within the Global Bioenergy Partnership (GBEP), IRENA, IEA Bioenergy and the Food and Agriculture Organization of the United Nations (FAO). More recently, the Biofuture Platform has been established, based on a proposal from Brazil. It aims to promote international collaboration and dialogue among stakeholders and to create an enabling environment for advanced bio economy-related investments.

Hydropower – Pumped Hydro Energy Storage

Hydropower is a well-established technology. It is mature and reliable, and, currently, the leading renewable technology for electricity production. The world's total installed hydropower capacity is estimated to have reached 1 270 GW at the end of 2017, with 20 GW added during the year (IRENA, 2018f). The total electricity generated from hydropower plants in 2016 was close to 4 100 TWh, representing around 16% of the world's electricity generation in 2016. Notwithstanding the mature stage of technologies, important innovations are being introduced and continue to be needed.

IRENA estimates that the total installed costs for hydropower projects currently range between USD 500/kW and USD 4 500/kW. However, projects adding hydropower capacity to an existing water dam may have costs as low as USD 450/kW. The LCOE for hydropower plants ranges between USD 40 MWh, for example, in Brazil, and USD 110/MWh for some installations in Europe.

The accelerated deployment of variable renewable energy technologies observed in recent years calls for measures that can increase the flexibility of power systems. Electricity storage is one of the key ways to integrate higher shares of variable renewable energy. At present, pumped hydro energy storage (PHES) is the main technology being used to provide energy storage services at a large scale. Hydropower plants with reservoirs provide built-in energy storage capability and are suitable for providing a quick response to electricity demand variations.

PHES total storage capacity is estimated at 169 GW, representing 96% of the 176 GW of energy stored in all electricity storage types as of mid-2017. Almost half of the world's PHES capacity is installed in just three countries: China (32 GW), Japan (28 GW) and the United States (22 GW). In 2016, an estimated 6.4 GW of PHES capacity was added, double that installed in 2015.

Figure 5.4 Raccoon Mountain Pumped-Storage Plant in Tennessee, USA

Photograph: Shutterstock

IRENA analysis indicates that, to realise energy transitions aligned with the climate objectives of the Paris Agreement and to facilitate the integration of 5 000 GW of PV and wind capacity, electricity storage capacity of more than 1 000 GW is required by 2030. Almost a third (325 GW) of this capacity should come from PHES.

The International Hydropower Association (2017) indicates that PHES has traditionally been used for arbitrage of electric energy (85.2%) (IHA, 2017). The business model was to take advantage of pricing differentials between on- and off-peak periods. However, the rapid uptake of variable renewables is limiting the opportunities for arbitrage. Also, new technologies are emerging fast and offering an increased range of flexibility options.

PHES technology is evolving and should soon be sufficient to harness new revenue streams, such as by providing grid services. Until recently, regulation of PHES power was available only for generation. New variable-speed PHES systems can increase plant efficiency and flexibility by enabling power regulation in both pumping and turbine modes. Ternary systems with a separate pump and turbine set can simultaneously be pumping and generating, resulting in a finer frequency control.

Hybrid systems, comprising variable renewables and PHES, are emerging as well. In the German Naturspeicher project, for example, vessels at the base of each of the four wind turbines act as the upper reservoirs. The wind turbine heights are increased due to the vessels at the base, allowing the turbines to harness stronger winds, while PHES regulates frequency variations in wind fluctuation. Another example of innovations in PHES is the use of seawater, which avoids the need to divert freshwater resources into a large reservoir and water losses through evaporation. This option is now being considered in various countries, including Japan, Chile and Australia.

New business models are also being considered for PHES. New operational concepts are needed to unlock additional revenue streams, such as by providing additional flexibility options to balance system operation. In the United Kingdom, a "cap-and-floor" pricing system for PHES has been proposed. Under this system, utilities are guaranteed a minimum price for output, while a maximum price limits the potential cost to consumers.

Another innovation area is the digitalisation of hydropower systems. Digitalisation can facilitate the operation of hydropower together with variable renewables, increasing power system flexibility and also opening up the possibility of providing ancillary services to grids. Companies like General Electric and Voith are now working on cloud-based solutions to assess the condition of equipment, such as generators and turbines, without the need to dismantle and reassemble them.

Enabling Electrification – Batteries and Electric Vehicles

Batteries will advance the energy transitions by permitting the integration of higher shares of variable renewable electricity into the power mix, accelerating off-grid electrification and indirectly decarbonising the transport sector. Battery storage systems in the electricity sector are used in four main segments, outlined below.

Grid services. Energy storage systems facilitate the integration of renewables on several fronts. First, batteries cope with the variability of renewables by storing energy when there is excess generation, by avoiding curtailments and by supplying electricity to the grid when resources are scarce. Second, batteries are flexible and fast-responding technologies that help to balance the system when sudden changes occur. Finally, they also promote the stability and reliability critical to the penetration of renewables, such as through operational reserves and voltage control.

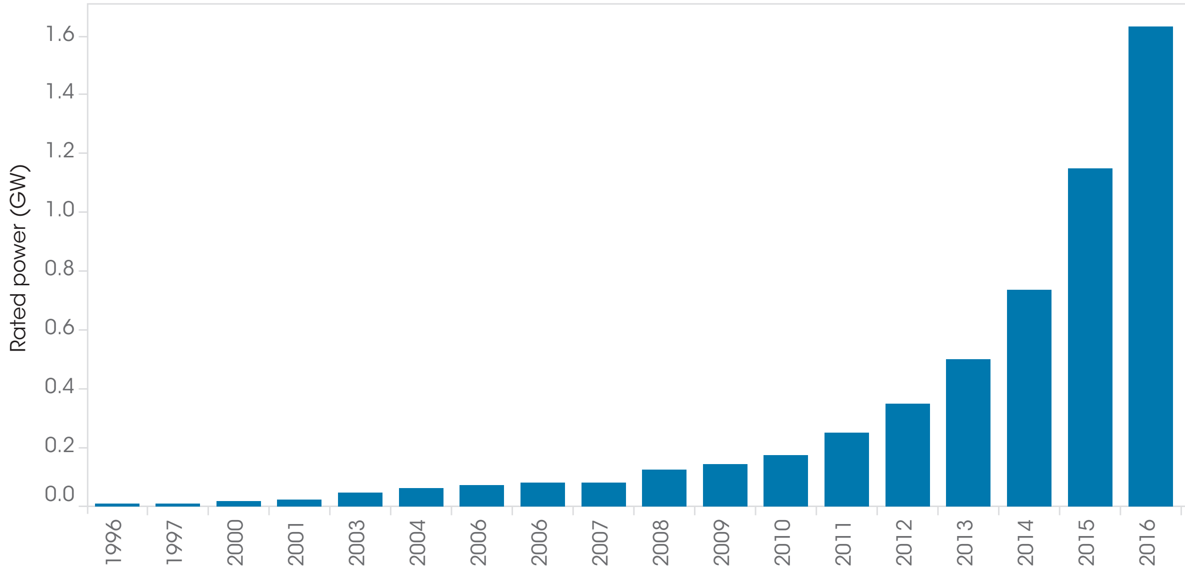
Behind-the-meter applications. Battery storage systems are used to increase the local self consumption of decentralised generation. As such, the amount of power prosumers obtain from the grid can be lowered, resulting in reduced electricity bills. Although currently not economically profitable for most private users, a general interest in new technologies and increased demand for local green electricity supply is driving many consumers to invest in small storage systems. Particularly in Germany, the market for residential storage systems has been growing rapidly. By June 2017, more than 70 000 storage systems with a cumulative capacity of close to 475 MWh had been installed in the German distribution grid (ISEA/RWTH, 2017). At present, many storage system manufacturers are building up distribution networks in Australia, Italy and the United States (California), as these appear to be promising markets.

Off-grid applications. To date, over 1 billion people, especially in rural areas, have no access to electricity grids (World Bank, 2018). Also, remote farms and mines often rely on diesel generators for power. In the last decade, more and more remote enterprises have begun to integrate renewable energy technologies, especially PV, into their generation mix to save fuel and optimise production costs. Adding electricity storage systems can raise the amount of renewable energy in off-grid systems up to 100%, allowing an entirely clean and local energy supply in remote locations.

Electromobility. Electric vehicles represent a paradigm shift for both the transport and power sectors, with the potential to decarbonise both sectors by coupling them. In other words, renewable energy and batteries, together, can help create a cleaner global energy matrix. Although the transport sector currently has the lowest share of renewable energy, it is undergoing a fundamental change, particularly in the light-duty vehicle segment where electric vehicles are an emerging solution. Accelerated deployment of electric vehicles represents an opportunity for the electricity industry as well. Electric vehicles can act as flexible load and decentralised storage resources capable of providing additional flexibility to support power system operation. With smart charging, electric vehicles could alternate their charging patterns to flatten demand peaks, fill load valleys and support real-time balancing of grids by adjusting their charging levels.

In the last 20 years, global battery installations grew exponentially, as rapidly decreasing costs and performance improvements stimulated investment (Figure 5.5). Yet battery technologies have yet to be deployed at scale in the energy sector.

Figure 5.5 Global stationary battery storage capacity, 1996-2016



Source: US DOE, 2017.

In the next three to five years, the storage industry in leading countries is positioned to scale up, and it could follow the now-familiar pattern of rapid growth seen in solar and wind technologies. Incremental improvements in energy storage technologies, developments in regional regulatory and market drivers, and emerging business models are poised to make energy storage a growing and viable part of the electricity grid (IRENA, 2017a). Grid services are expected to have increased economic applications due to cost declines, even as renewable electricity expands to serve more island, mini-grid and off-grid energy users. In the e-mobility sector, the sale of electric vehicles, electric buses and electric two- and three-wheelers is growing as performance improves and battery costs fall.

Heat and Cold Storage

Storing electricity in one season for use in another depends on TES systems. As a fundamental requirement, systems for storing thermal energy need to be able to manage large amounts of energy over long periods of time at a relatively low cost to respond effectively to seasonal supply. Global installed capacity of TES systems was about 2.2 GW in 2014, representing an estimated 1.6% of the total installed energy storage capacity worldwide.[17]

Thermal storage systems can be categorised by the mechanism of storage: sensible heat storage, latent heat storage and thermochemical heat storage. Sensible heat storage is commonly used for inter-seasonal storage. It can use hot water tanks or an underground system like borehole, aquifer, cavern or pit storage. The choice of system strongly depends on local geological conditions. A promising example is the world's largest thermal storage tank, constructed by the Big Solar Graz project in Austria for a solar district heating plant. Here, an underground tank of 1.8 million cubic metres (m^3) stores hot water for inter-seasonal demand. Sensible heat storage technologies can also achieve temperatures over 500°C, as is the case with CSP systems utilising molten salts, but the storage period ranges from hours to less than a day in large-scale applications.

In contrast to sensible heat storage, latent heat storage technologies have higher energy density and a more stable discharging temperature. These technologies involve a change of phase in the material, undergoing either a solid/liquid or a solid/solid process. Examples of materials used are ice, sodium acetate trihydrate, paraffin and erythritol.

17 Technologies considered for this calculation are pumped hydro storage, large-scale batteries, hydrogen, flywheels and compressed air energy storage.

Thermo-chemical heat storage can be hot or cold, and can also be used to control humidity. However, this technology mostly allows for storage periods of hours to days and is not yet suitable for seasonal storage purposes. Typical applications are adsorption of water vapour to silica gel or zeolites; interesting fields of application include the use of waste heat.

TES technologies are in their early developmental stages, and innovation is needed across all subcomponents, calling for research in: 1) novel materials, components and devices for enhancing response time; 2) low-cost manufacturing technologies for TES materials, components and devices; 3) degradation mechanisms of TES materials; 4) new thermodynamic cycles for enhancing conversion efficiency; 5) integration and optimisation of thermal energy storage in energy networks; and 6) better insulation.

Fostering Technology Innovations to Support Energy Transitions

Technological innovation in renewable energy and energy efficiency, stimulated by government-driven efforts, has the power to decarbonise the energy sector while also increasing wealth, promoting social inclusion and improving environmental quality and health (IRENA and IEA, 2017). A four-prong strategy for accelerating the energy transitions is outlined below and illustrated in Figure 5.6.

Increased innovation is needed to successfully transform the energy sector. To achieve cost reductions and performance improvements at the pace needed to efficiently transition the world's energy systems to low carbon, the world needs to invest more in innovation. All sectors can benefit from continued improvements in existing low-carbon technologies but, in some cases, the emergence of breakthroughs or a major change in production processes will be vital.

Technology development is not all that is needed. Innovation should also be aimed at creating new businesses and new jobs, helping industries to flourish and providing additional economic opportunities to increase wealth.

Renewable power already has a strong business case, but achieving its potential requires innovation in systems integration. Renewable generation technologies in the power sector are already economically viable, and innovation, together with economies of scale, will continue to reduce their costs, making the business case even stronger. The next step is to focus innovation efforts on integrating high shares of variable renewable energy, such as solar PV and wind, in power systems. So far, the integration of variable renewables has been enabled by flexibility options such as grid strengthening, demand-side management, energy storage, sector coupling and flexible conventional generation. Innovation in systems integration will reduce the costs of enabling technologies, such as energy storage and grid infrastructure, coupled with innovative approaches to operating power systems, designing markets and creating business models. Such innovations will make it possible to create reliable and affordable power systems that are predominantly based on renewable energy.

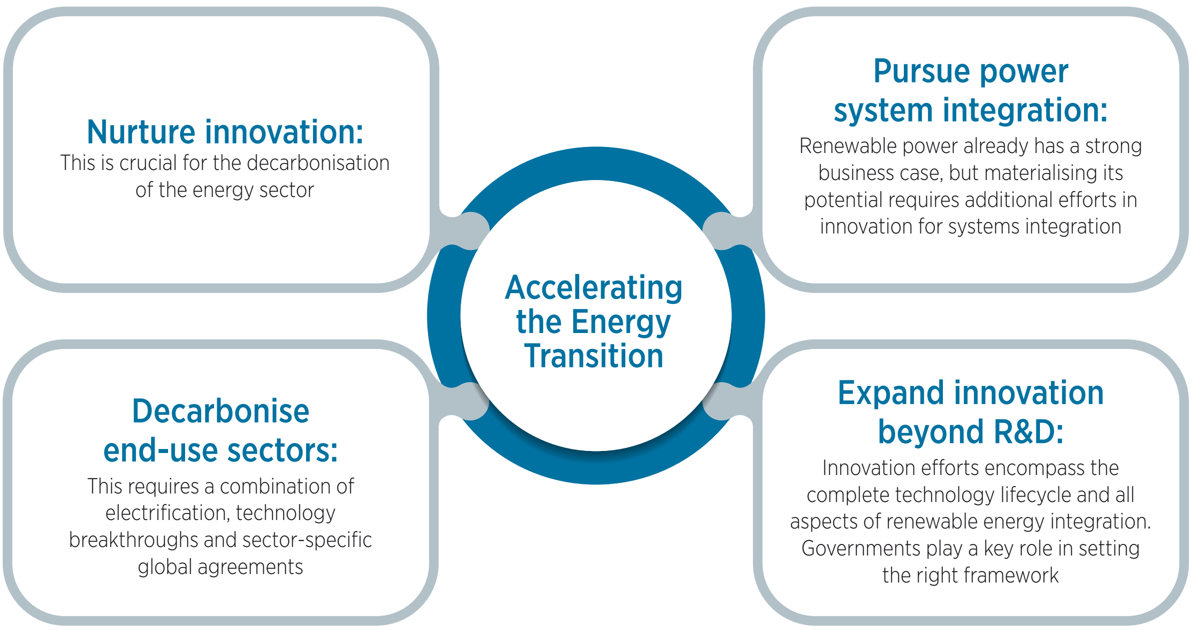
Transitioning end-use sectors will require a combination of electrification, technology breakthroughs and sector-specific policy measures. The electrification of end-use sectors could offer a win-win situation by reducing emissions while supporting the integration of higher shares of variable renewables in power systems. However, electrification is not an option in some energy demand sectors. Economically viable and scalable emission-reduction solutions have yet to be found for sectors such as iron and steel making, cement production, chemicals and petrochemicals production, maritime transport, aviation, freight or the replacement of non-sustainable traditional biomass. Industry and buildings are the most challenging sectors, followed by certain means of transport. These sectors require new technology solutions to be developed and commercialised quickly. Stepped-up R&D for energy efficiency and renewable energy solutions is urgently needed.

Innovation efforts must go beyond R&D, encompassing the complete technology life cycle and all aspects of renewable energy integration. Increased R&D investments are important, as are market-pull incentives, but to focus on either one in isolation will not bring the needed results. Efforts to increase innovation must cover the complete technology life cycle, including demonstration, deployment (technology learning) and commercialisation.

Furthermore, the innovation ecosystem should extend across a whole range of activities, including creating new market designs, building innovative enabling infrastructure, creating new ways to operate energy systems, establishing standards and quality control systems, and implementing new regulatory measures.

Governments have a key role to play in enabling innovation in collaboration with one another and with the private sector. To encourage initiatives in innovation, in particular in the private sector, governments have a key role to play in setting an ambitious agenda and ensuring a proper framework. Basic and applied research in academia and government laboratories is critical to provide expertise, skilled staff and development capacity. A holistic innovation framework encompassing goal-oriented science, technology and innovation programmes can also help to overcome other barriers that have hampered the deployment of decarbonised energy approaches. International co-operation creates a platform where experiences and best practices in renewable energy technology innovation are shared and transferred across countries.

Figure 5.6 Strategy for accelerating global energy transitions



Source: IRENA, 2017h.
Note: R&D = research and development.

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