IRENA
International Renewable Energy Agency

REthinking Energy 2017

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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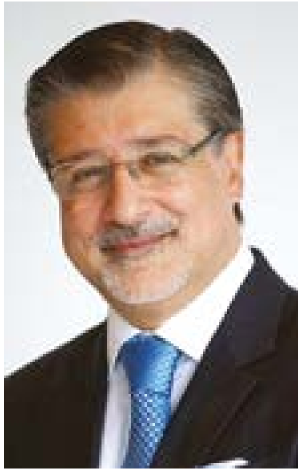
FOREWORD



Adnan Z. Amin

Director-General
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In 2015, the international community came together with renewed ambition to adopt the Paris Agreement and the 2030 Agenda for Sustainable Development and its 17 goals as key blueprints for the future we want. The success of both, however, will depend to a large degree on our momentum on renewable energy, not just for "access to affordable, reliable, sustainable and modern energy for all" (SDG7), but for every one of the goals and commitments the global community has set for itself.

This edition of *REthinking Energy* presents evidence and a compelling narrative of the remarkable ongoing transformation and how renewable energy is being produced and used – in the rapid growth of solar PV, for example, in game-changing storage innovation, in the success of fine-tuned policies and new financing mechanisms. A further boost has come from bold commitments by the private sector. Iconic companies such as Google, Apple, and Facebook are committing to procure renewable energy for their operations, while a vibrant small- and medium-size enterprise sector in emerging economies is pioneering new and successful models bringing sustainable energy to the energy poor.

But the world is never static; new challenges are bound to arise. Can the short-term trends that so clearly favour renewables be sustained? Will enough financing be forthcoming and in what form? Will technological change be rapid enough to drive innovation and investment? Will political commitment endure?

The Paris Agreement came into force in November 2016. More than 150 governments have now put forward their proposed contributions, a testament to a strong collective sense of purpose. Yet studies suggest that the existing commitments may not be sufficient to keep the global temperature increase below 2° Celsius, and certainly not below the 1.5° threshold that science says may be necessary to ward off a climate catastrophe, unless we are able to nurture and grow the global energy transformation at an unprecedented scale and pace.

The momentum of change to accelerate the energy transformation continues but raises important questions about the policy, technology and financial challenges ahead. Important developments and political change have created a dynamic if unpredictable environment. Will this momentum be sustained and grow?

That is certainly our hope. Renewables are a proven commodity. By any reckoning, a fundamental transformation of the world's energy and industrial systems is under way and this edition of *REthinking Energy* aims to be a thought-provoking contribution to the ongoing debate.

REthinking
Energy
2017

REthinking Energy 2017

Accelerating the global energy transformation

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Executive Summary

Renewable energy is a fundamental and growing part of the world's ongoing energy transformation. Governments all over the world are joining that consensus. The use of renewables is their prime choice for enhancing access to affordable, reliable and cleaner sources of modern energy services. More than 170 countries have established renewable energy targets, and nearly 150 have enacted policies to catalyse investments in renewable energy technologies. Many are looking to partner with an increasingly active private sector.

Recent studies by IRENA and its partners have shown clearly that renewables are competitive, attractive to investors and creating millions of new jobs. They present a compelling business case. This edition of *REthinking Energy,* the third in IRENA's series, examines the dramatic changes under way in the energy sector in many countries. Among them is the growing maturity of the renewable energy market, coupled with technology advancements and policy refinement. Together, these developments provide an opportunity to develop an energy system that underpins sustainable development objectives.

The foundations exist for accelerating the global energy transition, but efforts need to step up to achieve long-lasting change. Policy commitments still need to be strengthened, additional investments catalysed, and technological innovation fostered if new markets are to be geared up, efficiency enhanced and costs driven down even further.

According to nearly every measure, renewable energy is gaining ground. Today, one out of every five units of energy delivered to consumers comes from renewable sources. This is remarkably evident in the power sector, where renewables are growing at unprecedented rates, far outpacing growth in conventional technologies. Since 2012, new generating capacity fuelled by renewables has exceeded that fuelled by non-renewables by a widening margin. At 154 gigawatts (GW), capacity from renewables represented 61% of all new power generating capacity added worldwide in 2015 (IRENA, 2016b).

Renewables are now the first-choice option for expanding, upgrading and modernising power systems around the world. Wind and solar power, which commanded about 90% of 2015 investments in renewable power, are now competitive with conventional sources of electricity, as their costs have plunged in recent years. The cost of wind turbines has fallen by nearly a third since 2009 and that of solar photovoltaic (PV) modules by 80%. These developments are reflected in the levelised cost of electricity with some renewable technologies having reached grid parity. Currently, onshore wind, biomass, geothermal and hydropower are all competitive or cheaper than coal, oil and gas-fired power stations, even without financial support and despite relatively low oil prices.

Great potential remains for renewables. Currently, the share of renewable energy in total final energy consumption stands at 18.3%. About one-half of this portion is made up of modern renewables, evenly split between electricity and direct heat applications. The other half consists of traditional biomass used for heating and cooking. If all current national plans and policies are fully implemented without additional measures, the share of renewable energy in the total global final energy mix will rise only slightly by 2030 – from 18.3% to 21% – a measure of the extent of unexploited potential.

IRENA envisions a far more ambitious pursuit of all available renewable energy options and of energy efficiency, one that will result in a doubling to a 36% energy share for renewables by 2030. This doubling can be reached with available policy, investment and innovation interventions, while also achieving universal access to modern

energy without unsustainable use of biomass. This ambitious goal will require accelerated deployment of modern renewables and energy efficiency measures.

Accelerating the deployment of renewable energy will fuel economic growth, create new employment opportunities, enhance human welfare and contribute to a climate-safe future. Renewables already are a significant source of new employment, accounting for an estimated 9.4 million jobs in 2015 (including large hydropower). Asia is the leading region, and solar PV and bioenergy are the leading technologies. Were the share of renewables to reach 36% by 2030, employment could amount to an estimated 24.4 million (IRENA, 2016c).

The socio-economic benefits go well beyond jobs. Doubling the share of renewables could raise global GDP in 2030 by more than a percentage point over the baseline projection, or United States dollar (USD) 1.3 trillion in 2015 dollars – equal to the current combined economies of Chile, South Africa and Switzerland (IRENA, 2016e). Doubling would also save up to USD 4.2 trillion annually in avoided expenditures related to climate change and air pollution. In addition, cumulative savings of energy-related CO_2 emissions could reach 12 gigatonnes (IRENA, 2016d).

As the energy transformation quickens its pace, broader and deeper decarbonisation efforts are required. Beyond the power sector, more emphasis needs to be placed on the use of renewable energy for heating and cooling in buildings and industry and for transportation. The growing inclusion of renewables in all end-use sectors will rely on an enabling environment centred on the key dimensions of policy, finance and investment, technology and energy access. Each dimension is presented below.

Accelerating energy transformation through policy

Policies and regulations remain crucial to advance market development. As the renewable energy sector matures and expands, policies are being adapted regularly to suit changing market conditions. Significant recent policy trends have been the gradual shift in the power sector from tariff-based mechanisms to auctions, and the increasing need for additional flexibility measures into the power system.

A growing number of countries have held auctions to deploy renewables in a well-planned but flexible, cost-efficient and transparent manner. At the end of 2016, at least 67 countries had held such auctions, up from only six in 2005. Renewable power auctions throughout 2016 resulted in record-low prices for both solar PV and wind power. Some of the lowest wind power prices were recorded in North Africa, with Morocco achieving a median price at USD 30 per megawatt-hour, for example. Solar PV achieved new price lows in several countries, with a record-breaking bid in the United Arab Emirates (USD 29.9 per megawatt-hour). Understanding the factors behind such results can support the design of future auctions and drive accelerated deployment.

Renewable power increasingly comes from variable and distributed sources. As deployment of solar PV and wind power capacity surges, variable and distributed generation present challenges and opportunities. To capitalise on the opportunities, adjustments are required in power market design, system regulations, and operating procedures. Some of these relate to physical infrastructure, and others are defined by market design regulation. Some draw on supply resources, while others draw on demand-side resources. Some integrate the two. Some solutions are more long term, while others are more or less stopgap measures. What they all have in common is that they introduce some measure of additional flexibility into the power system. They can be grouped into six categories: supply side, demand side, transmission and distribution networks, storage, market design and system operation and management. Some solutions towards the integration of distributed and variable renewable energy (VRE) sources are already being implemented in some states in the United States and in Denmark, Italy and Germany, for example.

Regulators have begun making the changes needed to integrate variable, distributed renewable power on a large scale. Experience to date indicates that integrating large shares of VRE is not as technically challenging as often thought. Grid operators have successfully integrated VRE well above 30%, and without significantly increasing storage. For example, the grid operated by the German utility 50 Hertz TSO can absorb up to 70% VRE penetration without storage. Denmark, Ireland, Italy, Portugal and Spain have integrated VRE into their national grids successfully. In that process, system design and operation must ultimately be moulded to accommodate the rise of VRE rather than the other way around. At the same time, solutions must be economically efficient, serve system reliability and adequacy, and result in fair and equitable sharing of costs and benefits among all consumers.

Policy makers need to look more closely at heating and cooling for buildings and industry, and at the potential of renewables to fuel transport. Together, these end-use sectors account for most (60%) of energy-related CO_2 emissions. The good news is that some cost-effective renewable energy options are already available to meet these needs. Indeed, electric mobility as well as renewables-based thermal solutions will play a critical role in the future energy system. In addition, potential synergies between the power sector and end-use sectors call for a more holistic approach to energy policy. Combined with continued advances in energy efficiency, sector coupling will likely become the key to realising the full potential of renewable energy in the overall energy system.

Scaling up investment for a renewable future

Global investment in renewables has shown steady growth for more than a decade, rising from less than USD 50 billion in 2004 to a record USD 348 billion in 2015 (BNEF, 2016a), including large-scale hydropower. For the first time, in 2015, developing countries attracted the majority of renewable energy investments, with China alone accounting for about one-third of the global total. Growth in 2015 was due primarily to solar and wind power, which together accounted for about 90% of total global investments.

Current investment levels, however, are insufficient to meet international climate goals. Despite the new records set in 2015, total investment in renewable energy falls short of the estimated average annual investment of at least USD 770 billion that will be needed between 2016 and 2030 to double renewable energy's share in the global energy mix (IRENA, 2016f).

Targeted use of public funds to cover early-stage financing and offer guarantees for some of the investment risks can have a significant impact on the sector's attractiveness to private investors. To achieve a major scaling up of investment, limited public funds need to be used in a way that maximises the mobilisation of private finance, including from large-scale institutional investors. This means a shift from traditional public financial instruments (*e.g.,* grants and loans) toward risk-mitigation instruments such as guarantees that cover political, currency and power-offtake risks.

New capital-market instruments are helping to increase available finance by offering new groups of investors access to renewable energy investment opportunities. Green bonds for example have grown very rapidly over the past few years. In 2015, nearly half of the USD 41.8 billion in green bond–labelled proceeds went to renewable energy, with India and China at the forefront of expansion. The yield company (yieldco) is an instrument that helps to mobilise equity finance for renewable energy and improve market liquidity. After a period of consolidation in 2015, the market seems to be picking up again.

Institutional investors are increasingly moving into renewable energy investment, particularly in Europe, where several pension funds have invested in large wind projects. In principle, renewables are an appealing asset class for institutional investors because they offer stable returns over the long term. But the relatively small size of projects and the limited track record of renewables in new markets must be overcome. Certain institutional investors have shown growing interest in renewables in emerging markets, driven by strong support policies and regulations, and good resource potential, among other factors. In these same markets, domestic pension funds may become an important source of capital. Unlocking large-scale investments by domestic and foreign institutional investors will require continued focus on building pipelines of large-scale, investment-grade projects or through aggregation portfolios of smaller projects.

New business models promise new ways to finance renewable energy. The use of leasing is spreading beyond the solar PV market in the United States to Europe, China, India, the Pacific and, more recently, Africa. Leasing, with or without securitisation, has helped bridge the divide between investors and users of decentralised solar PV installations. In a similar way, energy service companies (ESCOs) are reducing financial and other long-term risks related to large-scale renewable heating and cooling systems. Another emerging business model involves corporate sourcing of renewable energy. More and more large corporations are opting for direct procurement of renewable electricity to power their operations and supply chains – often through power purchase agreements.

Ground-breaking and affordable technologies

Technological advances and falling costs are driving the adoption of renewable energy around the world, with the power sector leading the way. No technology shows this more clearly than solar PV. Global PV capacity soared from 40 GW in 2010 to 219 GW in 2015, when it accounted for approximately 20% of all newly installed power generation capacity (IRENA, 2016b).

Dramatic cost reductions have opened new markets for rapid growth. Solar PV costs – now half of what they were in 2010 – could fall by another 60% over the next decade. Utility-scale projects are economically competitive with new fossil-fuel generation, and solar PV is competing without financial support even in regions with abundant fossil fuel resources (IRENA, 2016l). Solar PV is poised to revolutionise the electricity system, enabling consumers to produce power for their own needs and feed surplus energy into the grid. Electricity from small-scale distributed PV already is cheaper than power from the grid in several countries, and PV is often the least-expensive option for remote or off-grid regions. Innovations in production techniques and in the development of technologies that are more efficient, more adaptable, lighter and cheaper will enable the use of solar PV not only on the ground and on rooftops, but also on building facades, windows, roads and other surfaces – developments that will make possible large-scale integration of solar PV into the world's cities and beyond.

Solar PV will grow the fastest in terms of capacity and output. Solar PV will account for as much as 7% of global power generation by 2030 – a six-fold increase from today (IRENA, 2016d, 2016i). Ongoing technological innovations, continuing economies of scale, additional automation in production, and economic pressures all will push costs down further. IRENA estimates that the levelised cost of electricity for utility-scale PV could fall by more than half between 2015 and 2025, and that global solar PV capacity could reach 1,760 GW by 2030.

New means for storing electricity will open the door for vast growth in VRE generation. Storage can add flexibility to power system infrastructure, operation, and market design, bridging gaps between supply and demand across space and over time. Among storage technologies, batteries have shown the most growth in recent years, driven primarily by the fast-growing market for electric vehicles and the deployment of VRE capacity. Batteries will play an important role in integrating VRE into existing electric grids and in the ongoing effort to provide access to the millions of people who are still without electricity.

Battery storage for electricity could increase from less than 1 GW today to 250 GW by 2030, according to IRENA estimates (IRENA, 2015h). The market value of battery storage reached USD 2.2 billion in 2015 and is expected to rise to USD 14 billion by 2020. In parallel, the costs of battery storage are declining. The cost of lithium-ion batteries, for example, has dropped to USD 350 per kilowatt-hour (kWh) (a 65% decline since 2010) and is expected to fall below USD 100/kWh in the next decade. Further advances in electricity storage can be unlocked through standards and policies that recognise and reward its present viability and future potential.

Modern, renewable-based energy services for all

Given the likely pace of grid-extension efforts, nearly 60% of the additional power generation needed to achieve universal electricity access by 2030 will come from off-grid solutions. Stand-alone and mini-grid solutions powered by renewables already provide electricity to nearly 90 million people (BNEF and Lighting Global, 2016) and meet a hierarchy of needs, from basic lighting to productive uses, thereby enabling people to climb the energy ladder. They are cost-effective and can be installed in modular fashion, linked to grid-extension plans.

Off-grid deployment depends on the right combination of policies, financing, technology and institutional capacity. Experience to date highlights the importance of stable policy and regulatory frameworks dedicated to the off-grid market; focused, adequate and streamlined institutional structures and procedures; relevant skills and training; customised financing and business models tailored to the electricity services required and to local conditions; and innovative technologies that capitalise on the scalability of renewables and on opportunities for demand-side management and efficiency.

Recent experience with mini-grids suggests the need for changes in policies and regulations (IRENA, 2016o). Legal and licensing provisions, for example, should be designed to minimise development costs and uncertainties. The risk to project developers of early arrival of the main grid should be mitigated through a combination of reliable rural electrification master plans and well-defined interconnection and compensation mechanisms. In addition, policy measures to facilitate access to finance are needed to improve access to equity, debt and grant financing at different phases of mini-grid development.

Renewables in support of the Sustainable Development Goals (SDGs)

Renewables are key to the goal of ensuring "access to affordable, reliable, sustainable and modern energy for all" (SDG7). Many energy solutions based on renewables are cost-effective, readily available, and easily customisable, providing sources of energy services that sustain livelihoods and improve human well-being.

Sustainable energy deployment reinforces other key goals. Renewables contribute to environmental sustainability by mitigating the local and global environmental impacts associated with energy consumption. They create conditions to further human development by facilitating access to basic services, improving human health and enhancing incomes and productivity. Renewables also create new jobs and spawn new local industries.

Renewables offer equally powerful solutions to problems of local and global environmental sustainability. At the global level, the most critical environmental impact of energy production and use is its contribution to climate change (SDG13). Renewable energy, combined with energy efficiency, gives the world a realistic chance of keeping the rise in global temperature below 2°C while also reducing air pollution. At the local level, renewables have a key role to play in the transition to sustainable urban energy (SDG11), including energy for heating and cooling, local power generation and powering electric vehicles. Well-designed renewable energy projects also can avoid negative effects of energy production and use on ecosystems and biodiversity (SDG15).

Renewable energy contributes to human development and well-being. By providing basic energy needs in a clean and sustainable manner, renewables bring wider benefits for health, gender equality and educational opportunity. More than four million people die prematurely each year from illnesses attributable to indoor air pollution from cooking with traditional biomass and inefficient cookstoves. This hazard can be alleviated by off-grid renewables for household uses, combined with improved cookstoves (SDG3). For the one billion people who depend on health facilities in remote and rural areas that presently lack electricity (WHO and World Bank, 2014), renewable energy can improve health services. By reducing or eliminating the time required to gather firewood, modern renewables can also free up time for women and girls to pursue an education (SDGs 4 and 5) or income-generating activities. Electricity also provides high-quality lighting at school and at home, as well as access to information technology.

A new paradigm is forming

The rapid growth of renewables reflects commitment by governments around the world in response to pressing challenges and emerging opportunities. A majority of countries has adopted national targets, formulated ambitious policies, and devised innovative investment and technology strategies. The private sector is also playing a critical role in scaling up deployment, signalling a near-global consensus that renewable energy technologies will be the engines of sustained economic growth and development.

Accelerating the pace of the energy transition and expanding its scope beyond the power sector will bring substantial social, economic and environmental benefits. With renewables, the economic growth on which the world's poor have pinned their hopes can be achieved in sustainable, environmentally friendly ways. Without them, international efforts to arrest climate change cannot succeed.

We are already embarked on a far-reaching transformation of the global energy system that presents a historic opportunity. If we are able to enter a grand global bargain that offers for the first time a real chance to overcome the developmental, environmental and social challenges of today's world with a technologically feasible and economically beneficial pathway to a sustainable future, we will have secured the future for our children and grandchildren.

Chapter 01

Current Status and Outlook for Renewable Energy

1.1 Introduction

Global demand for energy continues to rise, led by developing countries, reflecting an expanding global economy, rapid industrialisation, population growth, urbanisation and improved energy access. At the same time, the negative social, economic and environmental impacts that result from heavy reliance on fossil fuels are compelling governments to seek more sustainable options to meet energy demand.

Years of policy support combined with rapid technological progress mean that renewable energy has become an increasingly viable and cost-effective option. Governments around the world are rethinking their energy sector strategy and embracing renewable energy. As a result, unprecedented growth in renewable energy deployment over the past decade has driven a virtuous cycle of decreasing costs, rising investments and technology innovation.

Energy is not an end in and of itself. It is a critical ingredient in all economic endeavours, essential for the provision of all human needs, including adequate sustenance, shelter and healthcare. Even as the energy sector continues to expand, nearly a quarter of the world's population remains outside its fold, with more than a billion people living without access to electricity and nearly 3 billion relying on traditional energy sources for cooking and heating. Access to sustainable, secure and cost-effective energy through renewables offers a tremendous – and unique – opportunity to simultaneously provide modern energy to underserved populations, and serve sustainable development imperatives such as avoiding catastrophic climate change. As such, Sustainable Development Goal (SDG) 7 on energy – one of the 17 SDGs adopted in 2015 by the international community as part of the 2030 Agenda for Sustainable Development – is a key enabler for meeting a wide range of other SDGs (see Figure 1.1 and Chapter 6).

Figure 1.1 Linkages between SDG7 and other SDGs

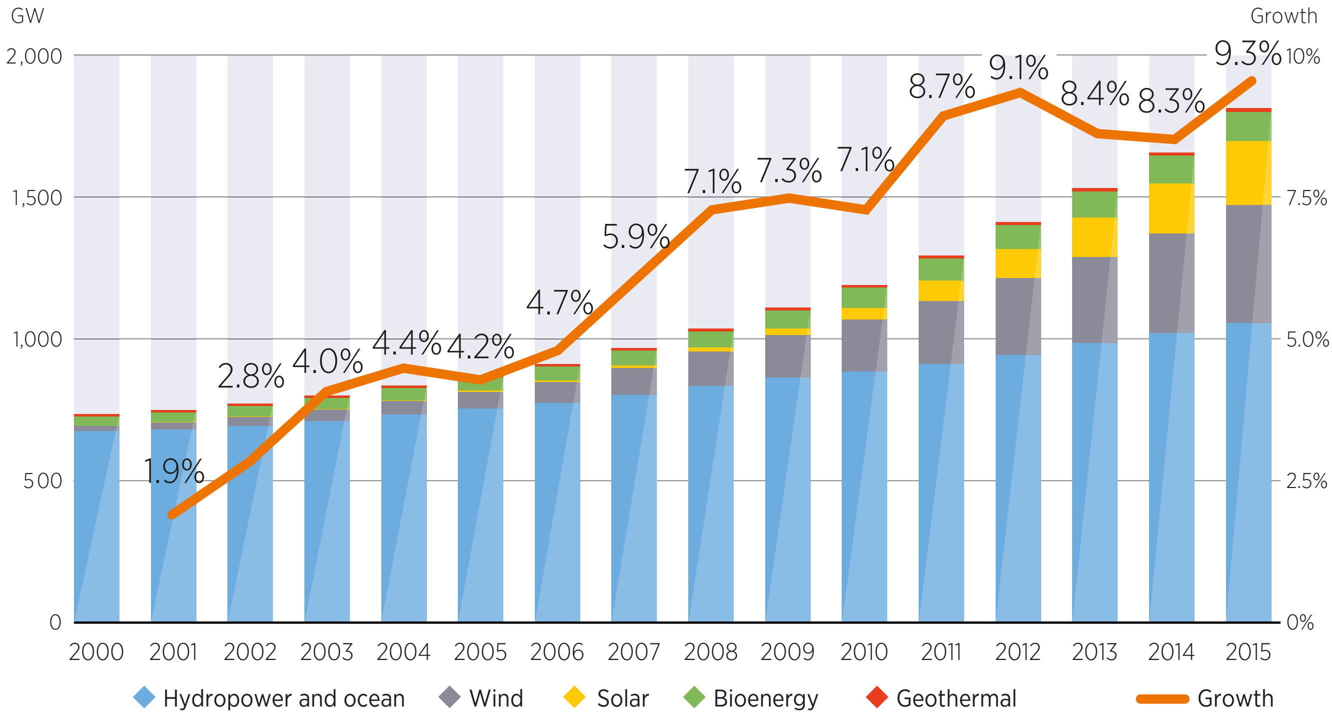
The foundations for the energy transition already exist. Growing maturity of the renewable energy market, coupled with technology advancements and policy refinement, provide an opportunity to develop an energy system that underpins sustainable development objectives. Following a review of key trends of the renewable energy landscape presented in this chapter, the report selects topical and critical issues in renewable energy policy, finance and technology that are emerging as essential for the development of the sector. Together, these can lead the world on a sustainable development path that reaps significant economy-wide benefits.

1.2 Current state of renewable energy

According to nearly every measure, renewable energy is gaining ground. For the vast majority of renewable energy technologies, capacity and output continue to grow as renewables in the power sector far outpace growth in conventional technologies. New markets and centres of manufacturing are emerging in every region of the world. More jobs are to be found in the renewable energy sector than ever before, and their numbers continue to rise. Years of policy support for renewable energy in key countries, momentum to mitigate climate change and enhance access to modern sources of energy, as well as improved cost-competitiveness, all have propelled renewable energy to become the engine of sustained economic prosperity.

In 2015, the contribution of all renewable energy sources to the global energy mix grew by the largest increment yet, particularly in the electricity sector (IRENA, 2016a; REN21, 2016). Renewable power generation capacity grew by 154 gigawatts (GW), an increase of 9.3% over 2014. Most additions were in wind, solar photovoltaic (PV) and hydropower (see Figure 1.2 and Annex 1 for capacity statistics by country). In 2015, additions of both wind power (66 GW) and solar PV (47 GW) exceeded those of hydropower for the first time. Hydropower capacity, already a very significant source of electricity, increased by

Figure 1.2 Renewable power capacity and annual growth rate, 2000-2015



Source: IRENA, 2016b

33 GW (or 3.3%) (IRENA, 2016b). The significant capacity additions in 2015 continued a long-term upward trend.

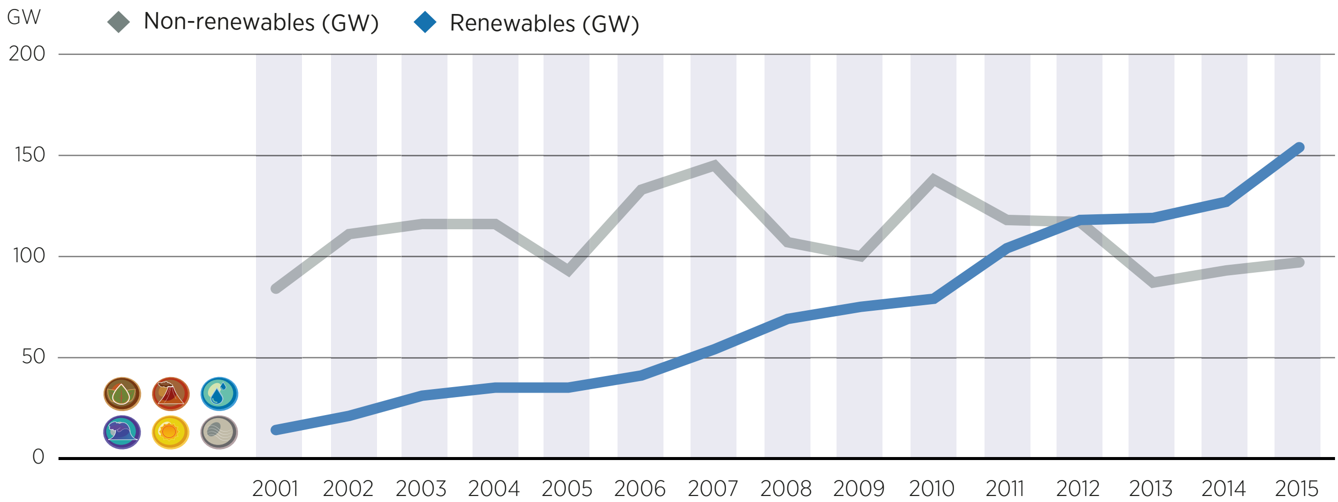
Renewable power technologies are often the first choice for expanding, upgrading and modernising electricity infrastructure around the world. Since 2012, renewable power capacity installations have exceeded non-renewables by a rising margin (see Figure 1.3). In 2015, renewable power capacity represented 61% of all new power generating capacity added worldwide.

By the end of 2015, renewable power generating capacity exceeded 1,811 GW and accounted for more than 28% of global capacity (IRENA, 2016a; IEA, 2015).[1] The bulk of that capacity harnessed hydropower (58%); followed by wind power (23%) and solar power (mostly solar PV, at more than 12%). Solar PV represented the most rapidly growing share.

Renewables provided an estimated 23.5% of all electricity generated in 2015 – 5,660 terawatt-hours (TWh) (see Figure 1.4) (IRENA, 2016a). Hydropower accounted for the largest share of renewable generation, followed by wind power, bioenergy and solar PV. The share of renewables in global electricity generation has risen every year, even as total electricity consumption has continued to grow. In recent years, renewable power generation growth has greatly outpaced increases in both overall electricity demand and the generation of non-renewables. For the five years up to 2014, annual renewable power generation grew by an average rate of 6.4% – nearly twice the annual growth rate of generation overall (3.4%) (IEA, 2016a). Over the same period, the annual increase in non-renewable generation averaged 2.6%.

Notwithstanding the growth in renewable energy, the world remains heavily dependent on conventional energy technologies. The share of renewable energy in total final energy consumption has increased from an estimated 16.7% in 1990 to 17.5% in 2000 and 18.3% in 2014. Modern renewables[2] account for about half of the renewable energy mix, split about evenly between electricity and direct heat applications,

Figure 1.3 Renewable and non-renewable power capacity additions, 2001-2015

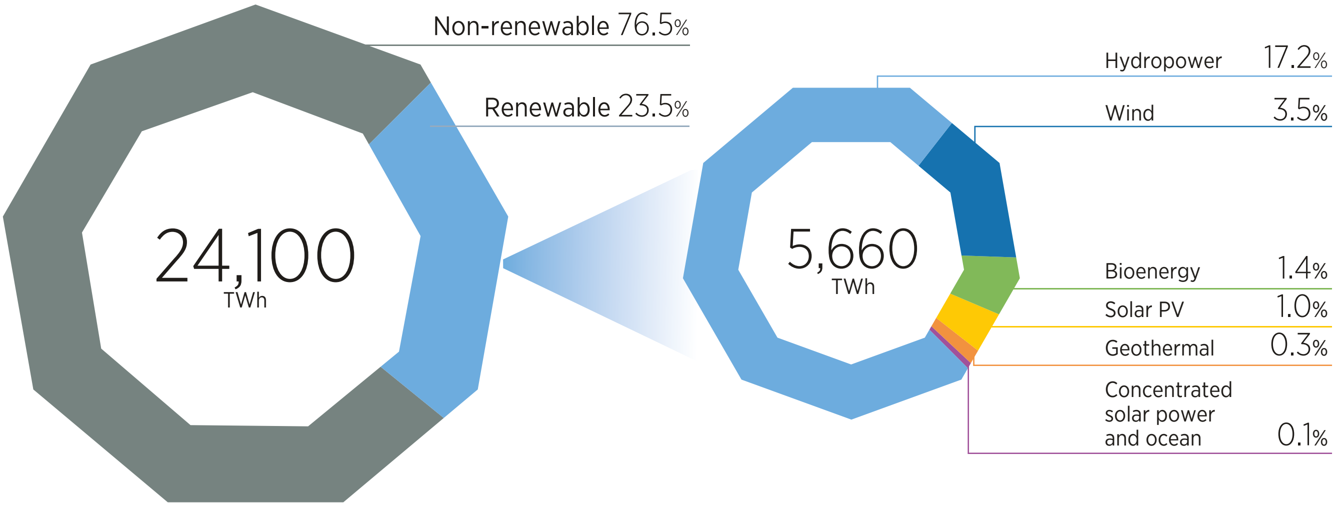


	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Renewables (GW)	14	21	31	35	35	41	54	69	75	79	104	118	119	127	154
Non-renewables (GW)	84	111	116	116	93	133	145	107	100	138	118	117	87	93	97

Source: IRENA, 2016b

1 Excludes 154 GW of pure and mixed pumped storage capacity otherwise included in hydropower capacity. The bulk of this 154 GW is pure pumped storage capacity that contains no renewable energy generation component but is instead a storage medium for grid power of any origin.
2 Including solar power and heat, wind power, hydropower, ocean energy, geothermal power and heat, and modern bioenergy.

Figure 1.4 Global electricity generation by source, 2015



Source: IRENA, 2016a and 2016b

with transport fuels accounting for a smaller share (see Figure 1.5). The other half of the renewable energy picture consists of traditional use of biomass for heating and cooking[3], mostly in developing countries.

Renewables overall are struggling to increase their share of the global energy mix for three main reasons. First, the traditional use of biomass is in decline as more people gain access to modern energy. This development improves quality of life and reduces unsustainable biomass harvesting. It slows the growth of total renewables in the energy mix, however, because fossil fuels often replace traditional biomass and modern uses of solid bioenergy are far more efficient than traditional open-hearth combustion. Second, total final energy use continues to rise. Third, the technologies that have grown the fastest – solar PV and wind power – have done so from a very low base. As a result, the use of modern renewable energy in electricity, heating, cooling and transport, as well as efficiency of energy production and consumption, have to grow even faster to make a timely and significant headway on the share of total final energy consumption.

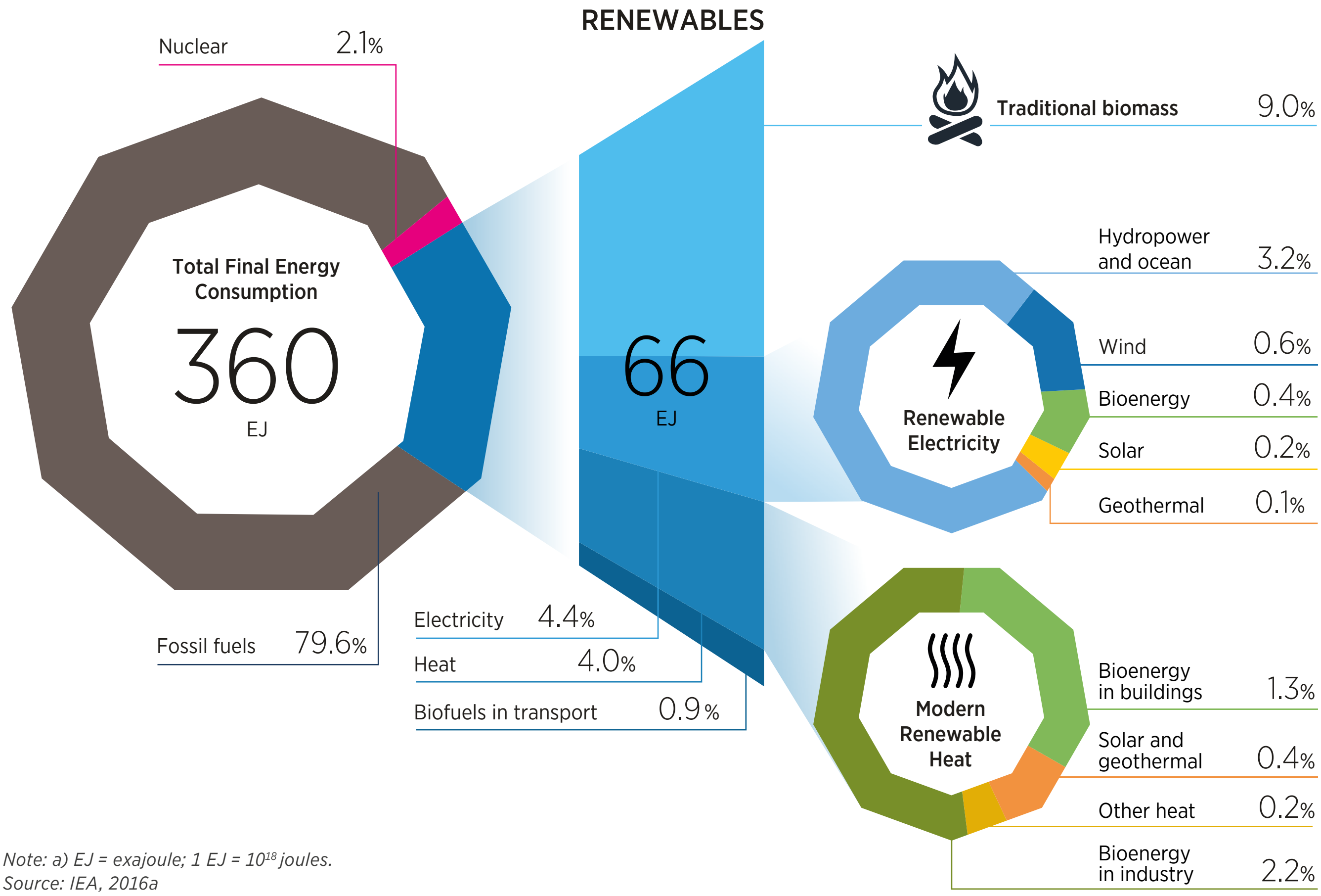
1.3 Driving forces and benefits of renewable energy

Policies have helped trigger a global expansion in the deployment of renewable energy, allowing costs to decrease rapidly, especially for solar PV and wind power (IPCC, 2014). Support policies introduced by early adopters played an important part in driving down technology costs. These policies created markets that led to the development of the renewable energy industry, ongoing technology advances and economies of scale. Countries pioneering these policies recognised the long-term environmental, economic and social benefits of renewables.

By the end of 2015, 173 countries had established renewable energy targets at the national, state or provincial level, with most countries also adopting related policies. Renewable energy support policies were in place in 146 countries by the end of 2015. At least 114 countries had policies directed at the power sector, 66 had transport-specific policies and 21 had policies to support renewable energy use in the heating and cooling sector (REN21, 2016).

3 The distinction is important because traditional biomass combustion often is environmentally unsustainable, and it carries significant health and social costs for households and communities. Consequently, the international community has agreed to phase out traditional use of biomass in favour of clean, and increasingly renewable energy technologies. This is a key development goal (see Chapter 6).

Figure 1.5 Total final energy consumption (EJ[a]) and renewable shares, 2014



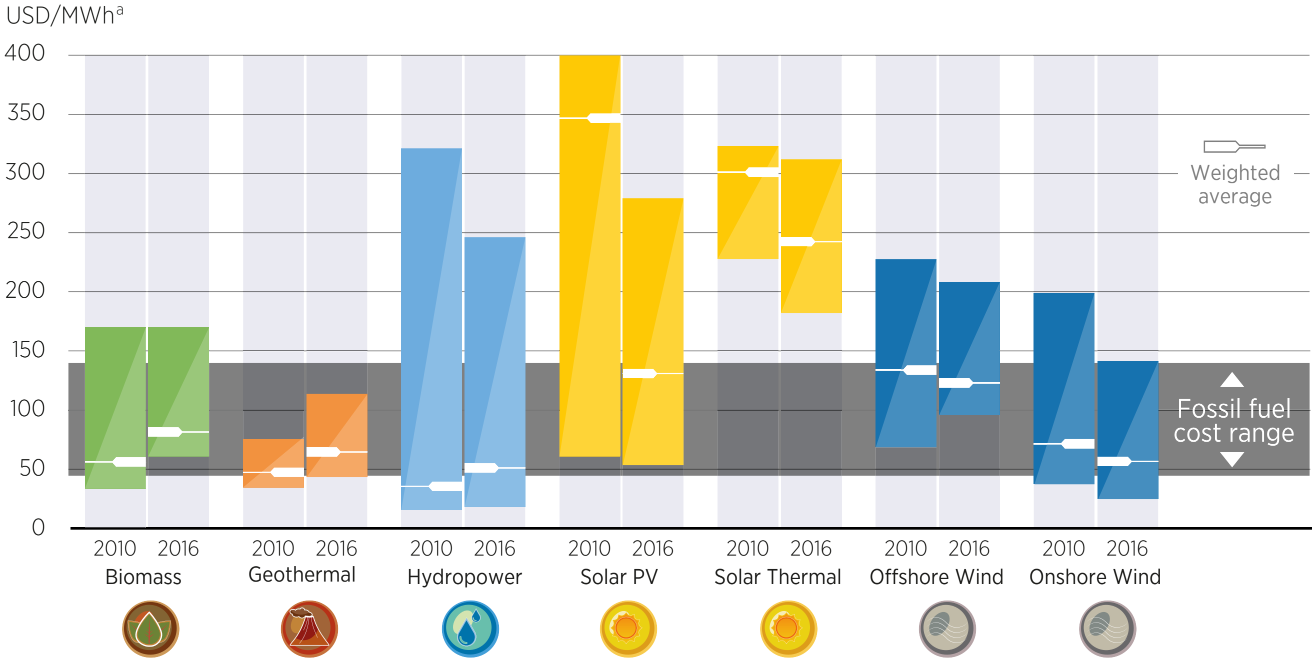
Note: a) EJ = exajoule; 1 EJ = 10^{18} joules.
Source: IEA, 2016a

The adoption of enabling policies, the emergence of new markets and growing competitiveness (see Figure 1.6) have all increased global investment in renewable energy – a fourfold rise over the past decade, reaching a record high in 2015. Investment in new renewable power capacity has exceeded net investment in additional fossil fuel capacity for at least three consecutive years. The difference was largest in 2015, despite the sharp decline in fossil fuel prices. Even when investment declined – notably in 2012 and 2013 – there was record growth in renewable power capacity, thanks to falling costs of technology.

Wind and solar power held a dominant market share, together accounting for about 90% of 2015 investments in renewable power. Bioenergy (including biofuels), geothermal, small-scale hydropower and ocean energy each received only 1-2% of investment. By country, China has become the most significant market, accounting for one-third of the 305 billion United States dollars (USD) invested in 2015. The once dominant European Union (EU) market has retracted somewhat in recent years, although the region's offshore wind sector is expanding.

Thanks to rapidly growing deployment, a wide range of social and environmental benefits of renewables is coming to the fore. The sector, for instance, has become a significant source of new employment in many markets around the world (see Figure 1.7). The number of jobs in renewable energy rose by 5% in 2015 to an estimated 8.1 million, plus an additional 1.3 million in large-scale hydropower (IRENA, 2016c). Solar PV was the largest single renewable energy employer, supporting 2.8 million jobs, up 11% from 2014. There were similar employment figures in bio-energy (including liquid biofuels, biomass and biogas) but these contracted slightly in 2015. Meanwhile, wind power experienced significant

Figure 1.6 Levelised cost of electricity for utility-scale power (ranges and averages), 2010 and 2016

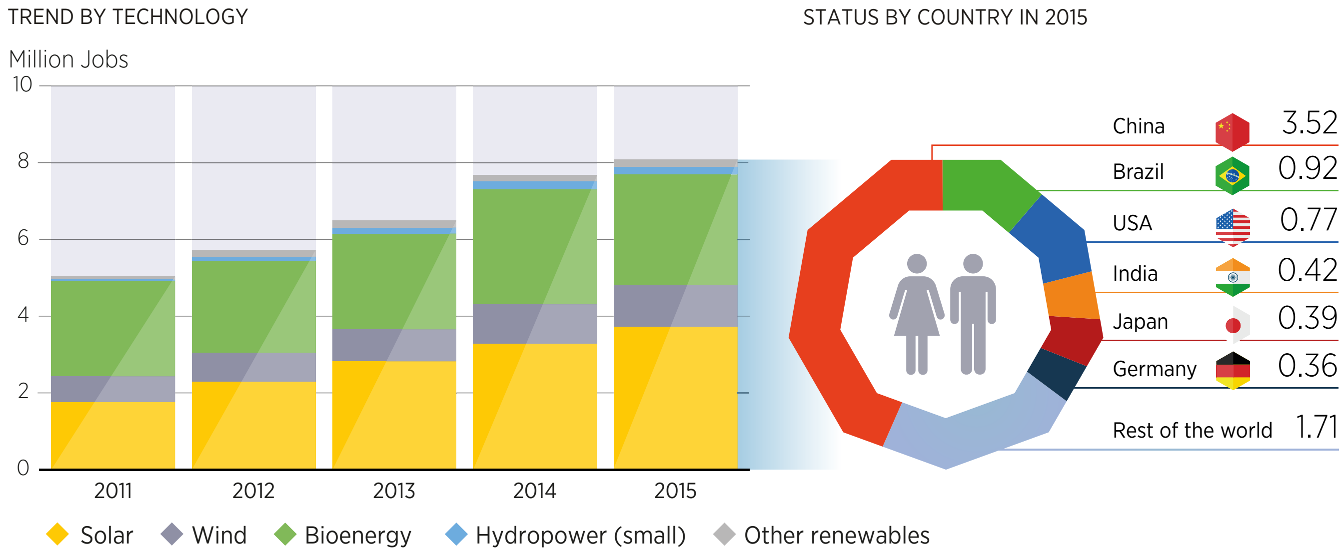


Note: a) MWh: megawatt-hour
b) All costs are in 2016 USD. Weighted Average Cost of Capital is 7.5% for OECD and China and 10% for Rest of World

growth, rising 5% in 2015 to 1.1 million. Asia provides 60% of renewable energy employment, largely due to the solar industry in China, where a major share of the world's PV and solar thermal heating technologies are manufactured and installed (IRENA, 2016c).

While global job numbers continue to rise, trends vary by country and region. Countervailing effects of increased labour productivity, as well as automation and mechanisation of production, contributed to slower growth in 2015 compared to previous years. However, the continuing growth

Figure 1.7 Global employment in renewable energy[a], 2011-2015



Note: a) Excluding large hydropower.
Source: IRENA, 2016c

in renewables employment contrasts starkly with the depressed labour market in the broader energy sector (IRENA, 2016c). Furthermore, higher productivity is expected to translate into lower prices, stimulating further market growth for renewables and sustained demand for labour in the sector.

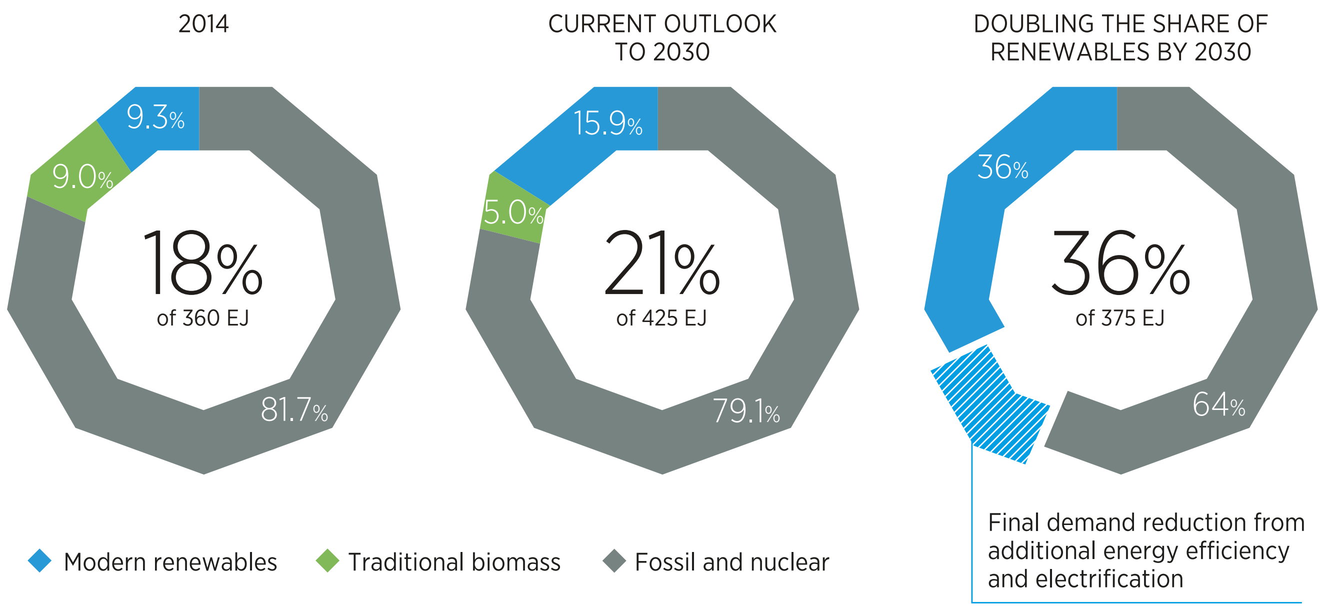
Renewable energy is also playing a greater role in decarbonising the world's energy system, which accounts for approximately three-fifths of all anthropogenic greenhouse gas emissions (IEA, 2016b). In 2015, the combined carbon dioxide (CO_2) emissions from fossil fuel combustion and industrial processes (such as cement production) stagnated for the first time at an estimated 34.3 gigatonnes (Gt) (IEA, 2016c). The *UNEP Emissions Gap Report* (UNEP, 2016) has even suggested a slight decline after years of gradually slowing growth. Although total greenhouse gas emissions continue to rise, there are signs the tide has turned for CO_2 emissions from fossil fuel use and industry (UNEP, 2016). The renewable energy sector is well positioned to accelerate its growth and contribute to decarbonisation and achievement of the SDGs.

1.4 Renewable energy outlook to 2030

The global potential for renewable energy is vast and far exceeds current and projected world energy demand. Given appropriate and sustained policy support for renewables and energy efficiency, today's renewable technologies could be harnessed on a scale sufficient to address climate concerns within a critical timeframe. At the same time, they can contribute significantly to the delivery of the SDG on modern energy access for all (SDG7).

IRENA projects that if all existing national plans and policies are fully implemented, the renewable energy share in the total global final energy mix would rise only slightly over the next 15 years – from 18.3% in 2014 to 21% by 2030 (see Figure 1.8) (IRENA, 2016d). This increase reflects strong growth in the deployment of modern renewable energy. However, it is expected to remain only marginally ahead of the combined effect of overall demand growth and the decline in traditional biomass.

Figure 1.8 Estimated and projected share of renewable energy in total final energy consumption, 2014 and 2030 under current outlook[a] and doubling scenario[b]



Note: a) Mid-2015. b) In the doubling scenario, reduction in final energy demand is due mostly to energy efficiency improvements. The rest of the reduction is due to electrification, which cuts final energy demand but not necessarily primary energy demand.

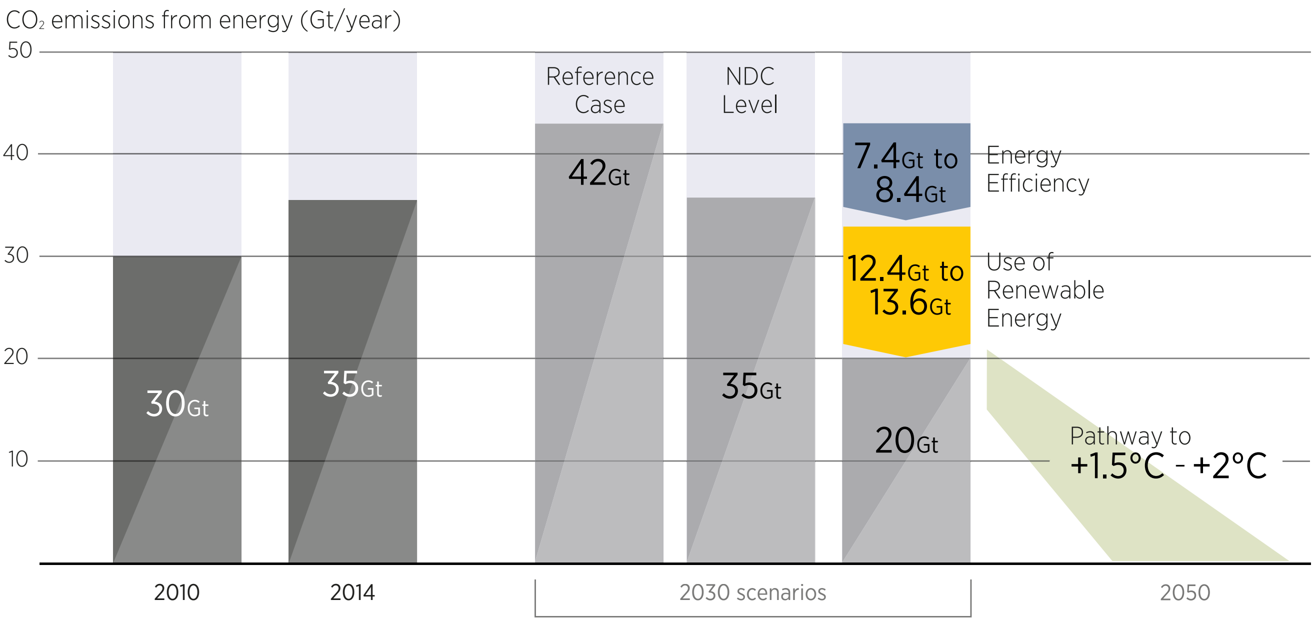
Source: IRENA, 2016d

Under the United Nations (UN) Sustainable Energy for All (SE4ALL)[4] initiative, the international community established a target to double the share of renewable energy (over 2010 levels) to 36% by 2030. This leaves a 15 percentage point gap compared to the business-as-usual path (IRENA, 2016d). The world could advance towards this objective if all Nationally Determined Contributions (NDCs) under the 2015 Paris Agreement were fully implemented, but would still not achieve 36%.[5] About one-third of CO_2 emissions reductions under the NDCs would arise from further deployment of renewable energy. The remainder would be contingent on advances in energy efficiency and the pursuit of other relatively low-carbon energy options (IRENA, 2016d).

IRENA's analysis concludes that the NDC commitments fall far short of the objective to set the world on a path towards stabilising global warming well below 2°C (IRENA, 2016d). Indeed, if fully implemented, combined CO_2 reductions that would accrue from the NDCs would amount to 7-8 Gt by 2030 relative to business-as-usual, instead of the 20-22 Gt reduction required.[6]

However, the analysis also shows that most NDCs underestimate the potential of renewable energy, the technological learning rate, and rapid cost reductions and innovation that are bound to continue over the coming years. With more ambitious yet credible commitments to renewable energy, by 2030 renewables can achieve up to five times the CO_2 mitigation reflected in current NDCs (IRENA, 2016d). Combined with significant energy efficiency gains, further reliance on renewable energy could halve estimated annual CO_2 emissions to about 20 Gt in 2030 (see Figure 1.9). This would be enough to keep the world on a 2°C pathway, with continuing advances thereafter.

Figure 1.9 Global energy-related CO_2 emissions between today and 2050



Source: IRENA, 2016d

4 This doubling objective was set in recognition of the role renewables can play in realising long-term climate objectives while also extending access to affordable and clean energy to all people. This goal was subsequently mirrored in the seventh UN SDG (SDG7).

5 The NDCs are part of the agreement adopted by 195 countries in Paris in late 2015 at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). Known as the "Paris Agreement", it entered into force in November 2016. Submitted by 189 countries, the NDCs outline concrete national (or regional, in the case of the EU) commitments towards the common aim of stabilising global warming well below 2°C.

6 This reduction is relative to a baseline estimate of 42 Gt of energy-related CO_2 emissions in 2030, based on the existing national plans of 40 countries (IRENA, 2016d).

1.5 Bridging the gap to 36%

The key question then is how to increase renewable energy use sufficiently. In order to reach a 36% share for renewable energy within the requisite timeframe while also achieving universal access to modern energy sources and eliminating unsustainable use of biomass, the deployment of modern renewables and energy efficiency improvements will need to be ramped up far more quickly than they would be under the current outlook (second pie in Figure 1.8). Indeed, IRENA envisages a far more ambitious pursuit of all available renewable energy options, as well as energy efficiency (third pie in Figure 1.8).

Recent trends in solar PV and wind power underscore the potential for the rapid scale-up of renewables. The combined average annual growth rate of the two technologies hovers around 20%, following consecutive years when it was closer to 30%. Even with a combined annual growth rate of 15%, installed wind and solar PV capacity would more than double every five years.[7] At 636 GW, these sources already accounted for about one-tenth of global generating capacity in 2015.

While the power sector is on track, more emphasis needs to be placed on the use of renewable energy for heating and cooling in buildings and industry, as well as for transportation. These sectors together account for a large portion of global energy use and about 60% of energy-related CO_2 emissions (IEA, 2016b). Several options, when combined with improvements in energy efficiency, could achieve a steep increase in the contribution of renewable energy to these sectors. Affordable mainstream options include a significant increase in solar thermal and in bioenergy use for industrial process heat, water and space heating (IRENA, 2016d).

In particular, greater sector coupling, *i.e.*, linking the electricity sector with heating, cooling and transport, can accelerate deployment. It allows renewable electricity to serve more varied energy needs (see Chapter 2). It also helps integrate variable (and often distributed) renewable energy sources such as solar PV and wind power. The increased use of heat pumps, for instance, enables the use of renewable electricity for heating and cooling. Sector coupling means surplus renewable electricity can be stored and transformed for use in industry, for managing thermal loads in buildings and for transport.

Additional measures will be needed to double renewables by 2030 and replace traditional biomass use with modern forms of energy.

7 Based on global generating capacity in 2014 of 6,163 GW (IEA, 2015).

These include relocating industry; modal shifts in transport; and replacing fossil fuels with electricity and biofuels not only in road transport but also in aviation and shipping (IRENA, 2016d). Doubling the share of renewables in the global energy mix by 2030 will require financial and political commitments to retire aging fossil fuel-based power plants before they become uneconomic.

1.6 Reaping renewable energy benefits: measuring the economics in 2030

The rapid transformation of the global energy system towards higher shares of renewable energy might result in some short- to medium-term incremental system costs. But these have to be set against the vast opportunities for cost-effective energy efficiency improvements. What is more, any such cost increments would be offset during and beyond the transitional period by associated economic, social and environmental benefits, as well as by avoided external costs.

IRENA analysis has estimated[8] that doubling the share of renewables would stimulate the global economy, improve human welfare and boost employment worldwide. It would raise global gross domestic product (GDP) in 2030 by an estimated 1.1% relative to a baseline projection, adding USD_{2015} 1.3 trillion – a sum similar to the combined economies of Chile, South Africa and Switzerland (IRENA, 2016e).

Global GDP would be boosted mainly by the economy-wide ripple effects of greater investment in renewables[9] and by reduced electricity prices in markets where renewables undercut alternatives. Lower prices would free up disposable household income otherwise spent on energy.

The transition to a 36% renewable share by 2030 would also create more jobs than in the business-as-usual scenario. Current trajectories suggest that jobs in renewable energy would grow from 9.4 million in 2015 to 13.5 million in 2030. That figure is projected to rise to 24.4 million in 2030 if the share of renewables is doubled. Over this period, the fossil fuel industry would be expected to lose 2.4 million jobs (IRENA, 2016e).

The higher share of renewable energy would probably only have a modest net effect on global trade. Under the reference scenario, global trade in goods and services is projected to reach USD_{2015} 50 trillion in 2030. Doubling the share of renewables would reduce this figure by around 0.1% due to decline in fossil fuel trade. However, it would be offset by greater trade and investment in goods and services required to install capital-intensive renewables, and by increased trade

8 In early 2016, IRENA completed the first global quantification of the macroeconomic impacts of renewable energy deployment. It used a macro-econometric model to analyse the economic impact of doubling the global share of renewable energy by 2030. The model reflects the impacts on global aggregate GDP, job creation, trade and human welfare compared with the baseline projection for that year (see IRENA, 2016e).

9 Such effects rely on the assumption that incremental capital investment steered toward renewables will not starve other sectors of the economy for capital. Competition for capital might reduce the positive impact on GDP (IRENA, 2016e).

in other products, due to the overall economic improvement (IRENA, 2016e).

Renewable energy benefits extend beyond the confines of traditional (and limited) measures of economic performance. Doubling the share of renewables by 2030 has a positive effect on three dimensions of human welfare: social (employment, health and education); environmental (avoided costs of greenhouse gas emissions and natural resource depletion); and economic (utility derived through consumption and investment needed for future consumption) (IRENA, 2016e).

Although it is difficult to quantify, the greatest improvements to human welfare probably arise from increased access to modern energy. Over 1 billion people would benefit from access to electricity, as would 3 billion people who currently rely on traditional biomass for their most basic energy services.

These benefits include better health, improved livelihoods, poverty alleviation, job creation, gender equality and greater access to clean water and food (IRENA, 2016e).

Increasing the share of renewable energy in the world's energy mix to 36% by 2030 is achievable, with a wide range of benefits. But significant new efforts will be needed to accelerate deployment – particularly in the transport, heating and cooling sectors, while also ratcheting up improvements in energy efficiency.

1.7 Conclusion

In a growing number of countries, renewables have emerged as a mainstream solution to meet energy demand in a cost-effective, secure and environmentally-sustainable manner. Global renewable energy deployment has increased rapidly in recent years and continues to grow at an unprecedented pace, particularly in the power sector. These developments have set in motion a rethinking, or transformation, of the global energy system.

Building on this momentum, renewable energy is well positioned to play a central role in the implementation of international agreements on both climate change mitigation and the SDGs. Accelerating the pace of the energy transition and expanding its scope beyond the power sector would bring substantial benefits from a social, economic and environmental standpoint.

Chapter 02

Policies, Regulations and Market Design

2.1 Introduction

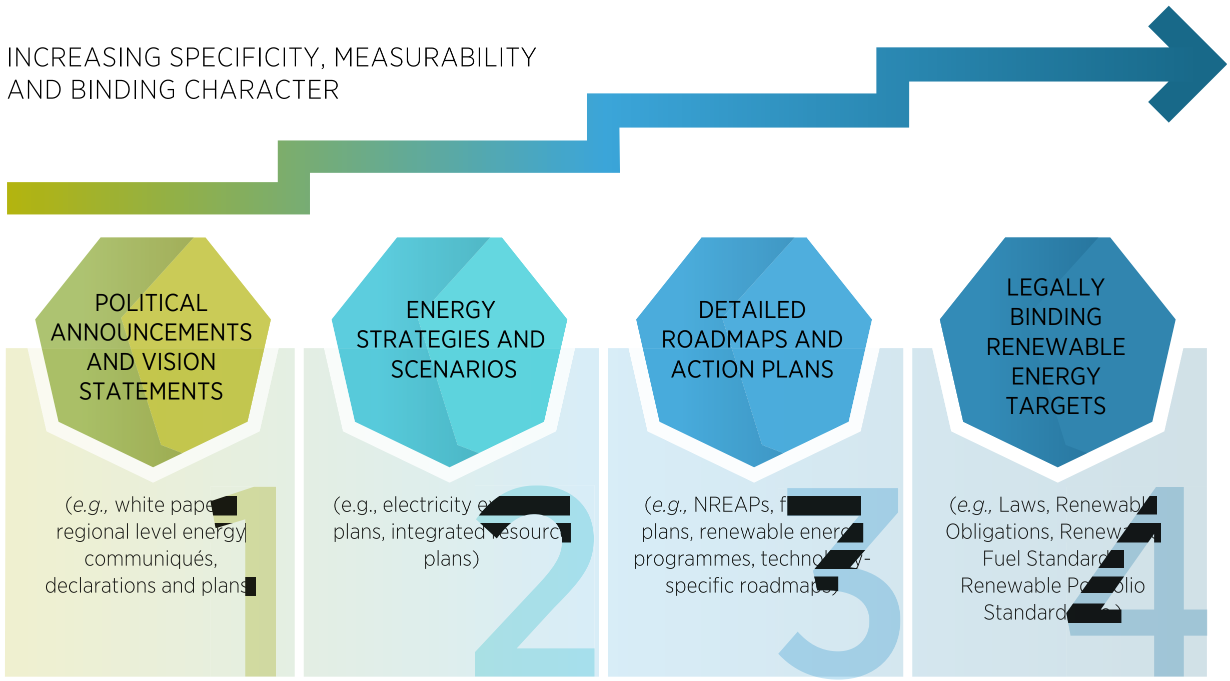
Signaling a global recognition of the benefits that renewables offer, the number of countries establishing renewable energy targets has continued to grow. As of year-end 2015, 173 countries had established renewable energy targets at the national or state/provincial level, up from 164 at the beginning of the year (REN21, 2016). Renewable energy targets have emerged as a popular mechanism to contribute to developing a clear vision for the development of the sector by indicating the envisioned trajectory of market growth, officially endorsed by national or local governments (IRENA, 2015a).

Renewable energy targets can take many forms, ranging from simple government announcements, to detailed and legally binding obligations with specific, quantifiable metrics. In some cases, targets are embedded within sectoral plans, as is the case in South Africa, or in national development plans such as in China and India. They can also take the form of legally binding obligations with clear compliance mechanisms as in Chile, the United States (US) and the EU Member States. In the wake of the Paris Agreement, around 74 countries have inscribed specific national renewable energy targets in their NDCs (REN21, 2016).

The diversity of renewable energy targets can be represented along a spectrum to visualise where they stand in relation to one another, depending on how specific, measurable and binding they are (see Figure 2.1) (IRENA, 2015a).

Recent target adjustments indicate a trend towards higher levels of ambition, especially in the power sector – the focus of the majority of targets with over 150 countries having set renewable electricity targets to date. Examples of recent target increases include Morocco, which aims to raise the share of renewables in total power capacity from 42% by 2020 to 52% by 2030 (Morocco, 2016). As renewable deployment gains momentum, a growing number of countries, provinces and cities are aiming for 100% renewable electricity targets by 2030. During the COP22 (attached) Conference in November 2016, 49 member countries of the Climate Vulnerable

Figure 2.1 Spectrum of renewable energy targets



Note: NREAP: National Renewable Energy Actions Plans.
Source: IRENA, 2015a

Forum agreed on the following: "We strive to meet 100% domestic renewable energy production as rapidly as possible" (Climate Vulnerable Forum, 2016). Renewable energy targets, however, gain credibility and provide a trajectory for the energy transformation only if they are accompanied by specific policies and measures (IRENA, 2015a).

Government policies to create markets for renewable energy technologies have facilitated deployment and enabled cost reductions through economies of scale and technology improvements. By the end of 2015, renewable energy support policies were in place in 146 countries, covering electricity generation, heating and cooling, and transport. In fact, 114 countries had implemented power policies, 66 countries transport policies, and 21 countries heating and cooling policies (REN21, 2016).

To this end, policy makers have devised a wide variety of policies to promote deployment (including, regulatory instruments and fiscal incentives) as well as enabling conditions for sector development, related to grid access, finance and socio-economic benefits. Table 2.1 provides an overview of the range of policies that have been adopted to date.

The types of policies needed differ according to national or local contexts. The appropriate policies depend on several factors, including the choice of technology, its maturity and associated barriers; the market share of renewable energy; and whether energy use is rising, stable or falling. To accelerate the pace of deployment, in line with global sustainable development objectives, government policies will remain crucial to address prevalent market-specific barriers. These barriers vary by end-use sector and technology, as the renewable energy sector matures (see Table 2.2).

Policies evolve as policy makers learn from experience and adapt to changing conditions – including changes to technologies, markets and other factors – to ensure that policies are as effective and efficient as possible. In many countries, support mechanisms are being adjusted continually to maintain a stable and attractive environment for investors while also increasing transparency and maintaining support for renewables in a cost-effective manner (IRENA, 2014a).

Table 2.1 Overview of the types of renewable energy policies and measures adopted

NATIONAL POLICY	REGULATORY INSTRUMENTS	FISCAL INCENTIVES	GRID ACCESS	ACCESS TO FINANCE[a]	SOCIO-ECONOMIC BENEFITS[b]
◆ Renewable energy target ◆ Renewable energy law/ strategy ◆ Technology-specific law/ programme	◆ Feed-in tariff ◆ Feed-in premium ◆ Auction ◆ Quota ◆ Certificate system ◆ Net metering ◆ Mandate (*e.g.*, blending mandate) ◆ Registry	◆ VAT/ fuel tax/ income tax exemption ◆ Import/export fiscal benefit ◆ National exemption of local taxes ◆ Carbon tax ◆ Accelerated depreciation ◆ Other fiscal benefits	◆ Transmission discount/ exemption ◆ Priority/ dedicated transmission ◆ Grid access ◆ Preferential dispatch ◆ Other grid benefits	◆ Currency hedging ◆ Dedicated fund ◆ Eligible fund ◆ Guarantees ◆ Pre-investment support ◆ Direct funding	◆ Renewable energy in rural access/cook stove programmes ◆ Local content requirements ◆ Special environmental regulations ◆ Food and water nexus policy ◆ Social requirements

Note: a) Instruments that support access to finance are crucial for deployment, considering the high upfront cost of some renewable energy technologies, and they are discussed in Chapter 3.
b) Some policies and measures can ensure the socio-economic benefits of renewables and help fulfil development goals discussed in Chapter 6.

Source: IRENA, 2015b

The most rapid evolution has occurred in the power sector, where renewables have experienced significant growth in deployment and advances in technology (particularly solar PV and wind power). Grid access policies have played an instrumental role in attracting investments in renewables, supported by regulatory policies. Although feed-in tariffs/premiums and quotas (or renewable portfolio standards) were the most widely adopted instruments by the year 2005, the rate of adoption of net metering and auctions significantly increased in the last decade. This reflects developments in the sector, such as the increasing maturity of technologies and the rise of decentralised solutions, as well as the growing preference for advancing renewables as effectively and efficiently as possible.

Up until now, renewable electricity support policies have concentrated primarily on financial incentives to create markets. Yet falling costs and increased awareness and demand for renewables

Table 2.2 Key barriers to renewable energy deployment

SECTOR & BARRIERS	COST BARRIERS	REGULATORY BARRIERS	MARKET ENTRY BARRIERS	TECHNICAL BARRIERS	OTHER BARRIERS
POWER	Relatively high initial capital costs for some technologies; subsidies for fossil fuels and nuclear power; unfavourable power pricing rules	Non-existent or insufficient legal framework for independent producers; restrictions on siting, construction and transmission access; arduous permitting processes and utility interconnection requirements; inadequate market operation rules	Lack of access to credit; higher cost of capital due to lack of experience; perceived technology performance uncertainty and risk; lack of technical or commercial skill and information	Integrating high shares of variable renewable energy (VRE) into existing grids	
HEAT	High initial capital costs compared to well-established conventional systems, such as gas boilers; subsidies for fossil fuels	Arduous permitting processes	Lack of access to credit and financial incentives; lack of local technical or commercial skills; insufficient public awareness of available technologies and the broad spectrum of application options	Integrating renewable heating and cooling systems into existing infrastructure; distributed nature of consumption; fragmentation of heating and cooling markets	Competition for investment dollars from other renewable energy technologies in the power sector (particularly solar PV) and from heat pumps and energy efficiency measures
TRANSPORT (BIOFUELS)	Higher costs relative to conventional fuels, in some markets		Lack of government policy to set up charging infrastructure; cumbersome permitting process for setting up charging stations	Immaturity of third-generation technology	Adverse effects such as indirect land-use change (ILUC) and further social/environmental concerns
TRANSPORT (ELECTRIC VEHICLES)	High cost for renewable energy technologies in personal vehicle transport relative to existing technologies	Lack of government policy to set up charging infrastructure; cumbersome permitting process for setting up charging stations	Lack of energy infrastructure (*e.g.*, electric vehicle (EV) charging stations)	Immaturity of technology; relatively short vehicle range	

Source: adapted from IRENA 2012a; Beck and Martinot, 2004; IEA-RETD, 2015; Wiederer and Philip (n.d.)

also mean that financial incentives are no longer as critical in many countries. Instead, new challenges have emerged for renewable energy and the entire power sector, calling for a shift in policy focus. The growing share of variable renewable energy (VRE) requires changes in power system operations, and the rise of distributed ownership and generation are challenging conventional actors and business models. In response, countries with more advanced renewable energy markets are shifting their emphasis towards the deeper integration of renewables in the overall design and functioning of energy systems. In particular, government policies and regulations are being reformulated to support and manage rapidly increasing VRE, while also facilitating the participation of new actors in the market and the creation of new business models.

This chapter concentrates on the dramatic change underway in the power sector in many countries. It examines the evolution of policy design to increase renewable energy deployment, specifically covering the rise of renewable energy capacity auctions. It also explores some of the challenges that are prompting innovative market design and technology, and discusses new policies and regulations creating conditions for enabling the more effective and efficient integration of distributed and VRE.

2.2 Auctions in the power sector

2.2.1 The rise of auctions

Renewable energy auctions have become increasingly popular for expanding renewable power generation in developed and developing countries and are often implemented jointly with other measures to incentivise renewable energy deployment. Over the past decade, the number of countries that have employed auctions has increased eleven-fold from six in 2005 to at least 67 countries by November 2016 (adapted from REN21, 2010-2015; and IRENA, 2017a).

The growing interest in auctions is due largely to their ability to achieve deployment of renewable technologies in a well-planned, cost-efficient and transparent manner while also fulfilling a number of other objectives. Examples include job creation, local ownership and development (as in the South African Renewable Energy Independent Power Producer Procurement Programme).

The main strengths of auctions relate to flexibility, price and commitments. The flexibility of design allows policy makers to combine and tailor different elements to meet deployment and development objectives, while taking various factors into account, such as the country's economic situation, the structure of its energy sector, and the maturity of its power market. The certainty on price and quantity ensures stable revenue guarantees for project developers (similar to the feed-in tariff) while at the same time ensuring that renewable generation targets are met more precisely (similar to quotas and tradable green certificates). In addition, auctions allow for real price discovery, which is particularly relevant in fast-changing markets with rapidly declining technology and other project-related costs (*e.g.,* due to evolving local supply chains and local market maturity). Finally, auctions lead to contracts that clearly state the commitments and liabilities of each party, including remunerations and penalties for underbuilding and delays to ensure the projects deliver in line with the bid (IRENA and CEM, 2015).

Auctions also have potential weaknesses. The risk of project delays or cancellations is attributed to the potential for over-aggressive bidding in the competitive environment of the auction, which has a variety of causes. These include excessive optimism about the rate of technology cost reductions and the underestimation of the financial consequences of a project delay. Another potential weakness is the associated transaction costs, which can be relatively high for both bidders and auctioneer. Small or new players are particularly affected by this. The administrative procedures necessary for them to participate in the auction (*e.g.,* feasibility studies and qualification arrangements, deposits or bonds) may constitute a barrier to participation.

The extent to which these strengths and weaknesses affect the ultimate result of an auction depends largely on policy design. This includes how well the process is adapted to the local context in terms of economic situation, energy sector structure, power market maturity and renewable energy deployment objectives.

2.2.2 Auction design

Auction design continues to evolve and to become more complex. To increase deployment in a cost-efficient way while meeting development objectives, auctioneers are adjusting and combining a variety of design elements. These design elements can be categorised under the auction demand, qualification requirements, the winner selection process and the sellers' liabilities (see Box 2.1). In other words: what does the auctioneer want, who gets to bid, who wins the bid and how can the auctioneer ensure that winning bidders meet their commitments?

For an auction to be successful, its design should ensure that competition between bidders is optimal in order to drive prices down while it is limited to bidders with the capacity to implement projects at the contracted price within the given timeframe.

Box 2.1 Categories of auction design elements

- **THE AUCTION DEMAND** refers to what is being auctioned, including amount of capacity, technologies to be included, how capacity is divided among them, individual project sizes and considerations on allocation of costs and responsibilities.
- **THE QUALIFICATION REQUIREMENTS** determine which suppliers are eligible to participate in an auction. Requirements, for instance, might be related to reputation, equipment, production site selection, ability to secure grid access, and ability to promote local socio-economic development.
- **THE WINNER SELECTION PROCESS** involves rules on applications to bid, specific bidding procedures, selection criteria for winning bids, clearing mechanisms and payment to auction winners.
- **THE SELLERS' LIABILITIES** relate to responsibilities and obligations stipulated in the auction documents. This includes commitments taken once a contract is signed, the remuneration profile and settlement rules and penalties for underperformance, delay or underbuilding.

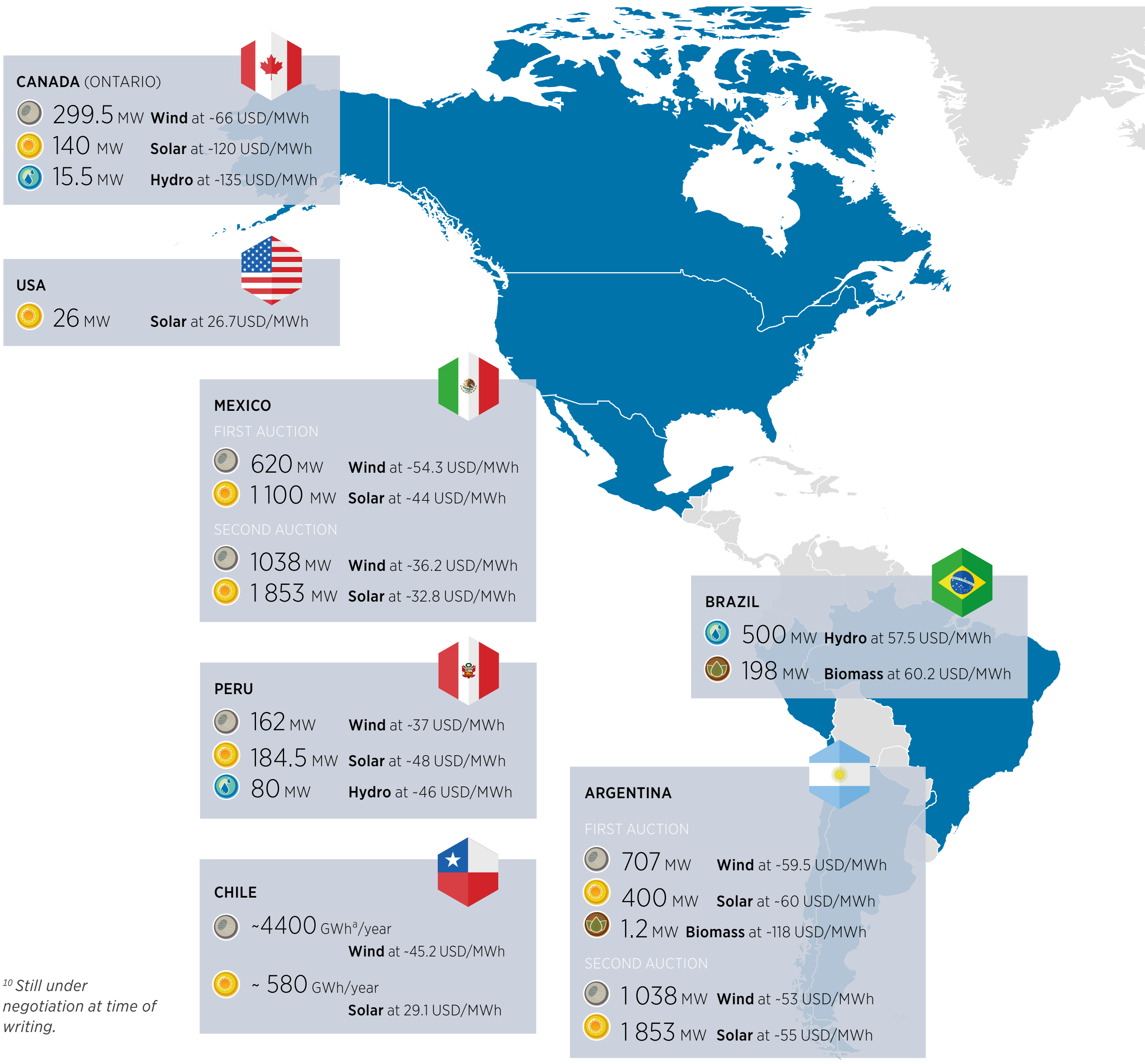
Source: IRENA and CEM, 2015

2.2.3 Auctions in 2015 and 2016

In 2015 and 2016, prices resulting from solar and wind energy auctions fell sharply across the globe. For wind power, some of the lowest prices were recorded in North Africa, where Egypt announced a winning bid price of USD 41/MWh in 2015. Soon after (in 2016), Morocco announced the lowest winning bid price at USD 28/MWh (with USD 30/MWh being the average price across all wind farms).

Prices also declined in auctions calling for new solar PV capacity. In Dubai in the United Arab Emirates, a record-breaking bid of USD 29.9/MWh for an 800 megawatt (MW) solar park was received in early 2016. A few months later, Abu Dhabi announced that it had received a lower price of USD 24.2/MWh[10] for its 350 MW auction (Bloomberg, 2016a). In Peru, prices fell as low as USD 48/MWh, and later in the year Chile announced record low prices of USD 29.1/MWh (IRENA, 2017a). Figure 2.2 illustrates the results

Figure 2.2 Highlights in renewable energy auctions, 2016



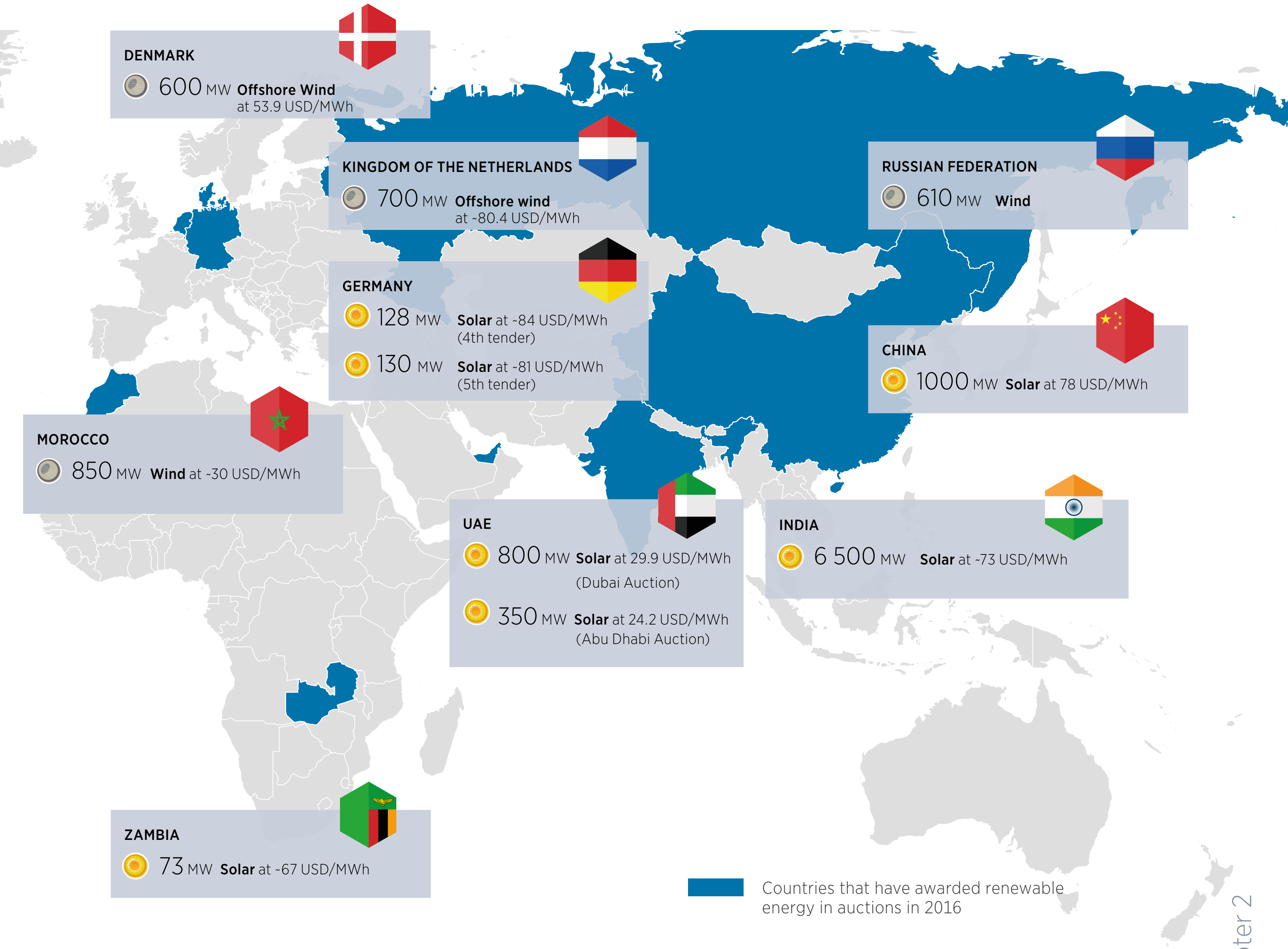
[10] *Still under negotiation at time of writing.*

of recent renewable energy auctions in different parts of the world. These projects are planned to be commissioned between 2018 and 2020, in most cases, with possible longer lead times for hydropower.

By 2016, solar PV bids in the most competitive countries came in below USD 60/MWh, as seen in Figure 2.3. The figure illustrates the sharp decline in (average) winning bid prices for utility-scale solar PV between early 2010 and mid-2016. It also reveals that prices are converging across a number of countries. However, a wide range between the highest and lowest prices persists, due to the resource potential, costs and enabling country-specific conditions.

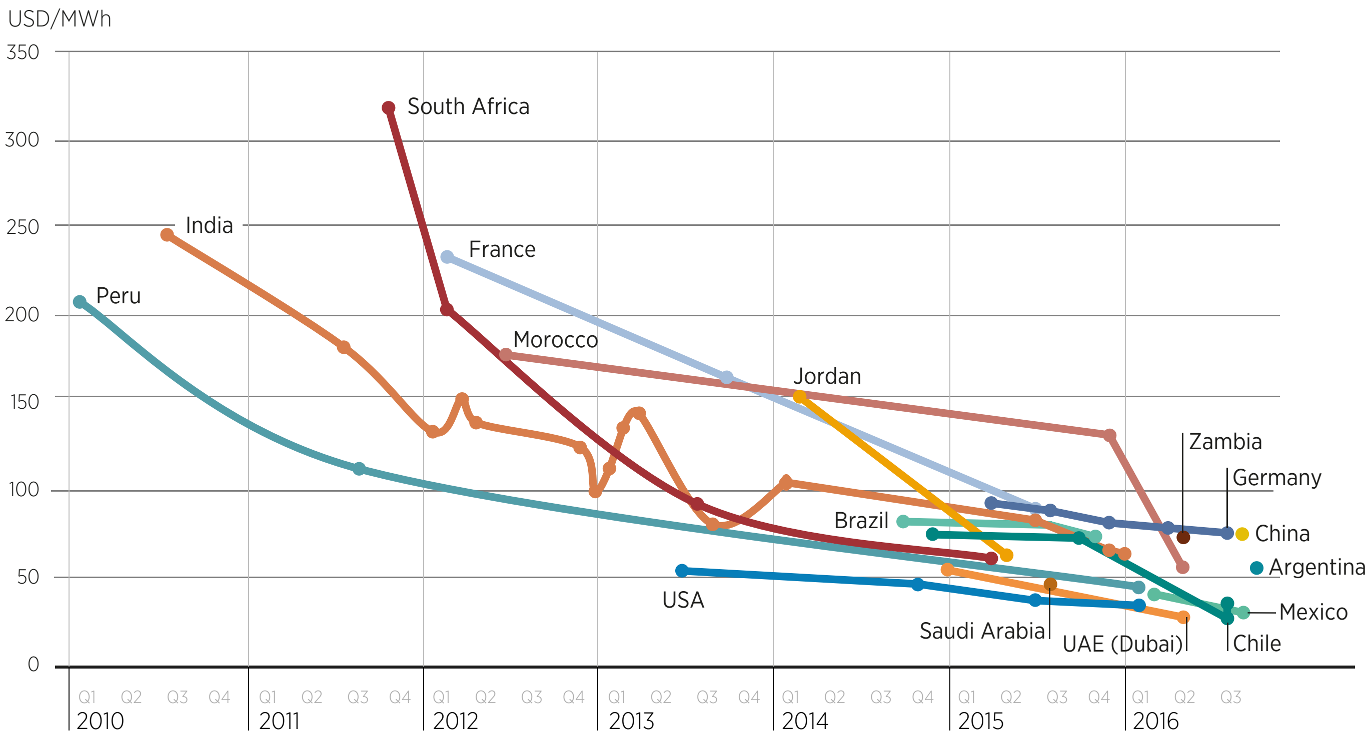
2.2.4 Factors contributing to low prices

What has driven the bid prices for wind and solar PV to such low levels? Two main reasons include falling technology prices and the competition created by auctions. However, the low bid prices are also attributed to access to finance



Note: a) GWh: gigawatt-hour.
Source: Countries that have implemented auctions to date based on REN21, 2010, 2011, 2012, 2013, 2014 and 2015; and recent bids from IRENA, 2017a

Figure 2.3 Evolution of utility-scale solar PV auction prices around the world



Source: IRENA, 2017a

and other country-specific economic conditions, investor confidence and a (perceived) low-risk environment, and additional renewable energy support policies. In addition, specific trade-offs in auction objectives can raise or reduce bid prices (IRENA, 2017a) as follows:

ACCESS TO FINANCE AND OTHER COUNTRY-SPECIFIC ECONOMIC CONDITIONS. A country's overall macroeconomic conditions affect project costs and hence the prices submitted by bidders. Conditions include the ease of doing business and access to finance, and the country's credit rating. General soft costs associated with building and operating a project also affect bid levels. Examples include the costs of labour, land and input energy. One example is the third phase result of the Al Maktoum Solar Park (USD 29.9/MWh) in Dubai. This was influenced by low soft costs, favourable loan terms (including relatively low interest rates and long loan tenure), and generally very low taxes in the UAE (Morris, 2016). Another important factor is the Emirate's long-term vision to deploy 5 GW of solar power capacity. The promise of a long-term market for renewables created investor confidence while also intensifying competition among bidders wishing to enter the market, which resulted in low bids.

INVESTOR CONFIDENCE. Auction bid prices are significantly affected by investor confidence in the renewable energy sector of a specific country and the risk level faced by project developers there. Where potential risks are mitigated by additional policies to support renewable energy, as well as by other factors, the cost of financing can decrease substantially. This lowers bid prices.

Investor concerns about demand-side responsibilities can be reduced by assigning a reliable off-taker and providing certainty and regularity in the procedures and schedules for auction rounds. The Dubai solar PV auction, for instance, succeeded in drawing low bids for a couple of reasons. The off-taker, the Dubai Electricity and Water Authority, was creditworthy, and both country and region had a long-term vision for solar deployment.

Public finance institutions can provide private developers with risk mitigation instruments such as guarantees, currency hedging instruments and liquidity reserves (see Chapter 3). In Chile, the contracts are denominated in USD and are adjusted periodically (according to the US Consumer Price Index) so that developers are shielded from interest rate risks and inflation risks.

ADDITIONAL RENEWABLE ENERGY SUPPORT POLICIES to support renewable energy deployment can contribute to low bid prices in two ways. Deployment policies, such as tax breaks or import duties, implemented in tandem with auctions, can reduce project costs and thus bid prices. Also, policies to develop local capacity through education and training can help create a local workforce that can both increase technology reliability and reduce the need to import talent.

TRADE-OFFS IN AUCTION OBJECTIVES. The various choices made when designing auctions present trade-offs between minimising bid prices and other objectives. Examples are described below.

- Local content requirements: there can be a trade-off between developing a local industry, developing a local industry and achieving lower prices. Auctions with minimal to no local content requirements can encourage foreign players to enter the market. This means renewables may grow more rapidly and in some instances at lower prices than might otherwise be the case. However, the country might forgo the benefits of domestic development which brings with it such benefits as employment, local value, skills and know-how.
- Bidding requirements and compliance rules: there is a trade-off between ensuring the successful and timely delivery of projects in line with the bid and achieving lower prices.
- Limiting the volume awarded to individual bidders: some countries limit the volume that can be awarded to any single developer to minimise risk and encourage more than one company to enter the market, thereby advancing deployment. However, such restrictions can hinder economies of scale.
- Greater government role: governments can take on the responsibility for some required tasks such as conducting resource assessments, selecting a site for the project and ensuring grid connections. If so, project risks and costs for potential bidders are reduced, lowering bid prices.

Clearly, bid prices are influenced by general macroeconomic and political conditions, the existence of additional renewable energy support policies and other considerations. However, it is important to gain a better understanding of the factors that led to record-breaking bid prices for solar PV and wind power in 2016 across different regions of the world to guide future policy design. In this light, it is also important to verify that the projects come online successfully and on time, and to gain an understanding of why they might not succeed (IRENA, 2017a).

With the rise of auctions, alongside other renewable energy support policies, ongoing cost reductions and rising electricity demand, numerous renewable energy projects (particularly solar PV and wind power) are being planned and are under construction around the world. The increasing share of variable renewable generation is prompting policy makers and regulators to reconsider power market designs and system planning and operation.

2.3 Integrating distributed and variable renewable energy into the power sector

Years of sustained policy support from several countries have lifted and advanced wind power and solar PV technologies to a point where they are ever-more competitive with non-renewable generation on the basis of energy costs alone. At this stage, particularly in advanced markets, some of the policy support need to shift towards a favourable market environment for integrating VRE resources to allow growth to continue in an efficient manner.

Depending on local circumstances, variability of renewable energy can raise some challenges for power system operations, especially at higher market shares. Moreover, a significant proportion of VRE capacity operating in several countries, such as the US and Germany, is distributed across the customer end of the distribution network, on rooftops and in the backyards of homes and businesses (see Box 2.2). This means other power system components, operating procedures and market design need some adjustments.

Policy makers, regulators and power system operators around the world – whether operating under a centralised utility structure or within liberalised power markets – must adjust and promote the growth in variable renewable power. They must ensure no interruption to the continuous transition to renewable systems. To that end, it is essential to pursue an efficient combination of measures as local conditions dictate. This means making full use of distributed energy resources for efficient system management; harnessing new data collection and control technologies to the same end; reinforcing grid infrastructure, generation and storage capability for system adequacy and flexibility; and designing power markets and operating protocols accordingly (IRENA, 2017b). All this must be achieved in ways that promise adequate, reliable and safe electricity services at reasonable prices while sharing system costs and benefits among all stakeholders in a fair and equitable manner. Indeed, integrating distributed and VRE into the power sector requires efforts at both the system and market level.

2.3.1 System and market considerations for variable renewable energy integration

Some fundamental changes have transformed many electric power systems in recent history: power market liberalisation and the proliferation of variable (and often distributed) renewable generation (see Box 2.3). This has presented power system operations, power producers and customers with many concerns and opportunities (IRENA, 2013a), which fall into two main categories: those pertaining to the physical system and its operation, and those to power markets.

System considerations for increased renewable power deployment relate to concerns with power system adequacy and operation, as well as power production, demand scheduling and balancing within the physical constraints of the interconnected power grid. Market considerations relate to the effects of varying degrees of renewable capacity deployment on power market design and operation, and to the implications for cost recovery of other critical system components, such as distribution networks and reserve generating capacity. However, the distinction between the two categories is not absolute, especially when identifying solutions. This is because improving market design helps resolve system-related concerns, and alleviating system-related constraints helps improve market function.

Examples of system considerations

Power system operators have always had to manage the electricity fed into the power grid to balance supply and demand in real time. This requires a considerable level of flexibility from other system resources in managing seasonal variability, daily and hourly ramping cycles, and minute-to-minute energy balancing.

Electricity generation from VRE fluctuates according to resource availability and may not coincide with the demand profile. Solar PV and wind power generation varies with daily and hourly weather conditions, and also according to daily and seasonal cycles of wind speed and solar

Box 2.2 Rise of mini-grid deployment in the United States

The US leads in terms of mini-grid capacity, with growing deployment in hospitals, universities, industrial plants, military facilities and communities. The need to improve reliability and resilience in the face of extreme weather and other eventualities has acted as the driving force behind most installations.

Communities and businesses are also more interested in reducing electricity costs, improving efficiency, encouraging local investment, creating jobs, and increasing renewable generation to meet sustainability goals. Most of the existing mini-grid capacity in the US relies on fossil fuels but the proportion of renewables has increased rapidly. By mid-2016, it accounted for 45% of the known pipeline (Chen, 2016).

Despite rising interest, mini-grids face regulatory, financial and technical hurdles (Wood, 2015; Grimley, 2016). Mini-grids have no universal legal definition or purpose, making their legal status unclear. Regulatory frameworks governing grid connection and disconnection, electricity sale and transmission, fair pricing of electricity bought and sold, land use and other factors are complex and can raise costs. They also vary from state to state. Such regulatory barriers make it challenging to finance projects. Appropriate business models are needed to attract capital but many options for mini-grids to generate revenue conflict with existing regulations. One technical hurdle is the lack of standardised computer controls. In addition, the response from utilities has been mixed. Some welcome mini-grids as a business opportunity but most perceive them as a threat.

Most community projects online or in the pipeline were motivated by state-level incentives, which have been directed mainly at pilot projects to test technologies and advance regulatory frameworks. New York's USD 40 million grant competition, "NY Prize", was launched in the wake of Hurricane Sandy and aims to jump-start at least ten independent community-based mini-grids across the state (St. John, 2014). A key part of the effort is to bring utilities on board. In 2016, the state adopted new standardised interconnection requirements, raised the size limit of distributed generation projects from 2 MW to 5 MW and reduced upfront interconnection costs. The aim of all this was to make grid connection easier and faster for distributed projects, including mini-grids (Powers, 2016).

Other states working to promote mini-grids include California and Alaska. In 2016, California awarded grants to several cities for mini-grid planning and design that includes renewable energy (especially solar PV) and launched work on a roadmap to remove barriers to development (Wood, 2016). Over the past decade, the federal government and state of Alaska have invested nearly USD 1 billion in mini-grids to use renewables to reduce electricity costs and dependence on diesel generators (Martinson, 2016).

Box 2.3 Changing roles and ownership structures

In centralised, traditional vertically integrated electric power systems, the utility plans builds and operates power generation plants, transmission infrastructure and distribution systems. The utility plans ahead, deciding how much new generation and transmission capacity to build to meet (growing) demand. It optimises the mix of baseload, cycling (intermediate-load) and peaking capacity to fit the aggregate load profile of its customer base at the lowest reasonable cost. In return, such monopolies (whether public or private) receive a guaranteed return on investment under the scrutiny of utility regulators who verify that investments and operating costs recovered through regulated tariffs are fair and reasonable.

Some fundamental changes have disrupted this structure. First was the restructuring and liberalisation of the power sector in many countries, mostly in the 1990s. This introduced competition in wholesale power generation among multiple independent power producers and sometimes also incorporated retail competition. As a result, the traditional vertically integrated utility was broken up, and its integrated system planning role was largely abandoned.

The second dramatic change to the system has been the proliferation of VRE – and particularly distributed VRE systems owned by non-utilities, individuals and businesses. These systems range from small rooftop solar PV to large-scale wind power plants. This significant change in the ownership structure of the power sector was driven by effective support policies such as feed-in tariffs and net metering, and subsequently by falling costs for these ever-improving renewable energy technologies. A third important change has been the progress and cost-decreases in data management and remote-control technologies that allows the efficient operation of mini-grids and their deployment.

Source: IRENA, 2017b

radiation. Variable resource forecasting models have improved significantly, and both daily and seasonal resource cycles are quite predictable. However, variable generation often deviates from expected values. The requirement for system flexibility has thus grown alongside the success of VRE. The greater the share of VRE, the greater the need for flexibility in the system.

The ability of power plants to modulate their output remains the primary component of system flexibility. As VRE sources increase requirements for flexibility, they may also displace certain generating assets otherwise well-suited for cycling (SWECO, 2015). This makes the generation asset mix a key consideration in combination with other sources of system flexibility.

Other system considerations relate to the interaction of variable and distributed renewable energy sources with transmission and distribution (T&D) networks. These include the implications of managing not fully predictable power flows, potential grid congestion and voltage variability when generation grows at the consumer end of the distribution grid. Regions with a high share of VRE can achieve the requisite flexibility in several ways. They can, for instance, improve interconnections with neighbouring power markets and export power during periods of high output and import power during periods of low generation. Existing regional interconnections may or may not be robust enough to meet this added load.

Examples of market-related considerations

The cost structure of renewable power (other than bioenergy) is notably different from conventional thermal power plants. It has very low or zero marginal cost because no fuel is necessary. Since rational market operation dictates that the least marginal cost energy be used before more expensive energy, all else being equal, renewables usually displace generation from sources with higher marginal costs. This includes all generation based on fossil fuel.

This shift in the dispatch order of power plants (the "merit-order effect") usually lowers power market clearing prices (price per MWh) in wholesale markets while also reducing demand for conventional energy plants (MWhs sold). This can be disruptive if the power system cannot adapt quickly. Power plants have long life spans and are built with certain expectations about how they will be run based on their physical location and the mix of other plants in the interconnected network. When that mix is rapidly changed, some existing plants may become uneconomical. Conversely, as the demand for flexible system resources grows, and if the flexibility is provided entirely by existing generating assets that now must recover their fixed costs through sale of fewer units of energy, their price per unit of energy will increase. The long-term impact on the average price of generation across the system is uncertain. Markets already endowed with reservoir hydropower, pumped hydropower capacity, strong regional interconnections or other sources of flexibility are in the best position to integrate VRE at minimal system cost.

There are also T&D market implications associated with rising shares of variable renewable generation. The cost of maintaining, reinforcing and operating T&D networks is usually recovered, for the most part, in the form of volumetric charges (per unit of energy delivered) rather than fixed charges. This has always been a sensible approach because consumers pay in proportion to the load they represent on the grid. However, distributed self-generation reduces the units of energy purchased from the grid, which in turn reduces the unit-based payment for T&D services. Reduced network charges result in lower revenue to the T&D operators and may undermine adequate cost recovery for system maintenance and operation, as well as for grid reinforcement and expansion.

Distributed VRE generation can be beneficial to the T&D network by reducing line losses and load on the grid when it coincides with periods of high demand. However, distributed or variable generation can challenge T&D networks at other times, depending on a range of factors that include location and seasonal variability.

2.3.2 System and market solutions for integrating variable renewable energy

Some solutions towards the integration of distributed and VRE sources are already being implemented in some US states, Denmark (see Box 2.4), Italy and Germany (see Box 2.5), for example.

Some of the solutions relate to physical infrastructure, and others are defined by concepts of market design. Some draw on supply resources, while others draw on demand-side resources. Some integrate the two. Some solutions are more long term, while others are more or less stopgap measures. What they all have in common is that they introduce some measure of additional flexibility into the power system. These flexibility measures can be grouped into six categories: supply side, demand side, T&D networks,

Box 2.4 Integrating VRE in Denmark

Denmark aims to completely phase out fossil fuels and to get 100% of all energy from renewables by 2050. It has set two interim steps. Firstly, it aims by 2020 to meet 35% of final energy demand from renewables and 50% of electricity demand from wind power. Secondly, it aims by 2035 to meet all energy demand for power and heating from renewables. Denmark is already a long way towards reaching these goals, with wind power meeting 42% of electricity demand in 2015 (REN21, 2016; Denmark.dk, 2015).

One of the biggest concerns to date has been balancing electricity supply and demand since some days wind power provides more electricity than the country can consume, while others are not very windy. Denmark uses a range of measures to integrate and balance the high share of VRE. One key element is the strong integration of its electric grid with neighbouring grids in Europe, including the Nordic Pool market. This enables Denmark to buy and sell power to balance its wind energy.

In addition, several innovations are playing an important part in increasing system flexibility (Martinot, 2016). One is Denmark's coupling of electricity and heat supply. About half the country's electricity comes from combined heat and power plants, many of which are fuelled by biomass. These feed into district heating systems and include thermal energy storage. These systems can vary the output of electricity (*e.g.*, increasing production of heat and storing it for later use) in response to changes in wind power output.

In addition, highly sophisticated day-ahead weather forecasting has been incorporated into Denmark's power system control and dispatch. Furthermore, the country's power control and market operations centre requires all large generators to provide updates when their output changes. It constantly updates weather forecasts in real time for the coming period in order to be prepared for output changes from variable renewables. As a result, VRE generation is quite predictable, ensuring efficient and reliable operations of the country's power system (Martinot, 2016).

Source: IRENA, 2017b

Box 2.5 Integrating VRE in Germany

Some of the measures to be taken in the short term to develop the future electricity market in Germany are described in Table 2.3 and they are categorised under three components: stronger market mechanisms, flexible and efficient electricity supply, and additional security. Strengthening the existing market mechanisms can be achieved through measures that "ensure that the electricity market endogenously maintains the necessary capacities and thus continues to ensure security of supply". Measures that contribute to a flexible, cost-efficient and environmentally compatible power supply are meant to optimise the electricity supply at both the national and European levels. Finally, additional security of supply can be facilitated through measures such as monitoring security of supply and introducing a reserve capacity.

Table 2.3 Overview of measures to develop the future electricity market in Germany

Component		No.	Measure
COMPONENT 1			**STRONGER MARKET MECHANISMS:** The measures packkaged in component 1 strengthen the existing market mechanisms. The required capacities can thus refinance themselves and the electricity market can continue to ensure security of supply.
	Measures	1	Guaranteeing free price formation on the electricity market
		2	Making supervision of abuse of dominant market positions more transparent
		3	Strengthening obligations to uphold balancing group commitments
		4	Billing balancing group for each quarter hour
COMPONENT 2			**FLEXIBLE AND EFFICIENT ELECTRICITY SUPPLY:** The measures of component 2 optimise the electricity supply at both European and national levels. They thus ensure a cost-efficient and environmentally compatible use of capacity.
	Measures	5	Anchoring the further development of the electricity market in the European context
		6	Opening up balancing markets for new providers
		7	Developing a target model for state-induced price components and grid charges
		8	Revising special grid charges to allow for greater demand side flexibility
		9	Continuing to develop the grid charge system
		10	Clarifying rules for the aggregation of flexible electricity consumers
		11	Supporting the wider use of electric mobility
		12	Making it possible to market back-up power systems
		13	Gradually introducing smart meters
		14	Reducing the costs of expanding the power grid via peak shaving of renewable energy facilities
		15	Evaluating minimum generation
		16	Integrating combined heat and power generation into the electricity market
		17	Creating more transparency concerning electricity market data
COMPONENT 3			**ADDITIONAL SECURITY:** The measures of component 3 provide additional security of supply.
	Measures	18	Monitoring security of supply
		19	Introducing a capacity reserve
		20	Continuing to develop the grid reserve

Source: BMWi, 2015

storage, market design and system operation and management (see Figure 2.4).

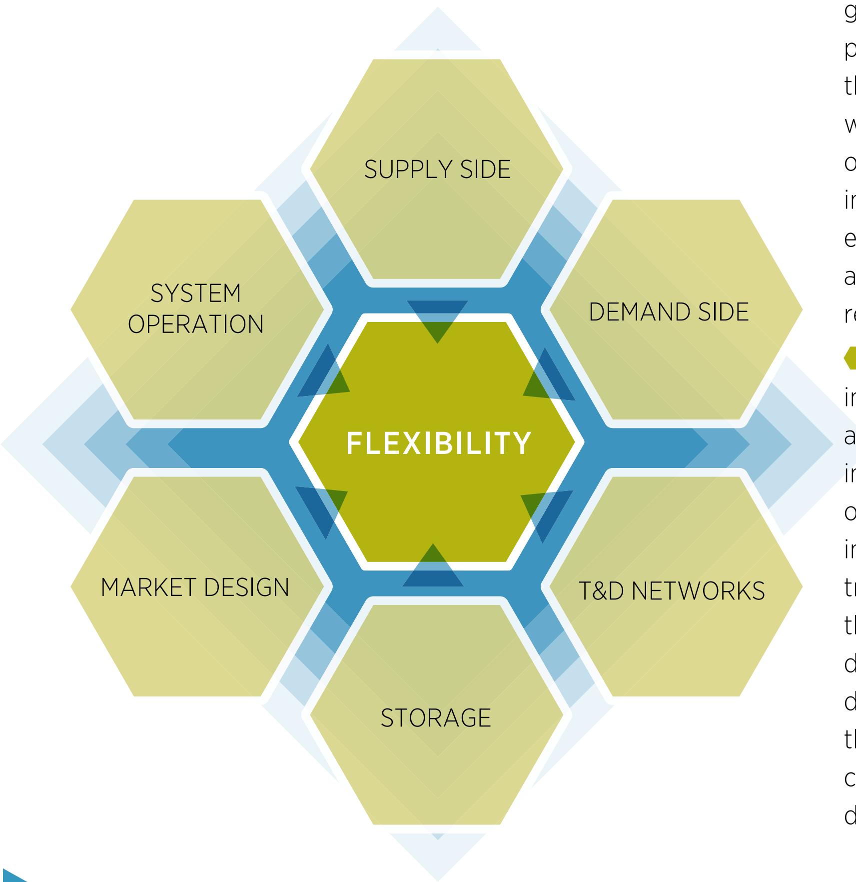
SUPPLY SIDE. System flexibility has always relied predominantly on the ability of generating resources to ramp output up and down in response to demand variation, network congestion and other system conditions. Increasingly, new thermal power plants are designed to accomplish this function in order to be of greater value to the power system. Non-variable renewables, such as bioenergy and geothermal plants, are well positioned to serve this function. Flexibility of output has always been a major advantage of reservoir hydropower and pumped hydropower.

DEMAND SIDE. Changes in variable generation, or various system constraints, can be addressed by time-shifting or reducing demand. This can be achieved in two ways: system operators or other entities that can control the load remotely on the basis of predetermined criteria. Alternatively, control systems operated under the customers' (demand) criteria can trigger a load response. When "smart systems" allow the consumer to know and react to the real-time electricity price, demand reduction can be "sold" by the consumer.

Several conditions need to be met to make these demand shifts. Both operational capacity and requisite technology solutions must be in place to: a) gather and share data for efficient resource and grid management ("smart networks"), and b) control both load (demand) and storage devices in response to real-time system conditions and expected variable generation. In addition, policies and regulations must allow and encourage the distribution utility (or other entities) to take on this expanded role of managing dynamic interactions with distributed energy resources. Finally, system tariffs must accurately reflect and communicate the cost and value of distributed energy resources (supply, storage and demand response). This enables the owners of those resources to make sound economic decisions informed by true system costs and conditions.

One of the greatest innovations for better integrating variable and distributed renewable generation will lie in the greater active participation of consumers, large and small, in the management of supply and demand. Markets work best and have the best chance of efficient outcomes when all parties to a transaction are informed and engaged. The power-producing electricity consumer thus needs to become an active contributor to system adequacy and reliability.

Figure 2.4 Six categories of flexibility measures



T&D NETWORKS. The transmission grid helps integrate VRE and provides added flexibility by acting as literal conduit to new variable energy installations and by connecting a larger network of markets. The larger the interconnected network in proper proportion to the strength of internal transmission linkages, the greater the flexibility of the system as a whole. All else being equal, more diverse and geographically dispersed supply and demand creates greater overall balance within the system. Transmission planners – ideally in co-operation with neighbouring control areas – design, plan and optimise transmission upgrades and extensions to be as cost-efficient as possible. This involves looking ahead to future additions to the generation mix, including utility-scale VRE installations.

The same applies to distribution grids with rising participation of distributed VRE. Distribution utilities need to advance VRE integration by expanding their roles as active managers of distributed resources in co-operation with self-generating customers. They need to handle the detail of demand response, storage, data flows and other issues associated with the transformation to smarter grid management. Better co-ordination between T&D system operators may also be needed with the growth in distributed VRE.

- STORAGE. Electricity storage is already a key source of system flexibility in many countries and will become more important as VRE generation increases. Solutions can be implemented within T&D networks or at the consumer end of the grid. Distributed storage solutions paired with distributed generation has the potential to relieve system concerns about variability and distribution grid impacts. There are also opportunities and advantages to using thermal storage for variable generation to serve distributed or centralised (district heating and cooling) thermal loads. (See Chapter 4 on electricity storage technologies).

- MARKET DESIGN. Power markets need to be designed and implemented to be flexible and responsive, pricing resources in harmony with their value to the system, in each hour of the day. The objective is to ensure efficient day-to-day management of the power system while providing adequate market signals for new investments.

The tariff structure can be modified to reflect real-time costs rather than long-term average costs. This is true for both energy and distribution tariffs. In conjunction with other measures, it can allow distributed energy resources – a mix of controlled generation, demand response and storage – to make supply and demand decisions that reflect real-time conditions. However, this assumes all market participants have been fully informed. This, in turn, depends on the implementation of the technological elements of the "smart network", including system management functions presumably in the hands of T&D system operators.

Power market flexibility and efficiency could be improved by allowing prices to communicate the true value of flexibility and by allowing differentiated pricing that better reflects system constraints according to geographic location. Again, under certain conditions, distributed energy can be given the opportunity to respond to the same market price signals. T&D tariffs may need to be refined if self-generation is considered to obstruct adequate cost recovery and fair cost sharing. However, T&D customers can benefit network resources when their self-generation relieves system load. Equally, it benefits the network when their potential to be active contributors to system adequacy and reliability as supplier of demand response and storage returns value to the system.

Market design is a complex exercise that means combining technological solutions and carefully balancing market tools for technical and economic efficiency. Poor design or acute unresolved physical system constraints can generate excess economic rent to some market participants and thus create economically inefficient outcomes.

- SYSTEM OPERATION. Due to the variability of output, it is difficult to fully "commit" the generation of a VRE resource well in advance and for any extended period of time. That does not mean the generation will not be available – merely that there is somewhat greater uncertainty within the timeframes of conventional power system operations. System operators may compensate in some cases by reducing the dispatch intervals to the sub-hourly timeframe. The shorter the timeframe, the greater the certainty about the level of VRE generation. Such adjustments are supplemented by better and more frequent resource forecasting. Better co-ordination between control areas is helpful to optimise resource allocation when operators are managing steeper ramp rates brought on by the higher shares of VRE. Naturally, all of this requires increasingly sophisticated monitoring, communication and control systems.

Box 2.6 Tackling curtailment in China

Over the period of a few years, China has become a world leader deploying non-hydropower renewable capacity, especially solar PV and wind power. However, China's transmission network expansion has not kept up with the surge in renewables deployment. Most of China's installed capacity is located far from its highly populated eastern coastal regions, resulting in widespread and persistent curtailment.

Wind power curtailment reached an average of 15% in 2015 and during the first half of 2016 it rose further still. The solar PV curtailment rate reached 31% in Gansu province during 2015. There are signs that hydropower has been affected but official data are not available (Shen, 2016; Liu, 2015). It is thus more difficult for China to reach its renewable energy and environmental goals, including climate targets. In addition, the renewable energy industry has lost significant potential revenue. Estimated losses in the wind power sector were as high as USD 2.8 billion (CNY 18 billion) during 2015 (Ying, 2016).

Where transmission infrastructure is available, renewables face competition from coal-fired generation due to grid inflexibility and a market structure that drives grid operator preference for coal. A slowdown in electricity demand growth and the construction of new coal facilities (projects approved during the economic boom) have' exacerbated this situation (Tianjie, 2016)

Reducing curtailment is a key priority, and several steps are being taken to this end (Dupuy, Porter and Xuan, 2016; Dupuy and Xuan, 2016; Ying, 2016). These are explained below.

GUARANTEED GRID CONNECTION AND PURCHASE, AND COMPENSATION FOR CURTAILMENT: A government regulation issued in late 2015 gives clean electricity producers priority over coal in selling to distributors and large industrial consumers. In early 2016, power transmission companies were ordered to provide grid connections for all renewable plants that comply with technical standards. In addition, a major policy announced in March 2016 mandates that grid companies purchase generation from renewable generators at least up to a specified number of hours.

QUOTAS AND GREEN CERTIFICATE SYSTEM: In 2016, provincial and regional targets were established for non-hydropower renewable electricity. At least 5% of electricity in Chinese grid operator networks must come from wind, solar or biomass. By 2020, power companies should generate at least 9% of electricity from non-hydropower renewables. In addition, plans were announced to establish a market for tradable "green certificates" (for non-hydropower renewables) by 2020 to help achieve these targets.

SITING: Feed-in tariff rates for wind and solar PV are highest in the eastern regions, which are more populated. A three-tier warning system has been launched to prevent further investment in wind power in some locations. Approvals for new construction will be put on hold in regions with a curtailment rate of 20% or more.

SYSTEM OPERATION: Early in 2015, grid companies were called upon to assume responsibility for integrating renewable electricity and reducing curtailment. The country's regions with the most wind and solar power production were urged to launch pilot projects to deal with curtailment. They could, for instance, increase the flexibility of non-renewable combined heat and power plants and increase local renewable electricity consumption (*e.g.*, district heating or energy-intensive industries).

TRANSMISSION: By mid-2016, 12 ultra-high voltage transmission lines were under construction to connect provinces of the northwest with coastal areas. The State Grid Corporation of China plans to spend USD 355 billion (CNY 2.3 trillion) over five years to expand its transmission network. This is an increase of 28% over the previous five-year period. Implementation and enforcement is still not easy, and only time will tell whether more measures are required.

Renewable generation can be curtailed by the system operator when either demand or the transmission network cannot accommodate the output. This may or may not involve compensating the generator. Curtailment can be a matter of system necessity and carry a lower economic cost than other solutions in the short term. However, it is wasteful as a long-term system operating tool and should therefore be reduced to the minimum (see Box 2.6). For the long term, renewable power should not be subjugated to system inadequacies. Instead, electric power systems must adapt to accommodate an ever greater share of VRE.

Power system regulators are just beginning to deal with the changes needed to successfully integrate the ever-growing market share of variable and distributed renewable electricity generation. The experience so far is promising. System operators are finding the constraints less difficult to overcome than they once feared.

2.4 Conclusion

Government policies have played a critical role in advancing renewable energy deployment, and this has stimulated technology improvements and driven down costs. Policies continue to evolve with experience and changing conditions. This is particularly true in the power sector, where the focus of policy support is shifting. The exclusive use of financial incentives is making way for policies to advance markets as effectively and efficiently as possible while also ensuring the integration of rising shares of VRE.

Power auctions have been the focus of some of the latest developments in policy design. Renewable power capacity auctions are being tailored to combine several design elements to fulfil a variety of development objectives beyond the acquisition of new renewable-based power capacity at low cost.

Like other instruments, auctions have limitations. These relate mainly to the risks of underbuilding and delays in project construction, and to the potential exclusion of small and new market participants. There are many trade-offs associated with the different aspects of auction design, and policy makers should make choices that reflect overall deployment and economic development objectives.

Recent solar PV and wind power auctions in several countries have resulted in record-breaking bid prices. It will be important to gain a better understanding of the factors driving these low prices, while also ensuring that projects will be realised as bid, to be able to integrate best-practice elements into policies in the future.

As solar PV and wind power deployment surges, variable output and in many cases distributed deployment create both concerns and opportunities for power system operators and market participants. They need to consider issues related to both systems and markets. System concerns centre mostly around the need to match supply and demand. Market concerns relate to economic and operational constraints either faced or caused by VRE sources. Most of these considerations can be resolved by increasing physical or operational system flexibility. Experience suggests that integrating a large share of VRE is not as difficult as initially expected. However, in several cases power system operators and regulators are still at the early stages of shaping and implementing strategies. During that process, it is of paramount importance that ultimate system design and operation be moulded to accommodate the rise of VRE rather than the other way around. At the same time, solutions must be economically efficient, serve system reliability and adequacy, and result in fair and equitable sharing of costs and benefits among all stakeholders.

Policies have been evolving in the power sector but relatively little progress has been made in heating and cooling for buildings and industry or in transportation. These sectors are important to human and economic development and have a significant effect on global climate change. There is major unrealised potential for renewables to meet future energy needs. Policy makers must therefore consider all end-use sectors and adopt a holistic approach to energy policy. Policies to advance energy efficiency (in appliances, buildings and vehicles) are also essential. This will ensure that more services can be obtained from the same amount of energy and will help increase the share of renewables as effectively and efficiently as possible.

Chapter 03

Recent Trends in Renewable Energy Investment, Financial Instruments and Business Models

3.1 Introduction

Attracting sufficient financing is a key condition to scale up renewable energy investment and harness wider socio-economic benefits. Investment in renewables has to increase significantly above current levels, which can be driven by the private sector interest in assets that promise long-term, stable returns. Renewable energy technologies have become a compelling investment proposition as their costs have declined in recent years, a trend that is making them increasingly cost-competitive with fossil fuel technologies, even amid low global oil prices.

Yet despite these opportunities, global investment in renewables remains below its potential. This is due to a number of factors discussed in this chapter that are often specific to market conditions, differing in particular between energy markets in developed and emerging economies. In many markets with high renewable energy potential, market barriers and the perception of high risk prevent private investors from participating more actively in renewable energy finance.

Investors' willingness to commit capital to the renewable energy sector is driven by the risk/return profile of investments. An analysis of the risks and barriers in renewable energy investments and recent experience with financial instruments sheds light on the challenges that need to be addressed (IRENA 2016f). Indeed, investment in renewable energy can be scaled up rapidly to accelerate the global energy transition if the right policy and financial instruments are used. Sound policy frameworks (as discussed in Chapter 2), the availability of a pipeline of investment-mature projects and local financial capacity are all key elements to scale up renewable energy investment. In addition, public finance institutions should direct a greater level of their limited resources to leveraging private capital in renewable energy investment, in particular, through risk mitigation and structured finance mechanisms. A critical element of this strategy is to link what are often relatively small renewable energy assets to large-scale investors. This includes institutional investors that only invest in larger deals of at least a few hundred million USD.

This chapter starts with a brief overview of the status of renewable energy investment in late 2016, and then highlights some recent trends and prospects, financial instruments, and evolving capital market tools and business models. These newer instruments and tools complement those that are traditionally used to mobilise investment, and all aim at impacting the risk/return profile of projects and bridging the divide between local energy industries and financial investors. Used together, they constitute a robust set of instruments that can accelerate renewable energy investment to the levels required, hinging upon the political will to direct the institutions in charge of the public finance agenda to use them effectively.

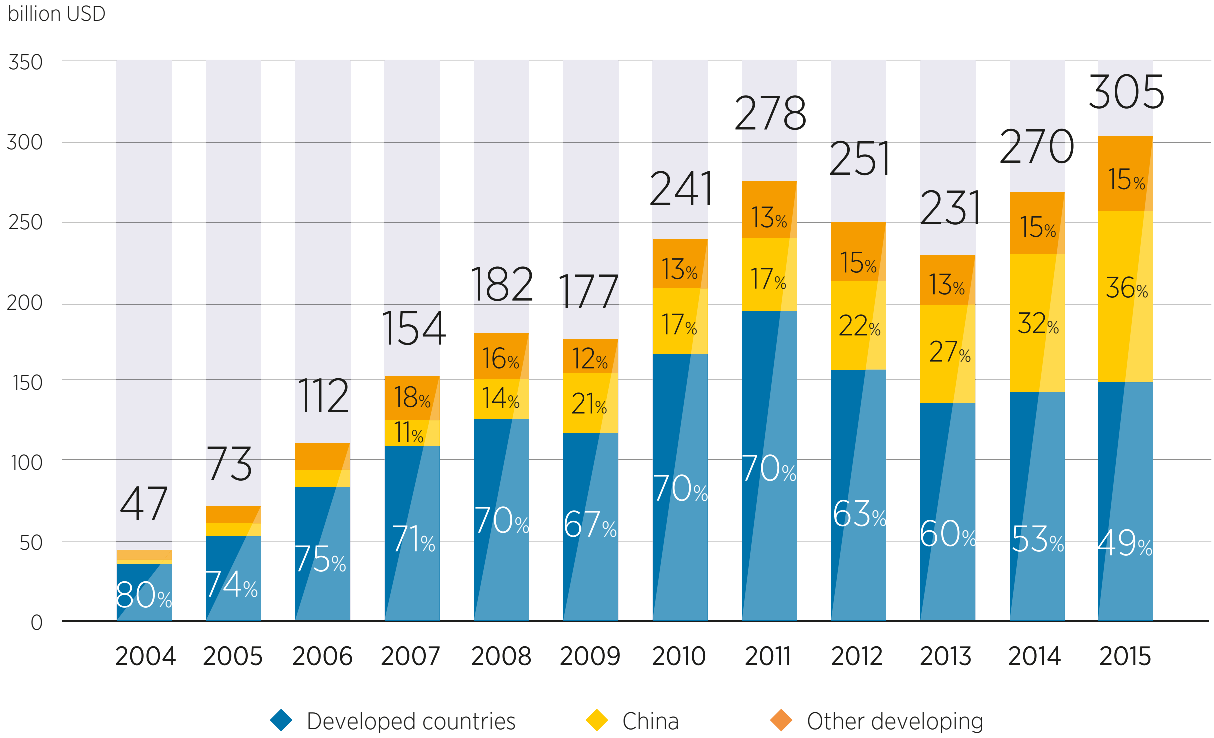
3.2 Global and regional investment trends

Global investment in renewable power has grown strongly over the past decade reaching USD 348 billion (BNEF, 2016a). Investment levels (excluding large-scale hydropower, i.e., >50MW) increased very rapidly in 2004-2011 from less than USD 50 billion to nearly USD 280 billion. After a two-year dip, it rose again to reach 305 billion in 2015 (BNEF, 2016a) (see Figure 3.1). Deployment has continued to grow at record levels thanks to decreasing technology costs. Developing countries have been experiencing faster growth than developed countries since 2012, reaching 22% last year.

In 2015, developing countries for the first time attracted the majority of renewable energy investments, continuing a progressive five-year shift, from 30% to 51% of total investments while developed markets witnessed a drop from 70% to 49%. This trend results from the weaker markets

[11] *The IEA estimates show that global renewable energy investment in 2015 amounted USD 313 billion (IEA, 2016d). The difference between these figures is due to a) different methodologies (IEA looks at the commissioned capacity whereas BNEF looks at projects that reached financial closure and were ready to start construction); b) technologies included. (The IEA includes solar thermal heat installations but BNEF does not; neither includes large-scale hydropower (over 50 MW)).*

Figure 3.1 Global investment[a] in renewables, and share by geography, 2004-2015



Source: BNEF, 2016a
Note: a) This includes all asset classes (asset finance, corporate research and development (R&D), government R&D, public markets, reinvested equity, small distributed capacity and venture capital/private equity). It excludes large-scale hydropower (over 50 MW) due to lack of data for the years before 2010. Figures are in current USD.

in Europe and declining activity in Japan and Canada.

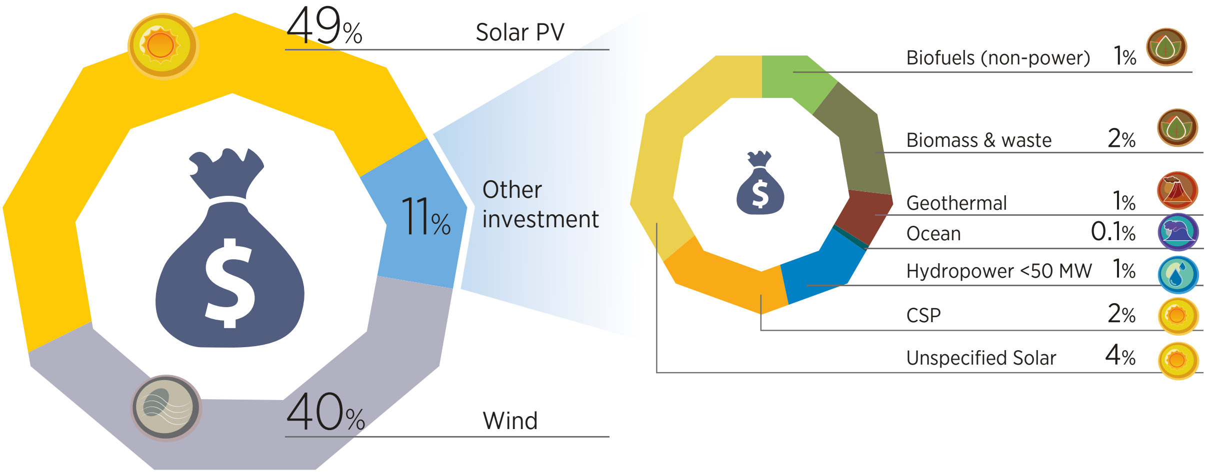
China alone was responsible for about one-third of global investment in renewables in 2015 (at USD 108 billion), giving Asia the regional lead with USD 161 billion. Japan and India were the other countries in the region with the most investment. Asia was followed by the EU (USD 52 billion). The EU remains a major market but has experienced an overall investment decline in recent years primarily due to policy changes and reductions in tariff support. The exception is EU offshore wind power investment, which grew sharply in 2015 to a record USD 17 billion.

Next was the US at USD 51 billion. The US experienced an investment rush before the pending expiry of the federal investment tax credit in 2015. Ultimately, a five-year investment tax credit extension was passed by the US Congress. This uncertainty initially slowed down investment in 2016, but provided some level of visibility to investors over the medium-term.

Investment also grew rapidly in Central and South America (USD 16 billion), with Brazil (primarily wind power) and Chile (solar power) leading the way. Lastly, investments in Africa and the Middle East increased by almost 75% in 2015 to around USD 12 billion. These regions focused on solar technologies (solar PV and CSP), which accounted for 77% of total investment; onshore wind power also attracted significant investment, especially in Sub-Saharan Africa.

Global investment growth in renewables was due primarily to solar PV and wind, which saw investment increase by 13% and 16% respectively over 2014. These two sectors saw substantial growth and accounted for about 90% of investments (see Figure 3.2). However, this trend also highlights the lack of diversification in the renewable energy mix.

Figure 3.2 Global investment[a] in renewables by technology, 2015



Source: BNEF, 2016a
Note: a) This includes all asset classes (asset finance, corporate R&D, government R&D, public markets, reinvested equity, small distributed capacity and venture capital/private equity). It excludes large-scale hydropower (over 50 MW). Figures are in current USD.

Despite the new records set in 2015, total investment in renewable energy is not enough to meet international climate goals. It falls far short of the estimated average USD 770 billion needed annually in 2016-2030 to double the share of renewable energy in the global energy mix (IRENA, 2016f).

Furthermore, preliminary data suggest that investment may have contracted again in 2016. This is due to several trends. The first is positive: falling technology costs, particularly for solar PV and onshore wind, mean that more power capacity can be installed even as investment levels remain unchanged. Second is the slowdown in China, the world's largest single investor in renewables. China's recent policy changes and reduced targets for 2020 (wind and solar power) have a significant impact on total global investment levels. Reductions in China could be balanced, at least to some extent, by new and rapidly expanding markets elsewhere in Asia and Latin America, and eventually also Africa, where overall energy demand continues to grow. Finally, growth in Europe has not picked up after the financial crisis, with the exception of the off-shore wind sector.

Global renewables investment needs to be scaled up significantly. Only then will renewables achieve their full potential and provide sustainable energy access for all while helping to limit global warming to below 2° Celsius. This can only be achieved with tailored public policies, programmes and tools to reduce risks and open up new avenues for investment, thereby expanding the pool of investors and the available capital.

3.3 Public finance instruments

The public sector plays a critical role in setting up an enabling environment, through policies and programmes, for investing in renewable energy. This can improve the risk-return profiles of projects, thereby increasing the sector's attractiveness to private investors. In addition, governments invest public funds in renewables, notably via multilateral and bilateral development finance institutions (see Box 3.1), national funds and other national finance institutions such as green investment banks. An increasingly important category is climate finance, which includes public financial flows to developing countries through public financial institutions (see Box 3.2).

Box 3.1 Renewable energy investment by international and national finance institutions

Public investment directed towards renewable energy by international and national finance institutions rose steadily in 2007-2011 from around USD 18 billion to almost USD 54 billion. Since 2011, investments have declined and in 2014 they totaled at USD 39 billion (see Figure 3.3) (BNEF, 2015).

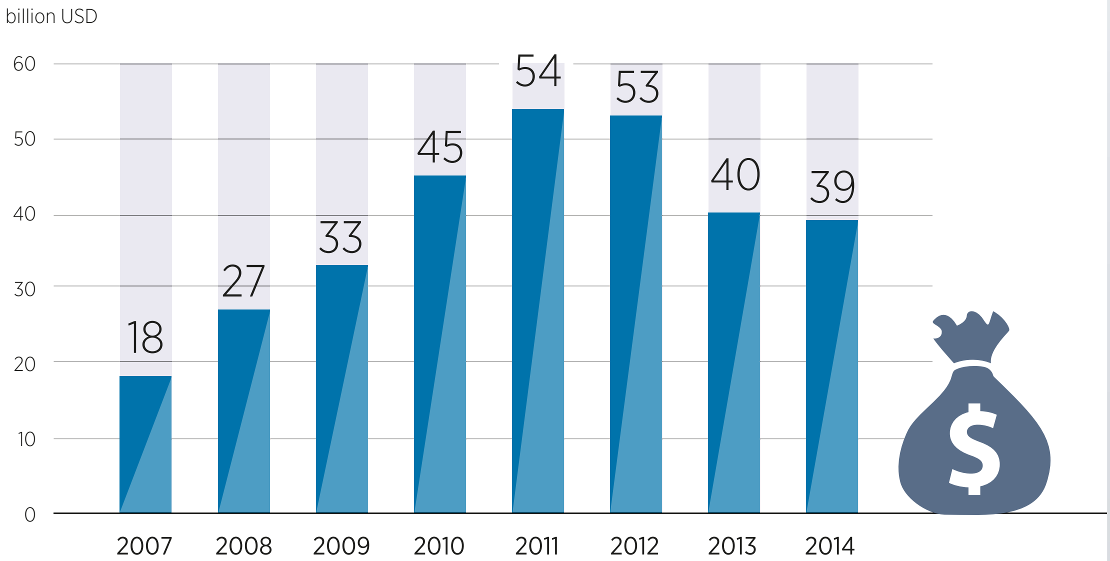
Public investments have declined slowly but steadily in Brazil, China and India since 2012. This is particularly marked in China, where private investment in renewables has increased rapidly. For example, total investment in renewables in 2014 rose by 41% while the China Development Bank, a major public investor, reduced its investment by half.

In other developing countries, public investment has grown far faster than private investment, and its share has increased continuously (reaching an average 33% in 2014). This trend has been driven largely by increased support for solar PV in South America and for onshore wind in Kenya.

In addition, the public sector continues to provide a major share of investments to a few large CSP plants in Morocco and South Africa as well as to geothermal power projects in Indonesia and Kenya. The higher technology and financing risks associated with CSP and geothermal power mean public support for their development is still widely required, especially in developing countries. It is usually provided in the form of syndicated loans that involve multiple development banks.

Source: IRENA, 2016a

Figure 3.3 Renewable energy investment[a] by development banks, 2007-2014



Note: a) Figures are in current USD.
Source: BNEF, 2015

Box 3.2 The role of climate finance in mobilising renewable energy finance

Climate finance typically refers to the financial resources paid to cover the costs of mitigating climate change and adapting to its impacts. In 2014, estimated global total climate finance amounted to USD 741 billion (UNFCCC, 2016). Climate finance presents an opportunity for developing economies to invest in clean energy in order to ensure sustainable economic growth compatible with international climate goals. In the Paris Agreement, developed countries reaffirmed their commitment to mobilise USD 100 billion per year by 2020 for climate action in developing countries and extended this goal until 2025. Climate finance can help mobilise the resources needed for developing countries' NDCs, which can play an important role in accelerating renewable energy deployment.

More specifically, climate finance can act as a catalyst for the financing of renewable energy projects in developing countries. A number of dedicated public climate finance channels have been established and resourced to fund climate action. These include the Global Environment Facility (GEF), the Climate Investment Funds (CIFs), and the Green Climate Fund (GCF). Development finance institutions, including bilateral agencies and multilateral development banks often function as implementing agencies for such climate funds. One crucial factor for countries to access climate finance channels for renewable energy projects is ensuring that their projects are investment-ready and linked to national development or energy plans.

To facilitate access to funding, the public climate funds provide preparatory support, for example through country readiness funding[a], and for activities such as building institutional capacity and developing national investment plans. Other funding goes to support project development. Such support can strengthen the programmatic framework for activities to be funded and enhance the quality of funding proposals. As these measures improve the consistency of investment frameworks, they can also help to mobilise additional public funding or private investment.

a) Specific to Green Climate Fund (GCF) and capped at USD 1 million per calendar year per country.

As global public funding is not expected to increase above its current share of 15% of overall renewables investment (IRENA, 2015c), to achieve the scale of investment needed, public finance institutions must help mitigate the risks of investments by addressing the obstacles that affect private finance. The perception of high risks in markets where renewables have little track record represents a major barrier to private investment in renewable energy projects, especially in new markets. Hence, there is a need to increase the use of financial instruments and policies that can provide guarantees to private investors and build the confidence necessary to attract more finance into the sector. Another bottleneck constraining the growth in investment is the lack of capacity and resources for project development. To overcome this challenge, early-stage financing of project development is important, and the same applies to the financing of new technologies.

Several governments have established financial mechanisms, such as national funds or green investment banks, to provide early-stage project development, issue loan guarantees, and fund other programmes to reduce the cost of capital. These mechanisms can help inject initial financing into a nascent sector or relatively new technologies; assume investment risks to increase confidence for private investors; and lower financing costs.

FUNDS TO SUPPORT EARLY STAGE PROJECT DEVELOPMENT AND INNOVATION

To improve access to financing for innovative, early stage projects, some governments have established funds or facilities that support renewable energy with public funding sources, such as taxes or utility surcharges. Examples include the Sheikh Mohammed bin Rashid Al Maktoum Fund to finance innovation in the UAE, and the National Clean Energy Fund in India.

The UAE fund was launched in 2015 with 2 billion United Arab Emirate Dirhams (USD 545 million). It aims to improve access to finance for pioneering projects in the early stages of development and targets renewable energy as one of seven priority sectors. The fund supports entrepreneurial innovators by guaranteeing them access to commercial loans to transform their ideas into funded projects. In 2016, another promising announcement was made by the UAE to create the Dubai Green Fund with a volume of about USD 27 billion to act as a market catalyst and provide loans to accelerate green investment (UAE Ministry of Finance, 2016).

India's National Clean Energy Fund supports clean energy research and innovative projects through grants and concessional loans. The funding source is a national tax on coal per tonne produced. Any R&D project or scheme containing inventive ways to adopt clean energy technologies are eligible for the support (IIP Network, n.d.; Sinha, 2016).

GUARANTEES TO MITIGATE RESOURCE RISK

Some national governments aim to take on investment risks to reduce the burden on the private sector by providing guarantees for riskier technologies and projects. The governments of Indonesia and Mexico, for example, have created facilities and programmes to encourage the development of geothermal energy projects.

The Indonesian government established the Geothermal Fund Facility in 2012 to provide financing for government projects or public-private partnerships that engage in geothermal drilling and exploration. The facility offers favourable project loans and takes an equity stake in projects selected through a bidding process (Berwin Leighton Paisner, 2016).

In 2014, the Government of Mexico deployed its Geothermal Financing and Risk Transfer Programme with USD 85 million provided by the Inter-American Development Bank (The Inter-American Dialogue, 2015). The programme offers loan guarantees during the exploration, drilling and development of geothermal projects in Mexico. The aim is to finance up to 300 MW of geothermal capacity over 10 years through efficient risk sharing with the private sector (The Inter-American Dialogue, 2015; Inter-American Development Bank, n.d.).

PROGRAMMES TO REDUCE THE COST OF CAPITAL

Other national programmes and funds aim to reduce financing costs through loan guarantees, low-interest loans funded by revenue bonds, or currency risk guarantee funds targeted at high hedging costs. Malaysia, India and the US state of Hawaii have adopted such programmes.

The Green Tech Financing Scheme in Malaysia provides partial guarantees for loans and rebates on the interest rate charged by financial institutions to support various green projects. The scheme is managed by an organisation under the purview of the country's Ministry of Energy, Green Technology and Water. Its funds (about USD 1 billion) are derived from a 1% surcharge on electricity customer bills (Green Tech Malaysia, n.d a&b).

The Indian government is working via a public-private initiative towards a facility to lower the cost of currency hedging in India, a major factor in the high cost of local debt in the country (see Box 3.3).

Implemented in 2014, Hawaii's innovative Green Energy Market Securitization Programme finances green infrastructure. It was designed to make low-cost capital available to low-income residents and tenants for clean energy loans. The state government issued USD 150 million in revenue bonds to fund this programme. Bond holders are repaid through a public benefits fund supported by a surcharge paid by residential utility customers on

Box 3.3 India's currency hedging facility

Foreign debt can increase the amount of capital available for renewable energy and provide a cheaper source of capital. A currency hedge – a strategy to reduce risks in the foreign exchange market – is often needed to protect against the risk of currency devaluation. When there is a mismatch between financing currency (foreign) and revenue currency (domestic) in a renewable energy project. The high cost or lack of hedging facilities for some currencies poses a barrier to mobilising foreign capital for investment in renewable energy.

To address this challenge, the Indian government has been experimenting with different concepts, such as a currency hedge fund or a currency risk guarantee (Dutta, 2015; Livemint, 2015). The government is also working closely with the India Innovation Lab for Green Finance to develop a currency hedging facility to cover the difference in exchange values between the Indian Rupee and hard currencies (*e.g.,* USD or euros) over the long term. The Lab is a public-private initiative that aims to seek out and help implement novel solutions for unlocking and scaling up investments in green infrastructure in India.

In October 2016, the Lab members endorsed the design of a customisable currency hedging product, which involves a foreign exchange (FX) hedging facility backed by a risk guarantee. This "FX Hedging Facility" aims to reduce the cost of currency hedging by targeting a particular tranche of currency risk, thereby allowing risks to be allocated to suitable parties and eliminating the credit risk premium (The Lab, 2016a). With strong support and endorsement from the Lab's members, including the Ministry of Finance and Ministry of New and Renewable Energy, the facility is moving forward on pilot projects with key financing stakeholders (The Lab, 2016b).

their electricity bills (Hawaii Green Infrastructure Authority, n.d.).

Sound policy frameworks and effective financial mechanisms driven by governments provide an enabling environment for private investors, who hold the key to scaling up renewable energy investment. By using capital market instruments, private investors – institutional investors in particular – can gain easier access to renewable energy investment opportunities. Business models supporting renewables allow for new types of investors and financing mechanisms, facilitating further private investment into the sector.

3.4 Capital market instruments

The rapid decline in technology costs has increased investor appetite for renewable energy investment projects. This in turn is making more capital available in many parts of the world. Green bonds and yield companies (yieldcos) are two innovative mechanisms gaining prominence. Their rise is underpinned by strong government commitments to establish an attractive market environment for renewables and by private sector interest in funding renewable energy projects. Such instruments open up opportunities to new classes of capital providers in the renewable energy sector while providing the necessary liquidity in the market and helping to reduce the cost of capital.

GREEN BONDS

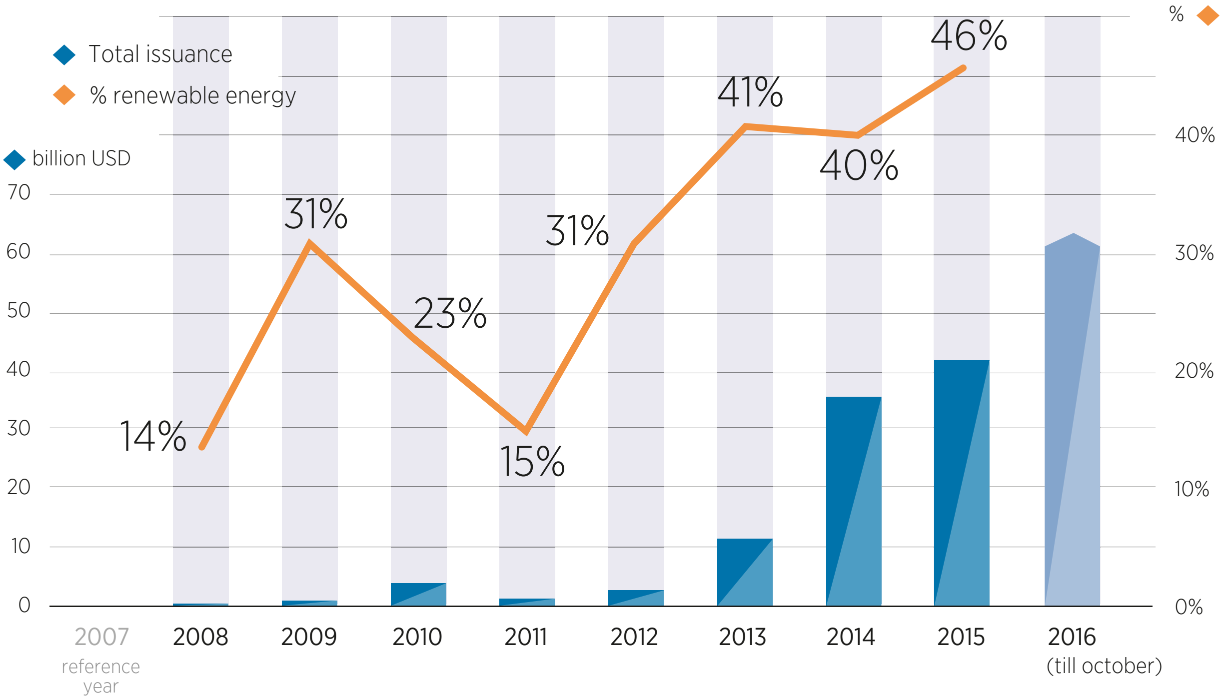
Green bonds are used increasingly as vehicles for institutional investors to invest in renewable energy assets in capital markets. They can offer a means for borrowers to raise large-scale, long-term financing from non-bank sources and at relatively low cost. The potential for the continued growth of green bonds needs to be further analysed because their success thus far relies on the high credit-rating of the issuing entity.

In 2015, nearly half the USD 41.8 billion green bond-labelled proceeds went to renewable energy projects, making renewables the biggest sector in the green bond universe (IRENA, 2016f). In 2016, more than USD 62 billion of green bonds was issued in the first 10 months alone, making this a record year (see Figure 3.4). Interest in green bonds is growing rapidly, particularly in emerging markets led by India and China (see Box 3.4). More recently, Mexico and Brazil also issued inaugural green bonds in December, 2016.

YIELDCOS

The yieldco structure emerged in 2014 as an option for energy utilities and other renewable energy asset owners to spin off operative assets from their balance sheets to develop, finance and implement new projects. In a typical yieldco structure, an

Figure 3.4 Growth in the global green bond market and renewable energy share, 2008-2016



Source: Climate Bonds Initiative (2016a); updated from the figure based on Unlocking Renewable Energy Investment: the Role of Risk Mitigation and Structured Finance (IRENA, 2016f)

entity transfers its operative renewable energy assets into a new company it fully owns. This new entity is listed thereafter, and new equity is raised through a share issue, while the parent company typically remains as a significant minority owner in the yieldco. As yieldcos grow through the purchase of stable, operational assets from parent companies, they can enable institutional investors to invest equity directly in corporations and thus own operational renewable energy assets (IRENA, 2016f).

The sharp decline of most US yieldco share prices in 2015 by an average of 40% raised concerns among many investors. Prices fell because the yieldcos could not raise public offerings at high rates and were unable to acquire new assets that could deliver steady cash flows for dividend growth (Konrad, 2015). As a result, no equity was raised for a period of time.

However, there were signs by late 2016 that the US yieldco market was starting to recover ground, despite steep price reductions in various stock markets and the financial difficulties of some parent companies in 2015. A number of yieldcos announced plans to issue new shares in 2016, although the scale was much smaller than before. In contrast to the period before 2015, the initial public offerings in 2016 were considered to reflect more realistic valuations. Yieldcos again have begun to acquire operating US wind power assets, with some yieldcos showing growth potential to acquire projects on the open market (Bloomberg, 2016b).

Box 3.4 Green bond markets in India and China

INDIA'S green bond market is expanding quickly, with more than USD 1.1 billion issued during 2015, and a total of USD 800 million in the first eight months of 2016. Following the inaugural green bond issuance by Yes Bank in February 2015, the Export-Import Bank of India and the Industrial Development Bank of India also raised funding via green bonds. Since then, the Indian market has seen the first corporate green bond issued by a wind power project developer; the first certified Indian green bond to be listed on the London Stock Exchange; and the first green bond issued by India's largest power utility (Climate Bonds Initiative, 2016b, 2016c; Mittal, 2015).

This rapid growth is due largely to the Indian government's strong commitment to supporting green financing mechanisms. In January 2016, the Securities and Exchange Board of India released its official green bond requirements, establishing guidelines for reviewing, reporting and tracking the progress of green bond issuance (Norton Rose Fulbright, 2016).

CHINA is the world's single largest green bond market. Chinese issuers led issuances in 2016, contributing to about one-third of total volume in the first nine months of the year (China Economics Net, 2016). The Chinese government offers tax exemptions or subsidies for green bond insurance to reduce financing costs and is currently creating national standards and regulations.

In December 2015, the Green Finance Committee of the China Society of Finance and Banking[12] published the Green Bond Endorsed Project Catalogue, which sets criteria for various projects and businesses to qualify as green (Norton Rose Fulbright, 2016). In September 2016, the People's Bank of China (the country's central bank) released green financing guidelines that highlight the national government's support for green bonds (China State Council, 2016).

This prompted the Bank of China, one of the country's largest state-owned commercial banks, to announce plans in September 2016 for the first green "covered bond" to be issued by a Chinese public entity. The bond will conform to both the People's Bank of China's Green Bond Guidelines and the international Green Bond Principles (Kidney, 2016). This structure can improve the rating of the issuance (ICMA, 2015), giving international investors easier access to the rapidly growing Chinese green bond market.

[12] *This committee works under the People's Bank of China.*

3.5 Institutional investment

Institutional investors are considered to be a major potential source of capital for scaling up renewable energy investment. Of the USD 90 trillion in institutional investor assets in developed countries in 2013 (OECD, 2015), the OECD estimates that up to USD 2.8 trillion may be available each year for new investment in clean energy (Kaminker and Stewart, 2012).[13] Given transaction costs, many renewable energy projects tend to be too small for institutional investors usually interested in several hundred-millions USD deals. Aggregation of several projects into larger bundles or portfolios helps to reach the critical size. This, in turn, requires standardisation and common financial structuring across projects.

Although the current volume of institutional investment in renewables remains low compared to the available capital,[14] recent years have seen an increase in commitments to renewable energy projects. Emerging trends include: growing domestic investment by developed country-based pension funds, particularly in Europe and their expansion into emerging markets, and increasing investment among some developing country-based pension funds.

INVESTMENT BY DEVELOPED COUNTRY INSTITUTIONAL INVESTORS

The most active institutional investment in renewable energy projects has occurred in Europe, where wind energy projects have been the primary focus. In 2015, total investment committed by institutional investors (*e.g.,* direct investment and project bonds) to European renewable energy projects reached a record USD 7 billion, up from USD 6.5 billion in 2014 (BNEF, 2016b). The increase was largely due to the high value of commitments (USD 2.08 billion) made by institutional investors via project bonds[15] that year, driven by low debt costs for projects (BNEF, 2016b).

Direct investment accounts for the smaller portion of the total but is rising rapidly. In 2015, direct investment by institutional investors reached USD 1.1 billion, driven mainly by pension funds. In the first half of 2016, pension funds committed more money in direct investment to renewable energy projects than they did in the whole of 2015 (BNEF, 2016b). Several European pension funds have invested directly in onshore and offshore wind power projects in their respective countries (BNEF, 2016b). They include PGGM (Kingdom of the Netherlands), PKA (Denmark), AMF (Sweden), and the London Pension Fund Authority and Greater Manchester Pension Fund (United Kingdom). These pension funds look either to generate high returns from building, aggregating and selling off assets, or to own plants over the long term and enjoy stable cash flow (Baker, 2015).

In addition, there is growing interest within some pension funds based in developed countries to invest in renewables in emerging markets. This is driven by favourable economics, including strong support policies for renewable energy investment. For example, Canada's second largest pension fund, CDPQ, announced in 2016 that it plans to invest USD 150 million in India's renewable energy sector over the next three years (Vyas, 2016). Australia's IFM Investors, owned by 30 Australian pension funds, has exposure to renewable energy (hydropower and wind power) via Pacific Hydro,[16] a company with investments in Latin America (Inderst, 2015).

INVESTMENT BY DEVELOPING COUNTRY INSTITUTIONAL INVESTORS

Institutional investors in Brazil, China, India and Russian Federation are known to have had assets worth about USD 6.5 trillion in 2013. These

[13] Low-carbon energy projects including renewable energy, energy efficiency, nuclear and fossil-fuel plants equipped with carbon capture and storage (Kaminker and Stewart, 2012).

[14] Infrastructure projects account for less than 1% of pension fund assets in OECD countries, and a far smaller share is allocated to sustainable energy infrastructure (OECD, 2015).

[15] A type of green bond which places proceeds into a separate company or special purpose vehicle directed at particular climate-related programmes or assets, such as renewable energy.

[16] The Pacific Hydro Group was acquired by China's State Power Investment Corporation in 2016 (King & Wood Mallesons, 2016).

included sovereign wealth funds and mutual funds, in addition to pension and insurance funds. Most of them are invested domestically (PPIAF and World Bank, 2014). Although they invest in renewables at a relatively small scale, domestic institutional investors in emerging markets are becoming increasingly important sources of capital.

At present, the banks' share of renewable energy investment in emerging markets is greater than that of institutional investors. This is partly because bank finance accounts for a larger share of infrastructure finance in general in emerging markets (*e.g.*, in China and India). In addition, institutional investors based in emerging markets are less interested in renewables than are their counterparts in Europe and the US (Climate Bonds Initiative, 2016d). Fiduciary duty calls for the demonstration of prudent decisions that put the interests of the beneficiaries above all else. This means investment by domestic institutional investors in emerging markets requires the managed capital to be deployed in markets that earn adequate risk-adjusted returns. These investments need to be suitable to the institution's specific constituencies, liquidity needs and liabilities (OECD, 2015).

As domestic renewable energy markets mature and track records accumulate, some pension funds in emerging markets may show greater interest in renewables. However, unlocking large-scale investments will require improvements in risk/return profiles and long-term pipelines with attractive, investment-grade projects. National governments can assist this process by building an enabling environment to improve liquidity. This would encourage institutional investors to participate more actively in the capital markets.

3.6 Emerging business models

A number of new business models are changing renewable energy financing, enabling the participation of new types of investors to finance renewable energy assets. Some of these models are innovative, while others are simply new to the renewable energy sector. Leasing has allowed to bridge the divide between investors and users of decentralised solar PV installations. Through securitisation, it is attracting large-scale institutional investors to the market. In a similar way, Energy Service Companies (ESCOs) are helping to overcome financial and other long-term risks for large-scale renewable heating and cooling systems, advancing renewables beyond the power sector. The third emerging business model highlighted in this section involves corporate sourcing of renewable energy, through various instruments such as corporate direct investments and power purchase agreements (PPAs), opening new avenues for financing renewables.

LEASING

Under the leasing model, customers contract a company to install a renewable energy system and pay rent for the system or a fixed price per kilowatt-hour (kWh) generated. Depending on the agreement, the leasing company might also be responsible for permitting, designing, installing and maintaining the system.

This model can be attractive to property owners because they can install a system without paying large upfront costs, and they can lock in long-term rates for electricity. Once a leasing company has been selected, property owners can avoid committing time for researching systems and arranging installation themselves. Depending on the agreement, customers can buy out the system, extend the contract or have the system removed for free at the end of the lease period. In return, the leasing company secures guaranteed buyers for the long term at fixed prices, ensuring a sufficient return on investment and increasing ease of financing. By working with multiple customers, companies can realise economies of scale in financing, system costs and operations.

Leasing has increased the pool of customers dramatically by reducing barriers to adoption. (Navigant Research, 2015).

Leasing became an important tool for renewable energy (particularly solar PV) early this decade and has helped to expand markets in Europe (*e.g.,* Italy, Spain and Portugal) and especially the US (Tabernacki, 2012). Leasing revolutionised the solar PV business in the US, bringing billions of dollars of institutional money into the solar PV sector in 2010-2011 alone. In 2014, leasing accounted for 72% of the US solar PV residential market (GTM Research, 2015).

The share of leasing in the US residential market appears to have peaked (loans and direct ownership play a greater role as system costs fall and loan options become more appealing). However, the model is becoming more popular elsewhere and spreading to European countries as well as China and India, the Pacific and more recently Africa (GTM Research, 2015; GTM Research, 2014; REN21, 2015). For example, large utilities in Germany have in recent years started leasing solar PV systems to prevent their market share from declining (Steitz, 2014).

Leasing is also starting to spread to new applications and technologies, such as pairing solar PV with energy storage systems for commercial and industrial micro-grid applications (Cichon, 2015). In addition, the application of the leasing model to small-scale distributed wind power has the potential to transform the market (Groom, 2016).

ENERGY SERVICE COMPANIES

Energy Service Companies, known as ESCOs, are suppliers of energy efficiency retrofits that guarantee savings to the customer in return for payment[17] typically proportional to the savings realised. In some instances, ESCOs incorporate a renewable energy component to the services provided. The customer benefits from predictable energy savings and self-generation of renewable energy at a fixed rate, all without having to face high upfront capital expenditure. The resulting monetary savings free up a revenue stream that accrues to the ESCO (JRC, 2016a; NAESCO, n.d.).

By guaranteeing targeted energy savings and tying user payments to the amount of electricity saved, ESCOs effectively absorb performance and operational risk. The amount of energy savings and cost of financing for the ESCO, largely depend on its expertise in implementing energy efficiency measures while successfully bundling a high number of contracts with many customers to diversify risks.

[17] *Where ESCOs finance and own the energy efficiency measures, financing costs are included in the payments to the ESCO.*

The ESCO model first emerged in the 1970s in response to the global energy crisis, as entrepreneurs found means to tackle rising energy costs by improving energy efficiency. The model is well suited to renewable energy generation and is most efficient in large volumes for industries and large institutions. It can resolve some of the major barriers to installing large-scale renewable heating systems, which include high upfront investment requirements and longer payback periods than those for most energy efficiency measures (Markogiannakis *et al.*, n.d.; US EPA, 2013).

The model has been used for renewable energy projects since at least 2005 when an ESCO installed a large-scale solar thermal water heating system in Pretoria, South Africa. By early in this decade, ESCOs were quite well developed in parts of Europe, particularly for biomass in district heating but increasingly for solar heating as well (Pantaleo, 2011; Bertoldi *et al.*, 2014). As solar heating systems continue to mature and expand to new markets, solar thermal ESCOs offer a promising business model for overcoming financial and other long-term risks (Schubert and Putz, 2014).

ESCOs are also playing an important role in the growing solar cooling industry. By 2015, the world's largest solar cooling installation was in the southwestern US. It was built as an ESCO project, and the ESCO owns and operates the system. Due to financing challenges, especially the inability to find a backer to pre-finance the project, the company devised a new fundraising model. Private investors funded fixed-interest loans to allow a private bank to finance a large part of the system. The ESCO is paid to deliver cooling energy over a 20-year period. In addition, it receives performance-based incentives from the local utility for the relief the solar cooling provides to the grid, especially during peak load hours (EuroHeat & Power, 2015). Some large solar cooling facilities in China and Singapore also operate as ESCOs (Schubert, 2013).

CORPORATE SOURCING

Recent years have seen a considerable increase in voluntary demand for renewable electricity by big corporations. By late 2016, 40% of the Fortune 500 companies had set clean energy targets (WWF *et al.*, 2014), and 51 businesses representing a market capital of USD 15 trillion had signed the Corporate Renewable Energy Buyers' Principles (WWF and WRI, 2016). More than 81 leading corporations had become part of RE100 (RE100, 2016), a global and collaborative initiative of businesses committed to using 100% renewable electricity.

Two dynamics are driving this development in the electricity market. On the demand side, businesses seek to secure long-term fixed-priced contracts for electricity while also meeting their climate and corporate sustainability goals by sourcing power from renewables. On the supply side, renewable energy developers and investors seek to reduce off-take risk by diversifying their long-term electricity customer base beyond the utilities.

Corporate sourcing can take different forms, including direct investment in renewable energy, procurement of certificates and PPAs (WRI, 2016). In the latter, companies contract directly the entity that owns the power generation asset, rather than going through utilities as has been the case traditionally. In the US, corporate renewable energy deals (in terms of power capacity) have doubled every year since 2012, exceeding 3 GW at the end of 2015 (RMI Business Renewables Center, 2016). They are expected to rise to more than 60 GW by 2025 (REBA, 2016). Elsewhere, the demand for corporate sourcing is rising with new renewable energy procurement deals sought in several countries, including Brazil, India, Mexico, Singapore and the United Kingdom (BNEF, 2016c).

Corporate electricity procurement strategies can play a major part in accelerating renewable energy deployment. However, to further scale up corporate renewable energy procurement, barriers such as regulatory challenges will need to be addressed and energy markets will need to be opened to third-party sales.

3.7 Conclusion

Since 2006, annual renewable energy investment has increased many times over, but growth has slowed down in recent years and total investment is not on the scale necessary to meet global climate objectives. To date, the power sector accounts for the vast majority of investments. While power sector investments need to continue to grow, investments in heating, cooling and transport require a massive scale up (IRENA, 2015c). Since the private sector must provide the lion's share of new investment, governments should focus on using limited public resources to catalyse private investment.

Risk mitigation instruments are among the most effective in mobilising private investment as they offer guarantees to investors and build the confidence needed to increase the volume of finance without high risk premiums. Risk mitigation is particularly important for early stage project development of geothermal energy, which requires substantial high-risk investments for exploration and drilling. Increased provision of financial instruments like currency risk guarantees and liquidity reserve facilities to cover off-taker risk could also make a significant difference. By using such mechanisms, public funds can be most effective in reducing the cost of capital and attracting private investment to the renewable energy sector.

New capital market instruments, such as green bonds and yieldcos, are helping to scale up available finance by enabling new groups of investors to access renewable energy investment opportunities. Institutional investors such as pension funds, are increasingly active in the renewable energy sector, but their potential remains largely untapped. Investment by such actors will likely gain traction driven by the search for new opportunities. This is partly due to the risk of stranded assets resulting from climate change-related policies. Given the relatively small size of many renewable energy projects, their aggregation into larger bundles or portfolios to reach critical size is essential to attract institutional investors.

Innovative business models can help to accelerate the growth of investment in a rapidly changing energy sector. The application of leasing and ESCO models to renewable energy projects will likely continue to spread to new countries and technologies. Corporations are playing a more active role as off-takers, directly procuring power generation assets, as renewables continue to offer increasingly cost-effective and stable energy supply.

To ensure that such trends accelerate, policy makers and public finance institutions must strengthen private sector participation through targeted policies and programmes. For example, policy frameworks for green bond issuance can attract significant new investment, as seen in China and India. Government-driven financial mechanisms can support early-stage project development and provide loan guarantees to help lower the cost of capital. The strategies to scale up renewable energy investment will require active participation by a broad spectrum of public and private actors, including development finance institutions, climate finance institutions, private equity funds, institutional investors, export credit agencies and green and commercial banks.

Chapter 04

Innovations in Technology

4.1 Introduction

Technological innovations together with improving policy frameworks, are paving the way for dramatic declines in the costs of renewable energy technologies. Since 2009, the prices for solar PV modules and wind turbines have fallen by up to 80% and 40% respectively. With every doubling of cumulative installed capacity, solar PV module prices drop 20% and the cost of electricity from wind farms drops 12%, due to economies of scale and technology improvements.

These dynamics have enabled renewables to outpace the growth in conventional technologies. In 2015, renewables reached a share of 23% in total generation capacity. The year of 2015, in particular, was a record period for renewable energy with annual solar PV installations reaching 47 GW and wind power reaching 66 GW.

This chapter provides an overview of how ongoing technological innovation, coupled with improving policy frameworks, are positioning renewables as a viable energy source in the power sector but also in the buildings, industry and transport end-use sectors.

In addition, this chapter focuses on solar PV which is by far the fastest growing source of electricity. It also presents an in-depth discussion on energy storage that provides a key solution to effectively integrate increasing shares of variable renewable energy (VRE) resources in power systems.

4.2 Overview of renewable energy technologies

In 2014, renewable energy's share in the total final global energy mix was 18.3%. The traditional uses of biomass for cooking and water heating accounted for half of this total, with modern renewable energy technologies representing the other half (see Chapter 1, Figure 1.5). Around half of the modern renewables are consumed in buildings, industry and transport end-use sectors for heating or direct uses (*e.g.*, liquid biofuels). The other half of modern renewables is used for producing electricity.

4.2.1 Renewables for heating and cooling

Within the end-use sectors, modern renewable energy technologies provide energy for water and space heating, cooling and cooking in buildings, and heating and steam generation in industries. Systems range from small-scale solutions to large-scale district heating networks and industrial facilities. Heat produced from bioenergy accounts for the largest share of direct modern renewable heat use by far (see Figure 1.5). In addition, renewable-based electricity can also be used to meet heating needs.

The capacity of modern renewable heating and cooling technologies continues to expand, with solar thermal and geothermal experiencing the most rapid growth, albeit from a relatively small base (see Table 4.1). Numerous technologies are available for end-use applications in buildings and industry, and most of these are commercially available (see Box 4.1). These technologies, particularly bioenergy, have been challenged in recent years by low fossil fuel prices. However, a range of factors influence their uptake, including policies (IEA, 2016e). Despite their great potential, modern renewables account for a small proportion of heating and cooling in buildings and industry.

4.2.2 Renewables for transport

In the transport sector, renewable energy can contribute in three main ways: liquid biofuels used in blends with conventional fuels or "neat" (100% biofuels); gaseous biofuels (biomethane) used in natural gas vehicles; and renewable electricity used to power electric and hybrid vehicles. Liquid biofuels account for the vast majority of

Table 4.1 Renewables in industry and buildings: scale, growth rates and penetration levels

Industry and Buildings	Units	Scale		CAGR[a] of scale (%/year)	Penetration level[c] (%)
		2010	2015	2010-2015	2015
INDUSTRY (HEATING & COOLING)					
Bio-heat	EJ[b]	8	8	0%	6.2%
Solar thermal					0.0%
- Concentrated solar thermal	GW	0	0.1	N/A	-
- Flat plate	Million square metres	0.06	1	0.8	-
Geothermal direct heat	EJ	0	0.02	N/A	0.02%
BUILDINGS (HEATING & COOLING)					
Biomass cooking (traditional)	EJ	31	33	1.3%	27.5%
Biomass cooking (advanced)	EJ	2	2.5	4.6%	2.1%
Biomass heat (modern)	EJ	3.1	4	5.2%	3.3%
Solar thermal	Million square metres	279.7	622	17.3%	1.4%
Geothermal direct heat	EJ	0.22	0.3	6.4%	0.3%

Note: a) CAGR = compound annual growth rate, b) EJ = exajoules, c) Penetration levels are estimated relative to total final energy consumption for end-use sector technologies.

renewable energy use in the transport sector (see Table 4.2), largely due to blending mandates. These have helped to support international markets and have shielded some liquid biofuels markets from the impacts of recent low oil prices. However, investment in new production capacity has declined in recent years due in large part to low oil prices. Biofuels, together with renewable-powered electric and hydrogen vehicles are the key options for decarbonising transport (see Box 4.1).

Table 4.2 Renewables in transport: volume, growth rates and penetration levels

	Units	Volume		CAGR of scale (%/year)	Penetration level[a] (%)
		2010	2015	2010-2015	2015
TRANSPORT[b]					
Liquid biofuels	Billion liters	100	129	5.2%	4.3%
Biomethane	Billion m^2	0	0.389	N/A	-

Note: a) Penetration levels are estimated relative to total liquid fuel demand for liquid biofuels.
b) There are 1.26 million electric vehicles and 200 million two- or three-wheelers, some of which are powered by renewable-based electricity. In themselves, they are not renewable energy technologies.

Box 4.1 Renewables for industrial heat and transport

Heating and cooling for buildings and industry, especially high-temperature heat, account for a significant proportion of global energy use along with fuel for transport. To attain a significantly higher share of renewables in global energy demand and to put the world energy system on a decarbonisation pathway, renewable applications in these sectors must be advanced.

Renewables can meet a far greater share of heat demand in buildings and industry than they do today. Bioenergy, geothermal and solar thermal technologies can easily supply low- to medium-temperature process heat; and electric heat pumps contribute with great efficiency, opening the door for renewable electricity sources. Solar thermal systems, whether flat plate and evacuated tube collectors (125°-250° Celsius) or solar concentrators (up to 400° Celsius), can serve diverse demands. They fall short only of industry's highest temperature demands. The applications are many, including food and beverage production, textiles, chemicals and pulp and paper manufacturing.

In metal production, the primary opportunity for renewables lies in electrolytic refining and smelting. For example, aluminium smelting requires vast amounts of electricity, although supply must be stable and uninterrupted, calling for non-variable renewable resources such as hydropower. Conversely, electric arc furnaces, which are used extensively in processing recycled steel, can schedule operations to coincide with power market conditions, including the availability of excess variable renewable electricity.

Opportunities exist for far greater use of renewable fuels and power in all forms of heavy transportation – aviation, marine applications and road freight – which together account for 35% of transport energy demand. Flights using biofuel, for example, currently represent merely 0.01% of total transport energy demand. However, the number of commercial flights using biofuel has increased significantly over the last couple of years. The downstream supply chain has developed in some places (such as at Gardermoen airport, Oslo), and there are now almost 100 initiatives

For road freight, options under consideration include electric highways and biomethane, as well as hydrogen generated with renewable electricity. The technologies needed are approaching commercialisation, but all options face technical and economic barriers, including the scale and cost of associated distribution and fuelling infrastructures.

Many of these options are already cost-effective, and their potential remains vast. Fulfilling this potential depends on further deployment and continued innovation in technologies, institutions, business models and policy mechanisms.

Sources: IRENA, 2015d; IRENA and IEA-ETSAP, 2015 ; IRENA, 2016d; IRENA, 2016g; IRENA, 2016h.

4.2.3 Renewables for power generation

Although renewable energy deployment and generation are rising in all end-use sectors, the power sector has experienced the most rapid growth (see Table 4.3). Hydropower continues to account for most global renewable power capacity (61%) and generation (76%). Concentrating solar power (CSP), geothermal and bioenergy-based power also continue to expand. Yet, as noted in Chapter 1, the annual growth of solar PV and wind power in recent years has outstripped that of all other renewable power generation sources. In 2015, these two technologies led the way in terms of newly installed capacity.

Hydropower, geothermal and some bioenergy-based power generation have been cost-competitive with fossil fuel-based generation for many years. Technological advances, standardisation and economies of scale in production, expansion into new markets with good resources, and improved financing conditions have all helped to drive down installed costs for solar PV and wind power. This makes solar PV and onshore wind generation cost-competitive with new fossil fuel-based generation in a significant and increasing number of markets (see Chapter 1).

This chapter focuses on solar PV and energy storage. Solar PV is one of fastest growing sources of energy and accounts for the largest share of annual investment in renewable technologies. In recent years, solar PV has seen the greatest cost reductions as well as some of most significant technology advances of all renewable technologies. IRENA projects that, if the world doubles the share of renewable energy in total final energy consumption by 2030, PV will experience the largest annual growth in power capacity and generation (IRENA, 2016i).

Energy storage technologies, particularly batteries, are also advancing rapidly. Storage is becoming an increasingly important tool for integrating a rising share of VRE, including solar PV, into existing power systems. Some countries also have a small but growing market for energy storage solutions with residential and commercial solar PV systems. In the future, storage will probably play a major role in providing energy for island systems and for access in remote areas of the developing world, particularly when combined with solar PV.

Table 4.3 Renewables in the power sector: capacity, growth rates and penetration levels

	Units	Capacity		CAGR of scale (%/year)	Penetration level[a] (%)
		2010	2015	2010-2015	2015
POWER SECTOR					
Bioenergy	GW	72	103	7.3%	1.6%
Geothermal	GW	10	12	4.4%	0.2%
Hydropower	GW	1,025	1,208	3.3%	19.0%
Ocean	GW	0	0.5	14.5%	0.0%
Solar PV	GW	39	219	41.4%	3.4%
CSP	GW	1	5	29.8%	0.1%
Wind onshore	GW	180	405	17.7%	6.4%
Wind offshore	GW	3	12	30.1%	0.2%

Note: a) Penetration levels are estimated relative to total installed power generation capacity.

4.3 Technology focus: solar PV

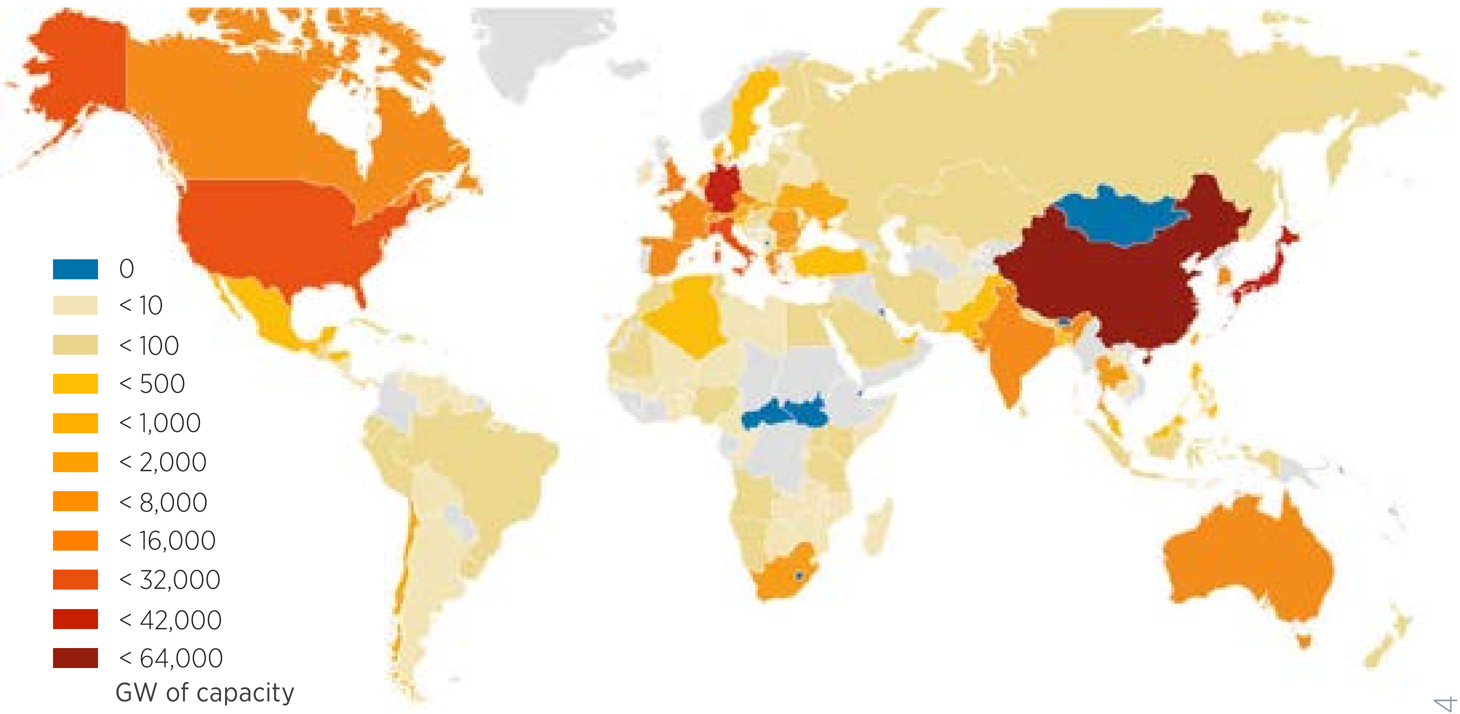
4.3.1 Current status

Cumulative global solar PV capacity soared from 39 GW in 2010 to 219 GW in 2015 (see Chapter 1), when it accounted for approximately 20% of all newly installed power generation capacity. By the end of 2015, 21 countries had 1 GW or more of solar PV installed capacity, up from five countries in 2009 (IRENA, 2016a; IRENA, 2016i). In fact, solar PV is now used in most countries around the world (see Figure 4.1). It is bringing electricity to millions of people who previously lacked access to modern energy services. An estimated 89 million people in developing countries have at least one solar lighting product in their home (BNEF and Lighting Global, 2016).

Solar PV is highly modular and can provide a wide spectrum of energy options for both on-grid and off-grid use. This ranges from very small lighting systems in remote villages of the developing world to residential and commercial rooftop systems or utility-scale projects (varying from 1 MW to several hundred MWs). There is also increasing interest in the use of solar PV for isolated and grid-connected mini-grids. This can be an attractive option for reducing or eliminating reliance on fossil fuels (*e.g.,* kerosene and diesel). Project lead times are among the shortest of any power generation technology (generally ranging from days to months, depending on project size), and PV's modularity allows for scaling up in the future, as needed.

In 2015, solar PV represented about 30% of renewable power generating capacity added worldwide; only the wind power industry installed more capacity that year. Solar PV accounted for nearly half the global renewable energy investments in the power sector, making up about USD 149 billion out of a total of USD 301 billion[18] (BNEF, 2016a). In addition, it is the world's largest renewable energy employer, accounting for an

Figure 4.1 Global cumulative installed solar PV capacity by country, 2015



Source: IRENA, 2016j

[18] Includes all asset classes (asset finance, corporate R&D, government R&D, public markets, reinvested equity, small distributed capacity and venture capital/private equity) and excludes large-scale hydropower (over 50 MW). The solar PV figure does not include corporate R&D, government R&D, public markets, reinvested equity and venture capital/private equity. Note that USD 12 billion was invested in "unspecified solar" during 2015 (BNEF, 2016a). At least some of this applies to solar PV, but is not included in the USD 149 billion.

estimated 2.8 million jobs worldwide in 2015, up about 11% over 2014 (IRENA, 2016c).

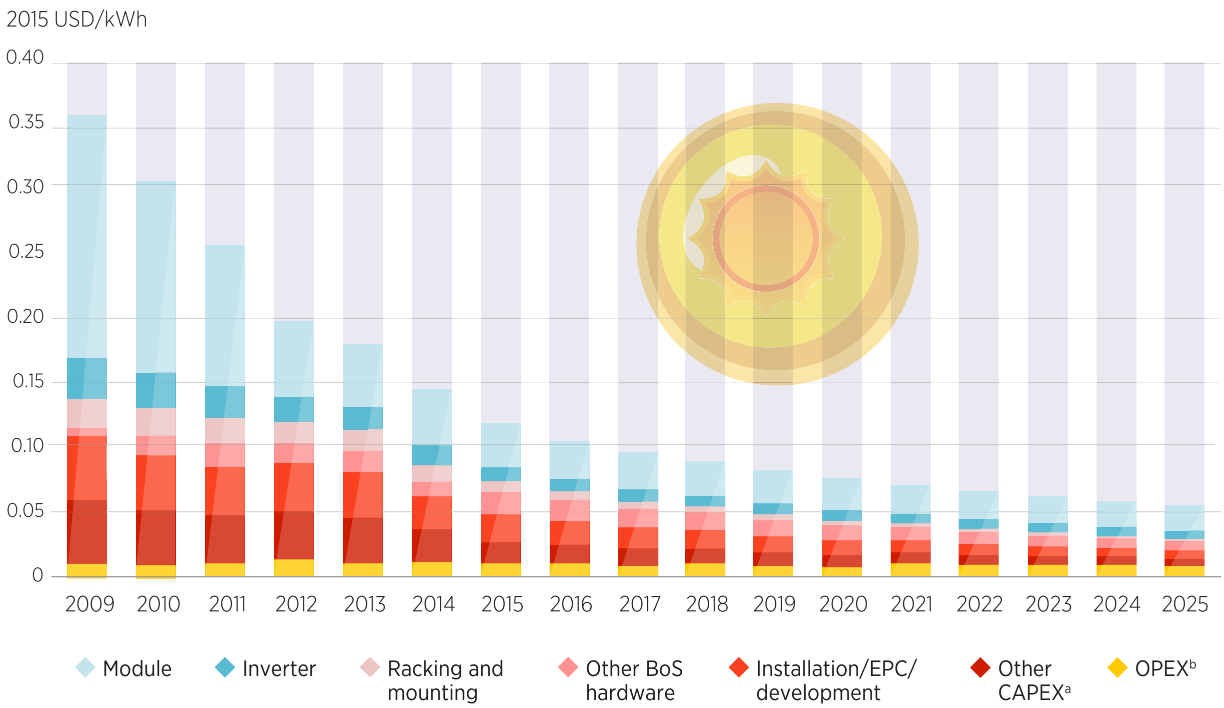
Despite the rapid rise in solar PV deployment, its contribution to global electricity generation remains small at around 1.2% in 2015. This is explained by several factors: the technology has been growing from a very low base compared to conventional generating technologies; overall electricity demand continues to rise; and solar PV has a relatively low capacity factor. Even so, solar PV met a substantial share of electricity demand in several countries throughout 2015, including Italy (7.8%), Greece (6.5%) and Germany (6.4%). It made up a far higher share of demand in these countries over brief periods of time (REN21, 2016; Shankleman, 2016).

IRENA estimates that solar PV generation already reduces global CO_2 emissions by 200-300 million tonnes[19] annually (IRENA, 2016i). This amounts to the annual CO_2 emissions (in 2014) of Argentina at the low end or Poland at the high end (JRC, 2016b).

In recent years, rapidly falling costs and government support policies have accelerated deployment, spurred technological innovation and created a virtuous cycle of falling costs through economies of scale and technological progress.

Between 2010 and 2015, the capacity-weighted average levelised cost of electricity (LCOE) of utility-scale PV fell by around 60% (IRENA, 2016k) (see Figure 4.2). This makes utility-scale projects economically competitive with new fossil fuel-based generation. Globally, the weighted average LCOE for newly installed utility-scale solar PV in 2015 was USD 0.13/kWh. This compares with USD 0.05-0.10/kWh from coal and natural gas (IRENA, 2016i). The most competitive utility-scale projects in 2015 were regularly delivering electricity for USD 0.08/kWh without financial support. Winning bids in auctions came in at even lower prices during 2015 and 2016 (see Chapter 2). Solar PV is competing without financial support even in regions with abundant fossil fuels (IRENA, 2016l).

Figure 4.2 Global weighted average utility-scale solar PV LCOE, actual (2009-2015) and projected (2016-2025)



Note: a) CAPEX = capital expenditures, b) OPEX = operating expenses
Source: Results use a 7.5% weighted average cost of capital (WACC); all other input assumptions are from IRENA (2016p)

[19] This estimate assumes that 200-300 TWh solar PV replaces coal power plants, which operate at 35% efficiency and emit 1 million tonnes of CO_2 per TWh.

Dramatic cost reductions have been the primary driver behind global market expansion, including in the household and commercial sector. In addition, new business models for financing solar projects and recovering solar PV revenues are opening new markets in developed and developing countries, while enabling local entrepreneurs to enter the industry (IRENA, 2015e). Electricity generated by small-scale distributed PV systems is already cheaper than power from the grid in Australia, Denmark, Germany, Italy, Spain, parts of the US and many island states. Commercial and industrial consumers are turning to PV and wind power through PPAs or even direct system ownership. In remote, off-grid regions around the world, solar PV is often the least expensive option for generating electricity (see Chapter 5).

4.3.2 Advances in PV technology

Several generations of solar PV technologies have seen significant progress on many fronts in recent years (see Table 4.4). The most established solar PV technology is wafer-based crystalline silicon (c-Si). C-Si technology entered the market more than 50 years ago and continues to account for the largest market share by far. Since then, manufacturers have reduced costs and increased efficiency significantly. The efficiency of commercially available c-Si cells is now at 21%-23% (the theoretical limit is 29%) (IRENA, 2016i).

While silicon solar PV technology has achieved maturity, several non-silicon technologies are under development and remain a long way from their technical limits. These include more advanced thin films, such as CIGS (copper indium gallium (di)selenide) and CdTe (cadmium telluride), which together represent 6.5% of the market share. In addition, several emerging and novel technologies offer the potential for even higher efficiency and lower cost (see Table 4.4).

Many technologies are experiencing major progress, passing new efficiency and other milestones on a regular basis. Cells are getting thinner, more flexible and easier to transport, with less resource-intensive and cheaper production techniques. Of the several emerging PV technologies nearing commercialisation (see Table 4.4), the most promising are perovskites and multi-junction cells (see Box 4.2).

Innovations continue in lightweight, adaptable and low-cost technologies, such as solar windows, solar roofs, spray-on solar and printed solar cells. Such developments will enable the use of PV not only on rooftops but also on building facades and windows, which will allow for large-scale integration of solar into the world's cities (IRENA, 2016i; Merck KGaA, 2016; REN21, 2016).

Box 4.2 Emerging technologies: perovskites and multi-junction cells

Perovskites are crystal-structured organic compounds that are simple to manufacture and are expected to be relatively inexpensive to produce commercially. Between 2009 and 2016, their efficiency rate increased more than fivefold from under 4% to over 21% (Kojima *et al.*, 2009; Lux Research, 2016). There are challenges to address before they can be commercialised, including replicating lab efficiency rates in other environments and reducing or eliminating the use of lead. Most importantly, problems related to durability and sensitivity to water need to be solved. Researchers continue to discover means to improve stability and address other challenges to commercialisation (IRENA, 2016i).

Multi-junction cells are made by stacking two or more cells with absorbers of different optical properties such that they absorb a larger portion of the solar spectrum. As a result, they convert energy into electricity more effectively (TU Delft, 2016). The theoretical efficiencies of these cells are close to 50%, but because manufacturing costs are high the cells have been used only for niche applications to date. Progress continued in 2016, including a new cell type with low manufacturing costs and practical efficiencies of 35% by researchers at the US Massachusetts Institute of Technology and the UAE's Masdar Institute. The researchers expect this technology to be ready for the market within a year or two (Solomon, 2016).

Table 4.4 Solar PV technologies and their market shares

TECHNOLOGY GROUP		MARKET SHARE 2015	DESCRIPTION
Wafer-based Crystalline Silicon (c-Si)	Mono-crystalline	93%	Made from silicon manufactured in such a way that it forms a continuous single crystal without grain boundaries. More efficient and more expensive than most other types of cells.
	Poly- or multi-crystalline		Made from silicon manufactured in such a way that it consists of numerous small crystals, forming grains. The most common type of cells used, with a 69% share of c-Si technology. Less expensive but also less efficient than those made from monocrystalline silicon.
Thin-film based	Amorphous Silicon (a-Si)	0.5%	Non-crystalline form of silicon deposited in thin films onto a variety of substrates (plastic, metal, glass). Contains no toxic heavy metals, but has low efficiency. Production discontinued in recent years such that market share is negligible.
	Copper indium gallium (di)selenide (CIGS)	2.5%	Manufactured by placing a thin layer of copper, gallium, indium and selenide on plastic or glass backing and electrodes on both front and back. Thin enough to be flexible, but performance is below that of polysilicon-based panels.
	Cadmium telluride (CdTe)	4%	The only thin film material to rival crystalline silicon thus far in cost per watt. But cadmium is toxic and supplies of tellurium are limited. Used in some of the world's largest PV power stations.
Emerging PV technologies	Concentrating solar PV (CPV)		The most mature emerging technology. CPV systems (optical sun-tracking concentrators/lens) focus direct sunlight on highly efficient solar cells (multi-junction cells). The high efficiency of these solar cells reduces the needed PV array area, which partially offsets the additional cost of the concentrating system.
	Organic PV and (OPV)/ dye-sensitised solar cells (DSSC)		Based on use of low-cost materials and manufacturing processes that consume low energy and are easy to scale up. Includes technologies based on active, organic layers that are suitable for liquid processing; hybrid DSSC, which retains inorganic elements; and fully organic PVs such as perovskite solar cells (see Box 2).
	Advanced inorganic thin-film		Includes advanced thin-film concepts, such as multicrystalline silicon thin films and the spheral CIS approach obtained from the high-temperature deposition process (> 600°C).
	Novel PV concepts		Depend on nanotechnology and quantum effects to provide high-efficiency solar cells that either tailor the active layer to better match to the solar spectrum, or modify the solar spectrum to improve energy capture.

Source: Fraunhofer ISE, 2016; IRENA and IEA-ETSAP, 2013

Potential also exists for integrating solar PV into transport infrastructure including existing roads, noise barriers and parking structures to take advantage of large surface areas. The Kingdom of the Netherlands built the first solar road (a bike path) in 2014. Companies continue to build and test similar technologies in Europe and the US (Koch, 2016). Beyond electricity generation, solar PV/solar thermal hybrid (PV-T) systems have become an option for generating both power and heat, with a large variety of technologies on the market (Dean *et al.*, 2015). All of these advances are opening up new markets and opportunities for solar PV around the world.

Manufacturing processes have advanced in parallel with progress and innovation in solar PV technologies. These advances are driven by strong, growing global demand for solar PV combined with downward pressure on panel prices.

Ongoing research concentrates on material savings and substitutions to reduce environmental harm from hazardous materials (*e.g.*, lead, cadmium and selenium) and to lower the costs associated with rare and expensive materials. Although recent studies agree that material availability is not a major short-term concern, it could impose limitations in the long term. R&D thus aims to further reduce a wide variety of inputs (such as glass, indium, silver and silicon) for each unit through reductions in wafer thickness and replacement with lower-cost alternatives.

For future generations of solar panels, raw material inputs for both c-Si and thin-film technologies are expected to decline significantly as the industry continues to mature and technologies continue to progress. This trend could cut the amount of rare and hazardous materials required for the production process. Equally, it could improve panel recyclability and resource recovery potential at the end of life (IRENA and IEA-PVPS, 2016).

4.3.3 A bright future for solar

Ongoing innovations in technology development, continuing economies of scale, further production automation and economic pressures will further reduce PV module and system component costs in coming decades. New technologies in turn will provide better performance at lower cost while improvements in quality of equipment and installation can also increase yield and lifetime of panels. The greatest potential for future cost (LCOE) reductions lie in the balance of system costs and finance costs. By 2025, all these factors combined could drive utility-scale LCOE down by more than half relative to 2015 levels (IRENA, 2016k), as seen in Figure 4.2.

Low-cost panels and easier installation will allow for a wider set of applications. Already, solar PV is deployed on rooftops, former landfill sites and water surfaces, and in a wide range of scales from tiny off-grid systems to enormous utility-scale power plants. Mini-grids based on renewable energy are starting to reach maturity. They can help integrate a higher share of PV into existing grids or provide electricity access to remote communities. Increasingly, solar PV will be incorporated into buildings, clothing, roads and elsewhere. The possibilities are almost limitless.

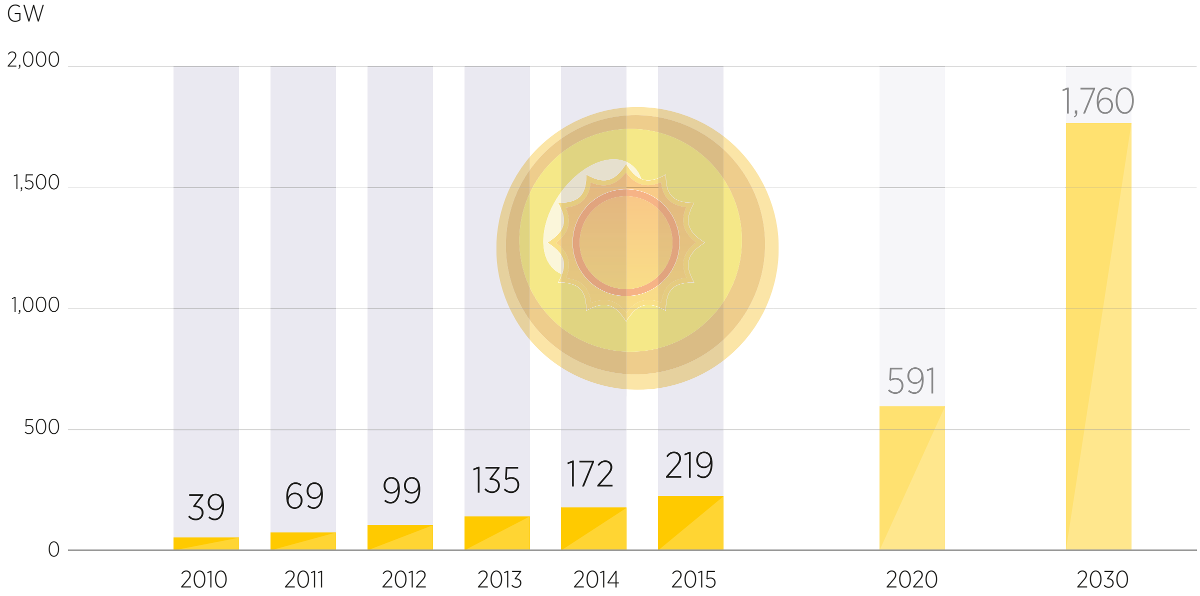
IRENA estimates that solar PV capacity could reach 1,760 GW in 2030 (see Figure 4.3) (IRENA, 2016d). Achieving this capacity by 2030 would require an average annual growth in total capacity of 15%. This compares with an annual growth rate of 27% in 2015 (IRENA, 2016a). According to IRENA estimates, solar PV could account for almost 7% of global electricity generation by 2030 (IRENA, 2016d).

4.3.4 Managing PV end-of-life

The growing quantities of solar PV panels in operation worldwide will one day become "waste". Already at the end of 2016, the expected cumulative global waste stream for solar PV panels was 43,500-250,000 tonnes.[20] This will continue to increase over time. A cumulative 1.7 million

[20] *The higher number reflects an early loss scenario, or failures that occur within the assumed 30-year lifespan.*

Figure 4.3 Solar PV global installed capacity 2010-2015 and projections to 2020 and 2030



Source: IRENA, 2016d; IRENA, 2016i

tonnes in 2030 and more than 60 million tonnes of waste is anticipated by 2050 under a regular loss scenario[21] (IRENA and IEA-PVPS, 2016).

In addition to the environmental benefits of recycling, the recovery of raw materials and emergence of new solar PV related industries required to manage waste also raises new opportunities for creating economic value. It yields materials that can be sold into global commodity markets or employed to produce new solar panels. For these reasons, innovations in collection, recovery and recycling have the potential to play an important part in building up the cradle-to-grave supply chain for solar PV.

Today, most end-of-life solar panels are treated in existing general recycling plants, which enable recovery of glass, aluminium and copper at cumulative yields exceeding 85% of panel mass. However, solar PV-specific recycling processes will allow an even greater portion of embodied materials to be recovered, some of them hazardous (*e.g.*, silver, cadmium and lead). For example, PV CYCLE (a non-profit PV waste management organisation in Europe) has achieved average recycling rates of 90% for silicon-based panels and up to 97% for thin-film panels. In early 2016, PV CYCLE announced a new record recycling rate of 96% for c-Si panels (PV CYCLE, 2016), reducing the residual by half.

Improving the resource and environmental sustainability of PV production and use can be achieved through enabling regulatory frameworks. Examples include end-of-life management policies that establish treatment standards and recycling requirements. However, only the EU has adopted PV-specific waste regulations thus far (IRENA and IEA PVPS, 2016). Other countries (*e.g.,* China, Japan and the US) are investigating the institutional capacity to implement end-of-life policies. In addition, industry groups and solar companies in some countries have begun voluntary development of collection and recycling processes (US SEIA, 2016).

Rising shares of solar PV generation, as well as other variable generation such as wind power, will require significantly greater flexibility in power system infrastructure, operation and market design (see Chapter 2). Distributed and variable generation, such as solar PV, is catalysing

[21] *Assumes 30-year average panel lifespan.*

innovations including smart appliances and energy storage that will help to integrate growing shares of VRE (IRENA, 2016i). The next section discusses options for increasing system flexibility and integrating VRE into the world's electric grids, with a focus on electricity storage.

4.4 Technology focus: electricity storage

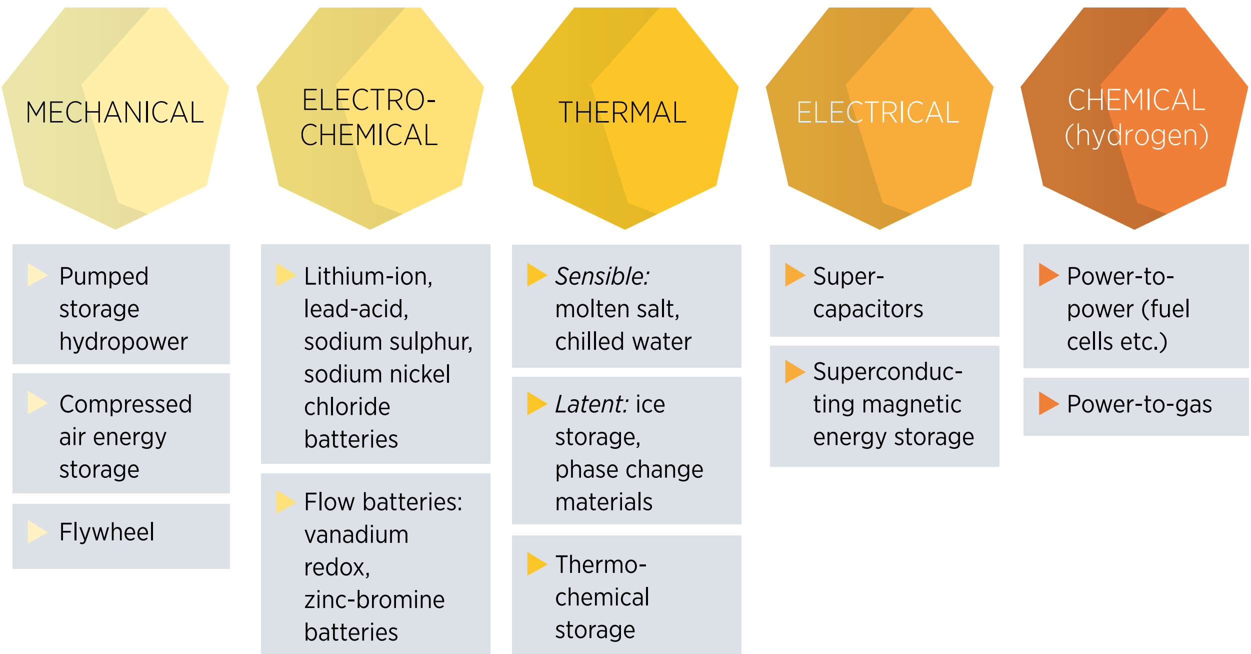
The ease of grid integration will vary from country to country. Some countries have already demonstrated the ability to maintain high shares of VRE. However, others may find it hard to integrate even a low share of generation from variable sources. In general, a 15%-25% share of VRE requires some additional fossil-fuel flexibility and more interconnectors. From around 25%, the need for innovative measures increases considerably (IRENA, 2016m). Integrating VRE will mean adjusting and adapting all elements of the power system. More flexible systems will be needed to manage and match electrical load and supply while also minimising costs (IRENA, 2016i; IRENA, 2017b). Electricity storage, which can bridge both temporal and geographical gaps between supply and demand, is one of many options for increasing system flexibility and integrating VRE generation (see Chapter 2).

Many experts view electricity storage as a potential game changer for managing and using electricity generated by VRE. Storage will be particularly important for distributed systems, for several reasons. First, renewable energy generation coupled with electricity storage is a technically and economically attractive alternative to diesel generators. Second, storage is one of the few viable solutions for integrating solar PV and wind power into existing power systems in remote areas and islands, where interconnections are weak and flexible power sources are lacking. Third, coupling renewable power with storage can improve power system security and reliability (IRENA, 2016i).

4.4.1 Electricity storage technologies

A great variety of electricity storage technologies can be applied to provide different functions at different locations (see Figure 4.4 and Table 4.5). Characteristics – including output capacity, efficiency, lifetime and discharge time – vary widely among technologies. No single electricity

Figure 4.4 Classification of energy storage technologies



Source: State of Massachusetts, 2016

Table 4.5 Types of storage technologies

STORAGE TYPE	DESCRIPTION
Pumped storage hydro	Uses excess electricity (*e.g.*, produced at night by coal or nuclear power) to pump water from a lower to higher reservoir; stored energy then generates hydropower during high-demand periods. Has largest power potential (per system) of any storage option, and longest life expectancy. Discharge time up to 24 hours or more.
Compressed air energy storage	Requires large, low-cost natural buffers such as caverns to store energy by compressing air; the compressed air is used in gas-fired turbines to generate electricity on demand. Discharge time is up to 24 hours or more. Efficiency is relatively low. Expansion is limited due to lack of suitable natural storage sites.
Flywheel	Stores electricity as mechanical energy, which is converted back to electricity when needed. Discharge time is seconds to minutes.
Batteries	Store electricity as chemical energy. Several types of batteries are available (see Figure 4.5). New materials and technologies are under development to improve performance and reduce costs. Discharge time is mostly 8-12 hours.
Thermal storage	Includes a number of different technologies that accommodate a wide range of needs. Allows for excess electricity to be converted to thermal energy and stored (short-term or seasonal) for later use. Generally not converted back to electricity, except in the case of concentrating solar (thermal) power technologies.
Supercapacitor	Stores electricity as electrostatic energy; often combined with batteries. Relatively high efficiency, with discharge times below 30 seconds.
Superconducting magnetic storage	Uses superconducting technology to store electricity. More research is needed.
Power-to-power/gas	Involves the conversion of electrical power to gas by splitting water into hydrogen and oxygen; hydrogen is then used as a fuel when needed or combined with CO_2 and converted to methane.
Hydrogen	Stored electricity is converted to hydrogen by electrolysis, and can be re-electrified when needed. Although it has a low range of roundtrip efficiency (30-50%), its use is growing due to much higher storage capacity in comparison with other energy storage technologies (*e.g.*, pumped hydro, CAES, and batteries).

Source: IRENA based on IRENA, 2015h and IRENA and IEA-ETSAP, 2012

storage technology scores well in all dimensions, and the technology of choice depends largely on system size, specific service required, electricity sources and the marginal cost of peak electricity (IRENA and IEA-ETSAP, 2012).

In addition, storage technologies are at different stages of maturity. The most mature is pumped hydropower, which is economically and technically proven worldwide. Pumped hydropower accounts for the vast majority of global electricity storage capacity, with up to 145 GW in operation (IHA, 2016) (see Figure 4.5). It has the potential for considerable expansion but it is not suitable for residential or small-scale applications.

After pumped storage, electrical batteries are the next most developed option. Demand for battery storage systems is increasing rapidly, although from a relatively low base. It is driven primarily by the small but fast-growing market for electric vehicles, as well as by the significant growth in deployment of variable renewable generating capacity (IRENA, 2016d).

Other emerging storage technologies include flywheels, power-to-gas and supercapacitors.

In addition, electricity can be stored in thermal form using boilers, heat pumps, ice and chilled water. This is often the least expensive form of storage, but it is more difficult to reverse thermal energy back into electricity. Instead, the stored energy is generally used as thermal energy when needed for space heating, cooling or in industrial processes (IRENA, 2015f). This is an example of sector coupling and the efficiencies that can result from combining power with other end-use sectors (see Box 4.3).

4.4.2 Battery markets and outlook

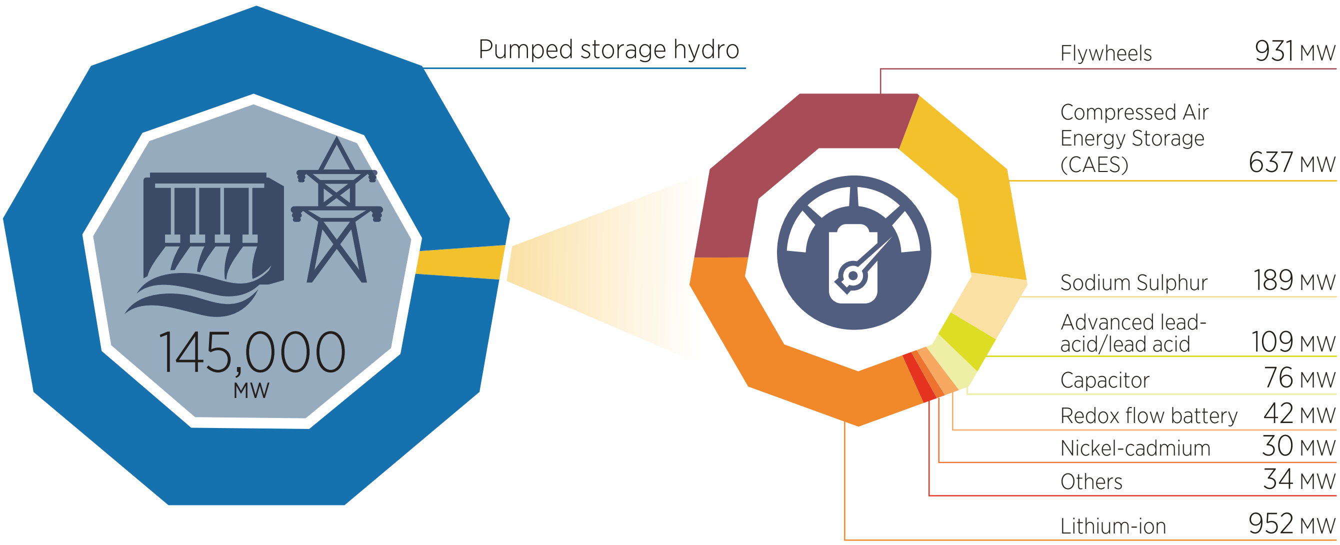
Among the many technologies available for electricity storage, batteries have experienced the most significant growth in recent years and are receiving the most attention. An increasing number of actors representing diverse backgrounds – including utilities, battery manufacturers and renewable project developers – is helping to drive competition (Eller and Dehamna, 2016).

Batteries are being deployed in four main applications to support VRE integration and improve reliability of electricity supply. These include households with solar PV; island systems and off-grid VRE for rural electrification; VRE smoothing and energy supply shifting; and fast, short-term electricity balancing in ancillary markets (IRENA, 2015f). In Germany, for example, some 10,000 rooftop solar PV systems are coupled to battery storage systems. Batteries also play a major part in providing energy access in the developing world, particularly when combined with solar PV in lighting systems and solar home systems (IRENA, 2015g).

Battery use is expected to increase substantially over the next few years, with the largest markets in North America, Europe and Asia-Pacific (see Figure 4.6) (Eller and Dehamna, 2016; GlobalData, 2016). Batteries are set to play an important role in VRE integration in existing electric grids and a key role in the ongoing effort to provide access to those still without electricity. IRENA estimates that pumped storage hydropower in 26 countries will increase from 150 GW in 2014 to 325 GW in 2030. Over the same period, the total available battery storage for electricity will increase from just 0.8 GW to around 250 GW (IRENA, 2015h).

Different types of batteries have different uses, but recent years have seen a significant shift from sodium sulphur to other battery types, particularly lithium-ion. Lithium-ion batteries

Figure 4.5 Share of various storage technologies in global electricity storage system (MW)



Note: Pumped storage data are for 2016; other data are for 2014.
Source: IRENA, 2015h; pumped storage data from IHA, 2016

Box 4.3 Role of sector coupling in realising higher shares of renewable energy

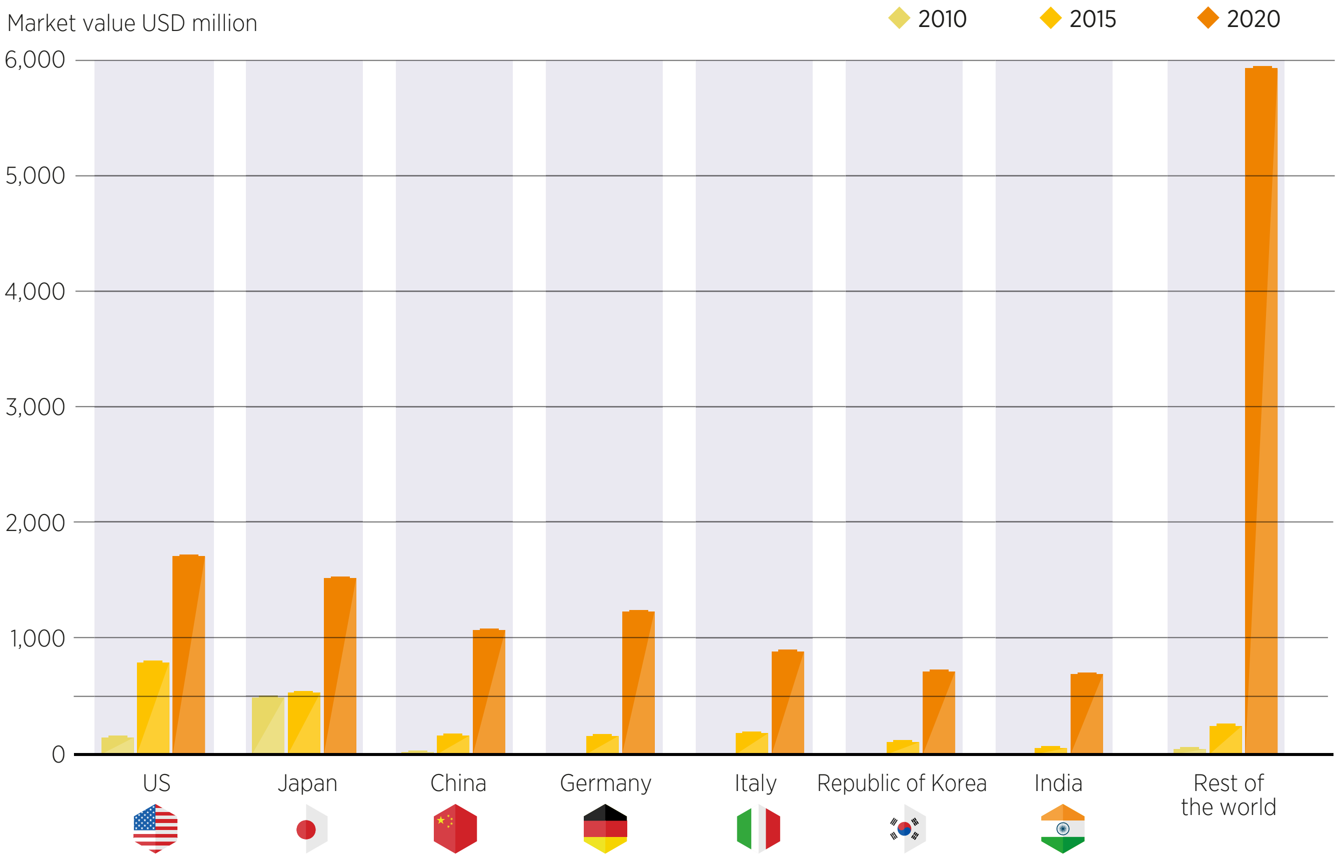
The coupling of the power sector with heating, cooling and transport offers significant opportunities for: integrating higher shares of VRE generation while also expanding the use of renewable energy in other end-use sectors and increasing efficiency of energy use. Sector coupling can be achieved in a number of ways, including:

- **Electrification of heating and cooling in buildings and industry.** Thermal grids (district heating and cooling) and individual building systems (*e.g.*, heat pumps) can serve as new markets for renewable electricity while also operating as demand buffers for variable generation. This can be accomplished by shifting thermal demand somewhat to better coincide with the ebb and flow of variable output, and by equipping district systems to store thermal energy for later use.
- **Electrification of transport.** Electricity is already used for many trains, trams and other forms of transport. Electric passenger vehicles also are growing in number, with more than one million plug-in electric vehicles estimated to be on the world's roads as of 2015. Electrification of transport enables the use of renewable electricity in vehicles through on-board batteries or hydrogen fuel cells. It also allows for the opportunity to balance VRE generation by timing battery charging and hydrogen production to coincide with surplus renewable electricity generation. A third potential advantage is to utilise such vehicles as two-way storage devices that can return electricity to the grid during peak demand periods or serve other electricity needs of the owner, depending on the circumstances.
- **Use of smart energy networks.** Timely and relevant information about supply and demand, and the flexibility thereof, will be an increasingly critical component of the production and distribution systems that couple renewable electricity with thermal applications and transport. "Smart" electrical and thermal energy networks will convey real-time information to both energy producers and consumers to optimise and synchronise supply and demand through a combination of supply-side flexibility and demand-side management and response. One component of this is to translate information on system imbalances into price signals so that the new transport and thermal demand can efficiently respond to changing conditions on the supply side by time-shifting demand, and even return stored energy to the grid when needed.

The potential synergy is substantial as the expanded use of renewables for transport and thermal applications, in turn, can balance grid power and perhaps offer other ancillary services for grid stability and security. Understanding how these services might be provided, and their economics, will be crucial to better assess the transition costs, or the savings, that can result from significantly higher shares of renewable energy. The coupling of the power sector with the heating, cooling and transport sectors is likely to become the key to realising the full potential of renewable energy in the overall energy system. The concept has already been put into practice in California, Denmark, Germany and China now is encouraging coupling to reduce curtailment of wind and solar power.

Source: IEA Electric Vehicles Initiative, 2016; IRENA, 2016d; IRENA, 2016g; IRENA, 2016n; Lutsey, 2015; IRENA, 2017b

Figure 4.6 Battery storage market value, top seven countries and rest of world, 2010, 2015 and 2020 (projected)



Source: IRENA based on GlobalData, 2016

have started to dominate the electricity storage market because of their high energy density, efficiency and relatively long life. In 2016, lithium-ion batteries accounted for about half new battery deployments, with advanced lead-acid, sodium sulphur and advanced flow batteries also having significant market shares (GlobalData, 2016; Tokash and Dehamna, 2016; US DoE, 2016).

Lithium-ion batteries are used widely in consumer electronics as well as in plug-in hybrids and electric vehicles. Their benefits include the ability to provide large amounts of energy for short periods of time and lower amounts of energy for longer periods. This makes them suitable for stationary (*e.g.*, solar PV systems) and mobile (*e.g.*, electric vehicles) electricity storage for all scales and applications (D'Aprile, Newman and Pinner, 2016). They also can be deployed rapidly.

Utility-scale systems were set up in a matter of months in 2016 for grid-based projects in North America (Randall, 2016). In addition, lithium-ion batteries are starting to appear in some solar home system markets, which up until now have relied primarily on relatively low-cost deep cycle lead-acid batteries (IRENA, 2016j). By 2025, it is expected that lithium-ion batteries will be included in up to 80% of all global electricity battery storage installations (IHS Markit, 2015).

4.4.3 Battery challenges, costs and benefits

There are several barriers to be overcome before battery storage can be fully integrated as a mainstream option in the power sector. However, there are promising signs of progress. Barriers to the widespread use of electricity storage include uncertainty on regulatory treatment; system costs; limitations to monetising the value of storage projects; utility acceptance; materials use; and performance and safety issues (IRENA, 2015f; State of Massachusetts, 2016). In addition, many stakeholders do not understand storage technologies in general or their potential benefits (Eller and Dehamna, 2016).

Cost remains the most significant obstacle. With the exception of pumped storage and conventional compressed air energy storage, cost has constrained large-scale deployment. However, costs of advanced battery storage systems are expected to fall. This is due to rising demand (particularly for electric vehicles), international competition and expanding manufacturing capacity. Indeed, costs of residential and utility-scale storage have fallen substantially and continue to fall, while performance is improving (IRENA, 2015h). In 2015, for example, lithium-ion battery prices reached USD 350/kWh, which is a 65% decline since 2010. They are expected to fall below USD 100/kWh within the next decade (McKinsey & Company and BNEF, 2016). Battery storage could become economically viable to support self-consumption of rooftop solar PV in locations with high residential electricity prices (IRENA, 2015i).

Despite further expected cost reductions, it is likely that the energy storage share of overall system costs will rise significantly in coming years, especially as VRE power generation costs continue to decline. However, storage provides a number of services that go beyond integration that are not necessarily easily monetised. These include increased system reliability and reduced

incidence of service interruption, T&D network support and increased efficiency (IRENA, 2015h; Eller and Dehamna, 2016). These added benefits would ideally be quantified and considered when evaluating storage as a system resource.

Another challenge that will increase along with battery storage is the economic and environmental cost associated with manufacturing and end-of-life. As with solar panels, end-of-life battery recycling improves material's availability and reduces environmental impacts and energy input related to future production. For example, using partially recycled materials can reduce energy input by about 40% compared to using virgin materials. Lithium, a rare earth material, is increasingly in demand as the use of lithium-ion batteries expands, drawing increased attention to the need for direct recycling. In addition, there are concerns about safety, expense and relative difficulty in obtaining cobalt (a critical component of popular lithium-ion chemistry), which have prompted researchers to work on new types of high-energy density, lightweight and durable batteries (IRENA, 2015f; IRENA, 2016g).

Giving electric vehicle batteries a second life in stationary applications is one way to at least postpone the need for recycling. China's State Grid Corporation is assessing the potential for second-life lithium-ion batteries to provide grid support (IRENA, 2015h). There is also great potential to use second-life batteries to expand rural electrification using renewable mini-grids (Ambrose, *et al.*, 2014).

4.5 Conclusion

Solar PV offers a bright future. It has enormous potential to transform how and where electricity is generated and by whom, and to improve millions of lives in the process. Solar PV has already exceeded all expectations, so that many international agencies and organisations are continuously raising their forecasts of future growth.

However, powerful policies are required. They need to incentivise deployment and help further drive down costs; establish end-of-life management strategies; and facilitate VRE integration into the grid. Only then will this bright future unfold for solar PV and other renewable energy technologies as envisioned by SE4ALL targets, the seventh SDG (SDG7) and global climate goals.

Grid integration will require innovative policies and regulations to encourage the development of more flexible and resilient power systems, including the development of electricity storage. In addition, coupling the power sector with the transport, heating and cooling sectors, combined with continued energy efficiency advances, will play a critical role in integrating a high share of renewable energy – particularly VRE. Sector coupling will maximise the potential for renewables to meet global energy demand.

Chapter 05

Energy Access and Development through Renewable Energy

5.1 Introduction

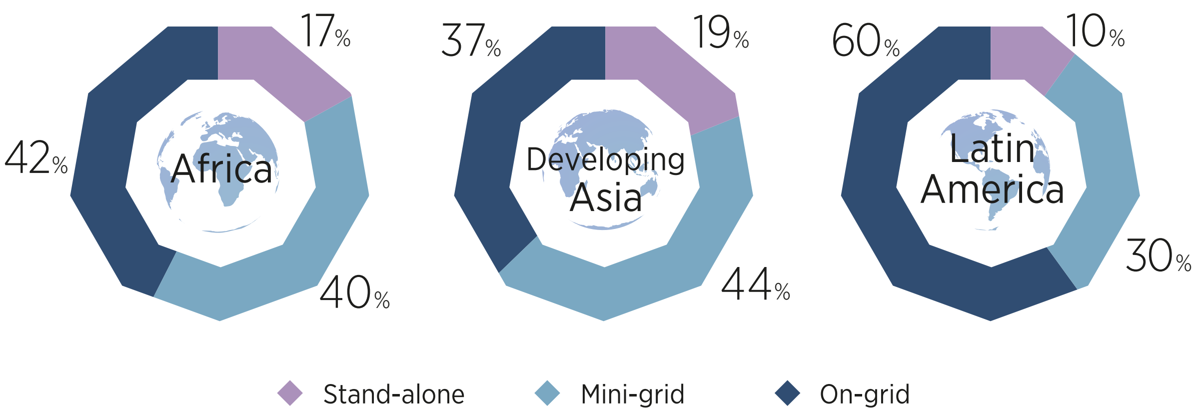
Access to modern energy services is central to achieving development goals, including those related to poverty eradication, ending hunger, health, education and gender equality. There have been significant strides in the last two decades in raising global access to modern energy. However, over 1 billion people (17% of the world's population) still lack electricity access, mostly in rural areas of Africa and developing Asia. Another 1 billion have unreliable supply (IEA, 2011). About 2.9 billion people rely on traditional biomass use for heating and cooking (SE4ALL, 2015[22]), which hinders advances in health, gender equality and economic opportunities in developing countries.

Electricity access, which is essential for stimulating socio-economic development, is the subject of this chapter. Policy makers and other stakeholders have a major task to complete. They need to extend electricity access to remote rural areas at a scale that can meet not only basic needs but also energy needs for productive uses. Historically, national electrification programmes have relied on large-scale, centralised power stations and power line extensions across the national landscape. Grid extension has not always succeeded in reaching rural or scarcely populated areas, so a continued focus on this approach alone will not be sufficient to achieve universal access.

To achieve universal electricity access by 2030, the current pace of expansion must almost double. It is estimated that off-grid solutions (stand-alone and mini-grids) will supply nearly 60% of the additional generation needed to achieve universal electricity access by 2030 (IEA, United Nations Development Programme and United Nations Industrial Development Organization, 2010, see Figure 5.1). Off-grid renewable energy technologies are well-positioned to supply the majority of this share.

Thanks to steep cost reductions in recent years, renewable energy technologies are now the most economical option for off-grid electrification in many rural areas (IRENA, 2015e). Renewable energy generation is often significantly cheaper

Figure 5.1 Estimated source of additional generation required to achieve universal electricity access by 2030 (by region)



Note: Figures are rounded. Total generation requirements: 468 TWh in Developing Asia, 463 TWh in Africa and 10 TWh in Latin America.
Source: Based on IEA, UNDP and UNIDO, 2010

[22] *SE4ALL is a multi-stakeholder partnership among governments, the private sector and civil society. It was launched by the UN Secretary-General in 2011. It aims to achieve universal access to modern energy services, and to double both the global rate of energy efficiency improvement and the share of renewables in the global energy mix by 2030.*

than diesel-fired generation or lighting provided with kerosene. At the same time, it avoids the environmental and social drawbacks of these energy sources. The modular nature of off-grid renewables, especially solar energy, allows them to be customised to meet local needs, deployed rapidly and scaled up as needed.

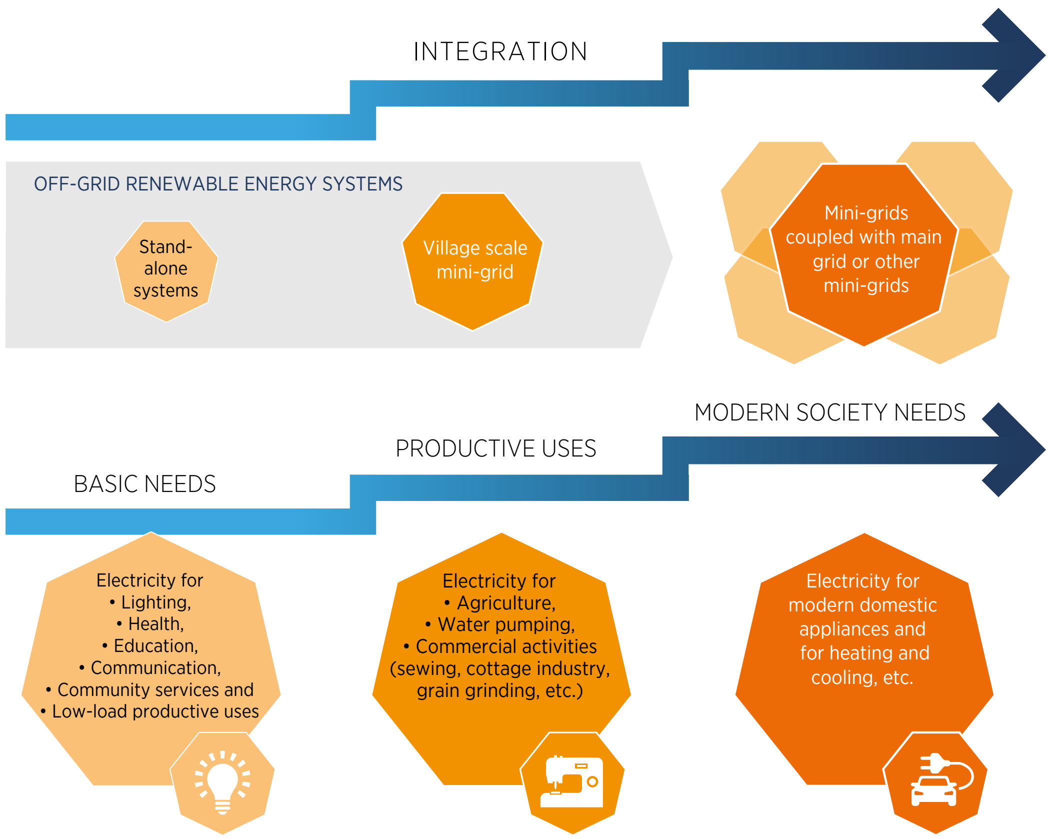
5.2 Off-grid renewables and universal electricity access

There is a growing track record in deploying off-grid renewable energy solutions for rural electricity provision. Almost 26 million households, or an estimated 100 million people in all, are served through such solutions. By 2015, stand-alone solutions, such as solar home systems, had provided about 20 million households with access to electricity. In addition, about 5 million households are connected to renewable-based mini-grids (IRENA, 2015g).

National energy access plans should consider off-grid renewable energy options as part of a broader strategy towards universal access. Figure 5.2 illustrates how this might be achieved, with off-grid solutions allowing households to climb up the energy ladder over time, progressing from basic needs to productive uses. By establishing a basic demand profile for an area, stand-alone systems can prepare the ground and build the economic foundation for larger systems, including mini-grids.

Mini-grids may be further integrated into regional mini-grids or the main grid where technically feasible. Indeed, ongoing advances in control system technologies and end-use efficiency (*e.g.*, in appliances) are enabling stand-alone power solutions to provide electricity services beyond basic needs.

Figure 5.2 Off-grid renewable energy and energy access



Source: Adapted from TERI, 2015

Enabling environment for off-grid renewable energy solutions

Electricity access will accelerate if the right conditions for deployment are created. There is no "one size fits all" solution. However, IRENA's continuing engagement with stakeholders (see Box 5.1) has identified four fundamental target areas (see Figure 5.3): policy and regulatory frameworks; institutional framework; financing and business models; and technology.

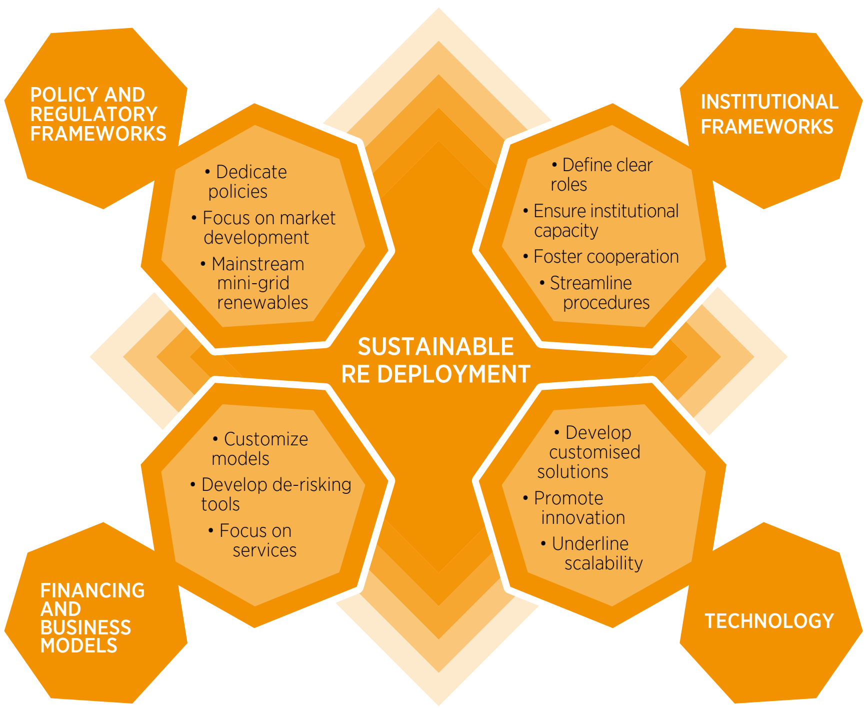
POLICY AND REGULATORY FRAMEWORKS

National frameworks need to be adjusted to the local context. However, certain core principles have emerged that can be replicated internationally.

First, off-grid renewable energy solutions need to be incorporated into rural electrification strategies. This sends a positive signal to market actors. The Economic Community of West African States (ECOWAS) Renewable Energy Policy, for instance, has set a target of promoting 60,000 mini-grids and 2.6 million stand-alone systems across the region by 2020 to serve 71.4 million people. Electrification strategies should identify clearly the areas to be reached by grid extension within a reasonable timeframe and the areas suitable for off-grid solutions (IRENA, 2016o). Official targets reduce uncertainty and provide clarity to both developers and rural communities.

Second, dedicated policies and regulations are required. National rural electrification strategies should be backed by dedicated policy and regulatory frameworks for off-grid renewable energy development. Traditional, centralised electricity sector frameworks should be adapted to support off-grid renewable energy deployment. India, for instance, released its draft national policy on renewable-based mini-grids in June 2016 (IRENA, 2016o). The policy's objectives include mainstreaming mini-grid solutions for improving access, streamlining project development procedures, providing frameworks for operating

Figure 5.3 Target areas for facilitating off-grid renewable energy solutions



Source: IRENA, 2013b

Box 5.1 International Off-grid Renewable Energy Conference (IOREC): IRENA's global platform for stakeholder engagement

IOREC is a global platform developed by IRENA to facilitate dialogue among stakeholders to promote off-grid renewable energy deployment. IOREC has thus far been held in Accra, Ghana (November 2012); Manila, Philippines (June 2014); and Nairobi, Kenya (September/October 2016).

Some of the key findings from the recent third conference are outlined below.

- The business case for off-grid renewable energy solutions to expand rural electricity access is now stronger, thanks to rapid cost reductions and technology innovation.
- Private sector interest and participation in the sector is growing as innovative business models are tried, tested and demonstrated.
- To advance towards the SDGs, off-grid solutions need to aim for the outcomes (improving lives through energy services) rather than energy delivery alone.
- Dedicated and stable policy and regulatory frameworks are needed to allow both mini-grid and stand-alone solutions to grow. These should be formulated in close consultation with sector stakeholders.
- Access to finance needs to be facilitated to ensure sector growth. Dedicated funds and de-risking tools will be crucial to bridge the financing gaps. Public financing should be complemented by private financing through innovative models, including public-private partnerships.
- High risk innovation capital is required to drive deployment, allow learning-by-doing and encourage bottom-up sector development. It is important to foster innovation partnerships, including incubators, and to stimulate local innovation.
- Off-grid renewable energy deployment can't be sustained without technical assistance and human capacity-building. This requires dedicated measures to identify skills-related needs and to determine how to meet them.
- Technology development is key to scaling up the sector. New storage and control systems, and further demand-side energy efficiency progress will transform energy access initiatives. Efficient appliances can unlock a wide range of rural electricity services, including those related to lighting, livelihoods, health and education.

The outcome papers from previous IOREC editions as well as presentations and other material are available at www.irena.iorec.org.

with local distribution companies, optimising access to finance and fostering innovation in mini-grid models.

Third, policies and regulations should be oriented towards market development. Policies, including incentive structures, need to be designed to attract investment and encourage local enterprises to contribute to sustainable market development.

INSTITUTIONAL FRAMEWORKS

An appropriate institutional framework is crucial to ensure the effective implementation of a national rural electrification strategy. Some countries have created new institutions with a mandate to support rural electrification activities. Others have placed the responsibility for rural electrification within existing ministries or agencies. The presence of an institution that exists for the express purpose of coordinating stakeholders, documenting processes and procedures, managing the project approval process, delivering capacity building, and facilitating the administration of financial and other incentive schemes is welcomed by mini-grid operators.

Rural electrification agencies have been established in several countries in Africa and other regions. Examples include Nepal's Alternate Energy Promotion Centre (AEPC) and the Rural Electrification Board in Bangladesh. In Africa, 30 rural electrification agencies and similar bodies have come together in the Association Africaine pour l'Electrification Rurale (African association for rural electrification), or Club-ER to accelerate the pace of rural electricity access (IRENA, 2016o). Although approaches differ according to country contexts, successful strategies generally include: clearly defined responsibilities, adequate institutional capacities, streamlined administrative procedures, and active cooperation among entities.

Relevant institutions need to have clearly defined roles and responsibilities to give developers certainty about administrative procedures and institutional contacts. Institutions that are implementing electrification strategies need to have adequate capacities ranging from technical knowledge and skills to stable budgetary allocations – assessments are necessary to identify the capacity gaps.[23] Simple and streamlined administrative procedures are required to reduce transaction costs incurred by developers, for instance, in procuring the necessary licences and permits. In addition, cooperation among diverse national and international institutions and agencies is essential for the creation of an effective and efficient environment for off-grid renewable energy deployment.

FINANCING AND BUSINESS MODELS

There is a huge market for off-grid renewable energy in rural areas lacking electricity access or with unreliable supply. Households and small businesses across the world spend over USD 36 billion annually on lighting based on fossil fuel – mainly kerosene (IFC, 2012). People in Africa alone spend around USD 10 billion each year (Lighting Africa, 2013). These figures are indicative of the potential market for a broad range of services relating to rural electrification. In order to be impactful, the private sector should offer business and financing solutions that are tailored to the local context (see Box 5.2); power essential services and productive uses; and de-risk investments in the sector.

Business and financing models tailored to local socio-economic conditions ensure greater penetration. Despite high expenditures on conventional energy options, rural households often are unable to afford off-the-shelf procurement of off-grid products. Financing schemes that fit household cash flows will help these solutions to become more widespread

Business models should focus on essential electricity services, including productive uses. This enhances the socio-economic benefits that arise from off-grid renewable energy deployment

[23] IRENA, in collaboration with the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), has started a clean energy mini-grids capacity needs assessment in West Africa, as a first step towards the expansion of joint capacity building support to ECOWAS member states. IRENA has also co-developed the Capacity Development Needs Diagnostics for renewable energy (CaDRE) tool (IRENA, 2012b).

Box 5.2 Tailored business and finance models: the case of pay-as-you-go models in East Africa

To tackle the challenge associated with the high upfront cost of stand-alone renewable energy solutions, innovative business and financing models have been developed. Pay-as-you-go (or PAYG) involves households or individuals procuring the system from a supplier by putting up a down payment, followed by daily, weekly or monthly payments for services that are set at affordable levels. Such an arrangement could take the form of a perpetual lease or of eventual system ownership after a defined period of time. The monthly payments are usually pre-paid and are mostly collected through mobile payment platforms.

To illustrate the case of one product in Kenya: for a deposit of USD 35, households receive the system and then make 365 daily payments of USD 0.43 through the mobile money system M-Pesa. When it is all paid off, the system belongs to the buyer. The PAYG model has gained substantial traction in East Africa where over 500,000 systems have been deployed. The ability to spread costs across smaller payments allows consumers to access electricity services beyond lighting, including mobile charging, televisions, fans and, in some cases, internet connectivity.

Source: Shapshak, 2016

as well improves project sustainability. Business models centred on stable anchor loads, such as community service centres, telecommunication towers and rural industries, often attract affordable financing more easily and are better equipped to provide higher tiers of electricity services.

De-risking tools can help attract both downstream (end-user) and upstream (enterprise) capital into the off-grid sector. Access to long-term, affordable financing allows developers to deliver products and services at lower cost. At the same time, affordable consumer financing means end-users can obtain the energy services and products offered. A perceptible shift is needed in donor funding away from partly or wholly subsidising off-grid renewable energy systems and towards supporting sustainable market creation (see Box 5.3).

TECHNOLOGY

Technology advances – in generation, balance of system components and end-use applications – are essential to the success of off-grid solutions for expanding electricity access in rural areas. Rapid technology improvements and large-scale deployment have cut the costs of renewable energy solutions and improved their competitiveness. Successful renewable off-grid projects often involve specific technology related factors around scalability, customisation and innovation.

Scalability of renewable energy technologies can be used to the advantage of off-grid systems. The potential to scale up off-grid renewable systems from small solar home systems to kilowatt (kW)– and even MW-scale mini-grids means they are adjustable to local conditions. This makes them extremely compatible with off-grid markets, which are characterised by diverse demands, varying resources and limited infrastructure.

Reliable and cost-effective off-grid systems require solutions that are customised to the local context. This includes generating assets (*e.g.,* solar modules or small hydropower turbines), balance of system components (*e.g.,* inverters, batteries, charge controllers) and appliances (*e.g.,* lighting devices, low-power television sets). In combination, these advances, customised to local conditions and needs, allow for the optimisation of system installations.

Innovative systems for control and demand-side management are gaining importance in the off-grid sector. On islands, the cost of generation can be cut by converting existing mini-grid installations based on diesel into hybrid systems using renewables. For many remote locations, diesel for power generation is so expensive (mainly as a result of high delivery costs) that hybrids are the most affordable alternative. Often these are made up of solar PV and battery storage with only minimal use of diesel. Advanced control technologies, load management and storage can help incorporate VRE into mini-grids and may eventually displace diesel generation altogether.

The four focus areas discussed in this section – policy and regulations, institutional framework, financing and business models, and technology – contribute to a wider enabling environment for off-grid renewable energy deployment. Each of these elements varies depending on the solutions (stand-alone or mini-grids), type of electricity service provided and local socio-economic conditions. To illustrate the specifics, the next section covers renewable energy mini-grids.

5.3 In focus: renewable energy mini-grids

Mini-grids fall between individual home systems and the main electric grid. They are often considered to be the most economical long-term solution for electricity access. They involve generation assets between around 1 kilowatt (kW) and 10 MW,[24] and supply electricity to multiple customers via a distribution grid that operates in isolation from the national grid. In unconnected rural areas, mini-grids have proved attractive for providing a wide range of electricity services (*e.g.*, household use, street lighting, water pumping, productive use). Their flexibility in terms of sizing, resource utilisation and management makes them highly adaptable to local needs and conditions.

Renewable-based mini-grids generate electricity using diverse and locally available renewable resources. They can range from solar battery-based direct current (DC) mini-grids for basic lighting and mobile phone charging, to bio-gasification plants that power electric motors in workshops and households, to mini-hydro plants. They are reliable and cost-competitive with fossil fuel-based generation systems, such as diesel generators, which are polluting and expensive to operate. Renewable-based mini-grids can also be a less expensive option than

Box 5.3 Solar home system finance in Bangladesh

Bangladesh's Infrastructure Development Company Limited (IDCOL) solar home systems programme is the largest off-grid electrification scheme in the world. The programme has come a considerable way between 2002 and 2016, dramatically scaling up its impact. About 280,000 systems were installed in 2002-2008, climbing to 4.1 million by November 2016 (IDCOL, 2016). IDCOL aims to reach 6 million systems by 2021.

Bangladesh's solar home systems programme is implemented through a large network of partner organisations. The IDCOL programme has targeted "downstream" end-users as well as "upstream" enterprises by acting as an intermediary between the funding agencies and the local partner organisations (such as non-governmental organisations and small and medium-sized enterprises). Partner organisations supply microfinance and technology to rural households. They also act as channels for all connections with households. They sell the system, liaise with system suppliers, supply operation and maintenance services, provide cash or credit finance and recover the debt.

Grants and concessional finance are the major financial components of Bangladesh's IDCOL solar home systems programme. They are designed to reduce external financial support from different funding agencies over time as technology costs decrease and markets develop. The capital buy-down grant per system has reduced gradually from USD 70 per system in 2003 to USD 20 in 2013. This grant was phased out in 2014 for systems of more than 30 watts (IRENA, 2013b; Rahman, 2016). The institutional development grant component has been eliminated, and lending rates offered under IDCOL having gradually increased.

[24] *Mini-grids for energy access are often classified into "micro-grids" and "pico-grids" to represent mini-grids of less than 10 kW. In OECD countries, the term "microgrid" is used very differently. It refers to a distribution and generation system with capacities in the hundreds of kWs or MW range that can operate independently or in conjunction with the area's main electrical grid. These microgrids often are installed to achieve exceptionally high levels of reliability for industrial applications, such as data farms or industrial processes for which a power outage could prove extremely costly.*

grid extension for reaching remote and rural communities.

Government agencies, state-owned utilities, co-operatives, community groups, NGOs and in some cases small local private firms have been the main driving forces behind the growth of mini-grids so far. However, limited economic viability and scalability of the traditional business models remains a key challenge for further growth in the sector.

Increased private sector involvement has several advantages. Further private participation in mini-grid financing through purely private ventures or public-private partnerships can complement government efforts, particularly those of public utilities. Private entities can reduce pressure on public utilities to invest in and operate mini-grids in rural areas, allowing them to concentrate on improving electricity services in more densely populated areas. Moreover, private sector mini-grid development tends to have a different emphasis from the traditional centralised model. It is more concerned with its customers and with long-term productive uses of energy (households, local businesses, agriculture and industry), building sustainability into the system and boosting the socio-economic benefits of electricity access. Other private sector advantages might include decentralised decision-making, local presence, community mobilisation and flexible management structures.

A shift towards greater private sector engagement in financing, developing, operating and managing mini-grids has occurred in recent years. Participants range from local entrepreneurs to large international utilities. Combining technology with new business and financing models, the private sector is deploying mini-grid solutions using diverse financing options. Given its importance, it is vital that governments adopt policies and regulations to facilitate private sector engagement. Recognising this need, several countries have turned to policies and regulations dedicated to mini-grid development.

Policies and regulations for private sector mini-grid development

The policy and regulatory landscape for mini-grids is highly dynamic as governments introduce dedicated measures, gain experience and incorporate this learning to shape a more effective framework. This evolution is essential for successfully adapting to local conditions and reducing deployment barriers. IRENA's analysis (IRENA, 2016o; see Box 5.4) of recent policy and regulatory developments relevant to the support of private sector mini-grids, examines legal provisions, tariff regulation, financing and arrival of the main grid.

LEGAL PROVISIONS. First and foremost, mini-grid operators should have the legal right to generate, distribute and sell electricity to rural consumers. Forming clear processes and procedures to facilitate project licensing, and streamlining requirements (particularly for smaller mini-grid projects) can reduce the costs and time required for project development. As a general guideline, fees and other development costs should not exceed 1%-2% of the total cost of a project.

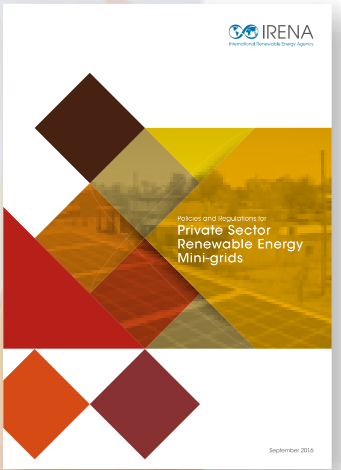
A common approach to mainstreaming processes and procedures is to establish a single-window facility hosted at a rural electrification agency or similar body, which reduces the number of institutions with whom developers must engage. The Indian state of Uttar Pradesh, for example, has established a one-stop shop at the New and Renewable Energy Development Agency for coordinating stakeholders, managing the approval process, facilitating capacity building, and administering financial incentive schemes (IRENA, 2016o). Information on processes and procedures should also be easily accessible (*e.g.*, Tanzania's online information portal, minigrids.go.tz).

TARIFF REGULATION. The viability and sustainability of mini-grids depend on well-designed tariff regulations. With costs of renewables decreasing, mini-grid solutions are becoming more competitive than grid extension. One approach to setting the tariffs of private sector mini-grids is to impose a national uniform tariff and provide viability gap funding. Another is to allow mini-grid tariffs that are high enough to cover costs but still well beneath current customer spending on conventional energy in off-grid areas. Increasingly, countries are taking a tailored-approach to tariff regulation. For example, they exempt small-scale systems (*e.g.*, less than 100 kW in United Republic of Tanzania and Nigeria) from tariff regulation (although communities can appeal in any tariff dispute) and regulate tariffs for large-scale systems (IRENA, 2016o). Common approaches include tariff caps or project-by-project approvals. However, the tariff determination approach should be standardised and well-defined to ensure systematic assessments and approvals by regulators.

ARRIVAL OF THE MAIN GRID. It is important to have an electrification strategy (location and timeline) to provide guidance and transparency to public authorities and private mini-grid developers. Kenya's National Energy and Petroleum Policy, for instance, provides the basis for the development of a comprehensive electrification strategy to-wards universal access by 2020 (IRENA, 2016o).

Well-defined interconnection or compensation mechanisms are also being employed to reduce risk to mini-grid operators should the main grid arrive. In Cambodia, for example, 250 formerly isolated mini-grids, have been licensed as small power distributors by the Electricity Authority of Cambodia (IRENA, 2016o). Operators also may be compensated for the residual value of the mini-

Box 5.4 Policies and regulations for private sector renewable energy mini-grids



Governments must play a key role in creating policy environments in which off-grid renewables can thrive. IRENA's recent report, *Policies and Regulations for Private Sector Renewable Energy Mini-grids* (2016), provides policy makers with the information they need to design and implement adaptable policies and regulations to support off-grid development.

Using recent case studies as reference points, the report analyses general and technology-specific policy and regulatory measures. It covers licensing, tariff regulation, risk relating to the arrival of the main grid, and access to finance for mini-grids. It can be downloaded at www.irena.org/publications.

grid assets rendered uncompetitive by the main grid, as is the case in Rwanda and in the United Republic of Tanzania, where regulators assign a depreciation scenario for fixed assets.

ACCESS TO FINANCE. Governments can take several measures to facilitate access to equity, debt and grant financing at different phases of mini-grid development. For example, improving access to information required for initial market assessments and co-operating with regional or global funding facilities can attract equity and grants during the project development stage. In 2015, Rwanda was awarded a USD 840,000 grant by the Sustainable Energy Fund for Africa to co-finance feasibility studies of 20 micro-hydro sites, rollout, and implementation plans that include tariff and business models for mini-grids.

Financial support such as public grants can be designed to leverage capital from commercial financial institutions. An example is the Inter-American Development Bank's USD 9.3 million programme implemented by Bancoldex, a commercial bank in Colombia that aims to deliver long-term concessional financing for private entities engaged in mini-grid development (IRENA, 2016o). In addition, public-private partnerships can be used to reduce risk and improve project bankability.

The regulation of renewable mini-grids is still evolving. However, a growing number of countries has recognised the opportunity offered by mini-grids and the potential for private sector engagement. These countries have introduced dedicated policies and regulations to establish a supportive environment for mini-grid development (IRENA, 2016o). Experience demonstrates that a considerable number of policy and regulation design elements work in tandem to facilitate mini-grid development (see Box 5.5 for Tanzania's example). A well-designed policy and regulatory framework not only improves project sustainability but also maximises the socio-economic benefits of renewable energy systems.

Policies and regulations for the mini-grid sector strongly influence deployment as well as innovation in technology design, finance and business models. They could also enable the participation of non-traditional entities, such as off-grid telecommunication infrastructure operators, in markets outside their core business.

Box 5.5 Mini-grid policy and regulation design elements working in tandem

Tanzania's Energy and Water Utilities Regulatory Authority (EWURA) announced in March 2016 the "Development of Small Power Projects Rules 2016", which laid out licensing and tariff regulation requirements for mini-grids. As a result, mini-grids with a capacity below 1 MW are exempt from applying for a licence and need only to register with the regulator for informational purposes. For Very Small Power Producers (less than 100 kW), the regulator requires no prior regulatory review or approval of proposed retail tariffs; however, it reserves the right to review the Very Small Power Producer tariffs if 15% of its customers file complaints.

If the main grid arrives, the mini-grid can become a small power distributor, keeping its retail customers and purchasing electricity at wholesale rates from the national utility. In addition, these small power producers can sell electricity to the main grid at standardised tariffs ("Small Power Producer Rules 2015"). The government has also established a standard PPA and tariff methodology for any electricity that these producers feed into the main grid. Tanzania's Rural Energy Agency offers results-based funding (performance grants) of around USD 500 per household or business connection. This is funded through a levy on electricity sales and donor contributions (Tanzania EWURA, 2016).

The evolution of mini-grid business models as well as associated capacity development needs have been addressed in IRENA's other work on the topic, including in the IOREC outcome papers (IRENA, 2013b; IRENA, 2015e). As noted earlier, appropriate policy and regulations, when combined with enabling institutional structures, customised business and financing models and technology solutions, help create an environment that faciliates the deployment of off-grid renewable energy solutions.

5.4 Conclusion

Off-grid renewable energy solutions are key to achieving universal access to electricity. Millions of people have already gained access to sustainable, clean and reliable electricity from renewable sources. Rapidly falling technology costs and improved reliability, as well as a growing track record of deployment and supportive policies, have strengthened the case for the accelerated adoption of stand-alone and mini-grid solutions.

Off-grid solutions are decentralised. This means that many project development activities occur locally, creating local jobs and incomes.[25] In addition, energy access is a major precursor to rural development, marked by considerable improvements in productivity, income and livelihoods. All these have knock-on effects. Key sectors such as agriculture, health and education, all benefit from access to modern energy services, and the modularity of renewable energy technologies means they can be customised to different applications. Indeed, renewable energy solutions have the potential to advance many SDGs.

Given these synergies, policy makers are encouraged to examine the opportunities that off-grid solutions offer for electrification and other facets of sustainable development. The following chapter discusses the part renewable energy can play in meeting not only the SDG on energy but also several other SDGs.

[25] IRENA's earlier work, including Renewable Energy Jobs and Access (IRENA, 2012c) and Renewable Energy and Jobs (IRENA, 2013b) investigated in depth the socio-economic benefits of off-grid renewable energy deployment, especially jobs.

Chapter 06

In focus: renewable energy and the sustainable development goals

6.1 Introduction

The Sustainable Development Goals (SDGs), adopted by the UN General Assembly in September 2015, provide a powerful framework for international cooperation to achieve both development and climate objectives. These SDGs underpin the 2030 Agenda for Sustainable Development (Agenda 2030) that officially came into force in January 2016. They define a path to end poverty, ensure prosperity and protect the planet and its inhabitants.

The central role of sustainable energy only came to the fore of the global development debate in the process of implementation and review of the Millennium Development Goals (MDGs), which were adopted in 2000. The absence of an energy goal had been one of the key limitations. Two years later, the international community publicly acknowledged the link between sustainable energy and poverty reduction at the World Summit on Sustainable Development in Johannesburg. Not long thereafter, UN-Energy was founded to facilitate coherent action on energy across the UN system. A growing body of empirical evidence and extensive cross-sectoral dialogue established a compelling rationale for increased access to clean energy to achieve the MDGs (Modi *et al.*, 2005; UN-Energy, 2005). This process culminated in the creation of the SE4ALL initiative in 2011, and the formalisation of the global energy agenda. Finally, in December 2014, the UN General Assembly proposed a set of SDGs that included a dedicated stand-alone goal on energy, SDG7. The goal aims to "Ensure access to affordable, reliable, sustainable, and modern energy for all." SDG7 was formally adopted in 2015 as part of Agenda 2030.

As a key constituent of SDG7, renewable energy contributes directly or indirectly to achieving all the other SDGs, many of which are interconnected across the three dimensions of environmental sustainability, human development and sustainable growth (see Figure 6.1). Renewables contribute to SDGs aimed at environmental sustainability by mitigating the local and global environmental impacts of energy consumption. They support human development by facilitating access to basic services, improving human health and supporting income generation activities. Finally, renewables also contribute to sustainable economic growth by generating economic benefits such as new jobs and industries.

The links between SDG7 and other SDGs are essential to maximise the development co-benefits. The 2030 Agenda recognises that "interlinkages and the integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is realised." Nevertheless, potential synergies between SDGs that could be mutually beneficial can be overlooked because they were not clearly identified. In fact, energy is currently only mentioned in the wording of 3 of the 169 targets of the Sustainable Agenda. Table 6.1 attempts to provide an overview of the linkages and synergies between SDG7 and all the other SDGs.

Table 6.1 Examples of linkages between renewables in SDG7 and other SDGs

SDG	LINKAGES	
1 NO POVERTY	Access to basic energy services is a prerequisite for eradicating poverty and stimulating economic activity. Decentralised renewables can enable significant savings on fuel spending, which disproportionately affects the poor in both developing and developed countries.	1
2 ZERO HUNGER	Renewable-powered pumping technologies can improve agricultural yields and reduce vulnerability to changing rainfall patterns, thereby helping achieve food security and improved nutrition. Renewables also provide energy for refrigeration and food preservation, which can reduce food waste.	2
3 GOOD HEALTH AND WELL-BEING	Improved cookstoves and clean energy for cooking reduce risks of respiratory diseases due to indoor air pollution. Decentralised renewables support the functioning of health clinics and hospitals in remote and rural areas. Renewables for power and transport reduce risk of diseases associated with outdoor air pollution.	3
4 QUALITY EDUCATION	Renewable-based power solutions allow study time after nightfall, access to information and communication technologies, and free up time previously required for fuel collection.	4
5 GENDER EQUALITY	Renewables relieve the burden on women and children of fuel collection and alleviate adverse health impacts of traditional biomass use. Renewable-based street lighting can improve safety and allows girls and women to attend educational, community or productive activities after dark.	5
6 CLEAN WATER AND SANITATION	Solar PV and wind power, the most rapidly growing technologies, consume up to 200 times less water than conventional technologies including thermal power plants. Water desalination and pumping with renewables can increase the supply of clean drinking water.	6
8 DECENT WORK AND ECONOMIC GROWTH	Renewables employed 9.4 million people globally in 2015 (including large-scale hydropower). Doubling the share of renewables in the global energy mix by 2030 could increase global GDP by up to USD 1.3 trillion and support over 24 million jobs in the sector. Providing off-grid communities energy for productive services enables economic development.	8
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Creation of local markets for renewables can create, directly and indirectly, new local businesses and industries. Development of infrastructure to support renewable-based charging for local transportation reduces local air pollution and greenhouse gas emissions.	9
10 REDUCED INEQUALITIES	Construction, commercialisation, installation and maintenance of renewable energy technologies create jobs and small businesses, leading to income generation and helping to overcome barriers to development. Relying on domestic energy sources frees local funds/foreign currency for non-energy purposes.	10
11 SUSTAINABLE CITIES AND COMMUNITIES	Cities can decarbonise their energy supply and use through renewables, notably in buildings (for heating, cooling, cooking and appliances) as well as for transport. Benefits can include reductions in pollution and in energy imports, as well as increased resilience.	11
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Renewables offer the potential to make the world's energy supply cleaner and safer, given that they are produced and deployed in a manner that is environmentally and socially sustainable.	12
13 CLIMATE ACTION	Scaling up renewable energy, coupled with energy efficiency, could put the world on track to keep the rise of temperatures within 2° Celsius, in line with the Paris Agreement. Renewables can support efforts for adaptation, *e.g.,* solar pumping and desalination can provide water amid changing climatic conditions.	13
14 LIFE BELOW WATER	Renewable technologies that replace or reduce consumption of fossil fuels can reduce pipeline and tanker traffic, reducing the risk of spills in water bodies. Renewable energy can reduce the risk of future warming and acidification of oceans by decreasing CO_2 emissions.	14
15 LIFE ON LAND	Well-designed renewable energy projects can avoid negative impacts on ecosystems and biodiversity compared with conventional energy sources. The use of modern renewables can displace fuel wood and charcoal in off-grid settings, thus decreasing forest degradation.	15
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Renewables can provide access to clean energy to those deprived of it, thereby decreasing social and economic inequalities within societies and between countries as well as contributing to peaceful and inclusive societies.	16
17 PARTNERSHIPS FOR THE GOALS	Linking renewable energy deployment with the broader goals of sustainable development requires enabling frameworks at the local level and global partnerships.	17

Source: IRENA, 2015c; ICSU, 2015; and Energypedia, 2016

Figure 6.1 Affordable and clean energy supports all the SDGs

6.2 Renewables and environmental sustainability

Environmental degradation and climate change are major threats to sustainable development. Renewables offer cost-effective and readily available solutions to address the pressing environmental issues facing humanity and the planet at both the global and local levels.

When countries devise strategies for meeting the SDGs, renewables should be recognised as the thread connecting economic and social development with climate change mitigation, reduced pollution, improved public health and a host of other environmental benefits covered by the SDGs. This section examines some of the links between renewable energy and three of the SDGs: Climate Action (SDG13), Sustainable Cities and Communities (SDG11), and Life on Land (SDG15).

6.2.1 Renewable energy and climate action (SDG13)

At the global level, the most critical environmental impact of energy is its impact on climate change. The global energy system accounts for approximately three-fifths of all anthropogenic greenhouse gas emissions (IEA, 2016a). In particular, the electricity sector accounts for over 40% of man-made (combustion related) CO_2 emissions. CO_2 intensity across energy technologies differs vastly according to components, power plant lifetimes, fuel types and waste intensity. Renewable energy technologies have some of the lowest lifetime emissions per kWh among electricity generation technologies (IRENA, 2014b). Renewables, along with energy efficiency, offer an immediate means to decarbonise energy systems thus giving the world a realistic chance of keeping global temperature rise to below 2° Celsius. IRENA analysis finds that a 36% share of renewables can reduce CO_2 emissions by up to 12 Gt worldwide compared with the business-as-usual scenario (IRENA, 2016d). This represents more than half of the required reduction to limit global warming to under 2° (see Chapter 1).

6.2.2 Renewable energy and sustainable cities (SDG11)

In the wake of the 2015 Paris Climate Conference and the Climate Summit for Local Leaders, cities are quickly emerging as important change agents in the sustainability agenda. In 2015, approximately 3.9 billion people – 54% of the global population (UN Habitat, 2016) – lived in cities and generated about 85% of global GDP. Cities are economic powerhouses, responsible for more than two-thirds of global energy consumption, and they produce about 70% of global CO_2 emissions. In the coming decades, global economic activity and population will be concentrated increasingly in cities, and energy demand will continue to grow rapidly. Thus, cities must play a central role in the transition to a sustainable energy system.

Renewables have emerged as the key solution to increase energy supply while decarbonising and improving the resilience of energy systems. More and more cities are setting ambitious renewable energy targets and taking serious steps to deploy renewable energy. Their ambition is to produce energy locally, save energy and money, create local jobs, promote sustainable urban development, reduce local air and water pollution, and support national and international (greenhouse gas) emissions reduction goals. In 2016, the Habitat III Cities Conference in Quito, Ecuador, adopted the New Urban Agenda, which guides future policies and approaches for urban development around the world. Discussions at the conference highlighted the role of municipal leaders and administrators in accelerating the switch to renewable energy at the local level, as planners, regulators, financiers and operators of urban infrastructure (IRENA, 2016p).

In contrast with most national governments, which concentrate primarily on the power sector, many cities and communities have gained significant ground across all sectors. The most widespread applications of renewable energy in urban buildings, for example, are rooftop solar PV and solar water heaters. Increasingly, district energy systems are relying on biomass, solar thermal

and geothermal energy to provide hot water and space heating and cooling.

Cities and communities are also promoting biofuels and renewable electricity in transport. The transport sector is the largest contributor to local air pollution in many cities. Globally, it accounts for 30% of total energy demand but can exceed 50% in many middle-income and fast-growing cities. Electric mobility based on renewable power is considered one of the most promising ways to reduce local pollution and global greenhouse gas emissions. It can make a critical difference to advancing renewable energy deployment and integration worldwide. In 2010, electricity supplied 1.3% of global energy use in transport. IRENA estimates that this share could increase to around 4% by 2030 (IRENA, 2016d). Public transport will account for 60% of total electricity use in transport, with various forms of electric vehicles (including two-, three- and four-wheelers) making up the remaining 40%.

6.2.3 Renewable energy and life on land (SDG15)

Well-designed renewable energy projects can avoid negative effects of energy production and use on ecosystems and biodiversity relative to conventional energy sources. Furthermore, replacing traditional use of biomass with modern renewable and efficient technologies can also reduce forest degradation and local pollution.

In rural areas where people lack access to modern energy services, large amounts of traditional solid biomass – including fuelwood, charcoal, animal dung and agricultural residues – are used daily for cooking and heating. In some developing countries, more than 90% of the population relies exclusively on solid biomass. In many cases, this biomass is obtained and used in an unsustainable manner (GIZ and Global Bioenergy Partnership, 2014) that contributes to local forest degradation and pollution. Modern, more efficient renewable technologies are providing sustainable alternatives. Improved cookstoves reduce the need for fuelwood, charcoal, and other biomass fuels through efficient combustion. They can achieve fuel savings of between 20% and 67% depending on the cooking methods they replace (open-fire cooking or less efficient stoves) (IRENA, 2016q). The introduction of biogas digesters offers further opportunities for reduction in fuel consumption. Biogas digesters in Nepal, for instance, have reduced household firewood consumption by 53%. On average, individual households that switched to biogas saved about 3 tonnes of fuelwood per year, avoiding almost 4.5 tonnes of CO_2 emissions per year (Katuwal and Bohara, 2009). By reducing the consumption of all kinds of unsustainable biomass, renewable and efficient technologies can also help decrease emissions of harmful pollutants.

6.3 Renewables and human development

Human development objectives focus on improving quality of life and do not assume that economic growth automatically provides greater opportunities to all. Human development is advanced through access to basic services (*e.g.,* education, health, water and food) and the availability of income-generating activities. Together, these services contribute to poverty alleviation and to improved well-being. Access to modern energy services with clean and sustainable energy is important for achieving both objectives. Scalable distributed renewable energy technologies also give people the opportunity to meet these basic economic objectives on their own terms and in ways that fit their needs.

6.3.1 Renewable energy and good health (SDG3)

By reducing emissions of pollutants, renewable energy technologies can significantly reduce risks to human health. Renewable energy can also play a critical role in delivering health services to people in remote and rural areas. It can improve access to clean water, improved sanitation and adequate nutrition.

Indoor and outdoor air pollution caused at least seven million premature deaths in 2012 (WHO, 2014) and affects more than 80% of the people living in cities (WHO, 2016). Indoor air pollution caused by leaky coal and wood cookstoves was linked to 4.3 million deaths in 2012. In addition, the use of kerosene lamps for lighting exposes people to health hazards such as burns. Outdoor air pollution, largely from coal burning and road transport, causes millions of premature deaths each year in both developing and developed countries (WHO, 2014). A study on China and India esti-mated that together these countries accounted for more than half of these premature deaths worldwide in 2013 (1.6 and 1.4 million people, respectively). The single greatest contributor in China is pollution from coal burning. In India, the equivalent is the burning of solid biomass for cooking and heating (Brauer *et al.*, 2016; Brauer, 2016).

Renewable and efficient cooking technologies like solar cookers, biogas and improved cookstoves can reduce respiratory diseases caused by indoor air pollution. These solutions also can be employed to heat food and boil water to prevent illnesses. Renewable systems that provide clean lighting eliminate the need for harmful and costly conventional lighting options. Finally, modern renewable energy systems that displace fossil fuel combustion in power plants and vehicles can significantly cut outdoor air pollution.

Burning fossil fuels for energy production is also expected to indirectly affect human health through its impact on the global climate. The World Health Organization (WHO) expects overall impacts of climate change on health to be overwhelmingly negative. Extreme heat, weather-related natural disasters, and the spread of vector-borne diseases will affect more and more people around the globe, particularly in developing countries (WHO, 2016).

Furthermore, around one billion people in the developing world are served by health facilities with no electricity, and many more people rely on facilities with unreliable access. Off-grid renewables can deliver reliable, affordable and sustainable energy to remote health care centres. They can generate electricity for medical devices, appliances and facility support functions (*e.g.*, lighting and water pumping) and can provide energy for sterilisation and for heating water and space. In 2013, 15% of hospitals in Uganda and 43% of hospitals in Sierra Leone used solar PV as a back-up for unreliable grid power (Adair-Rohani *et al.,* 2013; WHO and World Bank, 2014). Solar PV systems are increasingly providing refrigeration for storing and transporting vaccines. Off-grid renewable energy applications solve significant logistical problems and prevent vaccine losses in areas relying on refrigerators fuelled by kerosene or bottled gas, because these fuels are both difficult and expensive to procure.

6.3.2 Renewable energy and quality education (SDG4)

Education is one of the main engines for social change and a critical foundation of sustainable development. There is a positive correlation between improved access to modern energy services and educational achievements (Modi *et al.*, 2005). Hence, one of the indicators for monitoring progress towards SDG4 is the proportion of schools with access to electricity.

Around 300 million pupils worldwide (more than half the children attending primary schools in the developing world) go to schools with no access to electricity (Practical Action, 2013). If access is limited or non-existent, educational institutions cannot provide the right environment for delivering quality education or effectively make use of information and communication technology (ICT) tools. In addition, many children cannot study after school because their homes lack electricity for lighting or they lack the time required due to other responsibilities (*e.g.*, collecting fuel or fetching water).

Renewable energy solutions can make their lives easier by providing off-grid and cost-effective options that can be adjusted to local needs and are often significantly cheaper than fossil fuel alternatives. For instance, it is estimated that the deployment of 614,000 solar lights in Africa provided 765 million extra study hours for children in 2014. This resulted in improved performance, attendance and motivation (SolarAid, 2014). In Vietnam and Bangladesh, better school results were reported following the electrification of educational facilities (Khandker *et al.,* 2009) because schools equipped with PV systems allow teachers to use laptops and other technologies in their classes. In remote regions, electrification of educational institutions also incentivises qualified staff to stay on. Access to electricity provides them with better quality of life, improved safety (thanks to lighting) and better conditions for teaching and class preparation (SolarAid, 2014).

All these linkages make a critical difference to the aim of universal primary education as well as equal participation of boys and girls, which contribute to SDG5 on gender equality and empowerment (see Box 6.1).

6.3.3 Renewable energy and water (SDG6)

Water is a critical input for sustainable growth. Access to clean water requires energy inputs for extraction, pumping, treatment and desalination. In addition, the energy sector requires significant water inputs. Renewable energy can provide access to water in underserved areas. It can reduce costs, improve the reliability of water distribution networks and reduce water demand for electricity generation.

Renewable energy technologies are being deployed to meet energy demand along each segment of the water supply chain. Solar pumps are one example. They can supply water for drinking and crop irrigation purposes, increase access to piped water and reduce vulnerability to changing rainfall patterns. They decrease expenditure on conventional fuels, allow diverse cropping practices and improve crop yields (thus also contributing to SDG2 as explained below).

Energy costs often account for the largest individual share of the operating budget of a water utility (as much as 55%). Water utilities are increasingly relying on distributed renewable energy solutions to cut energy costs, improve the resilience of supply networks, and lower operational risks. Renewable energy resources can also provide energy for desalination infrastructure, thus contributing to the goal of clean water for future generations (SDG6). In regions with abundant solar resources, such as Gulf Cooperation Council countries, solar powered reverse osmosis desalination can produce water at a lower or comparable cost to fossil fuel technologies (IRENA, 2016l).

In the energy sector, annual water withdrawals for mining, processing and refining fuels and for electricity generation constitute about 15% of global fresh water use (REN21, 2015). Large-scale development of less water-intensive renewable energy technologies, such as solar PV and wind energy, can help reduce competition for water between power generation and other end-uses such as domestic consumption and irrigation.

Box 6.1 Renewable energy and gender equality (SDG5)

Renewable energy can contribute to gender equality in a variety of ways, particularly in instances where people lack access to modern energy services. Modern renewable fuels and electricity access can improve quality of life for women and provide them with opportunities to generate income.

Improved cookstoves and modern renewable fuels (*e.g.,* biogas) reduce health risks associated with indoor air pollution. By lowering or eliminating the time and effort spent gathering and carrying firewood, modern renewables can free up time for women and girls to pursue education or income-generating activities. Clean lighting provided by modern energy sources gives women flexibility in managing household tasks and can enhance personal safety, allowing participation in activities after dark (*e.g.,* classes and women's group meetings).

Female workers and entrepreneurs play a critical role in providing off-grid renewable energy solutions in the context of energy access. Indeed, integrating a gender perspective in the design of policies, products and services relevant to energy access is often essential if energy access initiatives are to succeed, because women often are their primary beneficiaries. In addition, commercial exchange of products and services can take place through women community networks and interpersonal relations, facilitating dissemination of technology and contributing to female empowerment. The organisation Solar Sisters in Africa has trained 1,200 women entrepreneurs who are marketing and selling off-grid solar PV solutions. Their efforts have benefited more than 200,000 people so far.

Renewables are also creating employment opportunities for women in both developed and developing countries around the world. A recent survey by IRENA shows that on average, women represented 35% of the workforce of the 90 companies that responded (IRENA, 2016c). This is a significant finding, considering that women account for only 20%-25% of the workforce in the energy industry overall (Stevens *et al.*, 2009). This finding indicates, at least in part, that women are strongly attracted to fields related to sustainability. The entry of more women into the renewable energy job market could enrich this fast-growing sector with a wider pool of skills and perspectives.

6.3.4 Renewable energy and nutrition (SDG2)

Over the last few decades, the global food chain has grown heavily reliant on energy inputs, particularly fossil fuels. This is due to the increased mechanisation of farming, production of fertilisers, food processing, transport and retailing. Integrating decentralised renewable energy into the different segments of the agri-food chain can bring substantial benefits to rural communities. At the same time, it reduces the food system's vulnerability to fuel supply shocks and lowers the sector's greenhouse gas emissions.

The different applications of renewables in the food supply chain are described in Figure 6.2. In primary production, for instance, renewable-based water pumping can increase yields, displace existing fossil-fuel based systems and expand irrigation in a way that is cost-effective and environmentally sustainable. Renewable energy can also provide cost-effective heating, refrigeration and motive power for processing and preserving food, which maximises productivity and profitability. In addition, food security is improved by nutrient retention and reduced food losses, which in turn helps to reduce hunger.

Figure 6.2 Renewable energy in the food supply chain

Source: IRENA, 2016q

6.4 Renewables and sustainable economic growth

There is growing evidence that renewable energy can prevent climate change while fuelling economic growth, improving human welfare, creating new jobs and developing new industries. The conventional view concerning trade-offs between economic growth and decarbonisation no longer holds.

Furthermore, the benefits of renewable energy - better human health, educational progress, poverty reduction, job creation and climate change mitigation go beyond the traditional (and limited) boundaries of GDP (see Chapter 1). Renewable energy deployment produces broader improvements to human welfare. IRENA estimates that doubling the share of renewables in the global energy mix by 2030 would increase global GDP in 2030 up to 1.1%, or USD 1.3 trillion (relative to the business-as-usual case). This is equivalent to adding the combined current economies of Chile, South Africa and Switzerland (IRENA, 2016e).

6.4.1 Renewable energy and no poverty (SDG1)

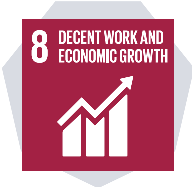
1 NO POVERTY

Access to reliable, affordable and environmentally friendly energy empowers individuals and communities to improve livelihoods, gain control over their energy supply, reduce fuel bills and eventually to escape from poverty. Benefits such as improved health, access to education, clean water and good nutrition, also contribute to improved well-being, encourage productive activity and create jobs.

Cost reductions in recent years have made renewables the most economical option for off-grid electrification in many rural areas (IRENA, 2015e). Off-grid applications, in particular, generate new businesses and productive uses, which create employment in the longer term. Over time, energy infrastructure needs to support rural communities as they move up the energy ladder (see Chapter 5), engaging in more income-generation activities. One project in Ghana that aims to provide access to modern energy services through improved cookstoves, grid access and solar PV pumps for agriculture and small-scale manufacturing has resulted in the development of 1,000 micro, small and medium-sized enterprises and the creation of 3,000 employment opportunities (IRENA, 2016q).

The modularity of most renewable technologies allows for gradual scaling, and projects can range from individual solar home systems to renewable-powered mini-grids. Systems can be expanded as required or as financing permits. Once the basic modern renewable energy technologies are in place, powered by local, indigenous energy sources, the poor are better positioned to sustain their livelihoods and to do so on their own terms. This helps strengthen local communities and increases resilience to potential security or environmental threats.

6.4.2 Renewables and decent work and economic growth (SDG8)



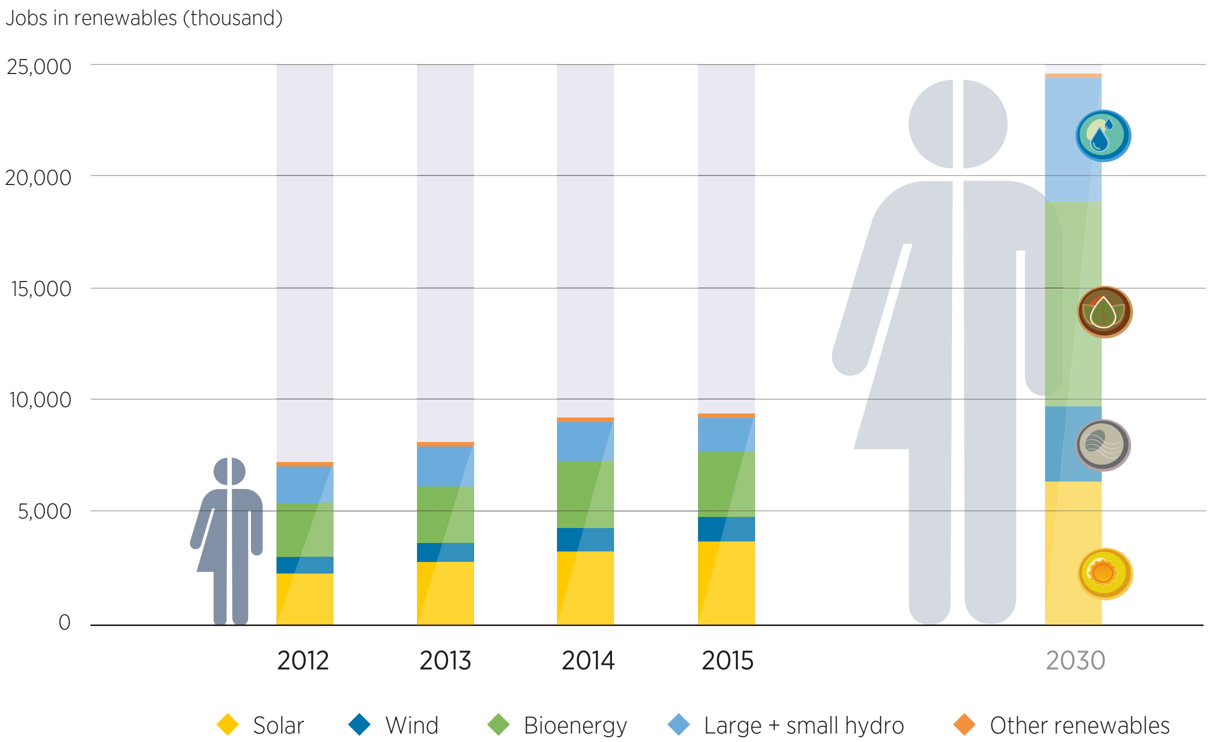
Sustainable economic growth and the advancement of human welfare are linked intrinsically to job creation. Jobs are essential to individual well-being and underpin broader socio-economic objectives such as poverty alleviation, social cohesion and productivity growth across the economy.

IRENA estimates that the renewable energy sector accounted for 9.4 million jobs worldwide in 2015 (including large-scale hydropower). Doubling the share of renewables could increase employment in the sector to beyond 24 million people by 2030 (see Figure 6.3). The number of jobs will increase in all technologies. Solar, bioenergy, hydropower and wind power will be the dominant employers (IRENA, 2016e).

Jobs will be created in all segments of the value chain (construction/installation, feedstock supply, manufacturing and operation and maintenance) and will form a global workforce with an array of skills. Construction and installation of renewable energy plants will be the largest segment by employment numbers, followed by feedstock supply (bioenergy), manufacturing, and operations and maintenance. As in any other industry, skills required for these jobs will vary by technology, geography and segment of the value chain.

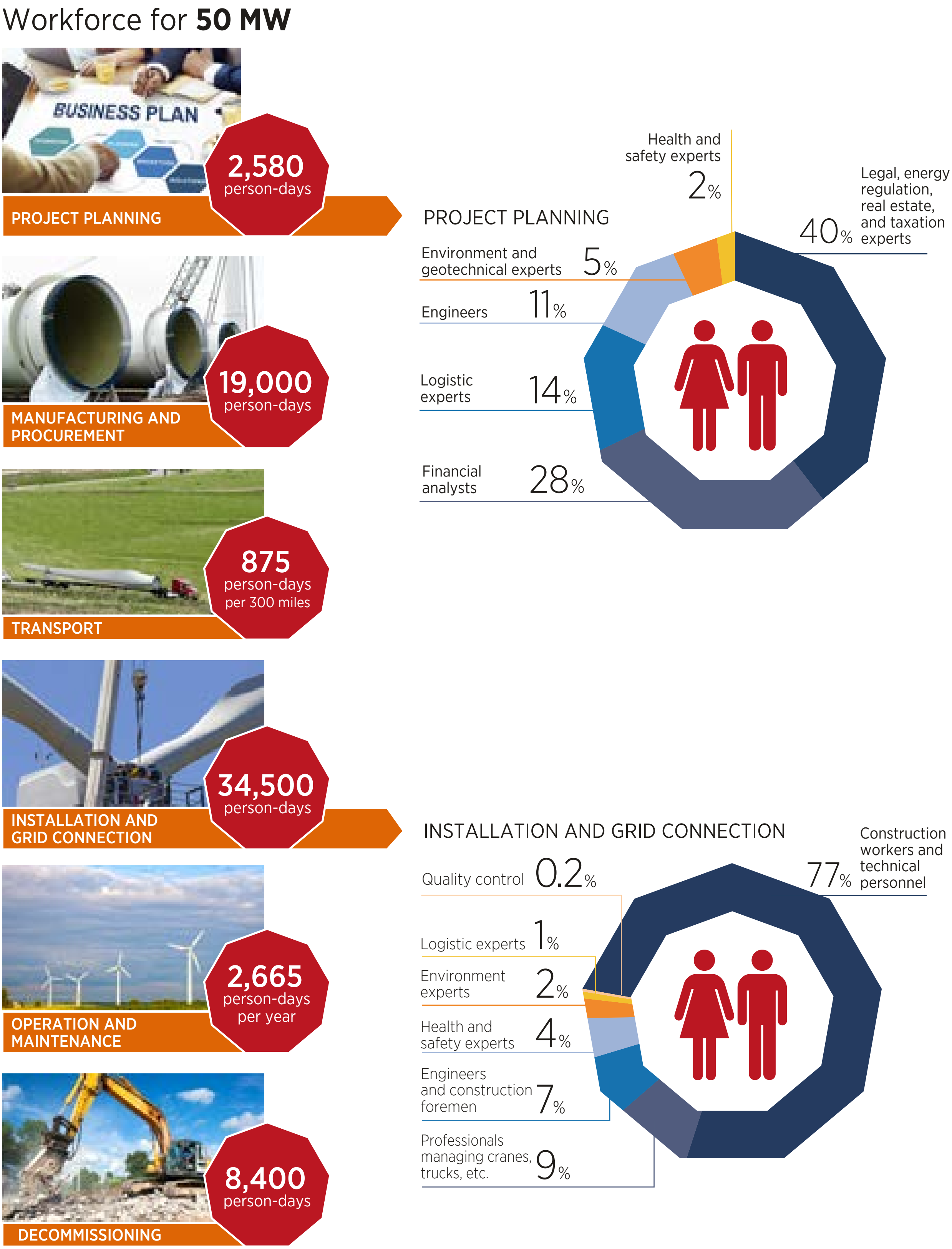
Although the detailed breakdown of the current renewable energy workforce by occupation and specific skill requirements is not known, data from existing projects provide interesting insights. For example, labour requirements in the wind power industry varies along the value chain. It ranges from 34,500 person-days required for installation and grid connection, to 2,670 person-days for project planning (see Figure 6.4).

Figure 6.3 Growth in global renewable energy jobs



Source: IRENA, 2016e

Figure 6.4 Workforce requirements along the wind power value chain



Source: IRENA, 2017c

6.5 The way forward: measuring progress

The true value of renewable energy goes beyond the energy services that it provides; its full potential lies in the ways that renewables avoid the negative environmental, social, political impacts associated with other forms of energy. To ensure that renewable energy helps to advance the SDGs, it is critical that renewables development and deployment be carried out in an economically, socially and environmentally sustainable manner. Just as renewable energy can help to achieve most if not all of the SDGs, several SDGs can shape the way renewable energy can best expand on a greater scale.

To this end, the development of a strong framework for monitoring and tracking progress towards achieving the SDGs is essential. In 2016, the United Nations Statistical Commission agreed on 230 individual indicators to monitor the 17 goals and 169 targets in the SDGs. They include five energy-related indicators that make up SDG7. For each of these, renewable energy should be measured along three broad dimensions: number of people using different types of energy; amount of renewable energy produced and consumed; and amounts invested in renewable energy. This task will require both an expansion in the scope of energy statistics and increased collaboration among agencies that collect socio-economic data – particularly important for capturing the linkages between SDGs.

Improved co-ordination on data collection in non-energy sectors could be useful in fields where the linkages between energy and other SDGs are particularly strong. The WHO has successfully combined and analysed household health and energy data to demonstrate the impacts of indoor air pollution on human health and mortality (WHO, 2014; WHO 2016). Large-scale household survey data have also been used to show how the use of renewable energy can bring about significant and cost-effective reductions in greenhouse gas emissions (Somanathan and Bluffstone, 2015). The inclusion, where appropriate, of simple measures of energy use in surveys of non-energy sectors

may reinforce evidence on linkages between renewable energy and other SDGs beyond the limited number of case studies and small surveys that are currently available.

The other major area where data could be improved is in monitoring the impacts of renewable energy projects that have been supported by incentives and other public policy measures. Generally, policy effectiveness is measured in terms of capacity installed or number of devices distributed, and there is little long-term monitoring of how policies affect people's lives. However, there have been some improvements. For example, several countries regularly evaluate the performance of biogas programmes across a number of different parameters (see, for example, IDCOL, 2013). Yet it is still uncommon to see the performance of renewable energy projects assessed in units other than energy capacity and production. For a more holistic approach to monitoring, energy statistics will need to include indicators that reflect the ways in which renewable energy improves people's well-being and livelihoods.

Energy is closely interlinked with economic development, human health and well-being, environmental health and security – virtually all the development goals the global community has set for itself. Clean, sustainable energy services thus permeate all these overlapping areas of human life, and either directly or indirectly help accomplish each of the development goals.

Chapter 07

Conclusion

In a growing number of countries, renewable energy has emerged as a mainstream solution for meeting energy demand in a cost-effective, secure and environmentally sustainable manner. Global renewable energy capacity and output have increased rapidly and continue to grow at an unprecedented pace, particularly in the power sector. These developments have set in motion a rethinking, or transformation, of the global energy system.

The rapid growth of renewable energy reflects commitment by governments around the world. More than 170 countries have established renewable energy targets, and nearly 150 have enacted policies to catalyse investments in renewable energy technologies. The private sector is also playing a critical role in scaling up deployment, signalling a near-global consensus that renewable energy technologies will be the engines of sustained economic growth and development going forward.

Building on this momentum, renewable energy is well positioned to play a central role in the implementation of international agreements on both climate change and the Sustainable Development Goals (SDGs). IRENA estimates that a doubling of the share of renewables to 36% by 2030 is technically feasible and economically viable.

Accelerating the pace of the energy transition and expanding its scope beyond the power sector would bring substantial social, economic and environmental benefits. Doubling the share of renewables in the world's energy mix by 2030 would increase global economic output by an estimated USD 1.3 trillion (in 2015 dollars) in 2030 relative to business as usual. It would also create millions of jobs and save millions of lives that would otherwise be lost due to air pollution. Some of the greatest welfare benefits would accrue to the more than 1 billion people who still lack access to electricity and the nearly 3 billion people who rely on unsustainable traditional biomass for cooking.

The foundations for accelerating the transition exist today. This report brings together the latest developments in policy, finance and technology that collectively drive the energy transformation.

Five overarching sets of actions, described here, can help decision makers step up their efforts to maximise the social, economic and environmental benefits of an accelerated transition.

Strengthening the policy commitment to renewable energy

Renewable energy policies play a fundamental role in attracting investments, increasing deployment and driving cost reductions. Although policies differ depending on context, they must support stable, transparent and predictable market conditions while being flexible enough to adjust to changing circumstances. Recent trends highlight the importance of market-based mechanisms, in particular auctions, and the need to adapt policies to integrate higher shares of renewable energy.

◆ To ensure efectiveness and efficiency, policies need to evolve based on lessons learned and to adapt to changing market conditions in a timely manner. With rapidly decreasing technology costs and growing sector maturity, policies to promote large-scale deployment in the power sector have shifted towards the use of auctions. Record-low bids in a variety of markets demonstrate the growing cost-competitiveness of renewables and provide valuable insights for governments on key policy elements that are helping to drive down costs. In designing auctions, policy makers need to weigh the trade-offs between price reductions and other policy objectives. As with any policy instrument, the success of an individual auction will depend largely on its design.

◆ As the share of variable renewable energy increases, new policy frameworks will be needed to facilitate the transition to smarter, more decentralised, more resilient and more flexible power systems. Measures to enhance flexibility – including policies to advance demand-side management and storage, and the necessary changes in market design – must be carried out in ways that provide adequate, reliable and safe electricity services at reasonable prices, while sharing system costs and benefits among stakeholders in a fair and equitable manner.

◆ A complete transformation of the energy system will not be possible without tapping into the synergies between renewables and energy efficiency and among end-use sectors. The coupling of the power sector with heating and cooling and transport, together with energy efficiency improvements, will be key to realising the full potential of renewables in the overall energy system. A more holistic approach to energy policy will help harness these synergies, allow for a smoother integration of renewables and create a more favourable environment for investments.

Catalysing additional investments in renewable energy

Notwithstanding the impressive growth in renewables over the past decade, a significant scale-up in global renewable energy investments is required to meet international energy and climate objectives. Public financing alone will be insufficient to reach the USD 770 billion needed annually through 2030, but it will play an important role in catalysing private investments to bridge the investment gap.

◆ Strong government commitment is required to reduce risk and the cost of financing in order to establish a stable and attractive market environment for renewables. Accordingly, greater policy attention should be given to ensure that public finance institutions have the right incentives to offer adequate financial instruments that reduce investment risks, thereby encouraging investment from a wider pool of investors.

◆ A focus on risk-mitigation instruments and structured finance can unlock substantial private capital from a range of new sources, including institutional investors. Risk mitigation instruments include partial credit guarantees to cover political risk, liquidity reserves facilities to cover off-take risks and currency hedges. Structured finance includes standardisation and aggregation of projects. Such measures can help develop a strong pipeline of attractive, investment-grade projects and work in tandem with capital market instruments, such as green bonds. They can open up opportunities to new classes of capital providers in the renewable energy sector, bringing the necessary liquidity to the market and helping reduce the cost of capital.

◆ A conducive environment for the private sector encourages business model innovation that can unlock even more private capital. Leasing and ESCOs are increasingly common in advanced and emerging markets. Leasing can bridge the divide between investors and users of decentralised solar PV installations; through securitisation it can attract large-scale institutional investors to the market. In a similar way, ESCOs are helping to overcome financial and other long-term risks for large-scale renewable heating and cooling systems. Corporate sourcing of renewable power through direct investments and PPAs, can play an important role in bringing additional finance to the sector, provided regulatory challenges and third party market access are addressed.

◆ The success of any investment strategy will rely on the active participation of a broad spectrum of public and private actors. These include development finance institutions, climate finance institutions, private equity funds, institutional investors, export credit agencies and commercial banks.

Fostering technological innovation to unlock markets and drive down costs

Technology advancement and innovation will be important for the energy transition. A continuous process of technology innovation will lead to better performance, improved reliability and lower costs. This dynamic is exemplified by the cases of solar PV and battery storage, key technologies for the energy sector transformation.

◆ Policy makers need to continue supporting innovations in solar PV-based technology to reduce module and system costs even further and enhance reliability. Lower costs and greater reliability will open up new markets for deployment and enable greater integration in electricity systems, ranging from solar home systems to mini-grids and national and regional grids. Several mechanisms – including dedicated funds and subsidies for supporting research and demonstration projects, public-private partnerships to advance the development of new technologies and financing options such as loans and public venture funds – can foster innovation.

◆ Major breakthroughs in complementary systems, in particular storage, will be instrumental in enabling the integration of larger shares of renewables in the electricity system. Cost-effective storage solutions could be a game changer. Significant advances have already been made in battery storage, and costs are falling rapidly. Concerted efforts are needed to address barriers such as uncertainty surrounding regulatory treatment, limitations in the ability to monetise the value of storage projects, utility acceptance, and performance and safety.

Bridging the electricity access gap through off-grid renewable energy solutions

More than a billion people live in areas that remain unserved by electricity infrastructure, constraining their access to basic services and limiting their potential for economic and human development. Off-grid renewable energy solutions (both stand-alone systems and mini-grids) are well suited to deliver cost-effective, tailored and environmentally sustainable access to modern energy services.

◆ National energy access plans should consider off-grid renewable energy technologies (both stand-alone systems and mini-grids) as mainstream solutions to complement grid-based options. Creating the enabling conditions for deployment of off-grid solutions requires the use of dedicated policy and regulatory frameworks, supportive institutional structures, customised financing and business models, and innovative technology solutions, as well as efforts to build human and institutional capacity. Each of these aspects varies depending on the type of electricity service provided, the local socio-economic conditions and technological solutions (*e.g.,* stand-alone systems or mini-grids).

◆ Sector-specific policies and regulations are needed to accelerate the pace of deployment of off-grid renewable energy technologies and TO facilitate private sector participation. In the case of mini-grids, which are expected to deliver the largest share of the additional off-grid generation, policy and regulatory frameworks must reduce barriers to market entry and keep development costs low through clear legal and licensing provisions. Also, tariff regulations should ensure that, once built, mini-grids are viable and sustainable. To address the risk of main-grid arrival, the establishment of comprehensive and accurate rural electrification master plans and the implementation of interconnection and/or compensation mechanisms, detailed planning is also required. Further, there is a need for dedicated financing instruments to bridge investment gaps.

◆ Backward and forward linkages in energy access can help ensure that projects are sustainable and maximise the resulting socio-economic benefits. A paradigm change is needed in the way off-grid solutions are deployed, with the focus shifting away from capacity or generation metrics (supply-side paradigm) towards livelihoods and services (demand-side paradigm). Such a shift can help suppliers customise energy solutions so that they are better able to provide opportunities for improving livelihoods, increasing productivity and generating income, thereby contributing to multiple SDGs.

Harnessing renewable energy to meet multiple Sustainable Development Goals

The value of renewable energy goes well beyond the energy services it provides. Deploying renewable energy to achieve SDG7 (on energy) will not only transform the energy system, it will also help countries meet the other SDGs, including the SDGs on poverty alleviation, health, water, nutrition, cities and climate.

◆ Policy makers need to adopt a more holistic view that considers the impact of renewable energy both within and beyond the energy sector. Energy sector strategies need to take into account the wide range of potential technology applications and the enormous opportunities created by those applications in terms of jobs, income and human welfare. To realise these benefits, a mix of policies is needed that covers deployment and industrial policies as well as education and training.

◆ Policy makers across sectors should integrate renewables as a key pillar of development strategies, thereby facilitating achievement of the SDGs. The decentralised and modular nature

of renewables allows them to cater to local energy demands in areas not served by the main electrical grid and to support rural communities as they move up the energy ladder.

◆ A strong framework for monitoring and tracking progress towards achieving the SDGs is required based on an expansion in the scope of energy statistics. In addition, collaboration among agencies that collect socio-economic data needs to be improved in order to better capture the linkages between renewable energy and the achievement of the non-energy SDGs.

ENERGY IS INTEGRAL TO ECONOMIC DEVELOPMENT, HUMAN HEALTH AND WELL-BEING, AND ENVIRONMENTAL SUSTAINABILITY –
virtually all development goals the global community has set for itself. Thanks to these interlinkages, access to clean and sustainable energy can positively influence livelihoods and economic growth, advancing progress on global development goals. Today more than ever, renewable energy presents a compelling case for accelerating the pace of the energy transition to reap the entire spectrum of economy-wide benefits.

Annex Renewable Energy Statistics

- Renewable electricity generating capacity in 2015 (in MW)
- Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL		Hydro/Ocean		Wind		Solar		Bioenergy		Geothermal	
	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	in 2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)
WORLD	1 964 655	5 294 465	1 208 192	4 020 801	416 638	713 846	223 948	197 077	102 820	399 496	13 056	77 014
AFRICA	36 447	130 829	29 470	121 914	3 142	5 054	2 094	1 974	1 126	2 195	614	3 195
Algeria	537	388	228	193	10	1	299	194				
Angola	933	5 019	921	5 000			12	19				
Benin	2	3	1	1			1	2				
Botswana	1	2					1	2				
Burkina Faso	39	100	32	90			7	10	0			
Burundi	59	164	57	161			2	3				
Cabo Verde	36	114			26	100	10	14				
Cameroon	723	3 807	721	3 805			2	2				
Cent Afr Rep	19	155	19	155			0	0				
Comoros	1	5	1	5								
Congo DR	2 429	8 032	2 429	8 032								
Congo Rep	209	1 021	209	1 021			0	0				
Cote d Ivoire	604	1 754	604	1 754								
Djibouti	0	1					0	1				
Egypt	3 506	14 724	2 851	13 352	610	1 332	45	40				
Eq Guinea	127	127	127	127								
Eritrea	1	2			1	2						
Ethiopia	2 489	7 361	2 157	6 817	324	526					7	17
Gabon	330	1 397	330	1 397								
Ghana	1 583	8 391	1 580	8 387			3	4				
Guinea	368	488	368	488								
Kenya	1 562	7 344	820	3 956	26	18	24	30	86	162	607	3 178
Lesotho	75	525	75	525			0	0				
Liberia	4		4									
Libya	5	8					5	8				
Madagascar	171	847	165	843	1	0	5	4				
Malawi	371	2 112	351	2 054			4	6	17	51		
Mali	190	982	184	974			6	8				
Mauritania	104	218	51	183	35	10	18	25				
Mauritius	151	596	61	91	1	3	18	25	71	478		
Mayotte	13	4					13	4				
Morocco	2 609	3 625	1 770	2 033	797	1 924	41	61	1	3		
Mozambique	2 193	16 209	2 186	16 198			7	11				
Namibia	353	1 512	332	1 485	0	0	21	26	0	0		

Annex Renewable Energy Statistics

Renewable electricity generating capacity in 2015 (in MW)

Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL		Hydro/Ocean		Wind		Solar		Bioenergy		Geothermal	
	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	in 2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)
AFRICA (continued)												
Niger	6	8					6	8				
Nigeria	2 060	5 363	2 041	5 339	2	2	17	22				
Reunion	377	942	134	426	15	16	180	236	48	264		
Rwanda	111	209	102	194			9	13	1	2		
Sao Tome Prn	2	7	2	7								
Senegal	111	348	78	318			8	13	25	18		
Seychelles	6	7			6	7	0	0				
Sierra Leone	88	130	56	105					32	25		
Somalia	3	7			2	6	1	1				
South Africa	4 877	2 626	2 288	3 958	1 053	600	1 272	1 098	264	77		
South Sudan	0	0					0	0				
Sudan	1 776	8 116	1 585	8 000					191	116		
Swaziland	186	565	62	244			1	1	123	320		
Tanzania	650	2 783	572	2 591			14	16	64	177		
Togo	67	90	67	89			1	1				
Tunisia	310	585	62	56	233	507	15	22				
Uganda	782	2 327	701	2 013			20	31	61	282		
Zambia	2 362	14 116	2 317	14 043			2	3	43	71		
Zimbabwe	877	5 559	773	5 403			4	7	100	148		
ASIA	779 947	1 888 071	498 748	1 570 748	160 166	197 776	88 164	62 055	28 975	85 083	3 894	23 094
Afghanistan	254	838	253	836			1	1				
Bangladesh	399	1 208	230	993	2	4	167	212				
Bhutan	1 614	7 148	1 614	7 147			0	0				
Brunei Darsm	1	2					1	2				
Cambodia	1 205	1 873	1 175	1 852	1	1	6	3	23	17		
China	503 796	1 253 230	320 914	1 060 107	129 340	158 271	43 194	25 007	10 320	22 900	27	145
Chinese Taipei	6 598	8 248	4 683	7 439	647	1 501	842	552	426	1 914		
India	82 117	185 569	46 256	134 193	25 088	33 455	5 167	4 910	5 605	17 960		
Indonesia	8 321	33 750	5 168	15 148	1	1	12	11	1 736	8 552	1 404	10 038
Japan	90 089	134 633	49 146	107 291	3 035	2 196	33 300	26 534	4 076	17 612	533	2 602
Kazakhstan	2 795	8 277	2 682	8 263	56	13	57	1				
Korea DPR	5 768	13 650	5 768	13 650	0	0						
Korea Rep	12 708	17 650	6 729	14 911	869	1 077	3 173	2 729	1 937	5 577		

to be continued – see next page

Annex Renewable Energy Statistics

Renewable electricity generating capacity in 2015 (in MW)

Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL 2015 (in MW)	TOTAL 2014 (in GWh)	Hydro/Ocean 2015 (in MW)	Hydro/Ocean 2014 (in GWh)	Wind 2015 (in MW)	Wind 2014 (in GWh)	Solar 2015 (in MW)	Solar 2014 (in GWh)	Bioenergy in 2015 (in MW)	Bioenergy 2014 (in GWh)	Geothermal 2015 (in MW)	Geothermal 2014 (in GWh)
ASIA (continued)												
Kyrgyzstan	2 952	13 298	2 952	13 298								
Lao PDR	3 948	17 440	3 917	17 434			1	0	30	5		
Malaysia	5 880	12 444	4 668	11 731			184	160	1 028	553		
Maldives	4	2			0	0	4	2				
Mongolia	77	195	26	69	50	125	0	1				
Myanmar	2 914	8 829	2 914	8 829								
Nepal	762	2 369	730	2 321			32	48				
Pakistan	8 004	35 269	7 224	33 201	256	459	210	241	314	1 368		
Philippines	6 186	19 809	3 551	9 811	387	152	132	17	186	196	1 930	10 308
Singapore	188	1 003	0	0			60	40	128	963		
Sri Lanka	1 735	3 745	1 626	3 561	76	147	16	18	17	19		
Tajikistan	4 638	16 312	4 638	16 312								
Thailand	8 353	14 443	3 500	6 018	223	305	1 605	1 564	3 025	7 050	0	1
Timor Leste	0	2	0	2								
Uzbekistan	1 762	10 311	1 761	10 310			1	1				
Vietnam	16 882	66 489	16 622	66 024	135	68			125	396		
C. AMERICA + CARIBBEAN	11 580	35 263	6 804	23 741	1 339	3 161	864	350	1 949	3 932	625	4 080
Antigua Barb	3	1					3	1				
Aruba	37	166			30	158	5	7	2	1		
Bahamas	1	2					1	2				
Barbados	9	10					9	10				
Belize	90	369	54	264			5	6	32	99		
BES Islands	11	41			11	41	0					
Costa Rica	2 448	9 075	1 937	6 717	268	735	1	2	40	84	202	1 538
Cuba	566	990	61	104	12	19	24	29	470	838		
Curacao	38	212			30	200	8	12				
Dominica	7	32	7	31	0	1	0	0				
Dominican Rep	724	1 896	612	1 584	85	247	16	20	11	45		
El Salvador	827	3 789	485	1 789			2	2	136	441	204	1 558
Grenada	1	1			0	0	0	0				
Guadeloupe	149	320	9	27	27	54	67	103	31	61	15	75
Guatemala	2 170	6 691	1 087	4 825	76		85	7	873	1 612	49	247
Haiti	54	141	54	141								

Annex Renewable Energy Statistics

- Renewable electricity generating capacity in 2015 (in MW)
- Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL		Hydro/Ocean		Wind		Solar		Bioenergy		Geothermal	
	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	in 2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)
C AMERICA + CARIB (continued)												
Honduras	1 433	3 159	632	2 589	176	397	455		171	174		
Jamaica	107	297	30	136	39	119	6	7	32	36		
Martinique	67	108			1	2	63	84	4	23		
Nicaragua	596	2 397	120	396	186	846	1	1	134	492	155	662
Panama	1 906	5 180	1 612	5 034	270	116	14	1	10	29		
Puerto Rico	318	348	100	81	125	218	88	48	5			
St Kitts Nevis	4	10			2	8	1	2				
St Lucia	1	0					1	0				
St Vincent Gren	6	25	6	25			1	1				
Trinidad Tobago	3	4					3	4				
US Virgin Is	4						4					
EURASIA	90 081	251 577	82 645	240 790	4 719	8 531	336	25	1 679	1 286	702	2 819
Armenia	1 302	1 996	1 298	1 992	3	4	1	0				
Azerbaijan	1 151	14 791	1 078	14 614	11	2	24	1	38	174		
Georgia	2 877	8 335	2 877	8 335								
Russian Fed	53 047	174 221	51 526	175 596	11	5	63	7	1 370	32	78	455
Turkey	31 704	52 234	25 867	40 253	4 694	8 520	249	17	271	1 080	624	2 364
EUROPE	493 296	1 133 347	213 402	631 392	144 173	258 146	98 661	99 160	35 507	169 767	1 553	11 458
Albania	1 824	4 726	1 823	4 725			1	1				
Austria	18 219	49 973	13 333	44 829	2 411	3 846	935	785	1 539	4 339	1	0
Belarus	74	253	36	121	3	11	5	2	30	119		
Belgium	7 678	12 170	1 429	1 507	2 225	4 614	3 119	2 883	906	4 399		
Bosnia Herzg	2 055	4 721	2 043	5 935	0	1	11	5				
Bulgaria	4 994	7 389	3 222	5 163	700	1 331	1 032	1 252	40	201		
Croatia	2 713	9 936	2 195	9 124	423	730	44	35	51	165		
Cyprus	253	317			158	182	85	84	10	51		
Czech Rep	5 491	9 172	2 257	2 961	278	477	2 084	2 123	871	4 663		
Denmark	7 129	19 358	9	15	5 063	14 453	790	596	1 267	4 294		
Estonia	525	1 389	5	27	341	604	6	0	173	758		
Faroe Islands	59	155	38	121	20	35						

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Annex Renewable Energy Statistics

Renewable electricity generating capacity in 2015 (in MW)

Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL		Hydro/Ocean		Wind		Solar		Bioenergy		Geothermal	
	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	in 2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)
EUROPE (continued)												
Finland	6 351	26 271	3 273	13 397	1 027	1 107	11	8	2 040	11 759		
France	43 836	91 404	25 662	69 105	10 358	17 249	6 549	5 909	1 267	4 938		
FYR Macedonia	694	1 291	641	1 207	37	71	16	14				
Germany	104 986	162 513	11 234	25 444	44 947	57 357	39 636	36 056	9 132	49 414	38	98
Greece	8 898	12 177	4 088	4 607	2 152	3 689	2 606	3 792	52	220		
Hungary	1 033	3 136	57	301	329	657	96	56	552	2 122		
Iceland	2 652	18 118	1 984	12 872	3	8					665	5 238
Ireland	3 085	6 384	529	987	2 486	5 140	1	1	69	535		
Italy	54 790	120 691	22 098	60 256	9 126	15 178	18 916	22 319	3 826	18 732	824	5 916
Kosovo	44	151	43	151	1	0	0					
Latvia	1 782	2 804	1 590	1 994	69	141	2	0	121	669		
Lithuania	1 479	1 510	877	1 087	424	639	71	73	107	400		
Luxembourg	1 531	399	1 330	1 169	58	80	120	95	23	116		
Malta	63	75					60	68	3	7		
Moldova Rep	23	327	16	312	1	1	3	1	3	13		
Montenegro	652	1 754	651	1 752			1	2				
Netherlands	5 881	11 707	39	112	3 431	5 797	1 498	785	912	5 013		
Norway	32 235	138 323	31 223	136 637	863	2 216	14	11	135	201		
Poland	8 375	19 842	2 364	2 734	5 100	7 676	71	7	840	9 977		
Portugal	11 865	31 567	5 746	16 412	5 079	12 111	454	627	562	3 055	25	205
Romania	11 277	27 126	6 613	19 279	3 244	6 201	1 301	1 616	119	504	0	0
Serbia	3 038	11 032	3 017	11 618	10	0	6	6	5	22		
Slovakia	3 297	6 229	2 523	4 462	3	6	533	597	238	1 417		
Slovenia	1 603	6 606	1 296	6 365	4	4	240	257	63	254		
Spain	51 316	110 268	20 184	42 970	23 008	52 013	7 132	13 673	992	5 414		
Sweden	26 997	85 810	15 996	63 872	6 026	11 234	111	47	4 864	10 766		
Switzerland	15 345	40 670	13 743	39 701	60	101	1 361	842	181	1 691		
UK	32 059	65 324	4 490	8 771	14 191	32 016	8 915	4 050	4 463	23 372		
Ukraine	7 094	10 279	5 704	9 291	514	1 172	825	483	51	169		

Annex Renewable Energy Statistics

- Renewable electricity generating capacity in 2015 (in MW)
- Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL 2015 (in MW)	TOTAL 2014 (in GWh)	Hydro/Ocean 2015 (in MW)	Hydro/Ocean 2014 (in GWh)	Wind 2015 (in MW)	Wind 2014 (in GWh)	Solar 2015 (in MW)	Solar 2014 (in GWh)	Bioenergy in 2015 (in MW)	Bioenergy 2014 (in GWh)	Geothermal 2015 (in MW)	Geothermal 2014 (in GWh)
MIDDLE EAST	17 487	27 774	16 214	26 387	245	272	986	1 166	42	160		
Bahrain	6	10			1	1	5	9				
Iran IR	12 024	19 283	11 890	19 008	117	256	17	19				
Iraq	2 513	2 931	2 513	3 141								
Israel	796	830	7	18	6	9	772	770	11	33		
Jordan	160	80	12	58	119	2	26	14	3	6		
Kuwait	0	0					0	0				
Lebanon	228	1 174	221	1 162	1	1	4	7	2	5		
Qatar	28	115					3	5	25	110		
Saudi Arabia	25	43					25	43				
Syrian AR	1 572	3 001	1 571	3 000	1	1						
United Arab Em	135	308			1	1	133	300	1	6		
N AMERICA	326 707	1 024 344	194 070	703 010	86 857	212 858	26 600	26 580	14 545	77 351	4 636	24 710
Canada	94 079	411 952	79 063	382 590	11 205	22 538	2 443	1 756	1 368	5 179		
Mexico	17 510	52 893	12 464	38 893	3 073	6 426	202	221	702	1 354	1 069	6 000
St Pierre Mq	1	2			1	2						
USA	215 117	559 497	102 543	281 527	72 578	183 892	23 955	24 603	12 475	70 818	3 567	18 710
OCEANIA	25 926	73 711	13 850	44 393	4 922	12 535	5 117	4 915	1 006	4 247	1 032	7 658
Australia	18 094	37 007	8 049	18 421	4 187	10 252	5 034	4 858	824	3 511	0	1
Cook Is	2	2			0	0	2	2				
Fiji	196	481	134	401	10	4	2	1	50	75		
Fr Polynesia	70	232	47	227	0	0	22	5				
Kiribati	2	2					2	2				
Marshall Is	1	1					1	1				
Micronesia	1	1					1	1				
Nauru	0	0					0	0				
New Caledon	124	358	78	288	38	57	8	13	0			
New Zealand	7 079	34 457	5 263	24 335	683	2 214	33	16	121	634	979	7 258
Niue	0	0					0	0				
Palau	1	1					1	1				
Papua N Guin	327	1 101	264	674			0	1	10	26	53	400

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Annex Renewable Energy Statistics

Renewable electricity generating capacity in 2015 (in MW)

Renewable electricity generation in 2014 (in GWh)

Country/ area	TOTAL		Hydro/Ocean		Wind		Solar		Bioenergy		Geothermal	
	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)	in 2015 (in MW)	2014 (in GWh)	2015 (in MW)	2014 (in GWh)
OCEANIA (continued)												
Samoa	16	44	13	38	1	2	3	5				
Solomon Is	2	2	0	1			1	2				
Tokelau	1	1					1	1				
Tonga	4	5			0	0	4	5				
Tuvalu	1	0					1	0				
Vanuatu	4	13	1	8	3	5	0	0				
SOUTH AMERICA	183 185	729 548	152 989	658 426	11 078	15 514	1 126	853	17 993	55 478		
Argentina	10 994	35 376	10 066	33 160	279	619	8	16	642	2 303		
Bolivia	556	2 357	494	2 233	3	8	7	0	52	116		
Brazil	116 687	430 940	92 062	373 439	8 715	12 210	23	61	15 887	45 229		
Chile	8 808	28 991	6 513	23 099	904	1 443	848	489	543	3 960		
Colombia	11 757	46 110	11 503	44 742	18	70			237	1 297		
Ecuador	2 593	11 954	2 401	11 458	21	80	26	16	144	399		
Falklands Malvinas	2	5			2	5						
Fr Guiana	160	563	119	500			39	51	2	12		
Guyana	43	41					2	3	41	38		
Paraguay	8 810	55 276	8 810	55 276								
Peru	4 680	22 887	4 166	22 201	240	258	96	199	178	229		
Suriname	187	1 172	180	1 165			5	8	2			
Uruguay	2 717	12 279	1 538	9 649	845	733	68	3	266	1 894		
Venezuela	15 190	81 597	15 137	81 503	50	88	3	5				

Note: Abbreviated country names are used here to save space and the official names of countries are shown in the original source.

Source: IRENA, 2016b

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ACRONYMS

CAGR	Compound annual growth rate
CDTE	Cadmium telluride
CIGS	Copper indium gallium (di)selenide
CNY	Chinese Yuan Renminbi
CO_2	Carbon dioxide
C-si	Crystalline silicon
CSP	Concentrated solar power
ECOWAS	Economic Community of West African States
EJ	Exajoules
ESCO	Energy service company
EU	European Union
Gt	Gigatonne
GW	Gigawatts
GWh	Gigawatt-hour
IDCOL	Infrastructure Development Company Limited
IOREC	International off-grid Renewable energy conference
GDP	Gross domestic product
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelised cost of electricity
MW	Megawatt
MWh	Megawatt-hour
NDC	Nationally Determined Contribution
PAYG	Pay-as-you-go
PPA	Power purchase agreement
R&D	Research and development
SDG	Sustainable Development Goal
T&D	Transmission and distribution
TWh	Terawatt-hour
UAE	United Arab Emirates
UN	United Nations
US	United States
USD	US dollar
WHO	World Health Organization
PV	Photovoltaic
VRE	Variable renewable energy

GLOSSARY

AGRI-FOOD CHAIN. Refers to the combination of activities that allow for the production, processing, storage and transport of products of agricultural origin, according to the consumers' needs.

AUCTIONS. Renewable energy auctions – also known as "demand auctions" or "procurement auctions" – entail a government issuing a call for tenders to procure a certain capacity or generation of renewables-based electricity.

BALANCE OF SYSTEM (BOS). The components of a solar photovoltaic (PV) system other than the solar PV panel itself. BoS refers to the wiring, inverters, switches and other related hardware. BoS sometimes includes non-hardware costs such as permitting and land acquisition as well.

BASELOAD. Refers to electricity generation that generally operates all the time, irrespective of electricity demand. Baseload power plants usually do not change their production to match demand.

BIO-DIGESTER. A technology that generates biogas from biological materials such as cow dung or crop waste. Typically operates by heating the materials in a pit or excavation, and capturing the emitted gases.

BIOFUELS, LIQUID. Made from biomass and used as fuels. They have qualities similar to gasoline, diesel or other petroleum-derived fuels. They include the following products: bioethanol, biogasoline, biodiesel, biojet fuel, etc. They are mainly used as transport fuels, but also for electricity generation (*e.g.,* in diesel generators) or for heating.

BIOFUELS, SOLID (BIOMASS). Solid biofuels include all solid non-fossil materials of biological origin used for energy, including products grown for such purposes and a wide range of waste products (*e.g.,* woodchips, crop waste, cow dung) of biological origin.

BIOFUELS, GASEOUS (BIOGAS). Flammable gas produced from solid biomass and waste (*e.g.,* cow dung or crop wastes) by anaerobic fermentation or thermal processes. Biogas from anaerobic fermentation mostly consists of methane and CO_2, which can then be processed to produce a pure methane gas (biomethane). It is mainly used for heat and power production, but may also be used as a transport fuel.

BLENDING MANDATE (BIOFUEL). Establishes a percentage of biofuel (ethanol or biodiesel) that must be blended with regular gasoline or diesel. Blending mandates usually specify who is responsible for the blending and at what point of the distribution chain it must be done. National mandates can apply to the whole country, or certain regions or metropolitan areas.

CAPACITY FACTOR. The ratio of the actual output of a power plant divided by the theoretical output of the same plant running at full capacity. The ratio is determined over a specific period of time, typically a year.

CYCLING AND PEAKING CAPACITY. Cycling and peaking power plants operate in response to changing electricity demand, which is typically higher during the daytime.

DISTRIBUTED GENERATION. Electricity generating facilities that are small (typically less than 1 MW) and located close to where the electricity is consumed.

END-OF-LIFE MANAGEMENT. The process of planning and implementing strategies to recycle and repurpose equipment and materials used for renewable energy generation.

ENERGY LADDER. The gradual improvement from basic energy access to productive energy use at the household level, sometimes related to an increase in household income.

ENERGY SERVICE COMPANIES (ESCOS). Providers of energy efficiency retrofits that guarantee savings to the customer in return for payment, which is typically proportional to the attained savings. In some instances, ESCOs incorporate a renewable energy component to the services provided.

LEVELISED COST OF ELECTRICITY (LCOE). A measure of the total cost to produce electricity, including capital costs, operating and maintenance costs, and the fuel costs. It can be calculated as the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using a discount rate.

MINI-GRID. Electricity grid with generation capacities from around 1 kW up to 10 MW, supplying electricity to customers who are off the national grid.

OFF-GRID RENEWABLE ENERGY. Renewable energy generation that is not connected to a larger electricity system or network.

POWER PURCHASE AGREEMENT (PPA). A contractual agreement between an electricity generator and an electricity retailer (such as an electric utility). A PPA typically sets a price for the electricity and a duration for the agreement.

VARIABLE RENEWABLE ENERGY (VRE). Electricity from solar or wind-fuelled electricity generating facilities for which the electricity output varies with the sun and the wind, respectively.

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