International Renewable Energy Agency

ARGENTINA 2018
BUILDING CONSENSUS FOR FAIR
AND SUSTAINABLE DEVELOPMENT

OPPORTUNITIES FOR ACCELERATING THE ENERGY TRANSITIONS THROUGH ENHANCED DEPLOYMENT OF RENEWABLES

Final Report

June 2018

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

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Introduction[1]

The world is experiencing a global energy transformation, driven by technological change and new policy priorities. This transformation creates a win-win situation: a strong economy and a healthy planet are mutually reinforcing. The global energy transformation manifests itself in all G20 countries, but for each country the transition to cleaner energy systems has specific features, reflecting specific circumstances and priorities, and hence reference is often made to energy transitions in plural.

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

At the first G20 Energy Ministers Meeting in October 2015, under the Turkish Presidency, renewable energy, energy efficiency and energy access were among the key themes for discussion. Ministers adopted the G20 Toolkit of Voluntary Options for Renewable Energy Deployment ("Toolkit"), which presents a set of voluntary options for G20 countries to accelerate the scale-up of renewable energy. IRENA was tasked to act as the central coordinator for the implementation of the Toolkit, in cooperation with other international organisations, across five action areas:

- Analysis of renewable energy costs, cost reduction potentials and good practices;
- Exchange of good practices on enabling national policy framework design and power system integration of higher shares of variable renewables;
- Development of a risk mitigation facility dedicated to renewable energy;
- Assessment of country renewable energy technology potentials and development of roadmaps, and
- Deployment of modern bioenergy.

At their 2016 meeting in Beijing under 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 aim to substantially increase the share of renewable energy by 2030 and to continue advancing the implementation of the Toolkit.

In 2017, in the context of its G20 Presidency, Germany requested IRENA and the IEA to analyse different options and investment implications for decarbonisation of the energy sector to meet the objectives of the Paris Agreement. At the same time, the Climate and Energy Action Plan for Growth attached to the 2017 G20 Leader's Declaration called on IRENA to support their efforts in providing a regular update report on the global transformation of the energy sector and further investment needs. It also welcomed the

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[1] This document has been produced by IRENA, at the request - and under the close guidance - of Argentina´s G20 Presidency 2018. Its contents have been discussed and enriched by the representatives of the G20 membership, but do not necessarily reflect their national or collective views.

progress achieved with the Voluntary Action Plan on Renewable Energy and the Toolkit, and called for their continued implementation in order to further scale up renewable energy deployment.

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

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, 193 countries agreed on the Sustainable Development Goals, including Goal 7.2 to substantially increase the share of renewable energy in the global energy mix by 2030. Accelerated deployment of renewables as a source of energy has multiple benefits, ranging from socio-economic benefits, including economic growth and job creation, to its contribution to addressing climate change and reducing air pollution, which has severe health impacts in many regions worldwide.

Renewable energy deployment has been growing rapidly in recent years, especially in the power sector, as the economics of renewables have improved, policy frameworks have matured and the field of applications has widened. Since 2012, more than half of the world's new power capacity additions were based on renewable energy and this share has been growing. Power from renewable energy sources represents about a quarter of the world's electricity production in 2017. While end-use sectors, such as heating and cooling, and transport are lagging behind, they start to show encouraging signs of transitioning, for example in the area of electromobility.

As country ambitions continue to grow, there is an increasing recognition that the energy transformation can offer significant economic opportunities and 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 is emerging on what forces will shape the transitions. IRENA's analyses have deepened the understanding of the key role accelerated renewables deployment can play in energy transitions and on the tools and instruments that have proven successful in the countries that are leading the global transformation.

The G20 members host around 81% of the world's total installed renewable power generation capacity and hold 75% of the total global deployment potential of all renewables in the energy sector for the period from 2010 to 2030, as estimated by IRENA. Even though 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. 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.

Chapter 1: The potential of renewables

Key messages

- The unfolding energy transformation will have a profound effect on global energy supply and demand. The share of renewable energy would rise from around 15% of primary energy supply in 2015 to just one-quarter, based on current and planned policies (business as usual) by 2050. IRENA's *Global Energy Transformation: A Roadmap to 2050*, however, shows that the share of renewable energy must actually rise to two-thirds of primary energy supply by 2050, which together with advances in energy efficiency will help achieve global development and climate objectives. To achieve this share, the pace of renewable energy deployment must accelerate six-fold.
- Such energy transitions are economically beneficial – but it will require a 30% increase in investments in low-carbon technologies compared to the business-as-usual. Further significant technology cost reductions will be major drivers for increased investments across the range of renewables and enabling technologies.
- Significant socio-economic benefits will accrue through this global transformation, including improved welfare largely driven by reduced health impacts of air pollution and lower climate change impacts, a 1% higher GDP growth and 11.6 million additional energy sector jobs in 2050.
- The energy transformation will also be the cornerstone of addressing climate change: Based on the "well-below 2°C" objective of the Paris Agreement, carbon dioxide (CO_2) emission intensity of the global economy needs to be reduced by at least 85% by 2050 in order to limit global average temperature increase to well below 2°C compared to pre-industrial levels. Renewable energy and energy efficiency measures can achieve more than 90% of the required energy-related emission reductions to set the world on that path.

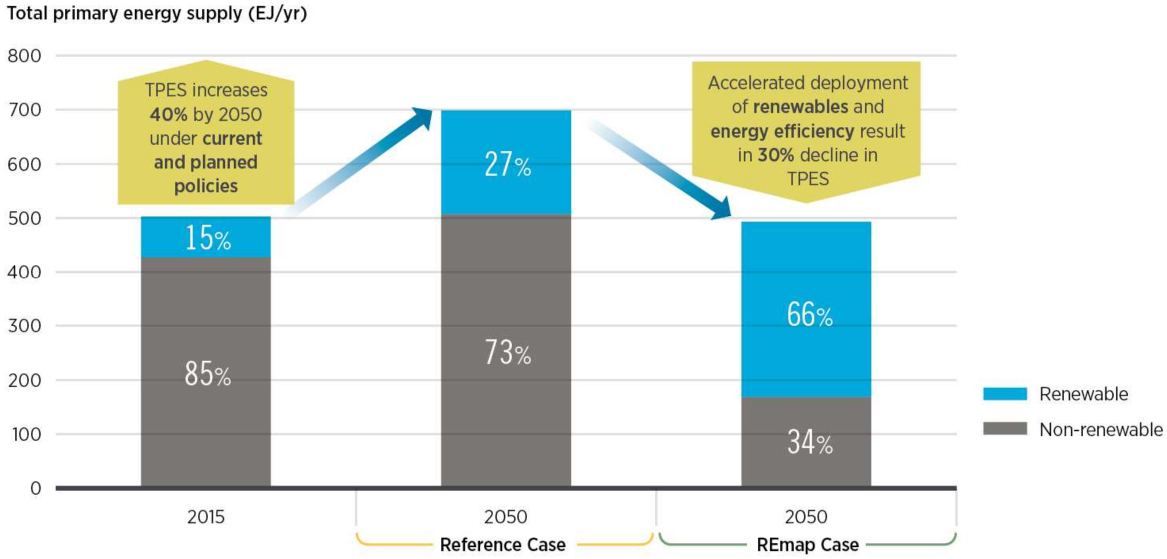
Key actions

- Governments have a critical role in accelerating the energy transitions. In accordance to 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 the energy transitions. Market signals and financial incentives for low-carbon solutions are central. Considering their higher greenhouse gas emissions, the governments of the G20 countries play a key role in this regard.
- Early action is essential to limit the planet's temperature rise 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 global transformation to an energy system that enhances efficiency and is based on renewable energy. Such a global energy transformation – seen as the culmination of "energy transitions" that are already happening in many countries – can create a world that is more prosperous and inclusive.

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

Figure 1.1: TPES and the share of renewable and non-renewable energy under the Reference and REmap cases



Source: IRENA, 2018a.

Furthermore, intensive energy efficiency improvements reduce energy cost for consumers and result in energy demand in 2050 which is close to today's level. Energy intensity improvements would need to increase from a projected 1.8% under business as usual to 2.8% per year by 2050. Such profound transformation will, however, require concerted government action.

To date, renewables account for a quarter of all power generation worldwide and they also account for the vast majority of global power sector capacity additions made since 2012, driven by their economic performance and supportive government policies (IRENA and IEA, 2017). In locations with adequate natural resources, solar PV, wind, hydropower, geothermal and biomass technologies can all now provide electricity that is competitively priced compared to fossil fuel-fired electricity generation. The level of development in locations is rapidly growing as technology improves and costs continue to fall at a rapid rate.

While the power sector is already transforming, electricity itself only accounts for around 20% of the final energy that is delivered to consumers. The remaining 80% of final energy consumed concerns direct-uses of energy for heating, cooling and transportation in end-use sectors (namely industry, buildings and transport). These direct-uses of energy are largely fossil-fuel based, with some sizable contributions of bioenergy, and small contributions of solar thermal and geothermal (IRENA, 2018a).

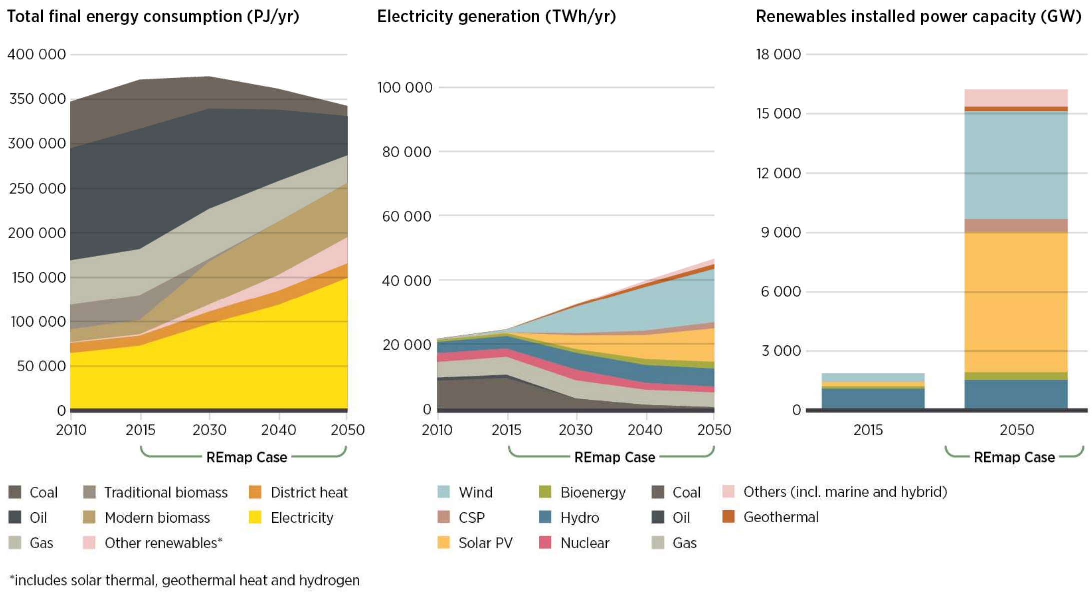
Overall, the main source of renewable energy as of today is bioenergy and this would continue to account for about one-third of renewable consumption by 2050, according to IRENA's 2050 REmap roadmap, where bioenergy would account for 22% of final energy use in transport, 14% in buildings, 19% in industry, and for power generation it would represent 4%. Modern bioenergy can play a vital role in the energy transitions if scaled up significantly. Although more modern bioenergy has been used in recent years, its growth is insufficient to support the requirements of the energy transitions. A much stronger and concerted effort is needed, particularly in sectors for which bioenergy could provide key solutions, namely shipping, aviation and various industrial applications. Along with this, it will be key to ensure that bioenergy is sourced from sustainable and affordable feedstocks.

While in IRENA's 2050 roadmap significant electrification of end-uses takes place, increasing the share of electricity in final energy from 20% to 40% by 2050, there still remains a large part of energy demand that will need to be met from non-electricity sources.

The share of renewables in transportation today is only 3%. This share is higher in industry at around 10%, and highest in the buildings sector at around one-third. Nevertheless, in the buildings sector, much of the renewable energy comes from traditional uses of bioenergy. On the other hand, already a quarter of the electricity consumed globally is supplied with renewable sources.

The share of renewables in electricity generation has been growing at a faster rate than in end-use sectors and the energy transformation will require looking not just at dramatically ramping up electrification of end-uses and renewable power, but also solutions beyond the power sector. Therefore, there is a clear need to include end-uses in planning, solutions and actions. IRENA's roadmap to 2050 shows that the renewable energy share can grow to 77% in buildings, 63% in industry and 58% in transport (IRENA, 2018a).[2]

Figure 1.2: Share of electricity in total final energy consumption, electricity generation mix, and renewable capacity developments for the REmap Case, 2015-2050



Source: IRENA, 2018a.

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

In the REmap Case, the share of renewable energy in the power sector reaches 85%, and wind and solar in power generation would increase to 64% by 2050, requiring policy measures to deploy a range of flexibility options 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]

A combination of electrification with renewable power and direct renewables deployment, underpinned by high-efficiency rates, will be the basis to transform these sectors to achieve a share of 65% of renewable energy in total final energy consumption (TFEC) in 2050.

Box 1: Falling costs of renewable energy technologies

Over the past seven years, solar PV module prices dropped by over 80%, and the global weighted average levelised cost of electricity (LCOE)[5] fell by 73% to USD 0.10/kWh in 2017. Onshore wind turbine prices have fallen by 30-40% between 2010 and 2017, with the global weighted average costs of electricity falling by 23% to USD 0.06/kWh in 2017. Utility-scale solar PV projects commissioned in 2017 had LCOEs as low as USD 0.05/kWh and onshore wind as low as USD 0.04/kWh (IRENA, 2018b), 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 and USD 0.04/kWh, and even lower for delivery by 2020[6]. Concentrated solar power (CSP) and offshore wind have seen auction results of USD 0.06 to USD 0.10/kWh in 2016 and 2017 for future delivery despite being in their infancy in terms of deployment.

The auction results for future delivery imply that, as innovation and economies of scale push costs lower and efficiencies higher, all currently 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) of 14% for offshore wind, 21% for onshore wind, 30% for CSP and 35% for solar PV (IRENA, 2018b) for the period 2010 to 2020.

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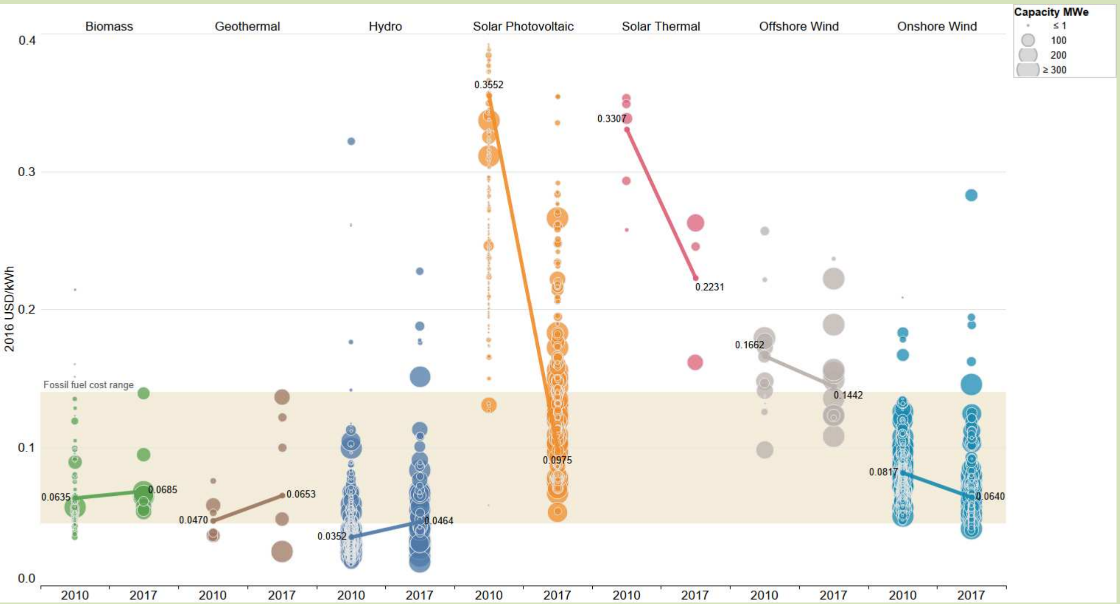
[3] *Chapter 5 further discusses the role of hydropower and power generation from bioenergy resources to provide flexibility.*

[4] *An often discussed flexibility option is storage, which comes in many forms. As of mid-2017, there was 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 REmap, 11,900-15,300 GWh of stationary electricity storage is expected by 2030, with only 51% from pumped hydro (for more details on hydro pump storage, please refer to Chapter 5 in this report). Furthermore, important synergies can be achieved that allow much higher deployment of variable renewables if smart electromobility solutions are widely deployed (IRENA, 2018c).*

[5] *All the LCOE numbers in this box exclude the impact of any local or federal financial support policies, they are for the year of commissioning and are based on IRENA's Renewable Cost Database that contains cost and performance details of 15,000 utility-scale power generation projects.*

[6] *Headline auction prices below USD 0.03/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).*

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



Source: IRENA, 2018b.

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 renewables-based energy system by 2050 as envisioned in IRENA's 2050 roadmap (REmap Case), 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 the 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 Gross Domestic Product (GDP) and employment. Across the world economy, GDP growth would increase by 1% by 2050 with cumulative gains through increased GDP from now till 2050 estimated at USD 52 trillion[7]. 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, the energy transformation can also boost overall employment in the energy sector, as it creates more jobs than those 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).

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[7] *For further discussion of the socio-economic impacts of the global energy transformation, see Chapter 2.*

Chapter 2: Success factors for G20 countries – the policy dimension and selected socio-economic impacts

Key messages

- G20 countries have adopted a variety of policy instruments to support renewable energy deployment. However, to advance the global energy transformation, support will have to be scaled up in all end-use sectors, while fulfilling domestic needs and priorities. Carbon taxes, along with other fiscal incentives, have shown to be effective tools when they provide a sufficiently strong signal.
- Renewable energy policies should be a 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 with policy design to respond to changing market conditions and arising challenges. An assessment of the impacts of policy choices is needed to evaluate their effectiveness in delivering the country objectives. When objectives are not entirely met, policy design needs to be adjusted.
- There is no sole instrument that can fulfil all countries objectives, and the choice of policies should be context-specific and tailored to the particular country 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 coordination among relevant government ministries and different stakeholders. This includes, for example, harmonising industrial and trade policies and extends to the coordination with industry associations and the educational sector for the establishment of dedicated training programmes. In order to avoid skill gaps, G20 countries should fully 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 the 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 in the 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 planning 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 G20 countries initially focused on market creation, but policy-making has since moved to facilitating cost-discovery and improving the cost-competitiveness of renewables. As the sector matures, it is important for policies to continue to adapt to changing market conditions while providing a steady framework for the 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 when 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 the GDP and offers a wide range of socio-economic benefits. In G20 countries and across 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 better gender balance.

This section discusses the latest developments in renewable energy policies in G20 countries in all end-use sectors and provides some good practices for advancing fair and just energy transitions in the G20 countries while maximising socio-economic benefits.

Renewable energy policy landscape

Countries in the G20 have set different types of renewable energy targets, including for power, end-use as well as those included in Nationally Determined Contributions (NDCs). The set targets range from 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 GW installed capacity of solar and wind by 2023). To achieve these targets, various policies have been implemented in different sectors, at times complemented with policies for system integration (see Chapter 4) and energy efficiency[8].

Policies supporting renewables in the power sector

As of 2017, all G20 countries have implemented some policies to support renewable-based power generation from large-scale and distributed installations, and 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 prices and innovative policy design. In 2017, Germany's offshore wind auction resulted in the majority of bidders not requesting any support on top of wholesale electricity prices[9], while the Kingdom of Saudi Arabia and the Russian Federation awarded

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[8] *Policies to advance energy efficiency in G20 mostly draw on economic incentives to drive the energy market for more advanced energy efficient equipment, reducing the upfront investment cost 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.*

[9] *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.*

solar and wind at very low prices[10] (Figure 2.1). Several G20 countries have used innovative policy design to address country-specific objectives and difficult macro-economic conditions. The Mexican auction, for example, tackled grid integration issues by providing local incentives/penalties, and auctioned tradable certificates along with capacity and energy to ensure renewable quotas are met. In India, the government tried and tested different designs using contracts with and without escalation as well as viability gap funding, for instance, to overcome risks related to off-take, inflation and currency exchange. Brazil, a pioneer in auctions, has introduced further innovation in their design to encompass more than just the initial bidding. In 2017, it has offered relief to developers that had bid too aggressively by auctioning the penalties, especially since the depreciation of the local currency was the main reason for default (IRENA, 2017h). In the European Union, the Commission's Guidelines on State Aid for Environmental Protection and Energy adopted in 2015 require the Member States who want to keep their support for renewable energy deployment to do so by using auctions. Some European countries, including France, Germany and Italy, adopted auctions for large-scale projects and kept feed-in tariffs (FITs) for small-scale installations.

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

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

** Price undisclosed at time of auction*

FITs have been successful in driving the solar PV and onshore wind sector in countries like Germany, Japan, China and Indonesia. Some of the challenges faced, however, may lead to a change in policy. For instance, Japan offered an administratively-set solar PV FIT (USD 119/MWh) irrespective of the project size, resulting in the surcharge increasing from 0.3 to 1.4 trillion yen 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

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[10] *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.*

costs linked to this charge[11] (Renewable Energy Institute, 2017). China's FIT (set in 2011 using auctions) has driven installed capacities in 2016 to the highest level globally, with a new record in additions set in 2017. However, issues related to the structure of its power market led to significant curtailment (IRENA, 2014d). 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 IPP and the state-owned power utility.

Fiscal and financial incentives have also played a major 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 the Investment Tax Credit and Investment Production Tax Credit have driven the wind and solar deployment, along with state-level Renewable Portfolio Standards, in the Unites States and the Republic of Korea. India, the United Kingdom, the United States and the Republic of Korea have also relied on renewable obligations[12], with different levels of success related to the respective capacity for enforcing penalties (IRENA, IEA and REN21, 2018). Indonesia's Geothermal Fund Facility, a risk mitigation scheme aimed at reducing the upfront developer risk, together with fiscal incentives such as tax allowances, tax holidays and the simplification of licensing procedures, are expected to accelerate geothermal exploration and development in the country (IRENA, 2017j).

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, for example, net metering is adopted in 41 states and several other jurisdictions and 99% of solar installations across the country were under a net-metering scheme in the year 2014, representing 44% of total solar PV installed capacity (IRENA, 2017c). Other G20 members have also implemented policies for distributed solar PV, including tax exemptions and net metering, such as Australia, Brazil, India, Italy, Mexico and South Korea, among others. As jurisdictions adopting net metering continue to face challenges related to net metering policies to better distribute the costs of grid operation, a number of amendments were made, such as in Brazil.

Policies to support standalone and mini-grid systems have been adopted in order to achieve 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 the development of mini-grids (IRENA, 2016d). This overarching approach to policy-making that combines deployment policies with financing instruments and measures for capacity building has been instrumental to the development of renewables in all G20 countries.

Experience in renewable energy policies in the G20 countries has shown the importance of stability and continuity of instruments in instilling investor confidence and attracting investment in the sector. The case of abrupt changes to the investment tax credit and production tax credit in the United States and how they impact the industry is a case in point. In Spain, retroactive changes to the regulatory instruments that supported renewables resulted in increased uncertainty for existing projects and weakened investment environment, increased the possibility of future legal claims against the government's measures, and significantly heightened policy and regulatory risk. Moreover,

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[11] *The surcharge is calculated by subtracting the avoided costs from thermal power and the office expenses for adjusting cost burdens from the total purchasing cost.*
[12] *Renewable Portfolio Standards in the Unites States and Renewable Purchase Obligations in India.*

policies need to ensure effectiveness and efficiency in deployment. In India, for instance, although fiscal incentives were successful at deploying wind energy, they did not lead to the most efficient installations as the incentives were not performance-based (IRENA, IEA and REN21, 2018).

Policies driving renewables in heating/cooling

Renewable energy in heating/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 some 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, Denmark's renewables in district heating were supported by such policy instruments. Municipalities were obligated to develop heat supply plans in heat-dense areas suitable for collective heat systems, in addition to energy taxes on fossil fuels, with some exemptions for biomass (IRENA, IEA and REN21, 2018). As a result, some European countries with above-average climate-related heat demand and extensive district heating networks have reached 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 some countries (e.g. the Netherlands and the United Kingdom), similar to the FIT for renewable electricity.

For the residential sector, a number of countries have adopted policies to promote solar thermal in buildings, with the most successful countries using mandates for new buildings. South Africa set solar water heater (SWH) targets that have been regularly updated and the country now aims to have 1.75 million systems installed by 2019 and 5 million by 2030. The programme relies on a rebate programme with free installations for low-income households but it has been progressing at a slow pace. In Brazil, solar mandates for new buildings have been set at 40% of hot water in Sao Paulo, while Rio de Janeiro requires all new and refurbished public buildings to meet at least 40% of their water heating needs with solar energy. The Brazilian approach seems to have been successful since solar thermal capacity doubled between 2010 and 2015.

Policies are increasingly supporting renewables for heat in industry in some G20 countries with emerging economies. In many G20 countries, a large proportion of heat demand is in industry and is growing rapidly, driven by economic growth. Industrial heat demand in India, for example, grew by 30% between 2010 and 2015. In industry, cogeneration with biomass has been incentivised by policies, for example, in India and Brazil, which have a large sugar industry and where bagasse is frequently used in cogeneration. In India, the Renewable Energy Development Agency (IREDA) provides loans for setting up biomass power and bagasse cogeneration projects and in Brazil subsidies are provided for bagasse cogeneration. The projects can participate in the auctions and they pay less to access the grid (as with wind and solar).

Carbon taxes can also be effective at driving renewables in heating/cooling and increasing system efficiencies and they have been introduced in some G20 countries. Mexico introduced a tax on carbon from fossil fuel use[13] in 2013, charging USD 3.50 per tonne of CO_2. India introduced a tax on coal in 2010 which 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 a number of renewable energy projects. As yet, these taxes are at a low level but if increased over time, could play an important role.

Clean cooking is supported by policies in G20 countries where people still rely on traditional biomass for cooking. While in some countries, such as China and Indonesia, there have been large reductions in the share of population relying on solid fuels for cooking, overall, the number of people without clean cooking access has stayed flat since 2000 due to population growth outpacing improvements in access (IEA, 2017). In India, the number of people without clean cooking access has even increased and clean cook stove programmes have had a limited impact. Barriers to clean cooking include high capital costs for 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 Cook stoves (GACC), a public-private partnership with the goal of getting 100 million households to adopt clean and efficient cook stoves and fuels by 2020.

Policies driving renewables in transport

Transport is the second largest energy end-user, accounting for 29% of the final energy consumption in 2015 (IEA, 2017), and it remains heavily fossil-fuel based with almost 93% of energy use from petroleum products, representing 65% of global oil final demand in 2014 (IRENA, 2016g). Therefore, many G20 countries have implemented policies to mandate the use of biofuels and promote electric vehicles (EV) 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 (RED) specified a 10% renewable content by 2020 – though this has been scaled back to 5-7.5%. 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. South Korea, for example, imports palm oil - the cost of compliance reached USD 77.5 million in 2014 and is estimated to reach USD 118.7 million in 2018 (biofuel digest, 2016). In Indonesia, mandatory biodiesel blending was increased from 10% to 15% in 2015, supported by subsidies, as biodiesel prices have been generally higher than those for petroleum fuels. In 2015, Indonesia started collecting a levy from the 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, 2017j).

Several countries, states and provinces in G20 have set targets for electric vehicles (EVs). Examples include the zero emission target set forth by the International Zero-Emission Vehicle Alliance (ZEV 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, with the goal of nearly all cars and vans on the road by 2050. India aims to have 6 million EVs (including hybrids) on the road

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[13] *Natural gas has been zero-rated.*

by 2020 and 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. The country also aims to install 12,000 charging stations to serve 5 million EVs by 2020. In the United States, California and several other states require ZEVs to make up around 15% of new car sales by 2025. California also requires that the renewable energy share of hydrogen for vehicles increases to 33% by 2022.

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

Some cities are developing zero-emission (at the tailpipe) transport strategies. In China, Taiyuan became the country's first city to replace its entire taxi fleet with EVs, and the city funded a network of 1,800 charging stations.

Although mandates and incentives for EVs are put in place in almost all G20 countries, they only lead to renewable energy deployment if they go hand in hand with renewable-based power generation. This can be done explicitly by, for instance, binding financial incentives for EVs to the use of renewable electricity. Nevertheless, integrated planning of electric mobility and electricity production, transmission and distribution is crucial. The uptake of electric mobility will increase the electricity demand and may create peak-demands linked to electric vehicles charging, creating the need for system-approach planning and measures for 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 the gross domestic product (GDP) and enables a wide range of socio-economic benefits including employment, local economic value creation and skill-building, and positive health impacts.

Relative to a business-as-usual trajectory, IRENA analysis finds that reducing global carbon dioxide emissions through renewables and energy efficiency would boost global GDP by 1.4% in 2030 and by 1.0% in 2050. The initial positive impact on GDP is due to a net investment stimulus in renewables, energy efficiency, grid improvements and energy flexibility. Changes in tax rates, mainly associated with carbon taxes and the phase-out of fossil fuels, boost GDP growth in the medium term. After a dynamic time-lag, indirect and induced effects become dominant and have a positive impact on GDP in the second half of the energy transitions period to 2050. As expected, global trade has a minor impact on the global GDP increase throughout the whole transitions, 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 construction, engineering and manufacturing of 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 across the economy, too, are positive. In the renewable energy sector, IRENA analysis shows that the number of jobs reached 10.3 million direct and indirect jobs worldwide by 2017 (Figure 2.2), with the potential to grow to 29 million 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. Job growth is driven by the net gains in employment as, for instance, per dollar of expenditure. Spending on 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 compared to coal or natural gas (UKERC, 2014).

Figure 2.2 Renewable energy employment, 2012-2017

Source: IRENA, 2018d.

Owing to the variety of generating technologies, the renewable energy sector spans a broad range of occupations and skills (IRENA, 2017c; IRENA and IEA, 2017). To avoid already evident skills gaps from widening, better coordination between the industry and education institutions is essential. Specialised training institutions also play a role. For example, the South African Renewable Energy Technology Centre (SARETEC) was established to offer accredited training, working closely with government, academia, and industry. In partnership with domestic education and research institutions, SARETEC is also 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 is still relatively scarce. IRENA's online survey of nearly 90 companies from more than 40 countries (IRENA, 2017i) suggests that women account for 35% of the labour force. This is higher than the 20-25% range that is typical in the conventional energy sector, but lower than the 40-50% economy-wide share in most OECD countries. 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 (child-rearing, 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 employment 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 that a specified portion of inputs to a renewable energy project be sourced domestically. Outside of 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; Hablemito lu, 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 due to be 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 wellbeing. Changes to the energy system, including policies and investments in support of renewable energy deployment, are assessed by how they impact economic growth. Studies indicate a positive effect emanating from transitions towards 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 a complete picture of 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 latest study, *Global Energy Transformation: A Roadmap to 2050*, suggest that welfare gains of 15% (relative to a business-as-usual scenario (Reference Case) are possible by 2050. This is mainly due to the reduction in negative health effects from 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. 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.

Chapter 3: Access to finance for developing countries and risk mitigation instruments

Key messages

This chapter focuses on renewable energy investments in developing countries. Where these markets are considered by investors as riskier, the cost of capital tends to be higher, reflecting a risk premium added on top of other costs. This is a result of real constraints or merely a reflection of a lack of track record in a country where little renewable energy capacity has been built. To overcome constraints that limit investor interest for renewable energy assets and to support an accelerated scaling up of investment in renewables[14], the following actions have proven successful:

- Create an enabling environment for renewable energy investments which would reduce 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 global capital for the renewable sector.
- Support the growth of new capital market instruments, such as green bonds, through which investors can invest in renewables. Successful development will entail a collaborative approach among the policy makers, security regulators, issuers and investors, and set forth robust and clear rules for issuance, reporting and use of proceeds from such instruments.
- Help develop a pipeline of investment-mature renewable energy projects through targeted use of public finance, support of initiatives and platforms which assist in project preparation and which connect various stakeholders, and by supporting standardisation of project procedures and documentation, as well as the development and uptake 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 which development finance institutions can use their high credit rating, access to market and knowledge of project finance to draw in a greater share of 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 affordability of new energy technologies for economically disadvantaged communities and 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.

Key action:

To support the implementation of the good practices aforementioned and build on synergies through international cooperation and pooling of risks, the G20 Energy Transitions Working Group may consider advancing the following action:

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[14] *Continuity and synergy should be maintained with existing initiatives in this area, such as the Investment and Infrastructure Working Group ("IIWG"), one of the main working groups of G20 mandated to recommend cooperative principles in global infrastructure investment, including with respect to financial engineering, risk allocation and mitigation.*

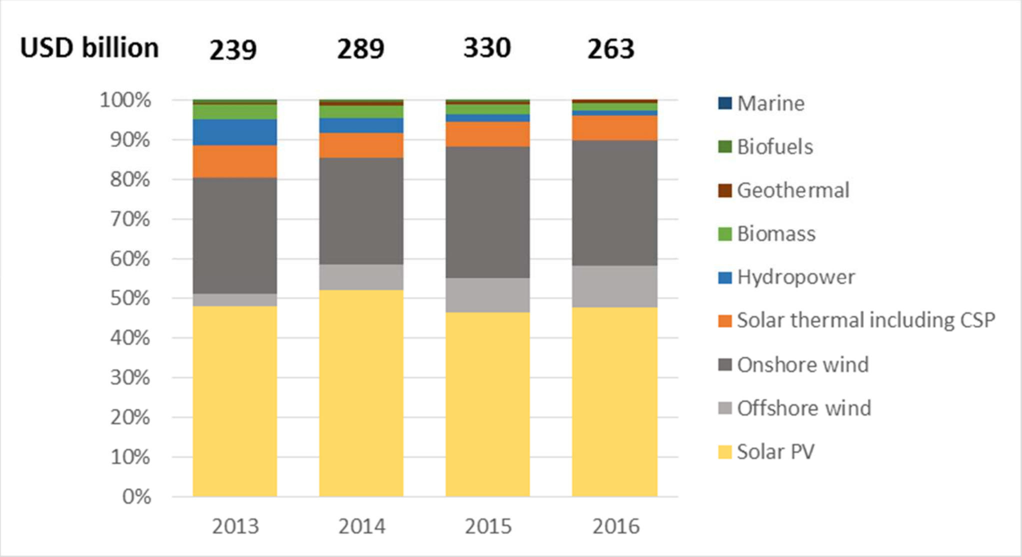
- Support the creation of a global risk mitigation platform dedicated to renewable energy to facilitate issuance of standardised guarantee/insurance products for renewable energy projects, and mobilise international capital to back up these guarantees and accelerate renewable energy investments.

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). Preliminary estimates by IRENA and CPI suggest that, in 2017, investment levels have remained stable compared to 2016, at around USD 265 billion. While annual investment declined in 2016, annual capacity additions steadily grew over time. This was partially due to declining technology costs, as well as to the time lag between the financial closure[15] 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, reflecting cost declines and investors' preference for large-scale projects.

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



Source: IRENA and CPI, 2018.

Capital flows into renewable energy in the last five years have been characterised by a notable geographic shift. While the initial investment occurred mostly in Europe and the United States, in the 2013-2016 period, the East Asia-Pacific region, dominated by investments in China, has been the main destination for renewable energy investment, accounting for one third of the 2016 total (or USD 88 billion out of the total USD 263 billion)

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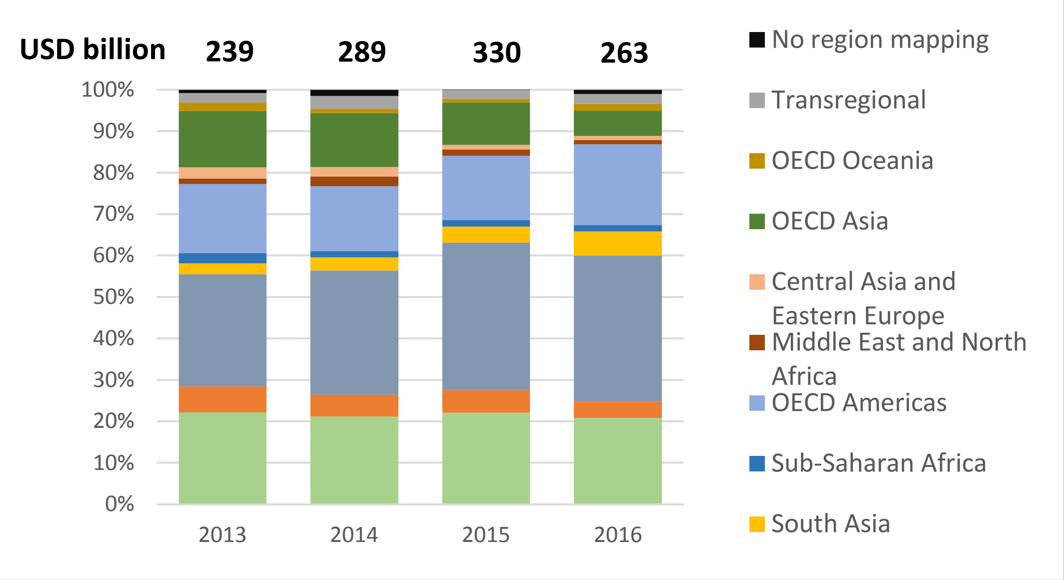
[15] *That is the time of investment.*

(IRENA and CPI, 2018). Western Europe came at the second place in 2016, with USD 53 billion, followed by the USD 51 billion investment made in OECD Americas (IRENA and CPI, 2018). While India and Brazil also had significant investments in renewables in 2016, other emerging economies in Africa, Asia and Latin America represent largely set-aside opportunities in terms of their renewable energy investment potential.

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



Source: IRENA and CPI, 2018.

While the bulk of renewable energy investment globally is provided by private sources (over 90% of direct investment[16] in 2016), direct public finance can play a key enabling role, covering early-stage project risk and getting new markets to maturity. Significant additional public resources are allocated every year to the implementation of a wide variety of support policies to promote 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: 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, maximise the socio-economic opportunities, as well as to minimise 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 upfront costs, project-specific characteristics and perceived high risks associated with renewable energy technologies, such as variability and performance risk. However, with the increasing cost-competitiveness of renewables over the years and accumulated experience in the sector, many project developers are now better able to

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[16] *Excluding expenditures for feed-in tariffs and other policy support measures.*

overcome such barriers and seize the opportunities that renewable energy projects can bring.

As the industry further matures, the main challenges include policy frameworks, availability of risk mitigating instruments and the scale of renewable energy projects. Some of the common risks in renewable energy projects, such as the power off-taker and currency risk, are still perceived as high in certain markets, in particular, 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, allow investors and developers to cover risks, thereby lowering financing costs and making renewable energy projects more attractive to investors. Focusing on such risk mitigation instruments offers public finance institutions strong leverage to mobilise private investment, which can be an effective strategy to maximise the impact of scarce public resources. International finance institutions are well-positioned to mitigate investment risks of renewables, but they have in the past dedicated only about 4% of their total infrastructure risk mitigation issuance value to renewable energy (IRENA, 2016h).

Developing economies face significant additional challenges in their ability to attract capital into renewable energy projects. This is mainly due to higher real or perceived risks, for instance regarding policy, regulatory or institutional frameworks which some investors consider non-transparent or unreliable, undeveloped capital markets, as well as a lack of local financial capital and capacity to develop investment-ready projects. Lack of local capacity can be in the form of inadequate transmission infrastructure, system design or inefficient permitting procedures. Lack of local capacity may also pose a constraint, since, for instance, local financial institutions in developing economies often lack expertise and experience in renewable energy, or more generally in project finance, resulting in a limited renewable energy project pipeline. Unfavourable national investment conditions and nascent capital markets lead to 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 paid by end consumers.

Unlocking investment for renewables deployment

To unlock investment opportunities in renewable energy in emerging and developing countries, the focus has to be placed on the alleviation of main risks and barriers. Addressing these requires a range of measures that enable investments, and improve both project and capital supply in the market. This requires action at the national level, but it can be supported through coordinated and joint international action.

Enabling environment

Developing energy policies to create a stable, long-term and streamlined basis for renewable energy deployment. An enabling policy framework is the foundation of greater and more efficient deployment of financial capital in the renewables sector. As described in Chapter 2, various policy instruments have been proven successful in many countries around the world, including the G20 countries, to encourage renewable energy deployment in the power and the end-use sectors. These instruments allow the creation of a level-playing field for renewables while catering to local conditions and policy priorities. The reduced cost of renewable energy technologies has reduced fiscal pressure on public budgets and hence eliminated a factor that placed the long-term stability of policy frameworks, which is so important for investors, at risk.

Enabling 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 large bulk of assets globally, and need to recognise renewable energy assets as an attractive part of their portfolio. This would help to scale up finance available for renewable energy investment and it would diversify investors' portfolios away from conventional energy assets that will be potentially 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 assets (of which renewable energy is often seen as a subset). These regulations can severely restrict investor's ability to allocate a portion of its assets to renewables. For instance, new financial regulations such as Basel III for banks and Solvency II for insurance companies require such institutions to hold more capital reserves for their long-term and less liquid assets (such as their investments into renewable energy assets) (UNEP, 2014). As a result, insurers and banks may decide to 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.

Adjusting and developing policies and guidelines to increase green bond issuance for renewables. Green bonds are capital market instruments that help scale up renewable energy and other 'green' investment by allowing investors to allocate their capital into listed and professionally managed funds. Governments can support the issuance by developing policies and guidelines for issuing green bonds. Policy frameworks for green bond issuance can attract significant new investment, as seen in China and India. The first step in creating such guidelines is for the key stakeholders to define a vision and identify opportunities related to green bonds. Government authorities, such as the securities market regulators and central banks, would then define criteria for which projects could be considered 'green' and procedures for how green bonds would 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.

It should be noted, however, that in many emerging economies, before green bonds issuances can be scaled up or even initiated, local or regional capital markets need to be first developed and strengthened in terms of their regulation and supervision. This is well beyond the scope of energy ministries, but is critical to establish investment attractiveness of a particular sector. While bonds are a source of debt finance, there are also important vehicles for green equity finance, such as YieldCo structures. These are discussed in IRENA (2016h).

Ensuring a viable project pipeline

Facilitating renewable energy projects from initiation to full investment maturity. The existence of a robust and continuous pipeline of new projects is a necessary precondition for the greater mobilisation of investments into renewables, particularly for larger investors such as institutional investors, as it would justify the commitment of large capital resources and efforts of risk-analysis teams (World Bank, 2015). Governments and development finance institutions (DFIs) can support project pipeline preparation 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. As these project preparation facilities represent a potentially promising area of development, more funding support should be made available to them. 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 the renewable energy markets.

Simplifying, streamlining and standardising project documentation to reduce transaction costs and speed up project development and financing process. 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 highly disseminated, capital intensive and scalable. Significant standardisation efforts have also been made at the country-level: examples include Argentina's RenovAr programme, Australia and South Africa's REIPPPP programme 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.

Facilitating aggregation to permit scaling-up of investment and to increase asset liquidity. Some large-scale investors would not be interested in even considering 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 underperformance of any single project, thus lowering the overall risk for investors. Standardisation of project documentation and terms is a prerequisite for aggregation of renewable energy assets. Once aggregated, renewable energy assets would be easier to sell, for example to large institutional investors or to energy utilities with renewable energy mandates. An example of seven solar projects aggregated into a larger portfolio in Jordan by the International Finance Corporation (IFC) is presented as a case study in IRENA (2016h, Chapter 5.3).

Improving capital supply

Institutional investors such as pension funds, insurance companies, endowments and sovereign wealth funds, can play a crucial role in scaling up of renewable energy investments, as they manage over USD 100 trillion in total assets (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 multiple significant benefits to institutional investors. These include fulfilment of fiduciary duties, asset diversification, as well as potentially high-yielding and long-duration returns that can match institutional investors' long-duration liabilities.

Institutional investors' commitments to invest directly in European new renewable energy projects have been growing, reaching over 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, 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 national wealth's vulnerability to falling oil prices (Fouche, 2017).

Engaging local financial institutions in renewable energy finance and improving 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 is therefore needed. On-lending, also known as financial intermediary lending, can increase the availability of local debt, improve access to local financing and help build local lending capacity (IRENA, 2016h). Public finance institutions can use their high credit quality 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 such 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, 2016h). Participation of a development finance institution in loan syndication can bring in local banks, because they can 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.

Promoting 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 energy power generation, storage and energy efficiency projects. While data on global volumes are lacking, in the case of Germany in 2012, for example, it has been estimated that citizens and cooperatives funded about 47% of the 73 GW of installed renewable energy power capacity (Farrell, 2014). Helping to further grow this sector, which has a broader range of considerations compared to 'traditional' investors and can therefore provide capital at lower cost, through initiatives such as Australia's National Community Energy Strategy (NCES, 2018), should help lower the overall cost of borrowing for renewable energy projects, especially for the scale gap between the utility-scale and household-scale projects.

Expansion of innovative low-cost financing models will increase affordability of new energy technologies and accelerate progress with energy access goals. Off-grid solar and other renewables provide a very cost-effective way of bringing rapidly clean energy to communities that currently rely on traditional biomass and which power grids will not reach within the foreseeable future. Several initiatives are tackling the challenge of a relatively high upfront cost of off-grid renewable systems through end-user financing schemes tailored to income profiles and demand. In Bangladesh, for example, this has translated into extending microfinance services to households to procure solar home systems, whereby upfront payments are typically 15% of the system costs followed by, generally, 36-month installment loan payments, similar to monthly expenditures on kerosene. In other countries, for example in East Africa, the pay-as-you-go (or PAYG) model is increasingly common, whereby households follow a payment scheme for different products and services, often via mobile money, in the form of a perpetual lease or eventual system ownership (IRENA, 2017a).

Promoting local currency denominated power purchase agreements (PPAs), or mixed currency PPAs, to enable local investors to invest in domestic renewable energy projects. Currency risk is a particularly acute risk in emerging markets with sometimes volatile macroeconomic conditions. Currency risk 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 such risk can be mitigated via hedging instruments, such as currency forward contracts and swaps, in emerging countries such instruments are not easily available or are potentially costly. As a result, PPAs are often denominated in a hard currency (such as USD or EUR) to avoid the mismatch for foreign capital providers. As a result, the currency risk is pushed onto local actors, in some cases the local utilities. The second implication of hard currency PPAs is that local investors, such as local pension funds, are excluded. To avoid such impacts, PPAs are increasingly being denominated in local currency, 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.

Creating 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 greatly help attract private investments into renewables. Such facility could also provide support for transaction costs, guarantee fees or technical assistance via grants. The basic approach of a dedicated facility has been supported and endorsed by G20 countries in the Toolkit which mandated IRENA to follow up on the development of a risk mitigation facility addressing the specifics of renewable energy (IRENA, 2016b). In this context, 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 the experiences in the use of specialised risk mitigation instruments covering various risks, such as counterparty, political and currency risks.

Taking a decentralised approach, either national development finance agencies or regional development banks can take the lead in providing capital and administering fund provision 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. This programme provides energy payment and sovereign guarantees through a national trust Fund for the Development of Renewable Energy (FODER). FODER's solvency guarantee was implemented using a guarantee account funded at all times, with an amount equivalent to 12 months payment of all PPAs subscribed, to back up any insolvency risk of the off-taker. 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 CAPEX of the project. This mechanism was implemented through a put option mechanism by means of which the project companies may terminate the PPA contract and sell the renewable energy to any third party, or to exercise the put option, assign the project assets to FODER and receive a cash compensation for it at a put option price equivalent to all non-depreciated CAPEX of the project. Such put option price was guaranteed by national bonds. The International Bank for Reconstruction and Development (IBRD) guaranteed and backstopped the government's 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 (KfW) and African Trade Insurance Agency (ATI) for Africa, which takes a regional approach, providing short-term credit lines with a guarantee to address power off-taker risk for independent power producers 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 the risk assessment standards and help increase the creditworthiness of renewable energy projects. In the end, the investors and lenders would de-risk their exposure at an acceptable price, and reinsurers and guarantors would achieve a better spread of risk and accept exposures that match their risk appetite. The concept would provide 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.

Chapter 4: Integration of renewable energy in power systems

Key messages

- **The power sector has been leading the way in the global energy transformation with increasing shares of renewable energy.** Taking this transformation to its potential as outlined in Chapter 1, however, requires a significant increase in renewables in the coming decades, with increasing shares of the overall energy system being electrified to achieve proper integration and efficient deployment, while acting in accordance with national circumstances, priorities and needs.

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

- **The transitions are witnessing the emergence of new actors in the energy system and redefining the role of existing ones**. Regulatory measures should facilitate the relationship between all stakeholders, including consumers, prosumers, aggregators, utilities, and distribution and transmission companies. In particular, it is important to enable the active and effective involvement of consumers and prosumers in the energy system's configuration and operation.

- **Policies and regulations are needed for electricity market design.** Markets (capacity, dispatching, and balancing) should be designed so that they can play their role to facilitate the optimal deployment of the flexibility resources, with adequate frameworks and incentives that encourage flexible behaviour on both the supply and demand side. Enough energy flexibility resources are available to support the transitions towards a renewables-based energy system, including 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 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 performance-based and focused on total system costs.

- **Policies and regulations for prosumers and the design of tariffs**. Retail tariffs are one of the main drivers of consumer and prosumer behaviour. Regulation should take advantage of this and actively promote self-consumption and demand response by adopting a cost-reflective design for retail and flexibility services retribution tariffs. Behind-the-meter generation and storage can yield benefits for both end-users and the power system as a whole. An appropriate tariff structure would need to be established to fully reap potential benefits.

- **Energy efficiency deployment** has a very important role to play in the transitions, directly mitigating emissions, accelerating the increase in renewables' shares, and in the context of an integrated energy system limiting the power sector growth and the requirements for renewable energy deployment. Policies and regulatory measures should leverage on the synergies between energy efficiency and renewable energy deployment, while striking the right balance between energy efficiency and flexibility.

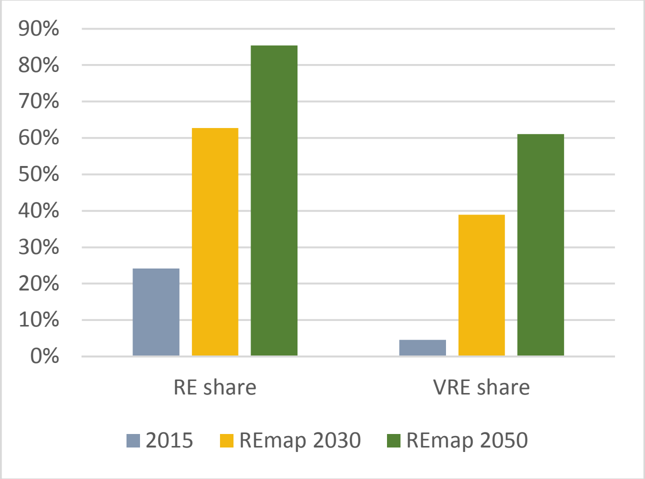
Key actions

- Remove the barriers that prevent the 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 for distribution network planning and operation that facilitate the participation of distributed resources in the energy market by focusing on performance-based regulation and on total system costs.
- Develop policies and regulations that establish the appropriate mechanisms for smooth interaction between existing and new stakeholders, including appropriate retail tariffs. These will strengthen the trust between prosumers, consumers and the other electricity system stakeholders, providing the required citizenship empowerment that enables unlocking the full transitions and smartness potential.
- Develop a vision and a roadmap for the electricity market that can support a renewable energy-based system. This requires going beyond addressing today's specific issues related to the increasing penetration of low marginal cost renewables into a power sector, envisioning an electricity market structure appropriate to support and guide the operation and configuration of a power system based on renewables.
- Encourage the deployment of the energy efficiency potential while ensuring the right balance between energy efficiency and energy flexibility in the context of an integrated energy system.
- Ensure higher levels of collective and individual ambition 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 higher shares of renewables.

Technology aspects

The power sector transformation to renewables is ongoing apace. The power sector has been leading the way in the global energy sector transformation. While each country is at a different stage of this process, many have successfully integrated a high share of renewables-based generation in their power sector, particularly by exploiting vast PV and wind resource potentials. These sources, referred to as variable renewable energy sources, are expected to have the largest growth potential through 2030 to 2050, and to help enable the electrification of the heat and transport sectors.

Figure 4.1: Shares of total renewable energy and variable renewable energy in total electricity generation (current statistics and projections according to the REmap study)



Source: IRENA, 2018a

The transitions to power systems with a high share of variable renewables will bring fundamental changes to power system operations. Reliable power system operations have traditionally relied on dispatchable fossil fuel plants or hydropower to meet supply and demand at all times, with their synchronous generators ensuring system stability. Limited output-dispatchability and the non-synchronous nature of variable renewables will require new ways of operating power systems, and the magnitude of challenges increases as the share of variable renewables increases (IRENA, 2017g).

At low shares, investment needs may be limited and focused on transmission reinforcement and minor retrofitting of power plants to increase their flexibility, in conjunction with increased electricity market and operation coordination at the regional level. Where the speed of deployment of variable renewables far exceeds the pace at which transmission capacity can be expanded, electricity storage can play an important role even at relatively low shares. It is worth noting that storage is only one possible source of flexibility and it will be competing with dispatchable generation (both renewable and fossil), interconnectors, demand-side management and sector coupling opportunities (e.g., thermal storage, EVs, etc.). At higher shares, the role of storage may become crucial, initially to provide grid services, complement the reduction in firm capacity due to the replacement of dispatchable generation with variable renewables (i.e. to meet net demand peaks) and perform short-term arbitrage. At very high shares of variable renewables (greater than 70-80%), seasonal storage could become necessary, where 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 increasingly available, including those which can be applied in a cost-competitive manner, and those emerging solutions that require further innovation. Policy-makers should focus on creating appropriate regulatory and market environments to facilitate variable renewables integration and minimise the cost of integration. Key solutions that exist today are discussed below.

Incorporating appropriate requirements for variable renewable energy in national grid connection codes is essential. In the past, power systems relied primarily on conventional generators to meet system stability requirements. As the share of variable renewables increases, they 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), EVs provide an opportunity to absorb variable renewable electricity at times of high solar and wind output, and potentially provide some grid services to smooth a potential generation adequacy challenge. Benefits from EV integration and smart charging can be seen already at low shares of variable renewables, but become significant at high shares, going 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 monetizable revenue streams reflect the value provided to the system. Other end-use sector-coupling opportunities may also provide the flexibility needed, including through thermal energy storage, district heating and cooling networks and the aggregation of smart appliances.

Cost of storage continues to fall but uncertainty regarding the future potential role of storage remains. In general, a limited amount of storage can provide significant benefits in most power systems, especially for ancillary services and to support meeting residual demand peaks (i.e. avoiding investments in peaking plants). Beyond this limited initial amount, country pathways for storage will be dependent on the specificities of each system (IRENA, 2017e). 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 at very high shares of variable renewables. In transmission constrained systems, or systems with a limited geographical footprint, storage may be an economical solution already at an early stage (e.g., on islands). An in-depth power system analysis is necessary to ensure that the value of storage for a specific system is carefully assessed. IRENA is developing a storage valuation framework to support such analysis.

Enhancing the planning frameworks to determine the best transitions path. Comprehensive transitions planning can minimise the technical impacts of integration of variable renewables and the associated costs. A series of coordinated planning studies is essential in identifying techno-economic bottlenecks, evaluating the cost-effectiveness of solutions to integration and building political consensus on the long-term goals. Crucially, while variable renewables can be deployed rapidly, transmission requires significantly more time, making planning essential for the cost-effective deployment of variable renewables. As part of the energy transitions analysis, IRENA has developed a ‘FlexTool’ to assist in assessing the optimal amount of cost-effective investments 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 technology rapidly emerge, new opportunities for renewable energy integration are becoming available in the power and end-use sectors. For example, major improvements to ICT and increased digitalisation can allow for greater engagement of power consumers through 'smart' devices or networks. ICT has enabled the emergence of aggregators and virtual power plants, and blockchain technology facilitates peer-to-peer exchanges. Such innovations are, and will continue to affect, the sources, boundaries and dynamics of value in the power sector landscape.

Market design aspects

While, in principle, the above-discussed technology 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 often necessary, with incentives that encourage flexible behaviour on the supply and demand sides at appropriate time intervals and locations, and 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 for demand (i.e. industry, commercial and electric vehicles).

As the electricity sector transformation gathers pace, the shares of variable renewables will need to rise significantly. The higher levels of penetration will introduce certain challenges in the electricity system and market for which early responses will be needed. Effectively tackling these challenges with increasing penetration of renewables requires the deployment of energy flexibility tools such as storage, demand response and an active role of renewable energy generation will need to be increasingly facilitated by efficient markets. These changes will require a rethinking of electricity markets to overcome the barriers that currently hinder the full range of flexibility options to fully participate (IRENA, 2017c, IRENA, 2014a).

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 in decentralised power generation requires new approaches to network regulation and advanced grid management methods.

Based mostly on IRENA's (2017c) report, *Adapting Market Design to High Shares of Variable Renewable Energy,* this section draws 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 related to electricity market design, distribution system, the prosumers and tariffs design.

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 the electricity and market systems, and compromise the reliability of services[17]. 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, the time frames).

Electricity markets are organised through different time frames: the long-term addressing capacity expansion, the short-term addressing electricity dispatch and the very short-term addressing real time balancing.

- Growing variable renewable energy shares, because of their lower marginal costs, within the current market structure, leads to low energy prices. This effect, together with increased cycling requirements to procure flexibility from conventional fossil-fuel plants, challenges recovery of conventional generators' investment costs (IRENA, 2017c), leading utilities to request reinforcing capacity mechanisms. This market modification, if undertaken, must focus on supporting and facilitating the transitions process, and avoid introducing barriers. In a renewable energy-based electricity system without regulated support for renewable energy generation, the low energy prices would not allow the required return on investment and would not provide a sustainable framework. The market structure therefore needs to be revised. One option is the incorporation of transitions-focused capacity mechanisms and/or premium tariffs as potential tools for complementing the energy market revenues.

- In the short-term market (i.e., day-ahead and intra-day markets), electricity is usually traded as a stable output for a certain period (trading block), which is usually one-hour long. 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 its generation, providing an improved characterisation of the required flexibility (IRENA, 2017c). An aggregator could enable and facilitate its incorporation into the system and market, as long as the barriers are removed.

- In the very short-term market (i.e., balancing market), which operates close-to-real-time, it is the responsibility of the system operator to ensure overall system security and stability. This requires an instantaneous (in the order of seconds) matching of electricity supply and demand. As volumes of renewable energy generation increase, addressing this aspect will require increased market participation of fast-responding energy flexibility. Properly designing balancing markets is essential to offer accurate incentives for flexibility. The system can procure flexibility from energy storage, demand response, and the capability from all renewable energy

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[17] *The right policies design can avoid or help reduce technical curtailment. At low levels of penetration, curtailment is unlikely to be required. As variable renewables' deployment grows, this may become a larger issue. However, the more flexibility there is, the less need for curtailment. The right policies can help unlock this flexibility. Curtailment may become necessary in systems with high shares of variable renewables and should be assessed at the investment stage to ensure investment recovery. However, significant curtailment at low shares of variable renewables is happening in some systems, mainly due to insufficient grid capacity, inflexible generation and market distortions.*

technologies to contribute to overall system regulation. In many power systems (Belgium, Denmark, Spain), renewable energy producers and even variable renewable energy producers, are considered responsible for their imbalances (IRENA, 2017c). But imposing penalties does not provide the required solutions. Technological innovation has proven to allow 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, 2017c). 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 experienced an increasing number of distributed energy resources connections. This is mainly driven by support policies and decreasing costs of renewables, and the empowerment of small and medium-size consumers by the spreading of 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 operations and planning, economic regulation, changing roles, and innovation (IRENA, 2017c).

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 gap between flexibility providers, markets and system operators. Moreover, they will have to integrate the flexibilities offered by distributed energy into their planning and operational practices. Comprehensive, holistic and inclusive planning of generation expansion, fully incorporating the potential from 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 volumes connected in a grid in the mid- and long-term. Without knowing how to estimate this impact, revenues linked to the current tariff structure could be insufficient to cover the 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 network costs' recovery and distribution operators' revenues, as well as enabling new streams of revenue that allow network operators to have a more active involvement in the transitions. Regulation should update the way distribution companies are rewarded: output/performance-based and total cost-based regulation should be adopted. For example, the United Kingdom's Office of Gas and Electricity Markets (OFGEM) launched a new regulatory model, called RIIO ('Revenue using Incentives to deliver Innovation and Outputs'). While before RIIO capital and operational costs were kept separate, under RIIO 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 role: A consequence of the increasing decentralisation of power systems is that the flexibility resources connected to the distribution grid become progressively needed to balance the systems' generation and demand. Adopting a role to facilitate this process is limited by existing provisions. To unlock the flexibility of 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 to rule 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 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 United States GridWise Alliance and the Indian Smart Grid Forum (IRENA, 2017k).

Policies and regulations for prosumers and the design of tariffs

Retail tariffs are one of the main drivers of consumers and prosumers behaviour. Regulation should take advantage of this and actively promote self-consumption and demand response by adopting a cost-reflective design for retail and flexibility services retribution tariffs. 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 deployment may bring about difficulties in ensuring cost recovery of grid services, leading to opposition and demands from utilities to reformulate the retail tariff structure. However, a tariff reformulation centred exclusively on this issue could lead to tariffs that penalise prosumers in ways that, together with the availability of increasingly affordable distributed storage, could even encourage prosumers to disconnect from the main grid (leading to the so-called utility death spiral).

Cost-reflective tariff structures should be deployed, which requires moving away from purely volumetric charges and introducing some kind of fixed charge (e.g., USD/meter-month), demand charge (USD/kW) or readjusting the weight between these two components where they already exist but do not properly reflect system's costs structure (IRENA, 2017c). Exposing consumers and prosumers to time-dependent pricing (time-of-use tariffs) would incentivise consumers to consume in those hours of the day and of the year when variable renewable energy resources are abundant, therefore 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 towards socket parity.

Implementing sharing economy approaches into tariff reformulation would facilitate the transitions by partly eliminating the resistance from those stakeholders that may feel threatened by the process, and by simultaneously engaging those other stakeholders currently without an active role in the system (prosumer empowerment).

Well-designed net metering schemes that encourage self-consumption can drive prosumers toward a more system-friendly behaviour. Regulations should consider the appropriate design elements, like the length and timing of the netting period and the actual value of net excess generation. These efforts would strike the right 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 mentioned above and regulatory measures. Different solutions are possible for the rollout of smart meters, from mandates to the distribution companies to free consumer choice. Brazil, for example, offers a middle path. The regulator passed a norm mandating 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.

Chapter 5: Innovation for emerging and deploying renewable energy technologies

Key messages

- The global energy transformation is powered by new and innovative technologies. Technologies that are not widely deployed today will have to play an important role in the transformation of the energy sector. IRENA's analysis indicates that more than 15% of the CO_2 abatement potential, or 4.8 Gt CO2/yr, could come from a combination of the following technologies:
    - Concentrating solar power (CSP)
    - Ocean energy
    - Offshore Wind
    - Geothermal energy
    - Bioenergy – advanced liquid biofuels
    - Hydropower – pump hydro energy storage
    - 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 both R&D to improve performance and cost and the innovative approaches to the deployment and scale-up of these technologies to fully realise their potential. While it is the private sector that ultimately must bring innovations to market, governments have a critical role to play in facilitating that. 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 and health.

Key actions

- Support and encourage established platforms to strengthen knowledge spreading and establish more cross-border cooperation on innovation in 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 control requirements 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 renewables technology innovation agenda, which identifies the critical innovation needs of developed, emerging and developing markets and designs collaborative strategies to address them. International collaboration should consider approaches to foster technology and knowledge transfer for renewable energy.
- Encourage a systemic approach to innovation that considers not just technology innovation but also innovations in systems, processes, market design and business models to accelerate the spread and uptake of innovations.

- Foster the transfer of technology from developed to emerging countries.

The global energy transformation is powered by new and innovative technologies. Emerging technologies that are not widely deployed today will have to play an important role in the transformation of the energy sector. IRENA's analysis indicates that more than 15% of the CO^2 abatement potential, or 4.8 Gt CO_2/yr, will come from the emerging technologies discussed in this section (IRENA, 2017b). Additional investment needs for these emerging technologies are estimated at USD 6 trillion, from 2015-2050.

This section briefly presents the current status and perspectives of select key emerging technologies. These technologies differ in their stage of development, including technologies in R&D stages, such as ocean energy, to technologies in early commercialisation, like advanced biofuels, CSP and offshore wind, and more mature technologies just starting to be scaled-up, like hydro pump storage and geothermal energy. The list of technologies discussed in this section is by no means comprehensive. There are many other interesting technology opportunities at various stages of development and a more comprehensive overview can be found in IRENA's report *Accelerating the Energy Transition Through Innovation* (IRENA, 2017b).

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 one gigawatt, 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 enable decarbonisation of the global energy system.

The significant advantage of CSP over PV is that it can integrate low-cost thermal energy storage 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 can be divided into 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 (ST) use a ground-based field of mirrors (heliostats) to track the sun (in 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 to USD 0.07/kWh for plants that will be commissioned in 2020-2022 and onwards. Moving forward, key improvements expected for PTC plants will enable significantly reduced installed costs, capital costs and LCOEs while also improving thermal storage performance. China is a key emerging market for this technology, where half of the costs is expected as the CSP market and technology mature. IRENA's analysis indicates that, by 2025, a reference PTC plant with 7.5 hours storage could see total installed costs decline by 33%, from USD 5 550/kW in 2015 to USD 3 700/kW (IRENA, 2016f). Potential cost reductions for CSP plants may result from:

- Cost reductions in the solar field component (mirrors, collectors, piping, etc.). This will contribute about one third to the total installed cost reduction potential.

- Learning effects, significant expected declines in the indirect costs for engineering and management, and in the owner's costs elements;

- Decrease in risk margins of suppliers and energy performance contracts (EPCs) parties along with increased commercial deployment of the technology;

- Reduction in the cost of indirect engineering and owner's costs.

These aspects will contribute approximately half of the total installed cost reduction potential of PTC systems to 2025. Over the same period, thermal energy storage system cost reductions will account for about one fifth of the installed cost reduction potential. At the same time, the overall efficiency of PTC plants is expected to increase from 15% to 17% by 2025.

Ocean energy

The theoretical resource potential of ocean energy is more than sufficient to meet the 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, 2014a). At present, ocean energy technologies are still in development stages, with most technologies in the prototype phase and some in 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 due to the early stage of development. It has been observed that tidal stream demonstration plants may have an LCOE between EUR 0.320 and 0.371 per kWh, while wave demonstration plants may have an LCOE between EUR 0.407 and 0.52 per kWh (IRENA, 2014b).

Ocean energy technologies are commonly categorised based on the utilised resource 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 the potentially significant environment impacts have previously ruled this technology 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 highest wave resource can be found between 30 and 60 latitude and in deep water (> 40 meters) locations with the southern latitudes having the most extreme power density, corresponding to the locations with the highest wind forces. Wave energy technologies have not seen a convergence towards a specific technology, as encountered with wind energy or tidal energy. A distinction can be made between different type of wave technologies: oscillating water column, oscillating bodies and overtopping devices (IRENA, 2014e). 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, generating energy from the movement of this buoy caused by all wave directions relative to the base connection. By June 2017, a cumulative installed 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, Russia, South Korea, the United Kingdom and the United States of America. A distinction is made between tidal range and tidal current technologies. The former makes use of tidal barrages, the latter extract energy from tidal currents. The highest share (> 90%) of installed ocean energy capacity is tidal range energy. However, it should be noted that this capacity mainly corresponds to just two installations; a 240 MW plant in France from 1966 and a 254 MW in South Korea from 2011. It is unlikely to see more of this large-scale tidal range installation in the near future due to high capital costs and environmental impact concerns. It is likely that technology will move towards tidal current technologies. In the coming years, a significant increase in installed capacity for tidal current is expected, growing from a cumulative installed capacity of 30 MW by June 2017 to 775 MW in 2020, demonstrating the growth in commercial deployment.

Figure 5.1: OTEC Project in La Martinique

Source: DCNS and Akuo Energy

Ocean thermal energy conversion (OTEC) technology. OTEC energy generation is based on the temperature difference between the surface and deeper layers of the ocean. At locations where this difference is around 20 C, energy can be produced using cycles with heat exchangers and turbines (IRENA (2014c) provides an OTEC technology brief). 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, and NEMO plant with a net capacity of 10.7 MW is under construction (See Figure 5.1). It is worth mentioning that 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.

Challenges for Ocean Energy. Further development of ocean energy technologies faces numerous challenges in the technology, environmental, infrastructure and economic domains. These challenges include the difficulties of deployment and maintenance, as well as ensuring reliable operation in harsh environmental conditions, lack of convergence entailing little shared learning that might reduce costs, and a current lack of economies of scale that would help costs fall to competitive levels. Challenges are summarised in the table below.

Figure 5.2. Challenges for Ocean Energy technologies

Challenges and Barriers	
Environmental & Social	Uncertainties on impact
	'Sharing' the ocean
Technology	Surviving environment (salinity, extreme forces)
	Lack of resource assessment
Infrastructure	Lack of grid-connection
	Lack of supply-chain support
Economic	Lack of funding
	High LCOE

To address the aforementioned barriers, tailored combinations of different policies need to be implemented to encourage research, development and stakeholders' engagement for commercial-scale ocean energy development

Offshore wind

Offshore wind technology allows countries to exploit new sites with high wind resources. 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 to decarbonise the energy sector. The first commercial-scale offshore wind plant was commissioned in 2002 in Denmark with an installed capacity of 160 megawatts (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 can reach 100 gigawatts (GW) by 2030, as innovation continues and the industry evolves (IRENA, 2016c). In 2016, average installed costs for a European offshore wind farm were at USD 4 697/kW. From 2010-2016, the global weighted average LCOE of offshore wind decreased from USD 0.17 to USD 0.14/kWh, while the prices awarded in auctions in 2016 and 2017 for projects that will be started up by 2020-2022 range from USD 0.06 to USD 0.10/kWh (IRENA, 2018b).

Developments in wind turbine technologies as well as in foundations, installation, access, operation and system integration have permitted moves into deeper waters, further from shore, to reach sites with better wind resources. Today, turbines are being routinely installed in water depths of up to 40 m and as far as 80 km from shore. These turbines, rooted in the seabed by monopile or jacket foundations, are still restricted to waters less than 50 m 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 m) with higher wind resources. Accordingly, floating foundations are potentially game-changing technology for offshore wind.

Figure 5.3: Sample of floating foundation designs

Source: IRENA, 2016a. 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, 2016a). The first full-scale prototypes for floating wind turbines have been in operation for several years with three main designs being tested (Figure 5.3): spar buoys, spar-submersible and tension-leg platforms.

2017 has seen significant and encouraging developments in floating foundations technology. The first offshore wind farm, deploying floating foundations, began operations in October 2017 in Scotland. The Hywind Scotland wind farm has a nominal power capacity of 30 MW, consists of five turbines of 6 MW each, and uses a spar buoys design (Hirtenstein, 2017). Based on progress seen in the market, three to five additional foundation designs are expected to have been demonstrated at full scale by 2020, and commercialisation of floating offshore wind could be anticipated between 2020 and 2025.

To accelerate floating offshore wind project development, policy-makers may facilitate private investment, through, for example, continued use of proven mechanisms focused on pre-commercial technology, such as extending support to demonstration plants, and providing sufficient confidence and visibility in 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 from 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 tectonic active 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, residential and non-residential sectors (IRENA, 2017f).

Global geothermal power capacity by the end of 2017 totalled 12.8 gigawatts (GW) (IRENA, 2018f), with annual electricity generation reaching 80.9 terawatt-hours (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 power plants range from USD 1 870 to USD 5 050 per kilowatt (kW), noting that 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 to USD 0.14 per kilowatt-hour (kWh).

Concerning heat applications, there are three main technologies: 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 the local economic development and allow to 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 others, size of the economy, market design, geographical location, as well as targeted type of applications (electricity, district heating and cooling, etc.).

A peculiarity of geothermal projects, especially those located in green fields, is the high resource risk during the exploration phase. Significant upfront cost for test drilling is required before confirmation of resource presence, and therefore before project profitability can be determined. This uncertainty during the early phase of a geothermal project makes it difficult to mobilise capital to higher risk project exploration phase, especially through the private sector. Innovative risk mitigation mechanisms, together with sound exploration, can play a vital role in reducing or sharing part of this risk, thereby leveraging private finance. To improve the enabling frameworks for investments for geothermal power generation and direct-use, governments and key organisations have joined forces to work together under the Global Geothermal Alliance. The initiative, coordinated by IRENA, was launched at COP21 in December 2015 with the aim to enhance dialogue, cooperation and coordinated action among public, private, intergovernmental and non-governmental actors.

Bioenergy – advanced liquid biofuels

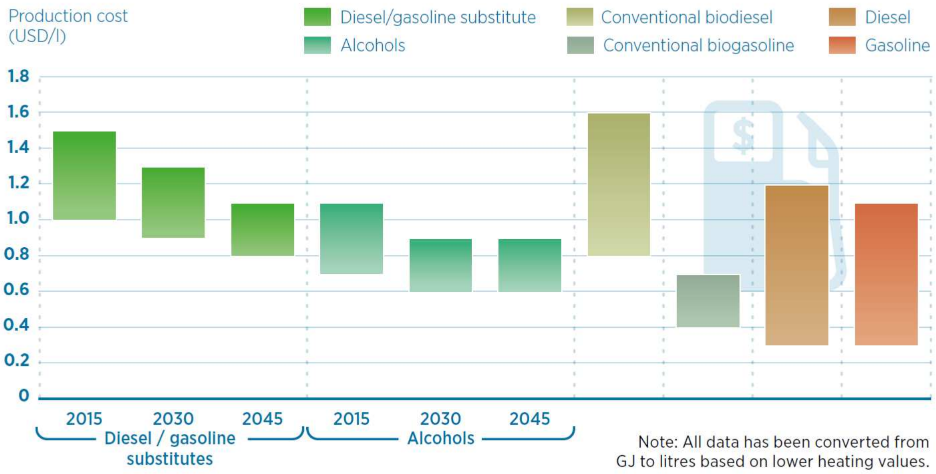
Bioenergy plays a vital role in achieving successful energy transitions towards a low-carbon energy system by the second half of the century. A great advantage of bioenergy is its versatility as an energy resource, as it can be converted into final energy for heat, power and transport fuels. IRENA analysis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

Today, around 4% of transport energy is liquid biofuels (137 bln litres in 2016). Liquid fuel demand is expected to increase globally, with most of the growth in Asia, especially China and India. IRENA projections suggest that, for successful energy transitions, 500 billion litres per year should come from liquid biofuels by 2030. In recent years, the growth was around 2% per year, whereas a growth of up to 10% per year would be 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, in particular the scaling-up of cellulosic bio-gasoline production to commercial levels, which is today limited.

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 biofuels 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, it would then be difficult for advanced biofuels production to compete with fossil-based gasoline and diesel. But at oil prices above USD 100, most advanced biofuels should be able to compete effectively.

Figure 5.4: Current and projected fossil fuel and biofuel production costs



Note: All data has been converted from GJ to litres based on lower heating values.

Source: IRENA, 2016c

For 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. It is therefore extremely important to establish sustainable, affordable and reliable feedstock supply chains 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 the current liquid transport fuel demand. Plants planned or under construction would add another 2 billion litres of capacity per year. These include plants producing ethanol, methanol, mixed alcohols, diesel and jet fuel, mostly located in Brazil, Europe and North America. Clearly, the pace will have to pick up exponentially, and projects 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 in Nevada, United States, the largest such plant in the world 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, 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 progress in advanced biofuels technologies, as many issues arise with scale-up from laboratory conditions, such as feedstock impurities and logistical requirements and the need for offtake arrangements. But commercial-scale pilot plants have a high-risk profile and will typically not be built if support is not 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. Internalisation of carbon cost in the market would encourage production and conversion of lignocellulosic feedstocks. Public procurement initiatives can create biofuel demand for 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 for 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: While technology development highly benefits from international collaboration between research institutes and industry, globalised biofuel markets also require internationally harmonised requirements. A number of collaboration platforms exist focused on bioenergy, which can be utilised to advance in bioenergy technology development and deployment. These platforms include, for example, the Global Bioenergy partnership, IRENA, IEA Bioenergy and FAO. More recently, the Biofuture Platform has been established based on a proposal from Brazil, aiming at promoting international collaboration and dialogue between all stakeholders and facilitating an enabling environment for advanced bio-economy related investments.

Hydropower – pump hydro energy storage

Hydropower is a well-established technology. It is mature and reliable, and currently, the leading renewable technology for electricity production. It is estimated that the total installed hydropower capacity in the world reached 1 270 GW at the end of 2017, with 20 GW added during the year (IRENA, 2018e). 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 for hydropower.

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 rapid growth in deployment of variable renewable energy technologies observed in recent years has resulted in a need and higher value for measures that can increase the flexibility of power systems. Electricity storage is one of the key options for integrating higher shares of variable renewable energy. At present, pump hydro energy storage (PHES) is the main technology being used to provide energy storage services at 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 total global energy storage from all electricity storage types as of mid-2017. Almost half of the world's PHES capacity is installed in only three countries: China (32 GW), Japan (28 GW) and the United States (22 GW). In 2016, an estimated of 6.4 GW of PHES capacity was added, doubling the amount installed in comparison with 2015.

Figure 5.5: Yanbaru Okinawa pumped hydro energy storage

Source: Agency of Natural Resources and Energy, Japan

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 photovoltaic and wind capacity, electricity storage capacity of more than 1 000 GW is required by 2030. Almost a third (325 GW) of this storage capacity should come from PHES.

The International Hydropower Association (2017) indicates that PHES has traditionally been used for arbitrage of electric energy (85.2%). The business model was to take advantage of pricing differentials between on-peak 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 in order to harness new revenue streams in addition to arbitrage, for example, by providing grid services. Traditionally, in PHES power, regulation is available only when generating. New variable-speed PHES systems can increase plant efficiency and flexibility by enabling power regulation in both pumping and turbine mode. 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. That is the case in the German Naturspeicher project. In this project, vessels at the base of each of four wind turbines act as the upper reservoirs. The wind turbine heights are increased due to the vessel in the base, allowing the turbine to harness stronger winds, while PHES regulates frequency variations wind fluctuation. Another example of innovations in PHES is the use of seawater, avoiding the need to divert freshwater resources into a large reservoir and water losses through evaporation. This option is now being considered in various countries, such as Japan, Chile and Australia.

New business models are also being considered for PHES. There is a need to identify new operational concepts that can unlock additional revenue streams, such as from providing additional flexibility options to balance system operation. There are proposals, in the United Kingdom for example, to adopt a ´cap and floor´ pricing system for PHES. Under cap and floor, utilities are guaranteed a minimum price for output but a maximum price is also set, which 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 GE and Voith are now working on developing cloud-based solutions to assess the condition of equipment, such as generators and turbines, without the need to dismantle and re-assemble them.

Enabling electrification – batteries and electric vehicles

Batteries will play a key role in facilitating the next stage of the energy transitions by helping to enable the integration of higher shares of variable renewable electricity, accelerating off-grid electrification and indirectly decarbonising the transport sector. Battery storage systems in the electricity sector are used in four main segments:

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

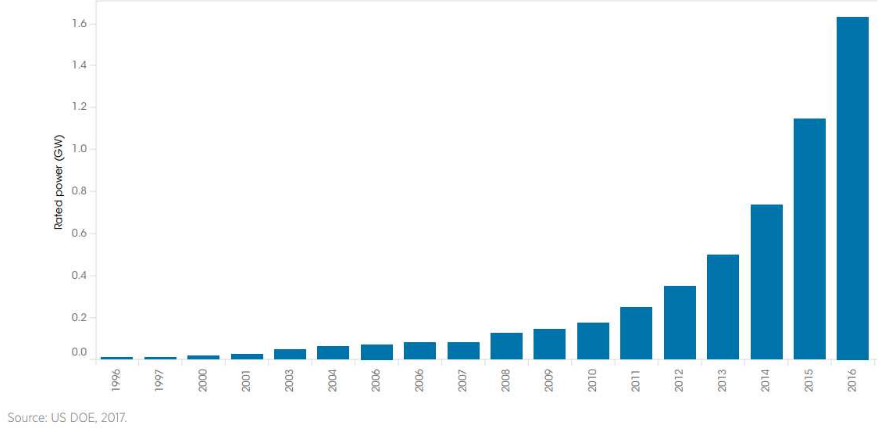
Behind-the-meter applications. Battery storage systems are used to increase the local self-consumption of decentralised generation. As such, the amount of power obtained from the grid can be lowered, resulting in reduced electricity bills for adopters. Although currently not economically profitable for most private users, a general interest in new technologies and the increasing 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 close to 475 MWh were 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 in the coming years.

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 are often off-grid since, traditionally, diesel generators are used 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 increase the implementable amount of renewable energy in off-grid systems up to 100%, allowing an entirely clean and local energy supply for remote locations.

Electromobility. EVs represent a paradigm shift for both the transport and power sectors, with the potential to decarbonise both sectors by coupling them. 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 EVs are an emerging solution. A significant scaling-up in EVs deployment represents an opportunity for the electricity industry as well. They can act as flexible loads and decentralised storage resources capable of providing additional flexibility to support power system operation. With smart charging, EVs could alternate their charging patterns to flatten peak demand, fill load valleys and support real-time balancing of the grids by adjusting their charging levels.

Battery technologies are currently in their infancy in terms of deployment in the energy sector. During the last 20 years, global installations of battery deployment grew exponentially, as rapidly decreasing costs and performance improvements stimulated investment.

Figure 5.6: 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 that is evident 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, 2017e). In the stationary sector, increased economic applications due to cost declines are expected for grid services, as well as a growing penetration of renewable electricity on islands/mini-grids and off-grid. In the e-mobility sector, as performance improves and battery costs fall, the sale of EVs, electric buses and electric two- and three-wheelers is growing.

Heat and cold storage

Thermal Energy Storage (TES) systems are key for seasonal storage, which essentially involves storing electricity in one season for use in another. As a fundamental requirement, these types of storage systems 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. The approximate amount of global TES installed capacity was 2.2 GW in 2014, representing around 1.6% of the total installed energy storage capacity[18] worldwide.

There are different types of thermal storage systems based on the mechanism of storage: sensible heat storage, latent heat storage and thermo-chemical heat storage. Sensible heat storage is one of the commonly used technologies for inter-seasonal storage. It can use hot water tanks or underground applications, like borehole, aquifer, cavern and pit storage. The choice of these technologies strongly depends on the local geological conditions. A promising example of this technology is the largest thermal storage tanks worldwide constructed by the Big Solar Graz project in Austria for a solar district heating plant. For this project, underground tank of 1.8 million m^3 stores hot water for inter-seasonal demand. Sensible heat storage technologies can also achieve high temperatures, over 500°C, as is the case of CSP 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 more stable discharging temperature. These technologies involve the change of phase in the material, could be either a solid/liquid or a solid/solid process. Some examples of phase change materials are ice, na-acetate trihydrate, paraffin and erythritol.

Thermo-chemical heat storage can be used to store heat and cold, as well as to control humidity. However, this technology mostly allows for storage periods from hours to days and has not been so suitable for seasonal storage purposes. Typical applications are adsorption of water vapour to silica-gel or zeolites and interesting fields of application include waste heat utilisation.

TES technologies are in early development stages. Therefore, innovation is needed across all the subcomponents of a TES system, demanding key research needs for innovation in: (i) novel materials, components and devices for enhancing response time; (ii) low cost manufacturing technologies for TES materials, components and devices; (iii) degradation mechanisms of TES materials; (iv) new thermodynamic cycles for enhancing conversion efficiency; (v) integration and optimisation of TES in energy networks, and (vi) better insulation.

Fostering technology development for the energy transitions

Technology innovation in renewable energy and energy efficiency, stimulated by government-driven efforts, would bring major benefits beyond decarbonising the energy sector, increasing wealth, promoting social inclusion and improving environmental quality and health (IRENA and IEA, 2017).

Increased innovation is needed to successfully transform the energy sector. Innovation is one of the key factors that will drive the energy transitions process. Many have recognised that the world is under-investing in innovation if the goal is to achieve the cost reductions and performance improvements at the pace needed to transition the world's energy systems to low carbon. All sectors can benefit from continued improvements in existing low-carbon technologies but, in some cases, the emergence of breakthroughs or

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

a major change in production processes will be vital. The required transformative innovation must not target technology development alone. It also should be aimed at creating new businesses and new jobs, helping industries to flourish, and providing additional economic opportunities to increase wealth.

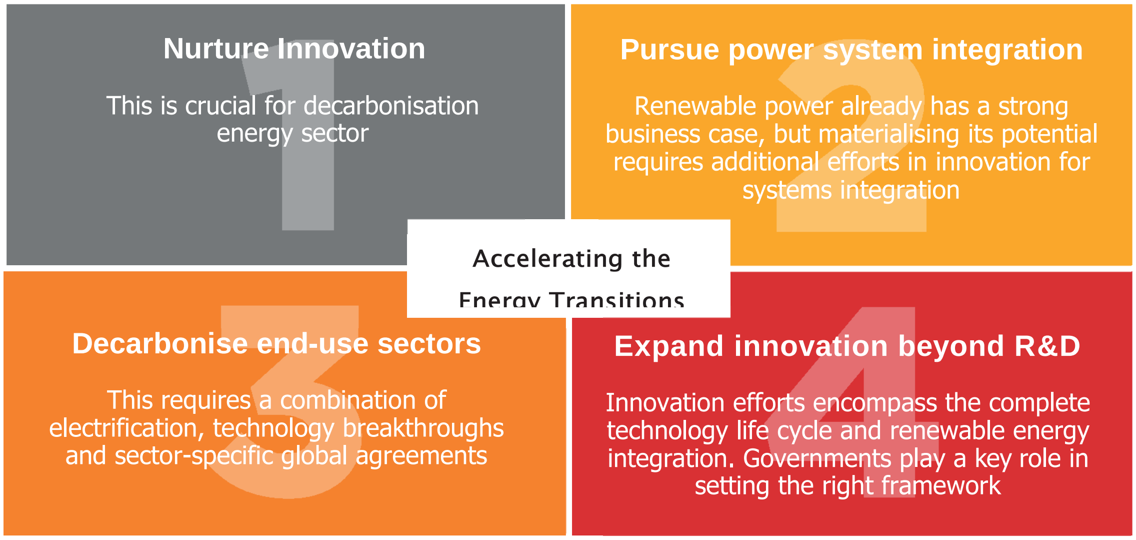
Renewable power already has a strong business case, but achieving its potential requires additional efforts in innovation for systems integration. Renewable generation technologies in the power sector are already economically viable, and innovation, together with economies of scale, will continue to reduce their costs, making the business case even stronger. The next step, therefore, is to focus innovation efforts on integrating high shares of variable renewable energy, such as solar PV and wind, in power systems. The integration of variable renewables has been enabled by such flexibility options 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 for 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 in reducing emissions while supporting the integration of higher shares of variable renewables in power systems. However, electrification is not an option in a number of energy demand sectors. Economically viable and scalable emission reduction solutions are 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 some means of transport. These sectors require new technology solutions to be developed and commercialised quickly. There are, therefore, urgent R&D needs for energy efficiency and renewable energy solutions.

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 well as market pull incentives, but either one in isolation with a limited focus will not bring the needed results. Efforts to increase innovation must cover the complete technology life cycle, including demonstration, deployment (technology learning) and commercialisation stages. Furthermore, the innovation ecosystem should extend across a whole range of activities, including creating new market designs, building innovative enabling infrastructure and 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 and need to further work together 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 for innovation. Basic and applied research in academia and government labs are both critical in terms of providing expertise, skilled staff and development capacity. A holistic innovation framework can also help to overcome other barriers that have hampered deployment of decarbonised energy approaches. Developing successful, goal-oriented science, technology and innovation programmes is of paramount importance. International cooperation also creates a platform where experiences and best practices in renewable energy technology innovation are shared and transferred across countries.

Figure 5.7: Strategy for accelerating the energy transformation



Source: IRENA, 2017b.

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