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THE GROWING WORLD OF RENEWABLE ENERGY

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International Foundation for Energy & Sustainable Development

THE ABDULLAH BIN HAMAD AL ATTIYAH FOUNDATION

DOHA - QATAR

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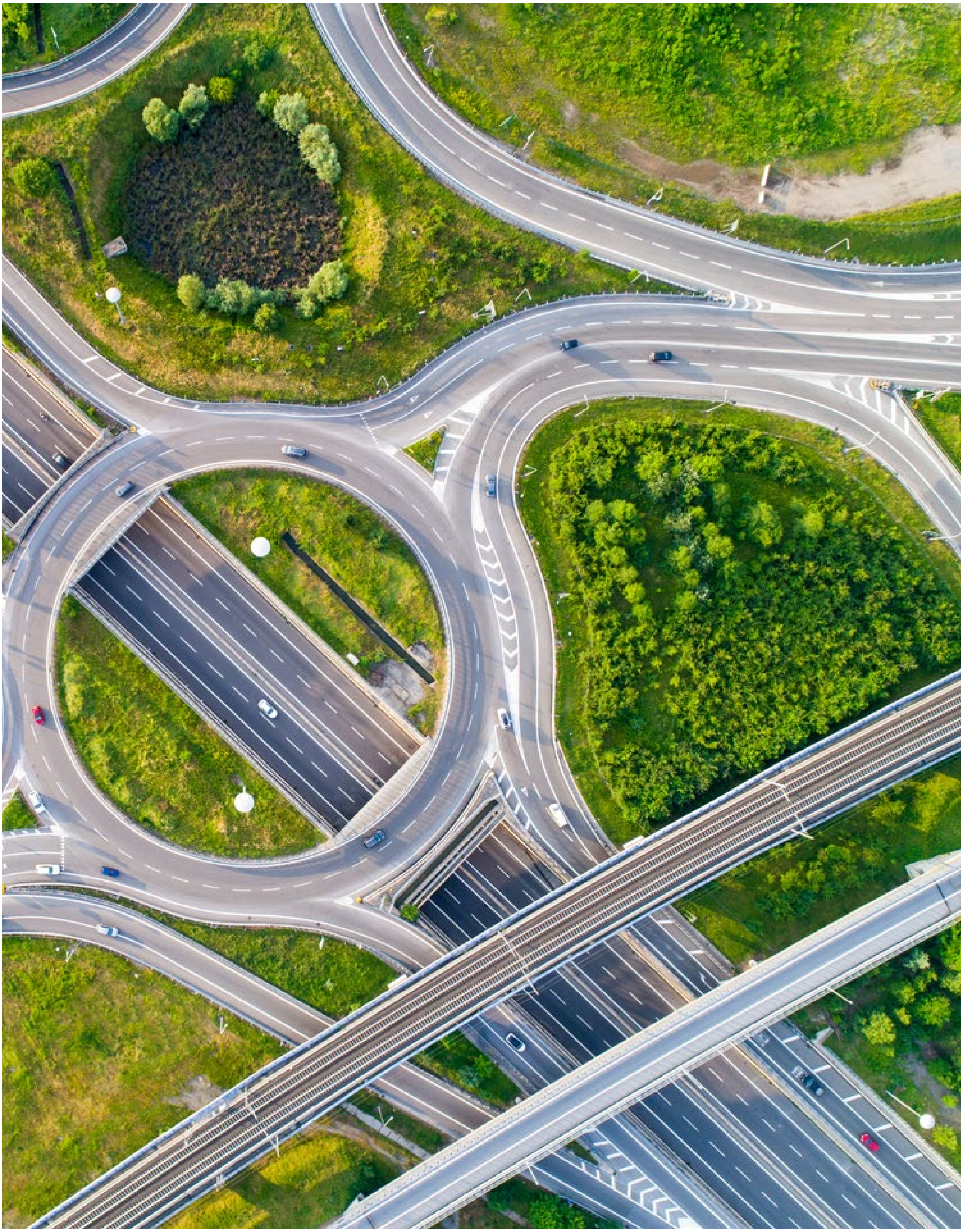


LIST OF ABBREVIATIONS

AC	Alternating Current
CARICOM	Caribbean Community
CH4	Methane
CO	Carbon dioxide
COP21	21st Conference of the Parties to the United Nations Framework Convention on Climate Change
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Concentrating Solar Power
DC	Direct Current
DISCOMs	Distribution Companies
EDF	Environmental Defence Fund
EIA	Energy Information Administration
EII	Energy intensive industries
EUETS	European Union Emission Trading Scheme
FID	Final Investment Decision
FITs	Feed in tariffs
GDP	Gross Domestic Product
GHG	Greenhouse gas
IEA	International Energy Agency
IOCs	International Oil Companies
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
LCOE	Levelized cost of electricity
LFR	Linear Fresnel Reflectors (LFR)
M&A	Mergers and Acquisitions
NDCs	Nationally Determined Contributions
NOCs	National Oil Companies
NRES	Non-renewable energy sources
OECD	Organization for Economic Co-operation and Development
PDS	Parabolic Dish Systems (PDS)
POME	Palm Oil Mill Effluent
PTC	Parabolic Trough Collectors (PTC)
PV	Photovoltaic
RD&D	Research, Development and Demonstration
RES	Renewable energy sources
ROCs	Renewable Obligation Certificates
SDGs	Sustainable Development Goals
SPT	Solar Power Towers (SPT)
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change

MESSAGE FROM THE CHAIRMAN

H.E. Abdullah Bin Hamad Al-Attiyah
Chairman of Abdullah Bin Hamad Al-Attiyah
International Foundation for Energy and Sustainable Development
Former Deputy Prime Minister and Minister of Energy & Industry

At the inauguration of the Al-Attiyah International Foundation for Energy and Sustainable Development in 2015, I described myself as a man who smells and lives energy.

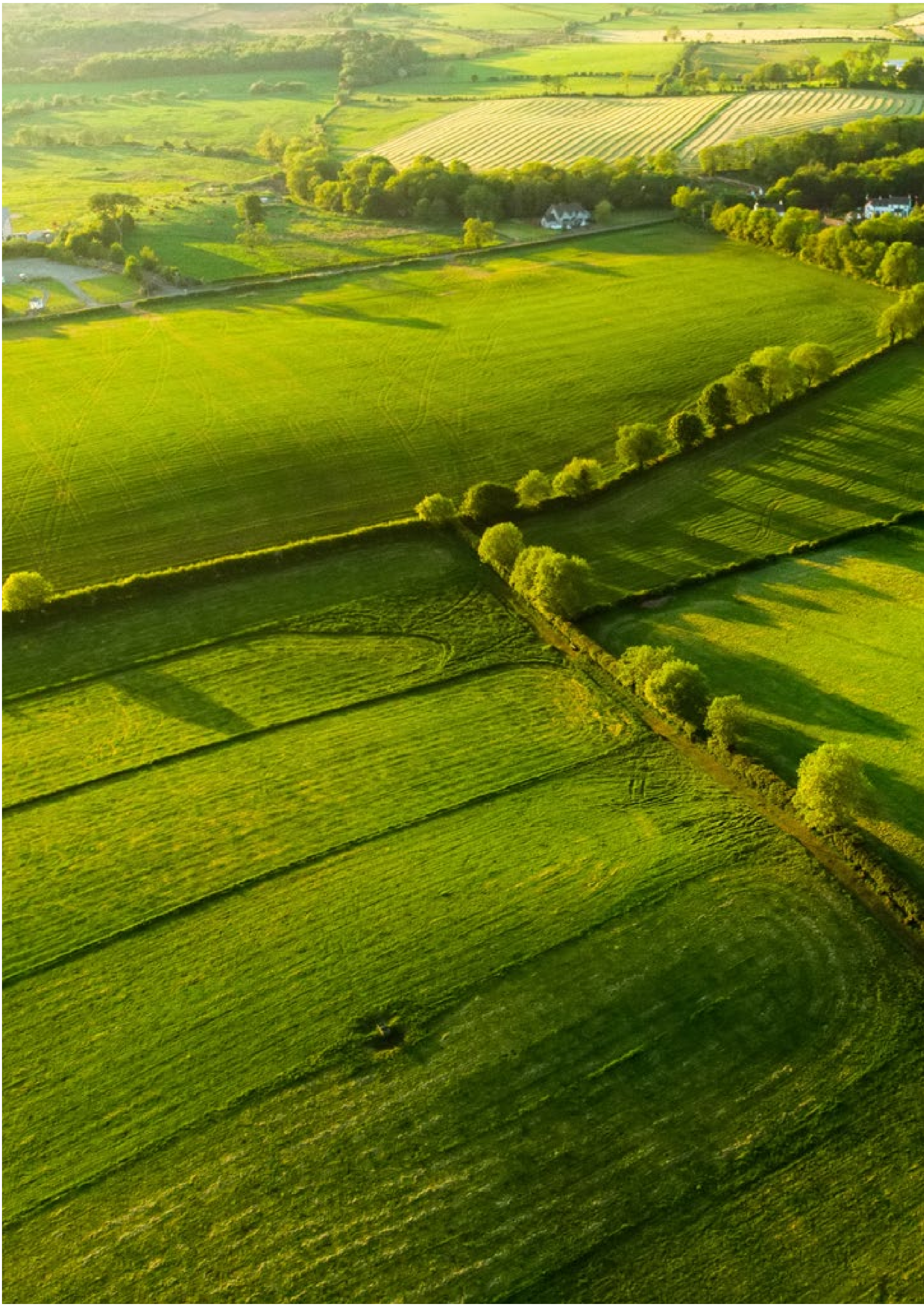
My life-long career was characterised by a strong passion for issues relating to sustainable access to energy, security of supply, climate change, socio-economic development, and transparency and accountability.

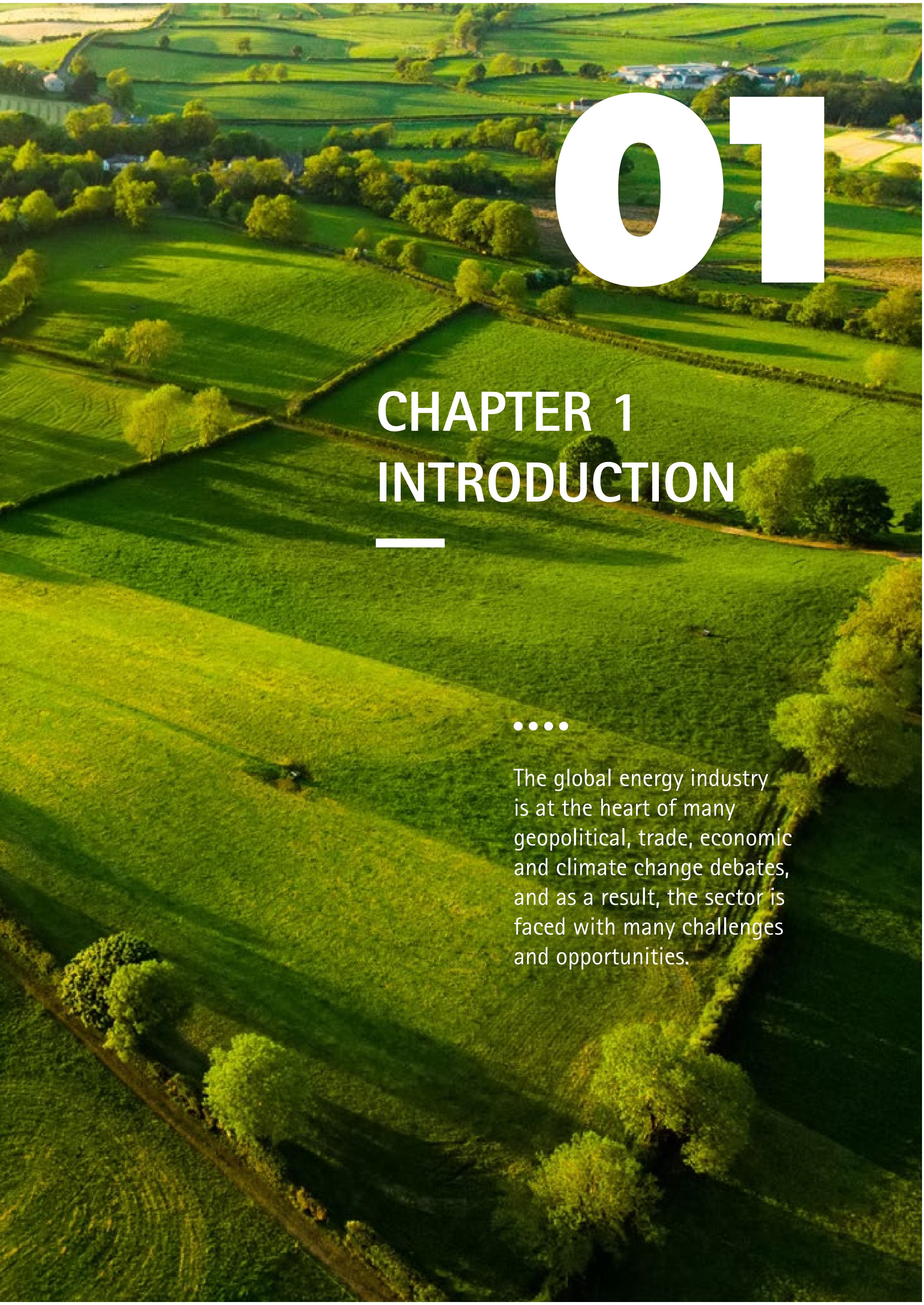
Serving as both the Chairman of the United Nations Commission on Sustainable Development (UNCSD) in 2006 and the President of the 18th Conference of the Parties to the United Nations Framework Convention

on Climate Change (UNFCCC-COP 18) in 2012, further underscore my commitment to issues relating to sustainable development, energy and climate change.

According to the Intergovernmental Panel on Climate Change (IPCC), human impact has been the main cause of warming observed since the mid-20th century. Our use of fossil fuels as an energy source contributes greatly to the problem. But we can change that by limiting greenhouse gas emissions and moving to renewable energy, which is fast emerging as a more viable solution to the world's energy problem. Renewable energy is at the centre of the transition to a less carbon-intensive and more sustainable energy system. Renewables have grown rapidly in recent years, accompanied by large cost reductions for solar photovoltaics and wind power in particular.

It is in this context that I consider it an opportune time for the Foundation to produce this book on "The Growing World of Renewables", with the objective to provide an authoritative information on renewable energy sources and review the driving forces behind the growth of this particular subsector of the energy industry. As Founder and Chairman of the Abdullah Bin Hamad Al-Attiyah International Foundation for Energy and Sustainable Development, I am honoured to launch another informative and insightful publication. It is my pleasure to present the book to industry practitioners, policy makers, academia, and any stakeholders who have an interest in the increasing role of renewables in current and future global energy mix.





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CHAPTER 1 INTRODUCTION

The global energy industry is at the heart of many geopolitical, trade, economic and climate change debates, and as a result, the sector is faced with many challenges and opportunities.

The world is witnessing increasing concerns about climate change; growing debate on economic transformation; market instabilities; technological advancements; demand by growing populations for transparency in business and governance; and the increasing quest for sustainable development. In this context, the negative effects of using unclean and unsustainable energy sources, is brought into sharper focus and energy diversification is an important driver for fostering long-term sustainable economic development and green-growth.

2013 - 2016

4%

growth in use of renewable globally

The global energy industry is at the heart of many geopolitical, trade, economic and climate change debates, and as a result, the sector is faced with many challenges and opportunities. Development of renewable energy is emerging as a major driving force behind a world that is gradually transitioning towards a low carbon, secure and affordable energy system. Whereas just a few years ago renewable energy contributed a negligible amount to the global energy mix, with advancements in technology and emergence of energy transformation policies worldwide, the share of renewables is growing rapidly. In 2013, renewables constituted 9% of global energy mix. This has grown to 15% in 2016.

The importance of limiting climate change is affirming the momentum of the growth of renewables. Many countries are setting targets for renewables in their national energy and climate change policies and strategies. From Africa to the Pacific to the Caribbean, countries are adopting policies and targets to promote renewable energy, driven by the need to reduce exposure to volatile market prices for fuel, high shipping costs, and adverse impacts of climate change.

Cost competitiveness has long been a major Achilles heel of the development of renewable energy, with the recognition that renewables can only be truly viable substitutes, if they can be produced and deployed at the same or cheaper costs as the competing fossil fuel sources of energy. Data from the International Renewable Energy Agency (IRENA) shows that renewables gradually became more cost-competitive every year and by 2015, when power generation from renewables rose to historic levels, wind power became one of the most competitive sources of electricity.

After years of steady decline, the costs of electricity generated from renewable energy projects launched in 2017, showed how renewable energy technologies have become increasingly competitive. The reducing trend in the costs of renewables is demonstrating the effectiveness of renewables to catalyze the much-needed investment for galvanizing energy transition. A recent report by IRENA, indicates that investment in renewable power could add about 0.8 percent to global GDP by 2050, and thereby boosting the world economy by $19 trillion.

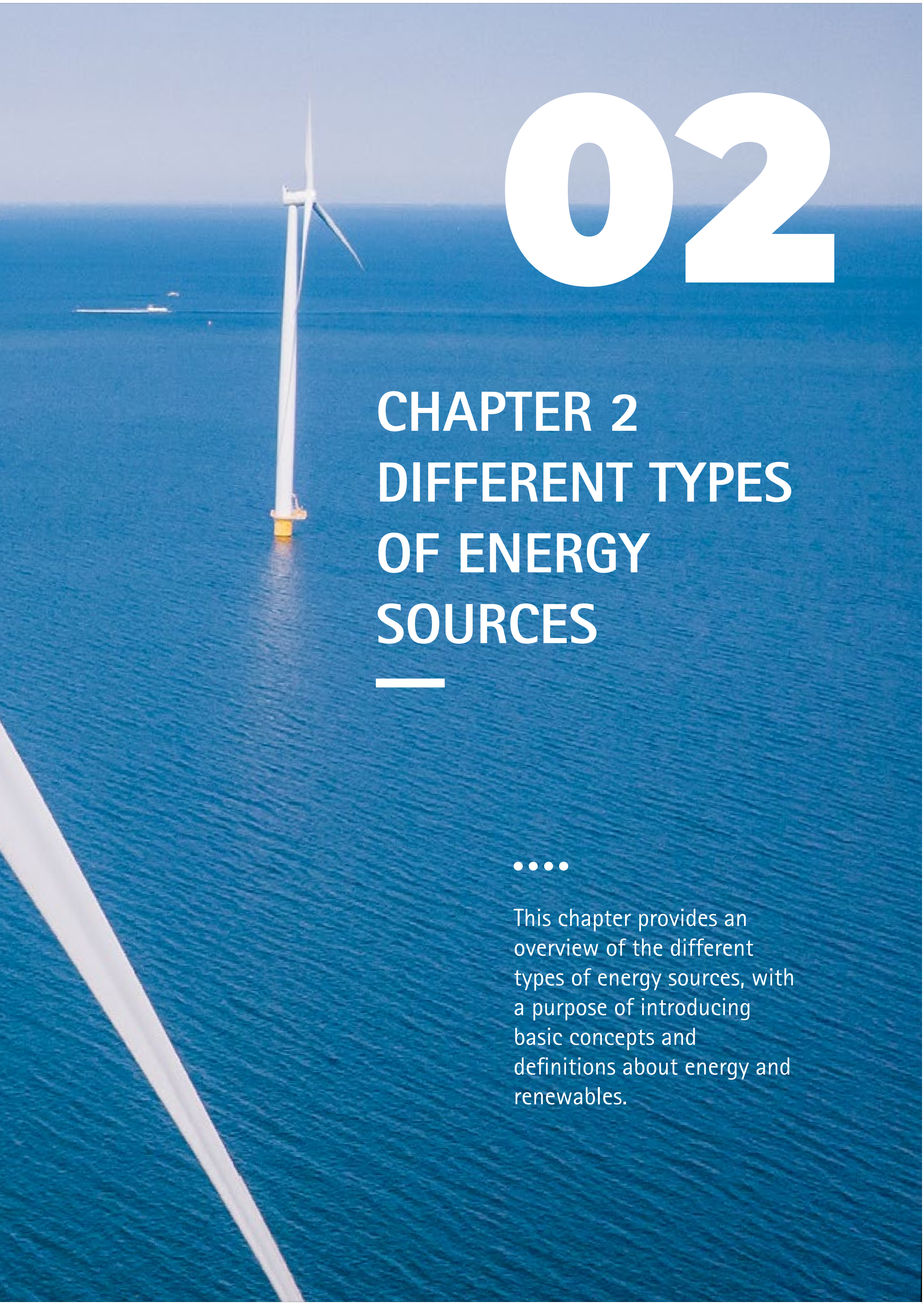
Countries are adopting policies and targets to promote renewable energy.

Although the competitiveness of renewable energy is improving, some questions still linger about some practical limitations and hurdles to be overcome if the world is going to reach a total fuel mix, comprising of 50% or greater share from renewables. While presenting the growing trend of renewables, this book also highlights the challenges that could prevent the renewable energy sector from reaching its full potential.

In this book, the Foundation aims to:

- compile comprehensive information on the growing world of renewables that could serve as a good reference source for government officials, policy makers, researchers, civil society and investors in the energy and related sectors;
- present an up-to-date overview and assessment of the status of cost and investment in renewable energy technologies;
- provide insights on the opportunities and challenges associated with renewable energy;
- review the efficacy of public and private sector investments in renewable energy, as a tool for addressing climate change and fostering sustainable development; and
- provide some additional insights, through invited papers, on work being done in this area.

The notable examples of wide spread initiatives by many countries and private companies to promote and develop renewable energy, are presented in this book. The book further highlights a compelling business case for energy companies to pursue significantly bolder and sophisticated measures that can attract large-scale flows of private finance in support of development of renewable energy technologies.



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CHAPTER 2 DIFFERENT TYPES OF ENERGY SOURCES

This chapter provides an overview of the different types of energy sources, with a purpose of introducing basic concepts and definitions about energy and renewables.

The term primary energy consumption refers to the consumption of primary energy, whereas final energy consumption refers to the total energy consumed at the end-user level.

Primary energy sources are divided into non-renewable energy sources (NRES) and renewable energy sources (RES).

This chapter provides an overview of the different types of energy sources, with a purpose of introducing basic concepts and definitions about energy and renewables.

Energy, in physics, is defined as the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. There are, moreover, heat and work—i.e., energy in the process of transfer from one body to another. After it has been transferred, energy is always designated according to its nature. Hence, heat transferred may become thermal energy, while work done may manifest itself in the form of mechanical energy. All forms of energy are associated with motion[1].

Energy exists in two forms; either primary or secondary.

Primary energy (e.g. fossil fuels) is the energy form that is found in nature that has not been subjected to any conversion or transformation, while secondary energy (e.g. electricity) is an energy form produced by the transformation of primary energy through an energy system (e.g. power plant). Secondary energy can be further transformed to other forms of energy through appropriate energy systems. Therefore, energy sources such as electricity or hydrogen, are obtained through the conversion of primary energy forms.

Primary energy sources are divided into non-renewable energy sources (NRES) (e.g. fossil fuels and mineral fuels, which are mainly uranium) and renewable energy sources (RES) (e.g. hydro, biomass, wind, solar, and geothermal).

The term primary energy consumption refers to the consumption of primary energy, whereas final energy consumption refers to the total energy consumed at the end-user level.

1. According to the Encyclopedia Britannica.

2.1 NON-RENEWABLE ENERGY SOURCES (NRES)

NRES are sources that cannot be replenished within a reasonable human timescale. In other words, they can be replenished but not easily and only over a long period of time (millions of years), which is beyond the human timescale. Thus, within the human timescale and requirement for use for development, NRES are exhaustible. NRES are extracted from the earth's ground and can be classified into either fossil fuels or mineral fuels.

Fossil fuels are formed over millions of years, through the action of earth's inner heat and rock pressure on the fossils (remains) of dead buried biological organisms. Examples of fossil fuels are coal, crude oil and natural gas that are extracted from the ground to be used either as a primary energy source or to generate other secondary energy sources. Products derived from coal, crude oil and natural gas, like refined petroleum products or coal products, are also considered as fossil fuels. For statistical purposes, nonrenewable energy waste that is collected from industries or municipalities is also considered as fossil fuel as it is used for combustion in the same way as fossil fuels. Thus, the main fossil fuels are coal, crude oil, condensate, natural gas liquids, natural gas, and non-renewable waste.

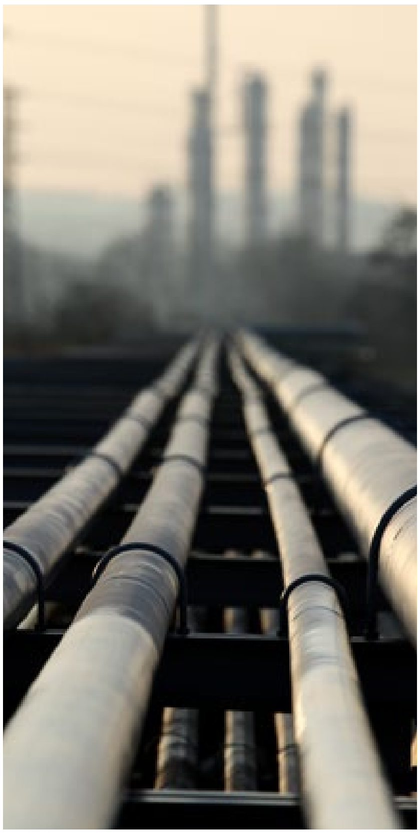
NRES are extracted from the earth's ground and can be classified into either fossil fuels or mineral fuels.

NRES are released from the ground in liquid, gas, or solid forms. Crude oil is used to make liquid petroleum products such as gasoline, diesel fuel, and heating oil. Propane and other hydrocarbon gas liquids, such as butane and ethane, are found in natural gas and crude oil. All fossil fuels are non-renewable, but not all NRES are fossil fuels. Coal, crude oil, and natural gas are all considered fossil fuels because they are formed from the buried remains of plants and animals that lived millions of years ago. Uranium, however, is not a fossil fuel, but it is classified as a non-renewable fuel. Uranium ore, a solid, is mined and used as a fuel in nuclear reactors.

Crude Oil

Crude oil is a mixture of hydrocarbons formed from plants and animals that lived millions of years ago. Crude oil exists in liquid form in underground pools or reservoirs, in tiny spaces within sedimentary rocks, and near the surface in tar (or oil) sands. Petroleum products are fuels made from crude oil and other hydrocarbons contained in natural gas. After crude oil is removed from the ground, it is sent to a refinery where different parts of the crude oil are separated into useable petroleum products. These petroleum products include gasoline, distillates such as diesel fuel and heating oil, jet fuel, petrochemical feedstocks, waxes, lubricating oils, and asphalt. Petroleum products can also be made from coal, natural gas, and biomass. Biofuels, such as ethanol and biodiesel, are also used as petroleum products, mainly in mixtures with gasoline and diesel fuel.

Petroleum is a major energy source for many countries. In the United States of America (USA), for example, petroleum is by far the largest energy source. Petroleum products are used to propel vehicles, to heat buildings, and to produce electricity. In the industrial sector, the petrochemical industry uses petroleum as a raw material (a feedstock) to make products such as plastics, polyurethane, solvents, and hundreds of other intermediate and end-user goods.



Crude oil is a mixture of hydrocarbons formed from plants and animals that lived millions of years ago.

Natural Gas

Natural gas is a fossil energy source formed deep beneath the earth's surface. Millions to hundreds of millions of years ago and over long periods of time, the remains of plants and animals (such as diatoms) built up in thick layers on the earth's surface and ocean floors, sometimes mixed with sand, silt, and calcium carbonate. Over time, these layers were buried under sand, silt, and rock. Pressure and heat changed some of this carbon and hydrogen-rich material into coal, some into oil (petroleum), and some into natural gas. Natural gas is used both as a fuel and to make materials and chemicals.

In some places, natural gas moved into large cracks and spaces between layers of overlying rock.

The natural gas found in these types of formations is sometimes called conventional natural gas. In other places, natural gas occurs in the tiny pores (spaces) within some formations of shale, sandstone, and other types of sedimentary rock. This natural gas is referred to as shale gas or tight gas, and is sometimes called unconventional natural gas. Natural gas also occurs within deposits of crude oil and this natural gas is called associated natural gas. Natural gas deposits are found on land and some are offshore and deep under the ocean floor. A type of natural gas found in coal deposits is called coalbed methane. Coalbed methane can be extracted from coal deposits before or during coal mining and it can be added to natural gas pipelines without any special treatment.

Natural gas withdrawn from natural gas or crude oil wells is called wet natural gas because, along with methane (CH_4), it usually contains natural gas liquids (NGL) ethane, propane, butanes, and pentanes and water vapour. Wellhead natural gas may also contain nonhydrocarbons such as sulphur, helium, nitrogen, hydrogen sulphide, and carbon dioxide (CO_2), most of which must be removed from natural gas before it is sold to consumers. From the wellhead, natural gas is sent to processing plants where water vapour and nonhydrocarbon compounds are removed and NGL are separated from the wet gas and sold separately. Some ethane is often left in the processed natural gas. The separated NGL are called natural gas plant liquids (NGPL), and the processed natural gas is called dry, consumer-grade, or pipeline quality natural gas. Some wellhead natural gas is sufficiently dry and satisfies pipeline transportation standards without processing.

Chemicals called odorants are added to natural gas so that leaks in natural gas pipelines can be detected. Dry natural gas is sent through pipelines to underground storage fields or to distribution companies and then to consumers. In places where natural gas pipelines are not available to take away associated natural gas produced from oil wells, the natural gas may be reinjected into the oil-bearing formation, or it may be vented or burned (flared).

Reinjecting unmarketable natural gas can help to maintain pressure in oil wells to improve oil production.

Coal

Coal can be classified into four main types, or ranks: anthracite, bituminous, subbituminous, and lignite. The ranking depends on the types and amounts of carbon the coal contains and on the amount of heat energy the coal can produce. The rank of a coal deposit is determined by the amount of pressure and heat that acted on the plants over time.

Anthracite contains between 86 per cent to 97 per cent carbon and generally has the highest heating value of all ranks of coal. Bituminous coal contains between 45 per cent to 86 per cent carbon. Subbituminous coal typically contains between 35 per cent to 45 per cent carbon, and it has a lower heating value than bituminous coal. Lignite contains between 25 per cent to 35 per cent carbon and has the lowest energy content of all coal ranks. Lignite coal deposits tend to be relatively young and have, generally, not been subjected to extreme heat or pressure. Lignite is crumbly and has a high moisture content, which contributes to its low heating value.

Anthracite contains between 86% to 97% carbon

2.2

RENEWABLE ENERGY SOURCES

In contrast to NRES, RES are naturally replaced at a rate that is either equal to or greater than the rate at which they are consumed, making them replenishable on a human timescale and potentially inexhaustible. Generally, the main use of renewables is to generate electricity (electric power generation), but they are also used in other sectors like heating and cooling, as well as for transportation.

RES are classified, based on how they are used or processed, into two major categories.

There are multiple or different types of RES, examples include: a, biomass, wind, solar, and geothermal. RES are classified, based on how they are used or processed, into two major categories – combustible and non-combustible renewables. Combustible renewables consist of biofuels or bioenergy (fuels of biomass) and renewable municipal waste, whereas non-combustible renewables are used or transferred through a different process other than combustion and include hydropower, wind, solar (thermal and photovoltaic), geothermal, tidal energy, wave power and heat pumps.

2.2.1 COMBUSTIBLE RENEWABLES

Biomass

Biomass is organic material originating from plants and animals, and includes: wood and wood waste, municipal solid waste, landfill gas and biogas, ethanol and biodiesel.

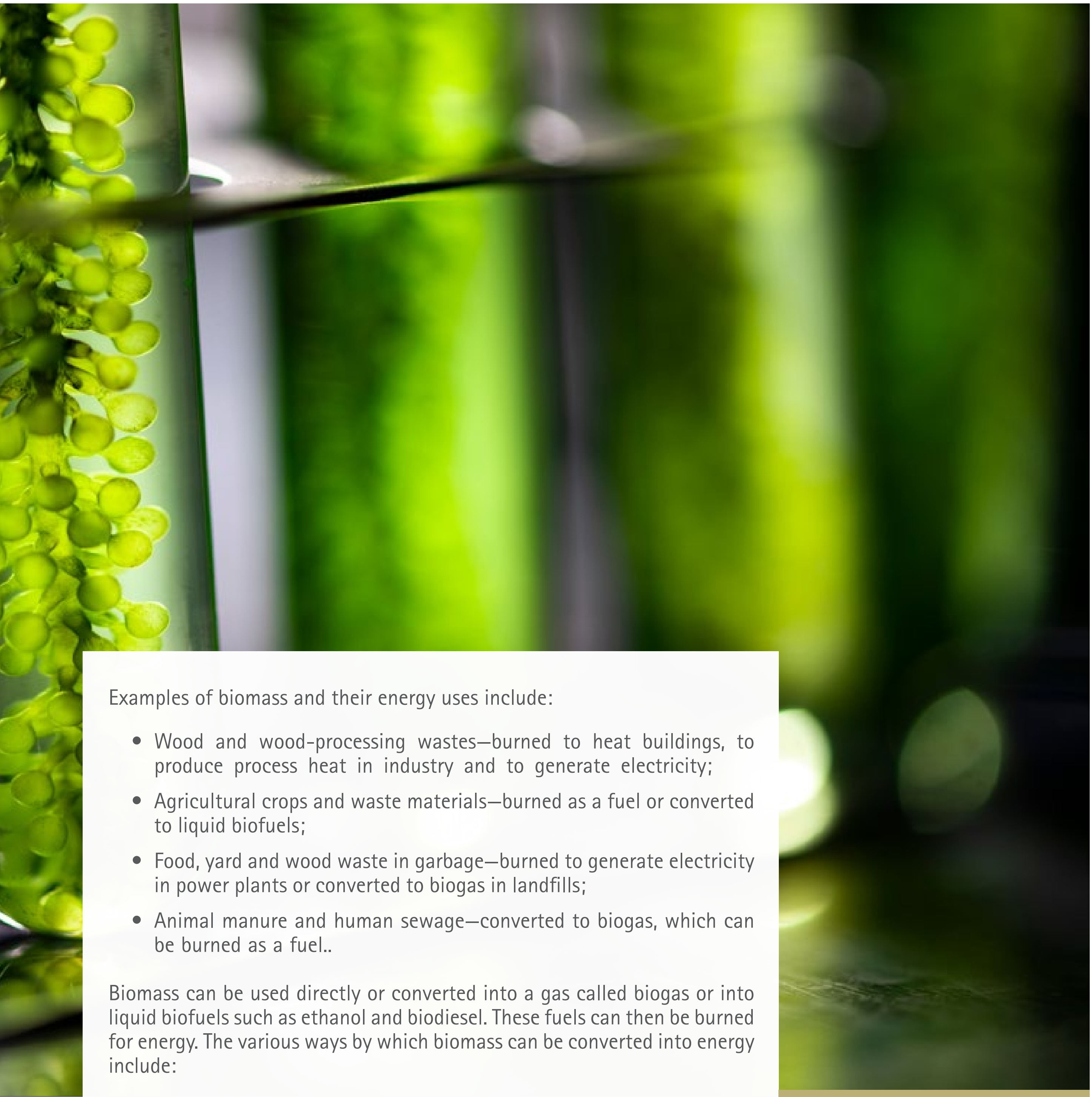
Biomass contains stored energy from the sun; the sun's energy that has been absorbed by plants, through a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can also be burned as fuels.

> **Ethanol, made from fermenting crops such as, corn and sugar cane to produce fuel ethanol can be used in vehicles.**

Biomass can be used directly or converted into a gas called biogas or into liquid biofuels such as ethanol and biodiesel

Biomass is organic material that comes from plants and animals

The chemical energy in biomass is released as heat



Examples of biomass and their energy uses include:

- Wood and wood-processing wastes—burned to heat buildings, to produce process heat in industry and to generate electricity;
- Agricultural crops and waste materials—burned as a fuel or converted to liquid biofuels;
- Food, yard and wood waste in garbage—burned to generate electricity in power plants or converted to biogas in landfills;
- Animal manure and human sewage—converted to biogas, which can be burned as a fuel..

Biomass can be used directly or converted into a gas called biogas or into liquid biofuels such as ethanol and biodiesel. These fuels can then be burned for energy. The various ways by which biomass can be converted into energy include:

- Solid biomass, such as wood and garbage can be burned directly to produce heat;
- Biogas formed when paper, food scraps, and yard waste decompose in landfills can be produced by processing sewage and animal manure in special vessels called digesters, where biogas, which is essentially methane is extracted;
- Ethanol, made from fermenting crops such as, corn and sugar cane to produce fuel a can be used in vehicles;
- Biodiesel, produced from vegetable oils and animal fats can be used in vehicles and as heating oil.

Biomass can be used directly or converted into a gas.

People have used wood for cooking, heat and light for thousands of years. Wood was the main source of energy for the world until the mid-1800s. Wood continues to be an important fuel in many countries, especially for cooking and heating in developing countries. Industry, electric power producers, and commercial businesses use most of the wood and wood-waste fuel. Industry use wood waste to produce steam and electricity, which saves money because it reduces the amount of other fuels and electricity that must be purchased. Some coal-burning power plants burn wood chips to reduce sulphur dioxide emissions.

Biogas is produced from biomass through the process of anaerobic decomposition. Anaerobic bacteria, bacteria that live without the presence of free oxygen, occur naturally in soils, in water bodies such as swamps and lakes, and in the digestive tracts of humans and animals. These bacteria eat and break down, or digest, biomass and produce biogas. Biogas is composed mostly of CH4 and CO2. The CH4 from biogas is the same energy-rich compound found in natural gas. The composition of biogas varies from 40 per cent to 60 per cent CH4 to 60 per cent to 40 per cent CO2, with small amounts of water vapor and other gases. Biogas is produced naturally by anaerobic bacteria in municipal-solid-waste landfills and is called landfill gas. Biogas forms in, and can be collected from, municipal-solid-waste landfills and livestock manure holding ponds. Biogas can also be produced under controlled conditions in special tanks called anaerobic digesters.

Biogas, when treated to remove CO2 and other gases, can be used as a fuel just like natural gas. The byproduct of the process of anaerobic digestion is called digestate, which is rich in nutrients and can be used as a fertiliser. Many landfills collect landfill gas, treat it to remove CO2, water vapor, and hydrogen sulphide, and then sell the CH4. Some landfills use the CH4 gas to generate electricity.

Many municipal sewage treatment plants and manufacturers such as paper mills and food processors use anaerobic digesters as part of their waste treatment processes. The biogas produced in anaerobic digesters to heat the digesters, which enhances the anaerobic digestion process and destroys pathogens, is collected and used to generate electricity that can either be used at the facility or sold.

The CH4 from biogas is the same energy-rich compound found in natural gas.

It is becoming common practice in some countries to mix gasoline with ethanol. In the USA, for example, nearly all the gasoline now sold contains 10 per cent of ethanol by volume. Any gasoline-powered engine in the USA can use E10 (gasoline with 10 per cent ethanol), but only specific types of vehicles can use mixtures with fuel containing more than 10 per cent ethanol. The USA Environmental Protection Agency (EPA) confirmed in October 2010 that cars and light trucks of model year 2007 and newer can use E15 (gasoline with 15 per cent ethanol). Some flexible-fuel vehicles, mainly in the America Midwest can now use E85, a fuel that contains 51 per cent to 83 per cent ethanol, depending on the season of the year.

Biodiesel is a fuel made from vegetable oils, fats or greases, such as recycled restaurant grease. Biodiesel fuel can be used in diesel engines without any modification to the engine. Pure biodiesel is non-toxic and biodegradable. However, biodiesel is usually sold as a blend of biodiesel and petroleum-based diesel fuel, with B20 (blend with 20 per cent biodiesel) being the commonly available blend of diesel fuel.

2.2.2 NON-COMBUSTIBLE RENEWABLES

Hydropower

Hydropower is energy recovered from moving water. People have a long history of using the force of water flowing in streams and rivers to produce mechanical energy. Hydropower was one of the first sources of energy used for electricity generation. It is one of the oldest sources of energy for producing mechanical and electrical energy. Hydropower was used thousands of years ago to turn paddle wheels to help grind grain before steam power and electricity were available.

Hydropower relies on the water cycle. Understanding the water cycle is important to understanding hydropower. The water cycle has three steps:

- Solar energy heats water on the surface of rivers, lakes, and oceans, which causes the water to evaporate;
- Water vapour condenses into clouds and falls as precipitation—rain and snow;
- Precipitation collects in streams and rivers, which empty into oceans and lakes, where it evaporates and begins the cycle again.

The amount of precipitation that drains into rivers and streams in a geographic area determines the amount of water available for producing hydropower. Seasonal variations in precipitation and long-term changes in precipitation patterns, such as droughts, have a big impact on hydropower production.

Because the source of hydroelectric power is water, hydroelectric power plants are usually located on or near a water source. The volume of the water flow and the change in elevation (or fall) from one point to another determines the amount of available energy in moving water. Water flowing through a pipe, or penstock, pushes against and turns blades in a turbine to spin a generator to produce electricity. In a run-of-the-river system, the force of the current applies pressure on a turbine. In a storage system, water accumulates in reservoirs created by dams and is released when needed to generate electricity.

Pumped Storage

Pumped storage is when another form of energy (usually electrical) is used to elevate a body of water. The water, therefore, acquires potential energy that can be released through water turbines. For this to be a viable source of energy, the cost of the energy used to pump the water must be less than the cost of the energy recovered. Pumped storage works best when cheap underutilised base load electricity is used for pumping and is then released when more expensive day time high demand electricity is needed. A good example of this type of usage is found in North Wales in the UK. When pumped storage is used in conjunction with other forms of renewable generation to pump the water up, it can help to resolve intermittency issues associated with other renewable technologies.

Pumped storage is the oldest kind of large-scale energy storage and works on a simple principle; two reservoirs at different altitudes are required and when the water is released from the upper reservoir to the lower reservoir, energy is created by the downflow, which is directed through a turbine and generator to create electricity. The water is then pumped back to the upper reservoir. Pumped storage hydropower provides a dynamic response and offers critical back-up during periods of excess demand by maintaining grid stability. Notwithstanding the current challenges facing the electricity market, resulting in absence of reward for capacity, there is an increasing critical role for pumped storage, going forward.

In the UK, for example, hydroelectric power stations, that include four conventional hydroelectric power stations and run-of-river schemes, accounted for 1.65 GW of installed electrical generating capacity in 2012. This represented 1.8 per cent of the UK's total generating capacity and 18 per cent of the UK's renewable energy generating capacity. There were also pumped-storage hydroelectric power stations providing a further 2.8 GW of installed electrical generating capacity and contributing up to 4,075 GWh of peak demand electricity annually.

The potential for further practical and viable hydroelectricity power stations in the UK is estimated to be in the region of 146 to 248 MW for England and Wales, and up to 2.593 GW for Scotland. However, by the nature of the remote and rugged geographic locations of some of these potential sites, in national parks or other areas of outstanding natural beauty, it is likely that environmental concerns would mean that many of them would be deemed unsuitable or could not be developed to their full theoretical potential.

US Electricity Generation has increased:

from

6 billion kilowatt-hours (kWh) in 2000

to

275 billion kWh in 2018

Wind Power

Wind is caused by uneven heating of the earth's surface by the sun. Because the earth's surface is made up of different types of land and water, it absorbs the sun's heat at different rates. One example of this uneven heating is the daily wind cycle. During the day, air above the land heats up faster than air over water. Warm air over land expands and rises, and heavier, cooler air rushes in to take its place, creating wind. At night, the winds are reversed because air cools more rapidly over land than it does over water.

In the same way, the atmospheric winds that circle the earth are created because the land near the earth's equator is hotter than the land near the North Pole and the South Pole. Atmospheric winds are also created or enhanced by the Coriolis effect. The rotation of the Earth causes this phenomenon on free moving objects on the Earth. Objects in the Northern Hemisphere are deflected to the right, while objects in the Southern Hemisphere are deflected to the left. The coriolis effect, thus tries to force winds to shift towards the right or left. Wind turbines use blades to collect the wind's kinetic energy. Wind flows over the blades creating lift, similar to the effect on airplane wings), which causes the blades to turn. The blades are connected to a drive shaft that turns an electric generator, which produces the electricity.

The amount of electricity generated from wind globally has grown significantly since 2000. For example, in the USA alone, electricity generation from wind has increased from about 6 billion KWh in 2000 to about 275 billion KWh in 2018. New technologies have decreased the cost of producing electricity from wind, and the growth in wind power has been encouraged by government and industry incentives.

Solar

The sun has produced energy for billions of years and is the ultimate source for all energy sources and fuels that we use today. People have used the sun's rays (solar radiation) for thousands of years for warmth and to dry meat, fruit and grains. Over time, people developed technologies to collect solar energy for heat and to convert it into electricity.

An example of an early solar energy collection device is the solar oven (a box for collecting and absorbing sunlight). In the 1830s, British astronomer John Herschel used a solar oven to cook food during an expedition to Africa. People now use many different technologies for collecting and converting solar radiation into useful heat energy for a variety of purposes. These technologies are described in Chapter 8.

Solar energy depends on the amount of sunshine reaching the surface of the earth. The amount of daily solar energy reaching the earth is many times greater than the total daily amount of energy that people consume. However, on the surface of the earth, solar energy is a variable and intermittent energy source because the amount of sunlight and its intensity varies by time of day and location. Weather and climate conditions affect the availability of sunlight daily and on a seasonal basis. The type and size of a solar energy collection and the conversion system determines how much of the available solar energy can be converted into useful energy.

One example of this uneven heating is the daily wind cycle.

Geothermal energy

Geothermal energy is essentially heat within the earth. The word geothermal comes from the Greek words geo (earth) and therme (heat). Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings and to generate electricity.

The slow decay of radioactive particles in the earth's core, a process that happens in all rocks, produces geothermal energy.

The earth has four major parts or layers:

- An inner core of solid iron that is about 2400 kms in diameter;
- An outer core of hot molten rock called magma that is about 2400 kms thick;
- A mantle of magma and rock surrounding the outer core that is about 2900 kms thick;
- A crust of solid rock that forms the continents and ocean floors that is 24 to 56 kms miles thick under the continents and 3 to 5 miles thick under the oceans.

Scientists have discovered that the temperature of the earth's inner core is about 6,000 degrees Fahrenheit (°C), which is as hot as the surface of the sun. Temperatures in the mantle range from about 200°C at the upper boundary with the earth's crust to approximately 4,000°C at the mantle-outer core boundary. The earth's crust is broken into pieces called tectonic plates. Magma comes close to the earth's surface near the edges of these plates, which is where many volcanoes occur.

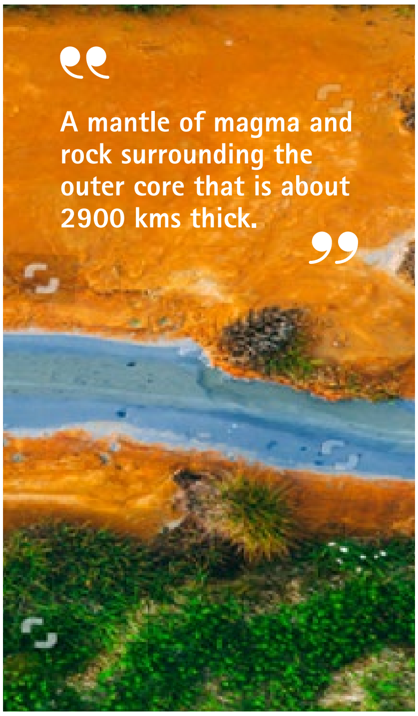
The lava that erupts from volcanoes is partly magma. Rocks and water absorb heat from magma deep underground. The rocks and water found deeper underground have the highest temperatures. Geothermal reservoirs are naturally occurring areas of hydrothermal resources. These reservoirs are deep underground and are largely undetectable above ground. Geothermal energy finds its way to the earth's surface in three ways:

- Volcanoes and fumaroles (holes in the earth where volcanic gases are released);
- Hot springs;
- Geysers.

Most geothermal resources are near the boundaries of the earth's tectonic plates and the most active geothermal resources are usually found along major tectonic plate boundaries where most volcanoes are located. One of the most active geothermal areas in the world is called the Ring of Fire, which encircles the Pacific Ocean.
When magma comes near the earth's surface, it heats ground water trapped. When magma comes near the earth's surface, it heats ground water trapped in porous rock or water running along fractured rock surfaces and faults. Hydrothermal features have two common ingredients-water and heat. Geologists use various methods to find geothermal reservoirs. Drilling a well and testing the temperature deep underground is the most reliable method for locating a geothermal reservoir. Geothermal electricity generation requires water or steam at high temperatures (150°C to 370°C). Geothermal power plants are generally built where geothermal reservoirs are located, within a mile or two of the earth's surface.

Ancient Roman, Chinese and Native American cultures used hot mineral springs for bathing, cooking, and heating. Today, many hot springs are still used for bathing and many people believe the hot, mineral-rich waters have natural healing powers. Geothermal energy is also used to heat buildings through district heating systems. Hot water near the earth's surface is piped directly into buildings for heat. Industrial applications of geothermal energy include food dehydration, gold mining, and milk pasteurizing. Dehydration, or the drying of vegetable and fruit products, is the most common industrial use of geothermal energy.

The USA leads the world in the amount of electricity generated with geothermal energy. In 2017, U.S. geothermal power plants produced about 16 billion KWh, or 0.4 per cent of the total U.S. utility-scale electricity generation. In 2017, seven states had geothermal power plants. California is known to generate the most electricity from geothermal energy in the world. The Geysers dry steam reservoir in Northern California is the largest known dry steam field in the world and has been producing electricity since 1960.



Tidal Energy

The gravitational pull of the moon and sun along with the rotation of the earth cause tides. In some places, tides cause water levels near the shore to vary up to 10 metres. People in Europe harnessed this movement of water to operate grain mills more than 1,000 years ago. Today, tidal energy systems are used to generate electricity, but producing tidal energy economically requires a tidal range of at least 10 feet.

The Sihwa Lake Tidal Power Station in South Korea has the largest electricity generation capacity at 254 Megawatts (MW).

Tidal barrages

One type of tidal energy system uses a structure similar to a dam, called a barrage. The barrage is installed across an inlet of an ocean bay or lagoon that forms a tidal basin.

Sluice gates on the barrage control water levels and flow rates, to allow the tidal basin to fill on the incoming high tides and to empty through an electricity turbine system on the outgoing ebb tide. A two-way tidal power system generates electricity from both the incoming and outgoing tides.

Several tidal power barrages are in operation around the world. The Sihwa Lake Tidal Power Station in South Korea has the largest electricity generation capacity at 254 Megawatts (MW).

The oldest and second-largest operating tidal power plant is in La Rance, France, with 240 MW of electricity generation capacity.

The third-largest tidal power plant is in Annapolis Royal in Nova Scotia, Canada, with 20 MW of electricity generation capacity. China, Russia, and South Korea all have smaller tidal power plants.

Tidal turbines

Tidal turbines are similar to wind turbines and can be placed on the sea floor where there is strong tidal flow. However, because water is about 800 times denser than air, tidal turbines must be much sturdier and heavier than wind turbines. Tidal turbines are more expensive to build than wind turbines but capture more energy with the same size blades. The tidal turbine projects in Scotland and South Korea currently have 1.5 MW electricity generation capacity, with the project in Scotland planning to expand electricity generating capacity to 400 MW. A demonstration tidal turbine project is under development in the East River of New York.

Wave Power

Waves are formed as wind blows over the surface of open waters in oceans and lakes. Ocean waves contain tremendous energy. The theoretical annual energy potential of waves off the coasts of the USA is estimated to be as much as 2.64 trillion KW-h, or the equivalent of about 66 per cent of U.S. electricity generation in 2017.
The west coasts of the USA and Europe, and the coasts of Japan and New Zealand, have potential sites for harnessing wave energy.

One way to harness wave energy is to bend or focus waves into a narrow channel to increase their size and power and use it to spin the turbines that generate electricity. Waves can also be channeled into a catch basin or reservoir where the water flows to a turbine at a lower elevation, similar to the way a hydropower dam operates. Many other methods of capturing wave energy are under development. These methods include either placing devices on, or just below, the surface of the water or, anchoring devices to the ocean floor.

Nuclear Power

Nuclear energy is energy in the core of an atom. Although nuclear sources cannot strictly be classified as renewables, because they are so abundantly available, some consider them to be emission free, CO2-friendly clean sources of energy. Therefore, there is no intention to present detailed information on nuclear energy in this book.

Atoms are the tiny particles in the molecules that make up gases, liquids, and solids. Atoms themselves are made up of three particles called protons, neutrons, and electrons. An atom has a nucleus (or core) containing protons and neutrons, which is surrounded by electrons. Protons carry a positive electrical charge and electrons carry a negative electrical charge. Neutrons do not have an electrical charge. Enormous energy is present in the bonds that hold the nucleus together. This nuclear energy can be released when those bonds are broken. The bonds can be broken through nuclear fission, and this energy can be used to produce electricity.

Mineral fuels like Uranium or Thorium are used to create nuclear energy through a nuclear fission process. Both fuels are assessed to be available in large quantities in the earth's crust, with a higher abundance of Thorium (three times more than Uranium), but they are highly radioactive elements. The fission process is used in nuclear power plants to generate electricity, but at the same time it creates large amounts of nuclear waste that can be highly radioactive and which requires treatment and isolation to avoid harming the environment and surrounding populations.

Thorium-based reactors are much less widespread than Uranium reactors. They are deemed to produce lower nuclear waste, but they have higher capital costs and, unlike Uranium, they do not produce plutonium which can be used for military purposes, as well as for nuclear fission.

During nuclear fission, a neutron collides with a uranium atom and splits it, releasing a large amount of energy in the form of heat and radiation. More neutrons are also released when a uranium atom splits. These neutrons continue to collide with other uranium atoms, and the process repeats itself over and over again.

This process is called a nuclear chain reaction. This reaction is controlled in nuclear power plant reactors to produce a desired amount of heat.

Nuclear energy can also be released in nuclear fusion, where atoms are combined or fused together to form a larger atom, although the development of the technology for harnessing nuclear fusion as a source of energy is still a long time away. There is ongoing research on this, but there is doubt if the technology will ever become commercially viable because of the difficulty in controlling a fusion reaction.

SECONDARY SOURCES OF ENERGY

Electricity

Electricity is the flow of electrical power or charge. Electricity has become a basic part of life and one of the most widely used forms of energy. Electricity is a secondary energy source because it is produced by converting primary sources of energy such as coal, natural gas, nuclear energy, solar energy, and wind energy, into electrical power.

Electricity is also referred to as an energy carrier, which means it can be converted to other forms of energy such as mechanical energy or heat. Primary energy sources are renewable or non-renewable energy, but electricity is neither renewable nor non-renewable.

Electricity use has dramatically changed daily life. Despite its great importance, few people stop to think about what life would be like without electricity.

Like air and water, people take electricity for granted. However, electricity is used in many ways from lighting, heating, and cooling homes, to powering televisions and computers. Before electricity became widely available, about 100 years ago, candles, whale oil lamps, and kerosene lamps provided light; iceboxes kept food cold; and wood-burning or coal-burning stoves provided heat.

Scientists and inventors have worked to decipher the principles of electricity since the 1600s. Benjamin Franklin, Thomas Edison and Nikola Tesla made notable contributions to our understanding and use of electricity. Benjamin Franklin demonstrated that lightning is electricity. Thomas Edison invented the first long-lasting incandescent light bulb. Before 1879, direct current (DC) electricity was used in arc lights for outdoor lighting. In the late 1800s, Nikola Tesla pioneered the generation, transmission, and use of alternating current (AC) electricity, which reduced the cost of transmitting electricity over long distances. Tesla's inventions brought electricity into homes to power indoor lighting and into factories to power industrial machines.

Hydrogen

The sun is essentially a giant ball of hydrogen gas undergoing fusion into helium gas. This process causes the sun to produce vast amounts of energy. Hydrogen is the lightest, simplest and most abundant element in the universe. It is a gas at normal temperature and pressure but condenses to a liquid at temperature of minus 217 °C. Each atom of hydrogen has only one proton. Stars such as the sun consist mostly of hydrogen.

Hydrogen occurs naturally on earth only in compound form with other elements in liquids, gases, or solids. Hydrogen combined with oxygen is water (H2O). Hydrogen combined with carbon forms different compounds—or hydrocarbons—found in natural gas, coal, and petroleum. Energy carriers allow the transport of energy in a useable form from one place to another. Hydrogen, like electricity, is an energy carrier that must be produced from another substance. Hydrogen can be produced—separated—from a variety of sources including water, fossil fuels or biomass and used as a source of energy or fuel. Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline), but it has the lowest energy content by volume (about four times less than gasoline).

It takes more energy to produce hydrogen (by separating it from other elements in molecules) than hydrogen provides when it is converted to useful energy. Never the less, hydrogen is useful as an energy source or fuel, because it has a high energy content per unit of weight, which is why it is used as rocket fuel and in fuel cells on some spacecrafts. Hydrogen is not widely used as a fuel now, but it has the potential for greater use in the future.

> Electricity has become a basic part of life and one of the most widely used forms of energy.

DISPATCHABLE AND NON-DISPATCHABLE ENERGY SOURCES

1.728

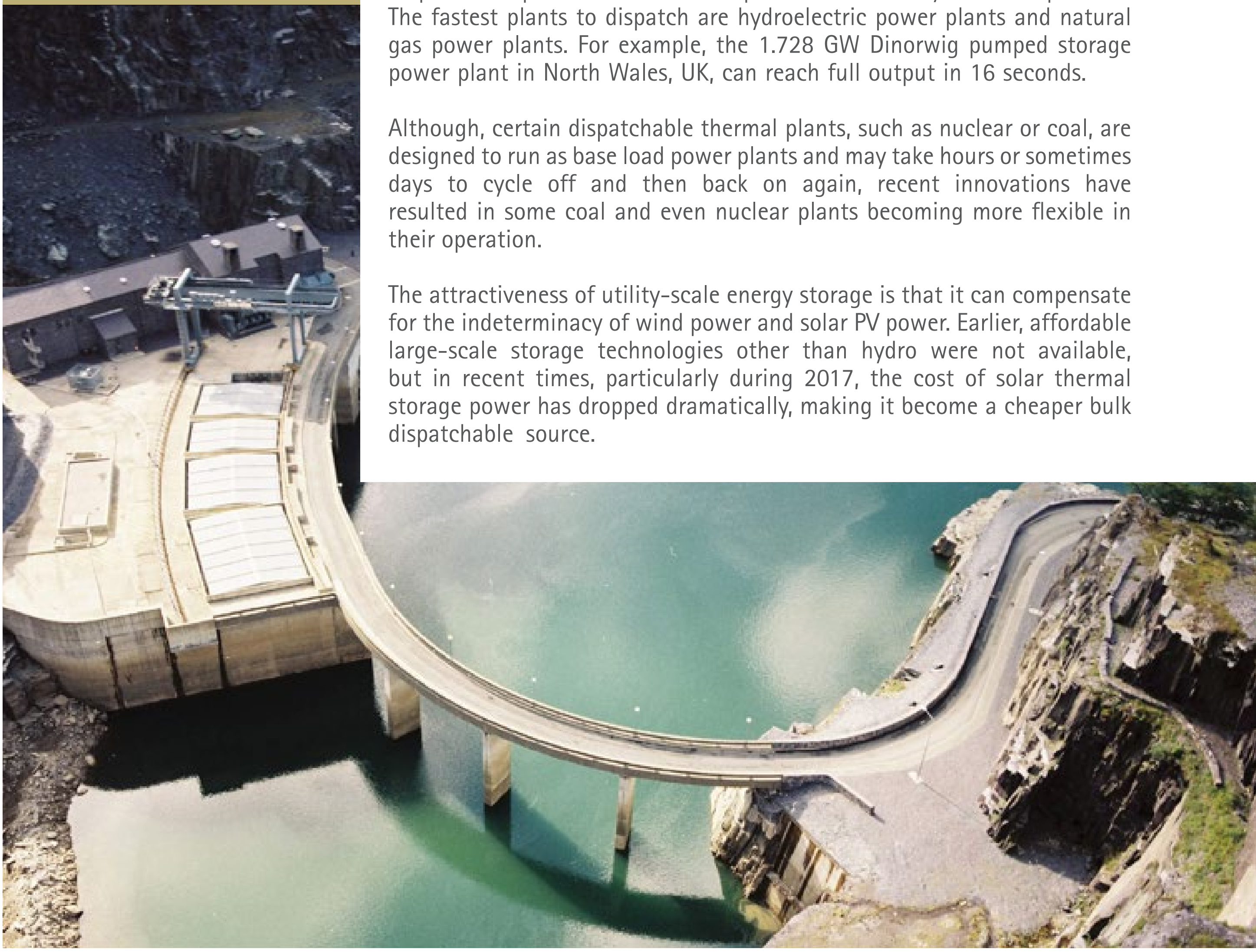
MW Dinorwig pumped storage power plant in North Wales, UK, can reach full output in 16 seconds.

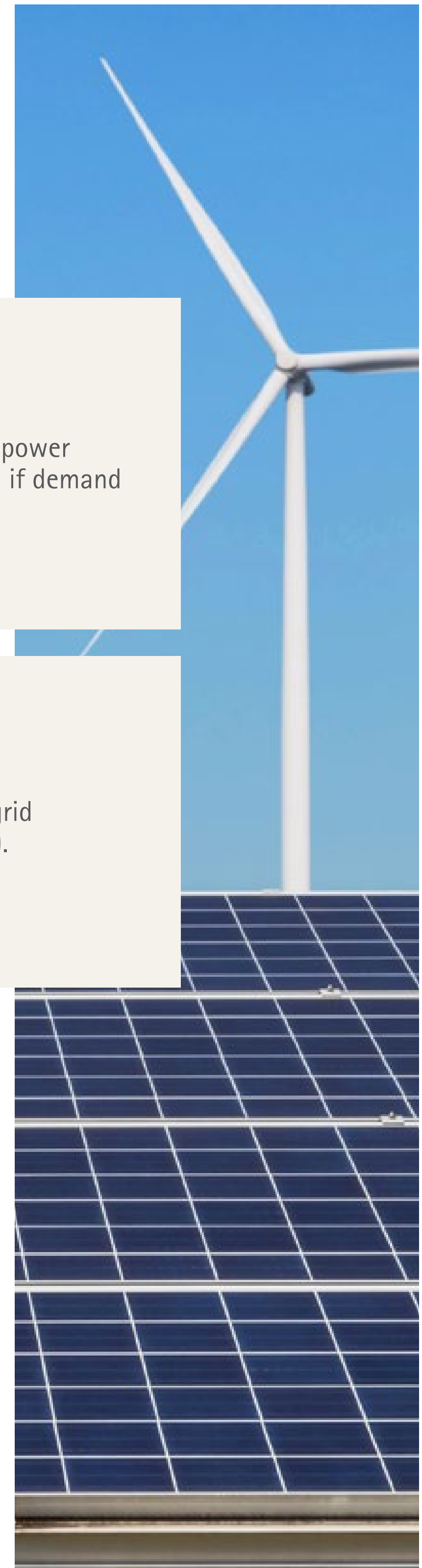
The consideration of energy sources, particularly RES would be incomplete without mention of mode of generation and supply - dispatchable and non-dispatchable. Dispatchable generation refers to sources of electricity that can be used on demand and dispatched at the request of power grid operators, according to market needs. Dispatchable generators can be turned on or off, or adjust their power output according to electricity orders. This is in contrast with non-dispatchable RES such as wind power and solar photovoltaic (PV) power, which cannot be controlled by operators. The only types of RES that are dispatchable without a separate energy storage are biomass, geothermal and ocean thermal energy conversion.

Dispatchable plants have different speeds at which they can be dispatched. The fastest plants to dispatch are hydroelectric power plants and natural gas power plants. For example, the 1.728 GW Dinorwig pumped storage power plant in North Wales, UK, can reach full output in 16 seconds.

Although, certain dispatchable thermal plants, such as nuclear or coal, are designed to run as base load power plants and may take hours or sometimes days to cycle off and then back on again, recent innovations have resulted in some coal and even nuclear plants becoming more flexible in their operation.

The attractiveness of utility-scale energy storage is that it can compensate for the indeterminacy of wind power and solar PV power. Earlier, affordable large-scale storage technologies other than hydro were not available, but in recent times, particularly during 2017, the cost of solar thermal storage power has dropped dramatically, making it become a cheaper bulk dispatchable source.





The main reasons why dispatchable power plants are needed are:

01

To provide spinning reserves (frequency control) in case a major plant becomes inoperable;

02

To balance the electric power system (load following) if demand suddenly increases;

03

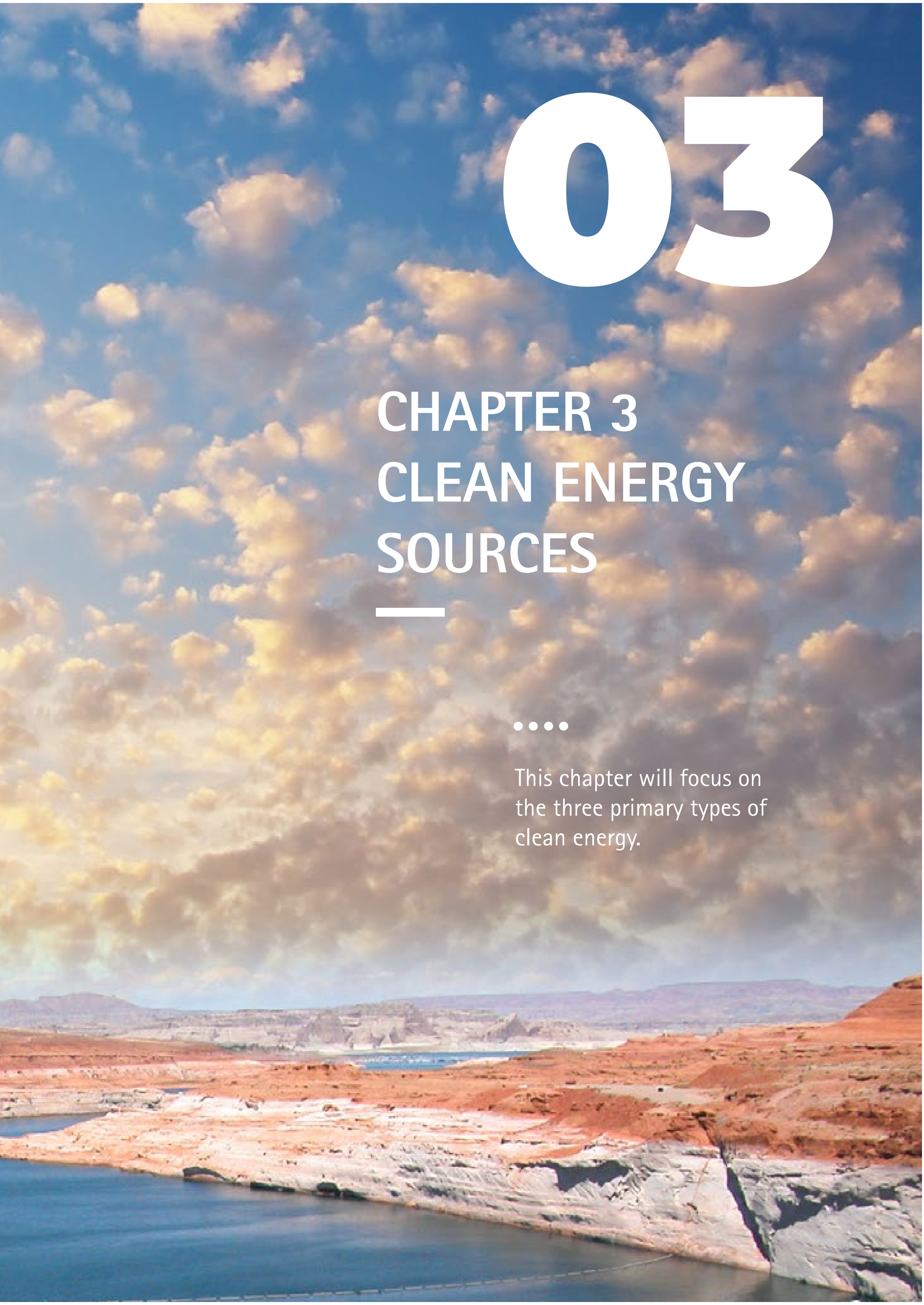
To optimize the economic generation dispatch (merit order);

04

To contribute to clear grid congestion (redispatch).

Examples of cases where the use of dispatchable generators are beneficial include:

- Load matches - slow changes in power demand between, for example, night and day, require changes in supply too, as the system needs to be balanced at all times;
- Peak matches – during short periods of time when demand exceeds the output of load matching plants, generation capable of satisfying these peaks in demand is implemented through quick deployment of output by flexible sources;
- Lead-in times - periods during which an alternative source is employed to supplement the lead time required by large coal or natural gas fueled plants to reach full output. These alternative power sources can be deployed in a matter of seconds or minutes to adapt to rapid shocks in demand or supply that cannot be satisfied by peak matching generators;
- Frequency regulation (generation of megavars) or intermittent power sources - changes in the electricity output sent into the system may change quality and stability of the transmission system itself, because of a change in the frequency of electricity transmitted. Renewable sources such as wind and solar, for example, are intermittent and need flexible power sources to smooth out their changes in energy production.



03

CHAPTER 3
CLEAN ENERGY SOURCES

This chapter will focus on the three primary types of clean energy.

Clean energy sources can be divided into three types:

1. Energy sources that produce energy (chiefly electrical energy) in a way that does not cause major emissions of CO_2 (and other pollutants) and that are generally self-replenishing within a reasonable timeframe consistent with timeframe for reuse;
2. Technologies that cause existing sources of electrical energy to be used more cleanly;
3. Technologies that improve non-electrical uses of energy so that it is used more efficiently.

This chapter will focus primarily on the first type and provide a brief summary of the other two types.

Energy sources that produce emission free energy

In this section, the various RES described in Chapter 2 will be thoroughly examined with regards to their impact on the environment. These RES are listed in this chapter for completeness and easy reference.

Biomass and the environment

Landfill gas with a high CH_4 content can be dangerous to people and the environment because CH_4 is flammable. CH_4 is also a strong greenhouse gas (GHG), with a global warming potential of at least four times that of CO_2. Biogas contains small amounts of hydrogen sulphide, a noxious and potentially toxic compound when in high concentrations.

In some countries, clean air regulations require municipal-solid-waste landfills of a certain size must install and operate a landfill gas collection and control systems. Some landfills reduce landfill gas emissions by capturing and burning or flaring the landfill gas. Burning the CH_4 in landfill gas produces CO_2, which is not as strong a GHG as CH_4.

"Burning the CH_4 in landfill gas produces CO_2, which is not as strong a GHG as CH_4."

Hydropower and the environment

In terms of water and air pollution, hydropower is likely the cleanest energy source. While hydropower is a much more environmentally friendly method of electricity production than coal, it nevertheless has a significant negative social and environmental footprint.

Hydropower facilities can have large environmental impacts, by changing the environment and affecting land use, homes, and natural habitats in the dam area. Most hydroelectric power plants include a dam and a reservoir. The serious multifaceted environmental impacts of hydropower dams include:

- Disrupting the natural ecology of rivers;
- Damaging forests and biodiversity;
- Releasing GHGs, especially during construction and decommissioning;
- Disrupting food systems and agriculture;
- Deteriorating water quality.

Operating a hydroelectric power plant may change the water temperature and the river's flow, changes that in turn, may harm native plants and animals in the river and on land. Dam and reservoir structures may obstruct fish migration and affect their populations. Fish and other organisms can be injured and killed by the turbine blades. Apart from direct contact, there can also be wildlife impacts both within the dammed reservoirs and

Hydroelectric plants built in semi-arid regions could also be as modest as

27 MtCO2eq per KWh

These emissions comprise of CO2 and CH4 directly from the reservoirs and from decomposed vegetation and soil in the flooded areas. These GHG emissions are, however, still considered relatively modest as compared to emissions from natural gas facilities and coal-fired power plants. Small run-of-the-river plants emit between 4.5-13.5 MtCO2eq per KWh, while emissions from large-scale hydroelectric plants built in semi-arid regions could also be as modest as 27 MtCO2eq per KWh. In comparison, the estimates of life-cycle global warming emissions for natural-gas-generated electricity are between 270 - 910 MtCO2eq per KWh and estimates for coal-generated electricity are between 635-1630 MtCO2eq per KWh.

downstream from the facility. Reservoir water is usually more stagnant than normal river water. As a result, the reservoir will have higher than normal amounts of sediments and nutrients. In addition, water is lost through evaporation in dammed reservoirs at a much higher rate than in flowing rivers. The accumulated sediments and nutrients can cultivate an excess of algae and other aquatic weeds. These weeds can crowd out other river animal and plant-life, if not properly controlled through manual harvesting or by introducing fish that eat the weeds.

Impact on land use - hydroelectric plants in flat areas tend to require verse land. The large Balbina hydroelectric plant in a flat area of Brazil, for example, flooded 2,360 square kilometers, while providing only 250 MW of power generating capacity (equaling more than 2,000 acres per MW). In essence, dams and reservoirs may cover people's homes, important natural areas, agricultural land, and archeological sites. Building of large dams often require relocating people, resulting in conflicts with concerned and affected communities. In many instances, such as the Three Gorges Dam in China, entire communities have also had to be relocated to make way for reservoirs. Flooding land for a hydroelectric reservoir has extreme social and environmental impacts – destructions of forest, wildlife habitat, agricultural land, and scenic lands.

Life-cycle GHG emissions associated with hydroelectric power plants vary greatly depending on the size of the reservoir and the nature of the land that was flooded by the reservoir.

Notwithstanding these social and environmental impacts, hydropower energy derived from falling or fast-flowing water is generally considered a mature clean energy technology. However, it is believed that there are further opportunities for optimising mechanical solutions geared towards upgrading existing plants, with a view to improving the efficiency and reducing the environmental impact of hydropower. Solutions to exploit energy production from little reservoirs or the development of hydro plants that can utilize small differences in the level of water (therefore not requiring the construction of massive dams) hold much promise. As such, several institutions are supporting hydropower research and development through funded research projects, aimed at realizing the full potential of hydropower and reducing the environmental impact.

> **Solar energy systems/power plants do not produce air pollution, water pollution or GHGs.**

Wind and the environment

Using wind to produce energy has fewer effects on the environment than many other energy sources. Wind turbines, with very rare exceptions, do not release emissions that can pollute the air or water and they do not require water for cooling. Wind turbines may also reduce the amount of electricity generation from fossil fuels, resulting in lower total air pollution and CO2 emissions.

An individual wind turbine has a relatively small physical footprint. On the other hand, groups of wind turbines (wind farms), usually located on open land, on mountain ridges, or offshore in lakes or the ocean, have large environmental footprints with some negative impacts on the environment. Modern wind turbines can be very large in size and may visually affect the landscape.

Cases of fire incidences and leakages of lubricating fluids have been reported for some wind turbines, but such occurrences are rare. The sound that the wind turbine blades make, as they turn in the wind, are found to be unpleasant by some people. Some types of wind turbines and wind projects result in the deaths of birds and bats and, thereby, contribute to decline in the population of species.

Solar and the environment

Solar energy systems/power plants do not produce air pollution, water pollution or GHGs. Using solar energy can have a positive, indirect effect on the environment, when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment. However, toxic materials and chemicals are used in the manufacture of the PV cells that convert sunlight into electricity.

Some solar thermal systems use potentially hazardous fluids to transfer heat. Leaks of these materials could be harmful to the environment. In some countries, the use and disposal of these toxic and hazardous materials are strictly regulated through environmental legislation.

As with any type of power plant, large solar power plants can have a negative impact on the surrounding environment. Clearing land for construction and placement of the power plant may have long-term effects on the habitats of native plants and animals. Some solar power plants may require water for cleaning solar collectors and concentrators for cooling turbine generators. Using large volumes of ground water or surface water in some arid locations may affect the ecosystems that depend on these water resources. In addition, the beam of concentrated sunlight that a solar power tower creates can result in the deaths of birds and insects that fly into the beam.

Geothermal and the environment

The environmental effects of geothermal energy depend on how the geothermal energy is used and how it is converted to useful energy. Direct use applications and geothermal heat pumps have almost no negative effects on the environment. In fact, they can have a positive effect, by reducing the use of energy sources that may have negative effects on the environment.

Geothermal power plants do not burn fuel to generate electricity, so the levels of air pollutants they emit are low or near zero. Geothermal power plants emit 97 per cent less acid rain-causing sulphur compounds and about 99 per cent less CO2 than fossil fuel power plants of similar size. Geothermal power plants use scrubbers to remove the hydrogen sulphide naturally found in geothermal reservoirs.
Most geothermal power plants inject back into the earth, the geothermal steam and water that they use. This recycling helps to renew the geothermal resource.

Tidal and the environment

A potential disadvantage of tidal power is the effect a tidal station can have on plants and animals in estuaries of the tidal basin. Tidal barrages can change the tidal level in the basin and increase turbidity - the amount of matter in suspension in the water. They can also affect navigation and recreational activities.

Nuclear and the environment

As stated in Chapter 2, nuclear sources are not strictly considered as RES, but because they are so abundantly available, some consider them to be an emission-free, CO2-friendly clean source of energy. For that reason, it is appropriate to highlight here, the major environmental impacts of nuclear.

An uncontrolled reaction in a nuclear reactor could result in widespread contamination of air and water. Unlike fossil fuel-fired power plants, nuclear reactors do not produce air pollution or CO2 while operating, but the processes for mining and refining uranium-ore and producing reactor fuel require large amounts of energy. Nuclear power plants also consist of large amounts of metal and concrete, which require large amounts of energy to manufacture. Thus, depending on the sources of energy used, some degree of air pollution and CO2 emissions is indirectly associated to nuclear power plants. If fossil fuels are used for mining and refining uranium-ore, or if fossil fuels are used when constructing the nuclear power plant, then the emissions from burning those fuels could be associated with the electricity that nuclear power plants generate.

A major environmental concern related to nuclear power is the creation of radioactive wastes such as uranium mill tailings, spent (used) reactor fuel and other radioactive wastes. The radioactivity of these wastes can range from a little higher than natural background levels, such as for uranium mill tailings, to the much higher radioactivity of spent reactor fuel. The radioactive materials can remain radioactive and dangerous to human health for thousands of years and are subject to special strict regulations that govern their handling, transportation, storage and disposal to protect human health and the environment.

An uncontrolled nuclear reaction in a nuclear reactor could result in widespread contamination of air and water.

Technologies that aid clean energy

In general, the concept of a clean energy revolution encompasses the technologies, strategies and innovative practices that support clean energy. Some of these are huge topics in their own right, but worth mentioning briefly in this chapter, in particular, as they relate to aiding clean energy when adopted with other energy sources.

Energy Efficiency

According to the International Energy Agency (IEA), energy efficiency can deliver 38 per cent of what is needed to keep our planet within the 2°C scenario of global warming by 2050. Taking that into account, it is prudent to put energy efficiency in the forefront of possible solutions and responses to the climate change challenge. The good news is that technologies and solutions for making energy efficiency happen already exist and make good business sense. All that is required is to accelerate the adoption of these technologies. The big question that remains is, how to accelerate the adoption of technologies and solutions needed for energy efficiency?

The IEA projects that, even though the potential climate impact from using less energy is enormous and pay-back time is low, only one third of the available energy-efficiency potential will be achieved under existing and discussed policies. Intervention from world leaders is required to create frameworks at global, national and regional levels, that make it easier to overcome barriers such as funding, policy incentives, knowledge sharing and education. In short, governments around the world must make it easier for citizens to become energy-efficient. The private and public sectors must work together to deliver state-of-the-art, innovative solutions and secure necessary financing.

Batteries

Batteries are not a source of energy, clean or otherwise. They are a mechanism for storing energy and are useful in two ways: (i) as a means of saving energy from an intermittent source such as solar or wind, to be used at a later time and, (ii) as a means of making energy portable for transportation. Although small batteries are ubiquitous, and their performance continues to grow as capacity increases and size reduces, their impact in terms of renewable energy is still relatively small, compared to large-scale batteries. The incorporation of batteries into grid systems can be truly transformational.

Storing electricity from renewable energy at scale, cheaply and efficiently, still poses a significant challenge. The common practice today, for managing intermittency and seasonality of renewable energy, is for utilities to fire up small "peak" power plants, typically fueled by natural gas, when prices and demand are high. However, in order to fully maximise the potential to generate energy from solar and wind, utilities would need to produce huge surpluses of energy during summer months and store that energy for use throughout the year. For context on the dwarfing of the growth of electricity storage capacity, the State of California currently maintains just 150,000 MWh of energy storage, as compared to the projected requirement of 9.6 million MWh of energy storage for generating 80 per cent of California's energy from advanced renewables. To attain the State's ultimate aspirational

goal of generating 100 per cent of its energy from advanced renewables would require 36.3 million MWh of energy storage. With the rapidly falling costs of solar and wind power technologies, increasing shares of variable renewable energy will become the norm, while efforts to decarbonise the transport sector are being accelerated by the use of electric vehicles. The need to accommodate variable energy supply, while providing undisrupted output in the electricity sector, as well as efforts to integrate renewables into the end-use sectors, has brought into the forefront the significant potential, as well as the crucial importance, of electricity storage to facilitate deep decarbonisation.

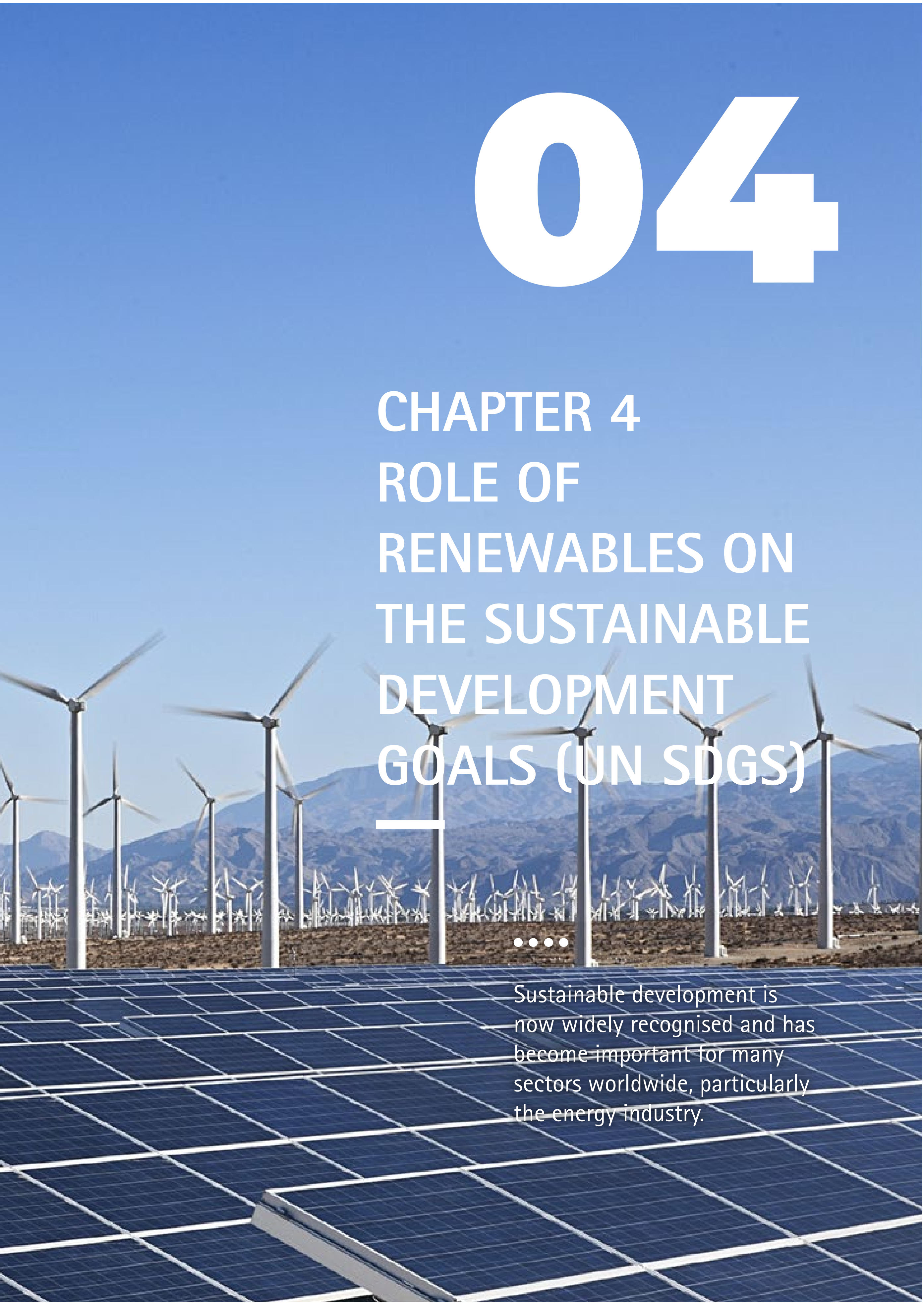
Fuel Cells

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. Fuel cells are different from most batteries, in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides that are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied. The first fuel cells were invented in 1838. The first commercial use of fuel cells came more than a century later, in NASA space programmes, to generate power for satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

In **1838**

the first fuel cell was invented

The concept of a clean energy revolution encompasses the technologies, strategies and innovative practices that support clean energy.



04

CHAPTER 4
ROLE OF RENEWABLES ON THE SUSTAINABLE DEVELOPMENT GOALS (UN SDGS)

Sustainable development is now widely recognised and has become important for many sectors worldwide, particularly the energy industry.

"The United Nations General Assembly proposed a set of 17 UN SDGs, which were adopted by world leaders in September 2015."

Sustainable development has become the center of recent national policies, strategies and development plans of many countries. The United Nations General Assembly proposed a set of 17 UN SDGs, which were adopted by world leaders in September 2015, as part of the global 2030 Agenda for Sustainable Development. These Goals clearly define the scale of ambition, transformation and fundamental common human values that the 2030 agenda embodies.

Sustainable development is now widely recognised and has become important for many sectors worldwide, particularly the energy industry. In a publication titled, Sustainable Development Goals and Energy Nexus, published in 2017, the Al-Attiyah International Foundation examined the connectivity between energy and each of the 17 SDGs. It sets out, under five main themes, some of the important considerations relating to the energy industry in the broader sustainability agenda of today's world.

The book specifically examines the role of the energy industry in the global pursuit of sustainable development through the lens of the UN SDGs. The connection between a nation's ability to achieve each of the 17 sustainable development goals and their access to sustainable energy was explored. All the 17 sustainable development goals were examined, and some insights were provided on how the contribution from the energy sector can be strengthened. The book further highlighted the fact that the world cannot achieve these sustainable development goals without energy.

In line with a highlighted key message of the book, that the global agenda for development requires efforts on several fronts and from all sectors of society, it is appropriate, in this chapter, to zoom-in specifically on how efforts to grow renewable sources of energy, could facilitate the realization of the global 2030 Agenda for Sustainable Development.

Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential. Working towards this goal is especially important as it interlinks with other sustainable development goals. Focusing on universal access to energy, increased energy efficiency and the increased use of renewable energy, through new economic and job opportunities, is crucial to creating more sustainable and inclusive communities and resilience to environmental issues like climate change.

At the current time, there are approximately 3 billion people who lack access to clean-cooking solutions and are exposed to dangerous levels of air pollution. Additionally, slightly less than 1 billion people are functioning without electricity and 50 per cent of them are found in Sub-Saharan Africa alone. Fortunately, progress has been made in the past decade regarding the use of renewable electricity from water, solar and wind power and the ratio of energy used per unit of GDP is also declining.

However, the challenge is far from being solved and there needs to be more access to clean fuel and technology and more progress needs to be made regarding integrating renewable energy into end-use applications in buildings, transport and industry. Public and private investments in energy needs to be increased and more focus must be placed on regulatory frameworks and innovative business models to transform the world's energy systems.

The sustainable development goal seven (affordable and clean energy) seeks to ensure that energy is clean, affordable, available and accessible to all and this can be achieved with RES, since they are generally distributed across the globe. Access concerns need to be understood in a local context and, in most countries, there is an obvious difference between electrification in the urban and rural areas. This is especially true in sub-Saharan Africa and South Asian region.

3
Billion

people lack access to clean-cooking solutions and are exposed to dangerous levels of air pollution.

Goal 7

Ensure access to affordable, reliable, sustainable and modern energy for all UN SDG 7.

Facts:

- 13 per cent of the global population still lacks access to modern electricity.
- 3 billion people rely on wood, coal, charcoal or animal waste for cooking and heating.
- Energy is the dominant contributor to climate change, accounting for around 60 per cent of total global GHG emissions.
- Indoor air pollution from using combustible fuels for household energy caused 4.3 million deaths in 2012, with women and girls accounting for 6 out of every 10 of these.
- The share of renewable energy in final energy consumption has reached 17.5 per cent in 2015.

Fact

Energy is the dominant contributor to climate change, accounting for around 60 % of total global GHG emissions.

Targets:

- By 2030, ensure universal access to affordable, reliable and modern energy services.
- By 2030, increase substantially the share of renewable energy in the global energy mix.
- By 2030, double the global rate of improvement in energy efficiency.
- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.
- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support.

Today, renewables have established themselves as the fastest growing source of new power generation in the world and account for a third of global power capacity. Societies around the world are on the verge of a profound and urgently necessary transformation in the way they produce and use energy. This shift is moving the world away from the consumption of fossil fuels toward cleaner, renewable forms of energy.

The rapid deployment of renewable energy has been driven mainly by a wide range of objectives (drivers), which include: advancing economic development, improving energy security, enhancing energy access and mitigating climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) categorised key drivers, opportunities and benefits of renewable energy into environmental (climate change mitigation and reduction of environmental and health impacts), energy access, energy security (e.g. diversity of fuel supply, fuel imports, balance of trade), and social and economic development (e.g. job creation, rural development).

Altogether, these drivers might be described as the pursuit of sustainable development, where economic prosperity is advanced around the world, while negative impacts are minimised. While such presumed benefits are widely cited as key drivers in political and energy debates, specific, documented evidence of such benefits remains rather limited for reasons including, a lack of adequate conceptual frameworks, methodological challenges and limited access to relevant data.

Relative to other types of energy from fossil fuels, nuclear power, and traditional biomass, modern renewables provide a variety of additional socio-economic benefits. In most jurisdictions, these socio-economic benefits are a major force driving policymakers to adopt renewable energy targets and support policies.

13%

of the global population still lacks access to modern electricity.

Renewables and energy security

Many countries import fossil (and nuclear) fuels from regions that are politically unstable or that might stop the flow of supply at any time. By contrast, renewable energy resources are diverse, they rely on natural flows (rather than exhaustible stock), are available locally (with type and amount of resource differing by location), and the technologies required for capturing and converting these resources into useful energy are available in the global market place.

Although the primary energy security focus of most countries revolves around maintaining access to fossil fuels, renewable energy is viewed increasingly as having a role in improving energy security. Europe, for example, depends heavily on natural gas that comes from Russia via pipelines that cross other countries (including Ukraine). When gas flows to Ukraine were restricted in the winter of 2014, much of Europe experienced a drop in supply. Thus, an important driver for EU renewable energy policies has been to reduce the region's dependence on imported fossil fuels, including natural gas.

In the Caribbean region, the high cost of imported fuel diverts resources away from economic development, reducing economic competitiveness and making these economies vulnerable to fuel supply shocks. To address such concerns (and to advance energy security and access to energy, economic development, and environmental and climate goals), governments of the region, the Caribbean Community (CARICOM) Secretariat, and several other national governments and international agencies committed, in early 2015, to support a transformation of the region's energy system through renewable energy and energy efficiency.

Other countries promoting renewables to advance security include: South Africa, where policies are driven by the country's plentiful renewable energy resources, concerns about energy security, and the desire to reduce fuel imports; Fiji, where renewable energy support and deployment are rising as renewable technology costs decline, with the aim of reducing heavy dependence on imported fossil fuels (which affects both energy security and prices); and Chile, which is promoting renewable energy to reduce dependence on energy imports, particularly from Argentina (which unilaterally cut off gas lines to Chile in 2008).

Energy security has been a driver of renewable energy support policies in the USA as well. Shortly before advanced drilling technology triggered a dramatic rise in domestic oil and gas production, the US Renewable Fuel Standard (along with the strengthening of fuel efficiency standards) was part of 2007 legislation to improve national security, by reducing dependence on imported petroleum. Further, the country's military appears committed to improving energy security in their operations through deployment of renewable energy. The US Navy, for example, is pursing renewables to "improve energy security, operational capability, strategic flexibility and resource availability."

Socio-economic benefits are a major force driving policymakers to adopt renewable energy targets and support policies.

Renewables and energy intensive industries

Energy intensive industries (EIIs) form the foundation and remain the backbone of many economies. As enabling materials industries, they link to every possible economic sector, including each other, forming an intricate arterial system of value chains. In the EU, for example, around 80 per cent of the goods produced by the energy intensive industries are consumed all over Europe, signifying the strategic importance of the sector to the European economy. EIIs will continue to play a constructive and solutions-oriented role in the global quest for energy and industrial transformation. These industries are critical to growth of the economy and, in many cases, will be providing the components for renewable energy generation or the materials required to lower the carbon intensity of consumer products.

"In Europe, for example, EIIs have played an important role in helping to meet Europe's current climate ambitions. Between 1990 and 2015."

Furthermore, energy intensive industries are critical to each other's value chains. The flow of materials to and from the EIIs forms a highly dense, integrated network with each other. Some of the most iconic examples of low-carbon solutions like electric vehicles, wind turbines, solar PVs or battery storage are enabled by energy intensive industries. EIIs also employ a significant percentage of the workforce in many countries. Particularly, in developed industrialised countries many of the energy intensive industrial sites are based in areas of relatively high underemployment and low standards of living. As such, their continued operations are vital to the economies of those areas, with foregone jobs often difficult to replace, with the antecedence political ramifications.

The positive contribution of energy intensive industries to sustainable development is enhanced further by notable efforts by the sector to address its negative impacts on the environment. In Europe, for example, EIIs have played an important role in helping to meet Europe's current climate ambitions. Between 1990 and 2015, EIIs reduced their GHG emissions by 36 per cent and accounted for 28 per cent of the total economy-wide emission reductions by the EU, even though they represented 15 per cent of EU total GHG emissions in 2015 (18.4 per cent in 1990). These reductions have come about due to a combination of factors:

- Improvements in energy efficiency;
- Fuel switching including increased use of biomass;
- Closures and lower production levels or capacity utilisation in some sectors, in particular, following the economic crisis of 2008;
- Deep reductions of non-CO2 GHG emissions in chemicals and fertilizers production (N2O and fluorinated gases emissions reduced by 93per cent between 1990 and 2015, in these sectors).

In recent years, not only have EIIs more than disproportionately helped reduce emissions from their own sectors, but they also contribute to emissions reductions in other sectors like transport, buildings, waste and power generation.

Economic benefits of renewables

Renewable energy technologies provide several economic benefits, particularly for energy importers. This is becoming increasingly true, as renewable energy costs (especially costs of solar PV and wind power) continue their rapid decline. The use of renewable energy helps to avoid a number of indirect economic costs associated with fossil energy production and use, such as, health care expenses. It can also help reduce the longer-term costs associated with global climate change, such as, the potential for sudden disruption and displacement of people and their economic activity. Thus, investments in renewable energy systems and associated infrastructures can result in sustainable development in every sense of the term – sustained economic growth that is environmentally sustainable. Below are some examples of economic benefits associated with renewable energy and how they are helping to drive the adoption of supportive policies.

Improve balance of trade and reduce price volatility

The majority of countries, states or communities import most, if not all, of the fossil or nuclear fuels that they consume. Investment in renewables can improve a country's or region's trade balance and can reduce fuel price volatility and supply risk.

Reduction of fossil fuel imports, and the associated economic savings (for consumers and for government budgets for related subsidies, etc.), is one of the key drivers for renewable energy policies, including the increasing trend by countries to set 100 per cent targets for renewables.

Denmark, for example, expects that its strategy to move toward 100 per cent renewable energy (power and heat by 2035, and fossil fuel-free economy-wide by 2050), will result in reduced energy expenditures relative to business as usual. The Danish city of Frederikshavn has set a more ambitious target of 100 per cent renewable energy by 2030 to become energy self-reliant and to avoid the impacts of fuel-price volatility, while also reviving and diversifying the region's economy.

From Africa, to the Pacific, to the Caribbean, island nations are adopting policies and targets to promote renewable energy, driven by the need to reduce exposure to volatile market prices for fuel (as well as high shipping costs). The African island nation of Cape Verde chose to aim for 100 per cent renewable energy, largely to eliminate its high dependence on imported fossil fuels. In addition to achieving huge cost savings, Cape Verde expects that its investments in renewable energy will result in new business sectors, environmental stewardship and social responsibility, enabling the country to become a global model for zero emissions and a regional knowledge hub.

Following a 2008 fuel price spike, the Marshall Islands, which depended heavily on imported fossil fuels, enacted the National Energy Policy and the Energy Action plan to improve the national economy and the lives of its inhabitants through renewable energy deployment. The island nation of Grenada expects that national savings associated with transitioning to renewable energy will be on the order of USD 300 million annually and that substituting renewables for fossil fuels will improve the balance of payments while also enhancing energy and food security.

Create jobs and develop new industries and skills

Studies suggest that while the renewable energy transition generally involves in the shifting of jobs by sector and location, the net impact on job creation is usually expected to be positive. In its Advanced Renewable Energy Scenario, an ambitious pathway towards a 100 per cent renewable and carbon-free global energy system for 2050, Greenpeace projects that there will be 48 million jobs in the energy sector in 2030, compared to 28 million jobs under the reference scenario. The International Renewable Energy Agency (IRENA) estimates that solar PV deployment creates twice the number of jobs per unit of electricity generated, as does coal or natural gas. Skills required for manufacturing, selling, installing and maintaining renewable energy systems and associated infrastructure vary significantly, with a variety of medium- and high-skilled opportunities.

A study by the Environmental Defense Fund (EDF) in 2017, found that solar and wind industries are each creating jobs at a rate of 12 times faster than that of the rest of the U.S. economy, concluding that solar and wind jobs have grown at rates of about 20 per cent annually in recent years, and sustainability now collectively represents 4-4.5 million jobs in the U.S., up from 3.4 million in 2011. In contrast, the compounded annual growth rate of employment in the fossil-fuel industry was -4.5 per cent from 2012 to 2015 and the average number of employees at US coal mines dropped by 12 per cent in 2015.

Renewable-energy jobs are widely geographically distributed, they're high paying, they apply to both manufacturing and professional workers, and there are a lot of them; making the authors of the EDF report believe that the right place to invest dollars is in renewable energy rather than fossil fuels.

Job creation has been a driver of renewable energy policies, that aim to help strengthen local economies, and to stem or reverse depopulation and brain drain. In Morocco, for example, the deployment of concentrating solar thermal power (CSP) is considered a means to multiple development objectives in local communities, including: job creation, skills development and training, as well as social development, socio-cultural enhancement, and climate change mitigation.

The US state of Iowa has supported ethanol production and deployment of other renewable technologies to create jobs that strengthen the state's middle class, increase in-state technology investment, reduce dependence on imported fuels, and provide cleaner air and water. Drivers for renewable energy policies in Scotland have included diversification of rural employment and skills development. In Tipperary, Ireland, a local renewable energy eco-village was planned to stem rural depopulation, to help develop skills and new enterprises, as well as to reduce CO2 emissions. The Chinese city of Dezhou enacted policies to support solar power demand and supply, with the aim of transforming Dezhou into "China's Solar City," creating jobs, building local capacity, fostering innovation, and attracting investment in the process.

In 2011, when announcing Germany's decision to phase out nuclear power, Chancellor Angela Merkel called for electricity of the future to be "safer and at the same time reliable and affordable," and called for Germany to be "the first major industrialised country that achieves the transition to renewable energy with all the opportunities – for exports, development, technology, jobs – it carries with it."

48 million jobs in the energy sector by **2030**

Meet rapidly rising energy demand

The modularity of many renewable technologies and relative speed with which they can be implemented, alongside their rapidly falling costs (particularly for solar PV and wind power), have made them the technologies of choice for meeting ever-growing global demand for energy, especially in developing economies. Brazil, which has been highly dependent on hydropower (historically meeting over 80 per cent of national electricity demand), has turned to other renewable technologies to meet rising electricity demand while reducing the country's vulnerability to supply shortages in drought years.

Chile has set a national target of 20 per cent renewable electricity (not including hydropower) by 2025 and plans to ease power shortages and resulting high prices in the central region (which increased 30 per cent over the period 2010-2015) by linking solar and wind power plants in the north to demand centers via a 3,000-kilometer transmission line.

In Africa, Egypt is advancing deployment of renewables in the electricity sector to help meet surging power demand and South Africa plans to increase significantly its electricity production from renewable sources to help stabilize the power grid and to alleviate power shortages that have caused rolling blackouts throughout the country.

Provide access to energy and alleviate poverty in developing countries

More than a billion people still lack access to electricity while more than two in five people around the world depend on traditional biomass for heating and cooking. In remote areas, electricity generated with renewable technologies is generally less costly than the alternatives, including imported diesel fuel and grid extension. Indeed, in many areas it may be the only viable option, economically or otherwise, within any reasonable timeframe. Renewables also can provide heating, cooling, and mechanical energy for crop irrigation and other productive services. The modularity of many renewable technologies means that they can be installed rapidly and scaled up as needed. Many countries have established targets and enacted support policies to scale up renewable energy to provide access to modern energy services for people living in remote and rural areas.

Increasingly, not only national but also regional and local governments are adopting renewable policies and targets to advance energy access. Sumba Island in Indonesia (population of 650,000) has adopted a local government plan that is supported by international donors and aims to achieve 100 per cent renewables by 2020; the plan is driven by the desire for a "just" transition that boosts energy access, improves local business and livelihoods, and safeguards public health.

In Africa, the Ugandan district of Kasese (home to about 130,000 households) set a goal to achieve 100 per cent access to energy services to meet all domestic, productive and social needs with renewable energy by 2020. The initiative is driven by the need to advance local development by eliminating poverty related to lack of access to energy, reduce health impacts associated with traditional use of biomass and kerosene, and reduce local deforestation and land degradation. When Kasese's target was set, only 7 per cent of households had access to the electricity grid; about 87 per cent used kerosene for lighting and 97 per cent relied on firewood and charcoal for cooking. An important consideration for the community, is also the important role of renewables in the fight against climate change, which is threatening nearby glaciers and thus their very sense of identity.

Alleviate fuel poverty and advance rural economic development in industrialised countries

In industrialised countries, where the majority of people have access to modern energy services, renewables can reduce fuel poverty and improve quality of life. The community project in Tipperary, Ireland, mentioned earlier, was established to invest in renewable energy combined with energy efficiency retrofits in order to reduce fuel poverty.

Japan's Nagasaki Prefecture, Goto City, developed an extensive renewable energy plan to cover more than 130 per cent of the region's total energy needs with renewables by 2030 in order to foster rural economic development.

There are also numerous examples in the USA. Washington, D.C. has implemented policies to promote renewables combined with energy efficiency to advance local economic development and reduce energy costs for the city's low-income residents. Another example is the Alaska Energy Authority, which is working toward a target of 50 per cent electricity from renewables by 2025. This initiative is designed to reduce energy costs for rural residents; some communities spend more than half of the average household income on electricity and home heating due to the fact that fossil fuels must be imported by barge and distributed by air or boat, making them relatively costly.

Keep energy revenue local

When fuel imports are displaced with local renewables, whether at the national or sub-national level, energy expenditures can spur further economic activity in the local economy.

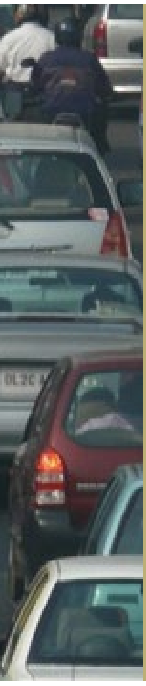
The US state of Hawaii adopted binding legislation in 2015 to aim for 70 per cent renewable electricity by 2030, and 100 per cent by 2045. Hawaii faces the highest electricity prices of any US state and an unsustainable dependence on imported fossil fuels. Renewable energy is expected to address both of these challenges, providing home-grown electricity at much lower cost. In 2014, East Hampton in New York state decided to meet 100 per cent of the community's electricity needs with renewables by 2020; the switch was considered "the right thing to do, both for the environment and for keeping more money in the local economy and creating jobs locally."

Similar motivations lay behind steps taken by the German district of Rhein-Hunsrück. In 2011, in an effort to retain the value added within the local economy, the district set out to displace its significant expenditure on fossil fuels through energy efficiency and local renewable energy production. By 2014, the district had become a significant net exporter of renewable electricity, mostly from wind power but also from solar PV and biomass power.

East Hampton in New York state decided to meet 100 per cent of the community's electricity needs with renewables by 2020.

Increase tax revenue

Local governments collect income and property tax payments from renewable energy project owners; the additional revenue enables governments to reduce tax rates for inhabitants, such as low-income residents, or to support additional public services. Washington, DC announced plans in December 2015 to install solar panels on roofs and parking lots of 34 government-owned facilities, where electricity would be purchased through a Power Purchase Agreement (PPA). City officials estimate that the plan will save taxpayers USD 25 million over the 20-year term of the PPA, while also spurring small business development and job creation. In addition, a separate deal, to meet one-third of the government's annual electricity needs with wind power, will save the Washington, DC city government (and thus, the taxpayers) an estimated USD 45 million over 20 years.



The estimated cost of health impacts associated with air pollution in China and India during 2010 was about

1.4

trillion USD

and

0.5

trillion USD.

The estimated cost of health impacts associated with air pollution in China and India during 2010 was about USD 1.4 trillion and USD 0.5 trillion, respectively.

Reduce public health costs

The burning of fossil fuels for energy production results in high economic costs for societies, in addition to tremendous physical suffering. By one estimate, the cost of health impacts associated with air pollution in the Organisation for Economic Co-operation and Development (OECD) countries (illness and death) was USD 1.7 trillion in 2010; road transport accounted for about half of this total. The estimated cost of health impacts associated with air pollution in China and India during 2010 was about USD 1.4 trillion and USD 0.5 trillion, respectively.

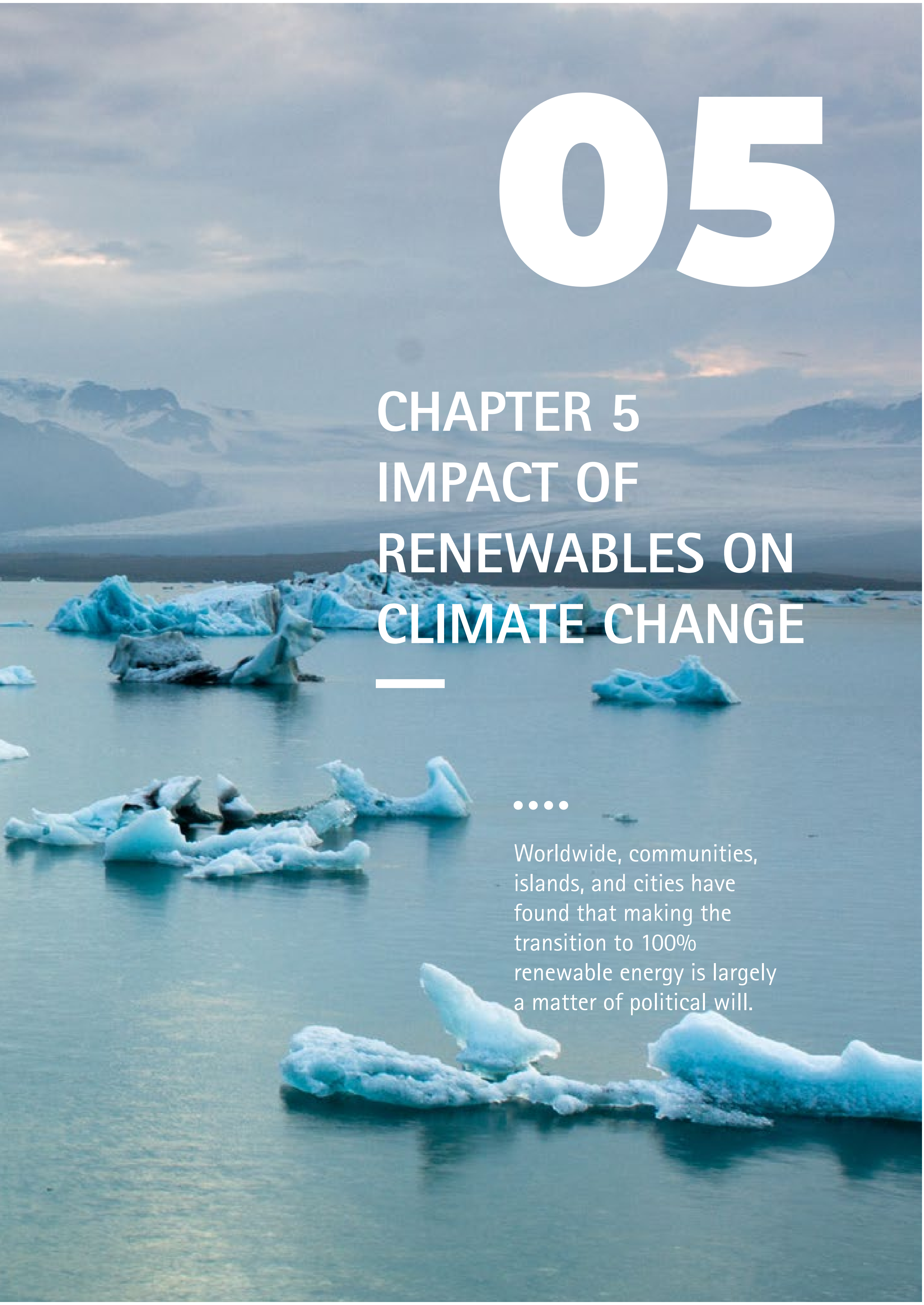
A 2007 study found that environmental pollution costs the Chinese economy about 10 per cent of total GDP. More recently, pollution in cities such as Beijing is causing widespread public discontent and prompting flights of capital and critical expertise, leading to further economic and social losses for China. In Europe as of 2012, air pollution and GHG emissions from industry, including power generation, cost the region at least EUR 59 (and possibly as much as 189 billion. It is the potential to reduce such costs through the deployment of renewable energy that has helped to drive renewable energy policies in the European Union (EU), China, Kasese District in Uganda, Vancouver in Canada, several US cities, and elsewhere.

As can be seen from the examples above, the majority of jurisdictions that are acting to advance renewable energy, do so for a multitude of reasons, crossing several categories of drivers. The relative importance of the drivers varies from place to place and may change or evolve over time.

The IPCC SRREN (2011) report determined that environmental factors and concerns about security of energy supply had played a significant role in driving policies in industrialized countries, whereas, economic opportunities had been the most important driver elsewhere. However, since 2016 the the significance of the drivers no longer appears to be so clear-cut, reflecting either an increase in available information about drivers around the world or, possible global shifts in priorities.

Global climate change and public health concerns due to air pollution in urban areas and heavy dependence on traditional biomass and kerosene in rural areas, are playing increasingly important roles in driving renewable energy policies across the global south. In addition, industrialised countries are now being driven by economic factors as well. Local communities everywhere appear to be increasingly concerned about resilience, local choice and control; all of which can work together to empower citisens and strengthen communities, both socially and economically.

An increasing number of jurisdictions worldwide are aiming for 100 per cent renewable energy. Although most are primarily targeting the power sector specifically, either through on-site generation or the purchase of renewable power generated elsewhere, increasing numbers are also including heating and cooling, and even transport. Aggressive targets (i.e. 100 per cent renewable energy) are being set at the local level, with towns and small cities at the forefront of this rapidly emerging movement. However, a growing number of larger cities (e.g. Copenhagen, Frankfurt, San Diego, San Francisco, Stockholm, Sydney, Vancouver) and even countries (e.g. Cape Verde; Denmark; Scotland; Sweden) are joining their ranks.



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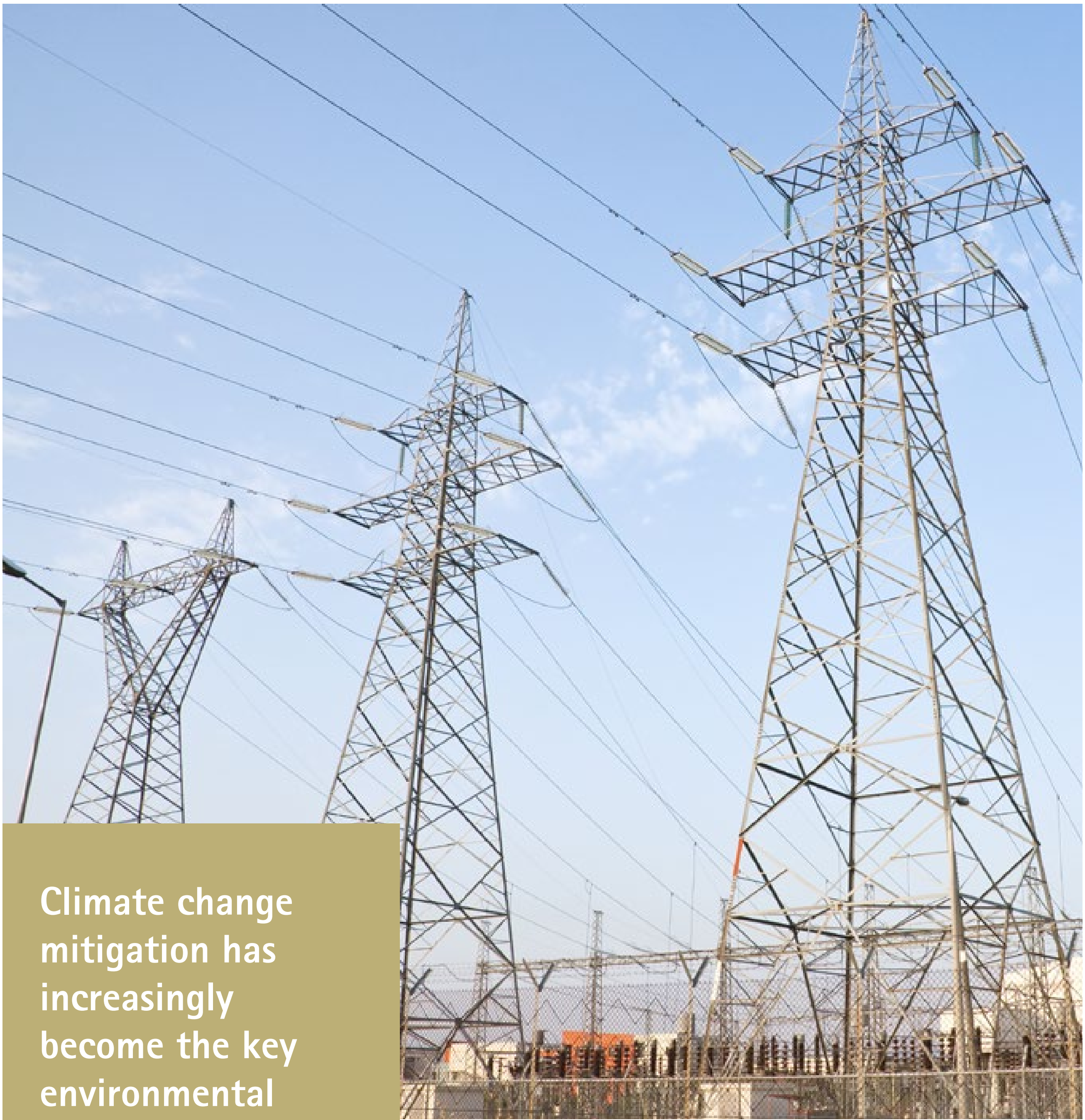
CHAPTER 5 IMPACT OF RENEWABLES ON CLIMATE CHANGE

Worldwide, communities, islands, and cities have found that making the transition to 100% renewable energy is largely a matter of political will.



Climate change mitigation has increasingly become the key environmental driver of renewable energy.

Renewable technologies are considered as clean sources of energy. Optimal use of these resources provides an exceptional opportunity for mitigation of GHG emissions and reducing global warming through substituting conventional fossil fuel-based energy sources.

The need for energy and its related services to satisfy human social and economic development, welfare and health is increasing. Returning to renewables, to help mitigate climate change, is an excellent approach which needs to be sustainable to meet the energy demands of future generations.

The European Commission believes that renewable energy can play a major role in tackling climate change, whilst also providing Europe with affordable and secure energy. In June 2019, a 20-month process of debate on a crucial aspect of the EU's clean energy package legislation concluded with an announcement of an informal agreement on a binding 32 per cent EU renewable energy target for 2030.

Worldwide, communities, islands, and cities have found that making the transition to 100 per cent renewable energy is largely a matter of political will; the required technologies are at hand. Additionally, an increasing number of governments at all levels are setting ambitious targets for renewable energy, with an ever-growing number of jurisdictions aiming for a 100 per cent renewables target. Local governments are pioneering this movement and are becoming incubators of regionally appropriate best practices and policies.

On a global scale, the deployment of renewable energy technologies has become an integral part of government strategies to address the various environmental and climate change challenges associated with the extraction, transport, refining and use of fossil and nuclear fuels. These challenges include damage to land from mining; pollution of air and water; consumption of vast amounts of fresh water, particularly for cooling at power plants; loss of biodiversity; risk of nuclear accidents; global climate change; and associated impacts on human health. Examples of how governments are using renewables to address these challenges include:

- Governments at all levels have enacted policies to support renewables in order to reduce health impacts associated with energy production and use. In China, for example, the quest for cleaner air and water has become an important driver of renewable energy targets and policies, alongside CO2 emissions reductions, job creation and economic development;
- Governments are turning to renewable energy to reduce water consumption associated with energy production. For example, Georgetown, Texas, a US city of more than 50,000 inhabitants, set 2017 as the target date to achieve 100 per cent renewables in the electricity sector, with the view to reduce water consumption in the sector; create opportunities for local economic development and provide protection against volatile fossil fuel prices;
- In the wake of the 2011 Fukushima Daiichi nuclear disaster, several Japanese cities and regions, including Hokkaido, Kyoto, and Osaka, set targets and enacted policies to promote renewables and energy efficiency. This was undertaken in order to reduce their reliance on nuclear power. As a direct response to the disaster in Japan; Germany has a plan to phase out its nuclear power facilities and replace them over time with renewable energy.

Indeed, climate change mitigation has increasingly become the key environmental driver of renewable energy. In combination with energy efficiency improvements, renewables now represent a key pillar in many governments' efforts to address climate change through decarbonisation of their energy sectors. This chapter considers climate change mitigation, as a key environmental driver of renewable energy.

Pre-Paris momentum on renewables

Prior to the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) in Paris, many countries and regions were increasing the deployment of renewables to address climate change.

For example, the EU 2020 target of 20 per cent energy consumption by renewables is intended (alongside an energy efficiency target) to assist Europe in reducing GHG emissions (relative to 1990) by 20 per cent.

India's National Solar Mission, part of the National Action Plan on Climate Change, launched in 2008, aims to promote ecologically sustainable energy growth, constituting "a major contribution by India to the global effort to meet the challenges of climate change."

Climate-driven action is certainly not limited to national governments. Renewables are playing an important role in the climate mitigation strategies of numerous states, cities and local governments. The Compact of States and Regions, launched in 2014, committed to GHG reduction targets, with most members setting renewable energy targets to achieve them.

As of December 2015, membership included 44 supporting states and regions on almost every continent, representing 325 million people and one eighth of the global economy.

By early 2016, over 450 cities from all continents and regions, representing more than 391 million people, had committed to the Compact of Mayors since its launch by UN Secretary-General Ban Ki-moon in 2014.

This global coalition aims to position cities as climate leaders and to demonstrate the global impact of local action. At COP21 in Paris, the Compact of Mayors announced a formal partnership with the Covenant of Mayors, which brings together thousands of local and regional authorities (mostly in Europe, but expanding globally) that commit voluntarily to implementing EU climate and energy objectives in their own territory.

Alongside COP21, the Climate Summit for Local Leaders issued a declaration that was signed by 1,000 mayors from around the world, pledging to support a transition to 100 per cent renewable energy by 2050. Other efforts to advance 100 per cent renewables include the 100 per cent RES Communities and RES Champions League in Europe, and the Global 100 percent RE initiative.

Alongside COP21, the Climate Summit for Local Leaders issued a declaration that was signed by

1000

Mayors

Many countries and regions were increasing the deployment of renewables to address climate change.

> The NDCs have become the cornerstone of global efforts to address climate change.

Nationally Determined Contributions (NDCs)

In preparation for the 21st Conference of the Parties (COP21) to the UN Framework Convention on Climate Change (UNFCCC), held in Paris in late 2015, 189 countries, representing an estimated 95 per cent of global emissions and 98 per cent of population, submitted Intended Nationally Determined Contributions (INDCs).

The vast majority of countries prioritized the energy sector in their plans, with most of these relying primarily on deployment of renewable energy and energy efficiency technologies to achieve their stated emissions reduction targets.

The adoption of the Paris Agreement in December 2015 by 196 countries that are Parties to the United Nations Framework Convention on Climate Change (UNFCCC) represented a breakthrough and paradigm shift in global climate action. The blueprint agreed on how to keep global climate change temperature well below 2 °C is seen by many world leaders that gathered in Paris in December 2015, as the last hope for humanity to preserve the foundations for a healthy planet.

Under the blueprint of the Paris Agreement, each country is expected to convert the climate action plan set in the INDC into a Nationally Determined Contribution (NDC).

The NDC, describing the targets of the country, and the means for reaching the targets, is expected to be reviewed every 5 years, with first review due by December 2020. As at 31 August 2019, 184 Parties have submitted their first NDCs (i.e. converted their INDCs into NDCs) and 1 Party has submitted their second NDCs.

The NDCs have become the cornerstone of global efforts to address climate change, that should be an important focus of attention by any sector, company and organization, wishing to understand what role they can play, and how they will be impacted by the new climate policies.

A review of the submitted NDCs provides some reflections on the role that the energy industry could play, in general; and the contributions that the renewable energy sector, in particular, could make to the global effort to combat climate change.

The three tables that follow show, the target, scope, salient points, and role of renewable energy, in the NDCs submitted by:

- Top 15 Countries plus the OPEC Members, excluding Russia (3rd), Iraq (4th), Iran (5th), Angola (14th), and Libya (20th); that have not submitted any NDCs to the UNFCCC, as well as, Venezuela (11th), Ecuador (26th), Congo (31st), Equatorial Guinea (37th), and Gabon (38th); who submitted their NDCs in Spanish or French;
- OECD Countries according to 2018 GDP Ranking, excluding Turkey, the only OECD country that has not submitted an NDC to the UNFCCC;
- Top 20 Countries by total GHG annual emissions in 2017.

List of countries by oil production (Top 15 Countries plus the OPEC Members)

Note: This table excludes Russia (3rd), Iraq (4th), Iran (5th), Angola (14th), and Libya (20th); that has not submitted any NDCs to the UNFCCC, as well as, Venezuela (11th), Ecuador (26th), Congo (31st), Equatorial Guinea (37th), and Gabon (38th); who submitted their NDCs in Spanish or French.

Rank	Country	Oil Production (bbl/day)	NDC Target	Scope, Salient Points and Role of Renewable Energy	Use of Markets
01	USA	15,043,000	26%-28% below its 2005 level in 2025.	Economy-wide target covering all IPCC sectors. Opportunities under existing laws and regulations.	Not now.
02	Saudi Arabia (OPEC)	12,000,000	Co-benefits of up to 130 million tons of CO2eq avoided by 2030 annually.	Through contributions to economic diversification and adaptation. Industrialization based on sustainable utilization of all energy resources, including investment in ambitious programmes for renewable energy.	No mention
06	China	3,980,650	By 2020, reduce CO2 per unit of GDP by 40-45% from the 2005. By 2030, reduce by 60-65% and achieve peaking.	Increase the share of non-fossil fuels in primary energy consumption to about 15% in 2020 and 20% by 2030. Increase the forest stock volume by around 1.3 billion cubic meters by 2020, compared to the 2005 levels and by around 4.5 billion cubic meters by 2030. Expand the use of natural gas, while promoting the development of hydro power, wind, solar, geothermal energy, bio-energy and maritime energy.	Yes. Steadily implementing a nationwide ETS, building on existing Pilots schemes.
07	Canada	3,662,694	30% below its 2005 level in 2030. Reduction of methane emissions by 45%	Reduce emissions across all sectors of the economy. Cover all GHG gases under the UNFCCC, as well as, reduction of black carbon – a short-lived climate pollutant. Using opportunities to generate renewable fuel from waste. Financial support for renewables.	Yes. Pricing carbon is central to Canada's plan.
08	United Arab Emirates (OPEC)	3,106,077	24% clean energy of total energy mix by 2021	Actions would be based on economic diversification that will yield mitigation and adaptation co-benefits. The focus of the target will be on renewable & nuclear.	Not mentioned.
09	Kuwait (OPEC)	2,923,825	BAU during the period 2020-2030. Peak by 2035.	In the context of the country's sustainable development plans. Projects related to energy from solid wastes and renewable sources (solar and wind).	No direct mention but open to use.
10	India	2,515,459	Reduce CO2 per unit of GDP by 20-25% compared to 2005 level, and 33-35% by 2030.	Context of developmental challenges the country faces. Promoting renewables through Renewable Energy Certificates (REC) and Renewable Purchase Obligation (RPO). Achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.	Yes. Perform Achieve and Trade (PAT) system and sellable RECs.
12	Mexico	2,186,877	Unconditionally reduce by 25% of BAU (based on 2013 baseline) by 2050. Net peaking from 2026.	Decoupling GHG emissions from economic growth. The commitment of 25% reduction could increase to 40% subject to a global agreement on carbon price, carbon border adjustments, technical cooperation, access to low-cost financial resources and technology transfer.	Yes. The conditional goal requires international market mechanisms.

Rank	Country	Oil Production (bbl/day)	NDC Target	Scope, Salient Points and Role of Renewable Energy	Use of Markets
13	Nigeria (OPEC)	1,999,885	20% unconditional reduction and 45% conditional from BAU by 2030.	Context of economic and social development, entailing annual economic growth of 5%, improve standard of living, and electricity access for all. Measures include achieving off-grid solar PV capacity of 13GW.	Not mentioned.
15	Norway	1,647,975	At least 40% reduction by 2030 compared to 1990 levels.	The emission reduction target will be developed into an emissions budget covering the period 2021-2030. Economy wide covering 100% of emissions. Renewable energy is among the priority areas for enhancing the national climate policy efforts of Norway.	Yes. Within the EUETS or mechanisms under the UNFCCC.
18	Algeria (OPEC)	1,348,361	7-22% GHG by 2030 compared to BAU and 9% reduction in energy consumption.	Algeria's mitigation strategy is based on a national programmes for renewable energy and energy efficiency, involving large scale deployment of photovoltaic, wind power and solar energy, to reach a target of 27% of total electricity generation by 2030.	Not mentioned.

OECD Countries According to GDP Ranking (2018)

Note: This table excludes Turkey, the only OECD country that has not submitted an NDC to the UNFCCC.

Rank	Country	2018 (USD)	NDC Target	Scope, Salient Points and Role of Renewable Energy (RE)	Use of Markets
01	Luxembourg (Collective EU NDC)	110,906	At least 40% domestic reduction in GHG emissions by 2030 compared to 1990 level	Collective for the EU and all its Member States. Economy wide covering 100% of emissions. Build on domestic legally-binding legislation, including renewable energy targets, already in place for the 2020 climate and energy package. The emissions in the EU and its Member States peaked in 1979.	No use of international credits. Use of EU-ETS.
02	Ireland	83,081	As for EU NDC	Part of the collective EU NDC	Only EUETS.
03	Switzerland	67,961	50% by 2030 and 70-85% by 2050 compared to 1990 levels.	Corresponds to an average reduction of GHG emissions by 35% over the period 2021-2030. Switzerland plans its climate policy in 10-year-steps, continuously strengthening its reduction targets.	Yes. Will use carbon credits.
04	Norway	65,603	At least 40% reduction by 2030 compared to 1990 levels.	The emission reduction target will be developed into an emissions budget covering the period 2021-2030. Economy wide covering 100% of emissions. Renewable energy is among the priority areas for enhancing the national climate policy efforts of Norway.	Yes. EUETS or mechanisms under the UNFCCC.

Rank	Country	2018 (USD)	NDC Target	Scope, Salient Points and Role of Renewable Energy (RE)	Use of Markets
05	United States	62,480	26%-28% below its 2005 level in 2025.	Economy-wide target covering all IPCC sectors. Opportunities under existing laws and regulations.	Not now.
06	Iceland	57,453	At least 40% reduction by 2030 compared to 1990 levels.	Iceland aims to be part of a collective delivery by European countries. A precise commitment for Iceland within such collective delivery has yet to be determined and agreed. Iceland's electricity production and heating comes almost 100% from renewable energy, with minimal emissions. Iceland considers the utilization of its renewable energy sources to have global benefits from a climate change perspective.	Yes. EUETS and part outside EUETS. Access to markets is very important.
07	Netherlands	56,326	As for EU NDC	Part of the collective EU NDC	Only EUETS.
08	Austria	55,529	As for EU NDC	Part of the collective EU NDC	Only EUETS.
09	Denmark	55,138	As for EU NDC	Part of the collective EU NDC	Only EUETS.
10	Australia	54,144	26-28% below 2005 levels by 2030, equal to cuts of 50-52% per capita and 64-65% per unit of GDP.	Commitments through direct action policy, including the Emissions Reduction Fund, that supports businesses and the community to reduce emissions, while improving productivity and sustaining economic growth. Under Australia's Renewable Energy Target scheme, over 23 per cent of Australia's electricity will come from renewable sources by 2020.	Yes. Trading and putting a price on carbon through the ERF.
11	Germany	53,752	As for EU NDC	Part of the collective EU NDC	Only EUETS.
12	Sweden	52,767	As for EU NDC	Part of the collective EU NDC	Only EUETS.
13	Belgium	50,442	As for EU NDC	Part of the collective EU NDC	Only EUETS.
14	Finland	48,248	As for EU NDC	Part of the collective EU NDC	Only EUETS.
15	Canada	48,107	30% below its 2005 level by 2030. Reduction of methane emissions by 45%	Reduce emissions across all sectors of the economy. Cover all GHG gases under the UNFCCC, as well as, reduction of black carbon - a short-lived climate pollutant. Using opportunities to generate renewable fuel from waste. Financial support for renewables.	Yes. Pricing carbon is central to Canada's plan.
16	UK	45,505	As for EU NDC	Part of the collective EU NDC	Only EUETS.
17	France	45,149	As for EU NDC	Part of the collective EU NDC	Only EUETS.
18	Japan	42,823	26% below its 2013 or 25.4% below 2005 levels by 2030.	The Great East Japan Earthquake and the accident at Fukushima, brought a drastic change in Japan's circumstances with regard to energy. Target ensures consistency with Japan's energy mix. Support developing countries	Yes, through Joint Crediting Mechanism
19	Italy	41,626	As for EU NDC	Part of the collective EU NDC	Only EUETS.

Rank	Country	2018 (USD)	NDC Target	Scope, Salient Points and Role of Renewable Energy (RE)	Use of Markets
20	New Zea-land	40,713	30% below 2005 levels by 2030.	Economy-wide target covering all sectors and all GHGs. Absolute reduction target managed using a carbon budget. In meeting its target New Zealand intends to use international market mechanisms.	Yes. Use of market mechanisms
21	South Korea	40,096	37% below BAU by 2030. (BAU is 850.6 MtCO2eq)	Making efforts to address climate change across all economic sectors in accordance with its Framework Act on Low Carbon, Green Growth. Power generators are to supply a portion of electricity from renewable sources and increasing this portion of renewable energy to reduce GHG from fossil fuel.	Yes. Use carbon credits from markets.
22	Spain	39,908	As for EU NDC	Part of the collective EU NDC	Only EUETS.
23	Israel	39,835	26% below 2005 per capita level by 2030.	Reducing its per capita emissions from 10.4 tCO2e in 2005 to 7.7 tCO2e by 2030. Sector specific targets include 17% of the electricity generated in 2030 to be from renewable. Remove barriers for the uptake of renewable energy.	No specific mention of markets.
24	Czech Republic	39,741	As for EU NDC	Part of the collective EU NDC	Only EUETS.
25	Slovenia	38,135	As for EU NDC	Part of the collective EU NDC	Only EUETS.
26	Estonia	35,498	As for EU NDC	Part of the collective EU NDC	Only EUETS.
27	Slovakia	33,924	As for EU NDC	Part of the collective EU NDC	Only EUETS.
28	Portugal	33,035	As for EU NDC	Part of the collective EU NDC	Only EUETS.
29	Poland	30,989	As for EU NDC	Part of the collective EU NDC	Only EUETS.
30	Hungary	30,666	As for EU NDC	Part of the collective EU NDC	Only EUETS.
31	Greece	29,592	As for EU NDC	Part of the collective EU NDC	Only EUETS.
32	Turkey	28,205	No NDC	No NDC	No NDC
33	Chile	25,168	30% below 2007 per GDP level by 2030. Could reach 35-45% subject to IMF grant.	Cost of electricity is one of the highest among OECD countries. Incentives for Non-conventional Renewable Energies (NCRE), pursuant to Law 20.698, requiring that, by 2025, 20% of the energy under supply contracts subject to said law be generated from non-conventional renewable energies.	Yes. Carbon pricing, carbon tax, and market mechanisms.
34	Mexico	20,145	Unconditionally reduce by 25% of BAU (based on 2013 baseline) by 2050.	Decoupling GHG emissions from economic growth. The commitment of 25% reduction could increase to 40% subject to a global agreement on carbon price, carbon border adjustments, technical cooperation, access to low-cost financial resources and technology transfer. Peaking from 2026.	Yes. The conditional goal requires markets.

Top 20 Countries by Total Greenhouse Gas (GHG) Annual Emissions in 2017

(It is based on data for carbon dioxide, methane, nitrous oxide, perfluorocarbon, hydrofluorocarbon, and sulfur hexafluoride emissions compiled by the World Resources Institute)

Rank	Country	GHG emissions (MtCO2e)	Level of global total	NDC Target	Scope, Salient Points and Role of Renewable Energy	Use of Markets
01	China	12454.7	27.51%	By 2020, reduce CO2 per unit of GDP by 40-45% from the 2005. By 2030, reduce by 60-65% and achieve peaking.	Increase the share of non-fossil fuels in primary energy consumption to about 15% in 2020 and 20% by 2030. Increase the forest stock volume by around 1.3 billion cubic meters by 2020, compared to the 2005 levels and by around 4.5 billion cubic meters by 2030. Expand the use of natural gas, while promoting the development of hydro power, wind, solar, geothermal energy, bio-energy and maritime energy.	Yes. Steadily implementing a nationwide ETS, building on existing Pilots schemes.
02	United States	6673.4	14.75%	26%-28% below its 2005 level in 2025.	Economy-wide target covering all IPCC sectors. Opportunities under existing laws and regulations.	Not now.
03	European Union	4224.5	9.33%	At least 40% domestic reduction in GHG emissions by 2030 compared to 1990 level	Collective for the EU and all its Member States. Economy wide covering 100% of emissions. Build on domestic legally-binding legislation, including renewable energy targets, already in place for the 2020 climate and energy package. The emissions in the EU and its Member States peaked in 1979.	No use of international credits. Use of EU-ETS.
04	India	2379.2	6.43%	Reduce CO2 per unit of GDP by 20-25% compared to 2005 level, and 33-35% by 2030.	Context of developmental challenges the country faces. Promoting renewables through Renewable Energy Certificates (REC) and Renewable Purchase Obligation (RPO). Achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.	Yes. Perform Achieve and Trade (PAT) system and sellable RECs.
05	Russia	2199.1	4.86%	No NDC	No NDC	No NDC
06	Japan	1353.3	2.99%	26% below its 2013 or 25.4% below 2005 levels by 2030.	The Great East Japan Earthquake and the accident at Fukushima, brought a drastic change in Japan's circumstances with regard to energy. Target ensures consistency with Japan's energy mix. Support developing countries	Yes, through Joint Crediting Mechanism
07	Brazil	1017.9	2.25%	37% below 2005 levels in 2025. 43% below 2005 levels in 2030 (indicative, only for reference purposes). Increase sustainable biofuels in energy mix to 18% by 2030.	All policies, measures and actions to implement Brazil's NDC are carried out under the National Policy on Climate Change (Law 12,187/2009), the Law on the Protection of Native Forests (Law 12,651/2012, hereinafter referred as Forest Code), the Law on the National System of Conservation Units (Law 9,985/2000), related legislation, instruments and planning processes. Cogeneration of electricity using biomass, already achieving 75% of renewables in electricity supply and 40% of renewables in total energy mix. Increase to 45% of renewables in the energy mix by 2030.	Yes. Only units within UNFCCC mechanisms are recognized.

Rank	Country	GHG emissions (MtCO2e)	Level of global total	NDC Target	Scope, Salient Points and Role of Renewable Energy	Use of Markets
08	Germany	894.1	1.98%	As for EU NDC	Part of the collective EU NDC	Only EUETS.
09	Indonesia	744.3	1.64%	26% (41% conditional on support) against BAU by 2020. 29% (41% conditional on international support) below BAU by 2030.	For 2020 and beyond, Indonesia has set ambitious goals for sustainability related to production and consumption of food, water, and energy. Promulgated relevant legal and policy instruments, including the national action plan on GHG emissions reduction as stipulated in Regulation No. 61/2011. Embarked on a mixed energy use policy to achieve renewable energy at least 23% in 2025 and at least 31% in 2050.	No specific mention of the use of carbon markets in the NDC.
10	Canada	738.4	1.63%	30% below its 2005 level in 2030. Reduction of methane emissions by 45%	Reduce emissions across all sectors of the economy. Cover all GHG gases under the UNFCCC, as well as, reduction of black carbon - a short-lived climate pollutant. Using opportunities to generate renewable fuel from waste. Financial support for renewables.	Yes. Pricing carbon is central to Canada's plan.
11	Mexico	733.0	1.62%	Unconditionally reduce by 25% of BAU (based on 2013 baseline) by 2050.	Decoupling GHG emissions from economic growth. The commitment of 25% reduction could increase to 40% subject to a global agreement on carbon price, carbon border adjustments, technical cooperation, access to low-cost financial resources and technology transfer. Peaking from 2026.	Yes. The conditional goal requires markets.
12	Iran	716.8	1.58%	No NDC	No NDC	No NDC
13	South Korea	673.5	1.49%	37% below BAU by 2030. (BAU is 850.6 MtCO2eq)	Making efforts to address climate change across all economic sectors in accordance with its Framework Act on Low Carbon, Green Growth. Power generators are to supply a portion of electricity from renewable sources and increasing this portion of renewable energy to reduce GHG from fossil fuel.	Yes. Use carbon credits from markets.
14	Australia	580.1	1.28%	26-28% below 2005 levels by 2030, equal to cuts of 50-52% per capita and 64-65% per unit of GDP.	Commitments through direct action policy, including the Emissions Reduction Fund (ERF), that supports businesses and the community to reduce emissions, while improving productivity and sustaining economic growth. Under Australia's Renewable Energy Target scheme, over 23 per cent of Australia's electricity will come from renewable sources by 2020.	Yes. Trading and putting a price on carbon through the ERF.
15	Saudi Arabia	546.8	1.21%	Co-benefits of up to 130 million tons of CO2eq avoided by 2030 annually.	Through contributions to economic diversification and adaptation. Industrialization based on sustainable utilization of all energy resources, including investment in ambitious programmes for renewable energy.	No mention

Rank	Country	GHG emissions (MtCO2e)	Level of global total	NDC Target	Scope, Salient Points and Role of Renewable Energy	Use of Markets
16	UK	546.3	1.20%	As for EU NDC	Part of the collective EU NDC	Only EUETS.
17	South Africa	510.2	1.13%	Commitment in the form of a peak, plateau and decline (PPD) GHG emissions trajectory, translates to emissions in a range between 398 and 614 Mt CO2-eq by 2025 and 2030.	Transitioning international mitigation commitment from a relative "deviation from BAU" to an absolute peak, plateau and decline GHG emissions trajectory range, based on science and equity. Context of the environmental right set out in Section 24 of the Constitution, 2030 National Development Plan, 2011 National Climate Change Response Policy, and the National Sustainable Development Strategy. Private investment through Renewable Energy Independent Power Producer Procurement Programme (REI4P) has already totaled US$ 16 billion. REI4P to be expanded at an estimated incremental cost of US$3 billion per year ten years. Decarbonized electricity by 2050. Invest US$513 billion in Electric Vehicles between 2010 and 2050, with the aim of having 20% Hybrid Electric Vehicles in total fleet by 2030.	No specific mention of the use of carbon markets in the NDC.
18	France	440.8	0.97%	As for EU NDC	Part of the collective EU NDC	Only EUETS.
19	Italy	420.8	0.93%	As for EU NDC	Part of the collective EU NDC	Only EUETS.
20	Turkey	408.5	0.90%	No NDC	No NDC	No NDC

Summary of renewable energy profile for some key countries

The renewable energy profile for 15 selected countries (8 Developed and 7 Developing) from the lists of countries in the above three tables are summarized below.

Brazil

As of 2018, renewable energy accounted for 79 per cent of the domestically produced electricity used in Brazil. Brazil relies on hydroelectricity for 65 per cent of its electricity, and the Brazilian government plans to expand the share of biomass and wind energy (currently 6 per cent) as alternatives. Wind power in Brazil amounted to an installed capacity of more than 8 GW as of 2015. Wind strength being more intense from June to December, coinciding with the months of lower rainfall intensity, wind energy is considered to have the greatest potential in Brazil during the dry season. It provides a hedge against low rainfall and the geographical spread of existing hydroelectric resources, making wind a potential good complementary source of energy to hydroelectricity.

79%

of the domestically produced electricity used in Brazil in 2018 was from renewable energy

Brazil held its first wind-only energy auction in 2009, in a move to diversify its energy portfolio and several foreign companies participated in the bidding that led to the construction of 2 gigawatts (GW) of wind production with an investment of about USD 6 billion over the following two years. The industry hopes the auction will help kick-start the wind-energy sector, which already accounts for 70 per cent of the total in all of Latin America. The potential for wind energy in Brazil is estimated at 143 GW. Brazil's wind energy production grew from 22 MW in 2003 to 602 MW in 2009, and to over 8,700 MW by 2015. The Brazilian Wind Energy Association and the government have set a goal of achieving 20 GW of wind energy capacity by 2020. Developing wind power sources in Brazil is helping the country to meet its strategic objectives of enhancing energy security, reducing GHG emissions and creating jobs.

The oil shocks in the 1970s, made Brazil focus more attention on developing alternative sources of energy, using the country's large sugarcane farms as a leverage for the development of sugarcane ethanol. In 1985, 91 per cent of cars produced that year ran on sugarcane ethanol. The success of flexible-fuel vehicles, introduced in 2003, together with the mandatory E25 blend throughout the country, have allowed ethanol fuel consumption in the country achieve a 50 per cent market share of the gasoline-powered fleet by February 2008. Brazil is currently the second largest producer of ethanol in the world and is the largest exporter of the fuel. Over half of all cars in the country are of the flex-fuel variety, meaning that they can run on 100 per cent ethanol or an ethanol-gasoline mixture. The proportion of light vehicle running on pure ethanol is expected to increase to over 80 per cent by 2020.

More than 1 million people in Brazil work in the production of biomass. Biomass reduces environmental pollution as it uses organic garbage, agricultural remains, wood shaving or vegetable oil. Refuse cane, with its high energy value, has been used to produce electricity. The recent interest in converting biomass to electricity comes not only from its potential as a low-cost, indigenous supply of power, but for its potential environmental and developmental benefits. The low level of CO2 emissions from renewably grown biomass, is generating a lot of interest in biomass as a globally important mitigation option for reducing the rate of CO2 buildup in atmosphere by sequestering carbon and by displacing fossil fuels.

China

China is the world's leading country in electricity production from RES, with over double the generation of the second-ranking country, the USA. In 2013, the country had a total capacity of 378 GW of renewable power, mainly from hydroelectric and wind power. China's renewable energy sector is growing faster than its fossil fuels and nuclear power capacity.

China's energy needs are so large that, notwithstanding China having the world's largest installed capacity of hydro, solar and wind power in 2015, renewable sources provided only 24 per cent of its electricity generation. Most of the remaining 76 per cent energy required in 2015 was provided by coal power plants. In 2017, renewable energy comprised 36.6 per cent of China's total installed electric power capacity, and 26.4 per cent of total power generation, showing the steady rise in share of renewable sources in the energy mix in recent years. The government gave a strong signal to increase the share of renewables in the country's energy mix by developing in 2013, an Action Plan for the Prevention and Control of Air Pollution. The Action Plan issued by the State Council sees renewables as a source for reducing air pollution, ensuring energy security, and mitigating climate change. Unlike oil, coal and gas, the supplies of which are finite and subject to geopolitical tensions, renewable energy systems can be built and used wherever there is sufficient water, wind, and sun.

China is the world's leading country in electricity production from RES.

India

India is one of the countries with the largest production of energy from renewable sources. In the electricity sector, renewable energy accounts for 34.6 per cent of the total installed power capacity, with large hydro dominating at an installed capacity of 45 GW (13 per cent of the total power capacity) as of 31 March 2019. The other remaining RES accounted for 22 per cent of the total installed power capacity of 77.641 GW.

In the same period, wind power capacity was 37 GW, making India the fourth-largest wind power producer in the world. The country has a strong manufacturing base in wind power with 20 manufacturers of 53 different wind turbine models, exporting to Europe, the USA and other countries.

The government target of installing 20 GW of solar power by 2022 was achieved four years ahead of schedule in January 2018, through both solar parks as well as roof-top solar panels. This record achievement spurred the country to set a new target of 100 GW of solar power by 2022. Four of the top seven largest solar parks worldwide are in India including the second largest solar park in the world at Kurnool, Andhra Pradesh, with a capacity of 1 GW. The construction of the Bhadla Solar Park, in Rajasthan that was due for completion by the end of 2018, would become the world's largest solar power plant, with a capacity of 2.25 GW.

By 31 March 2019, power from biomass combustion, biomass gasification and bagasse cogeneration reached 9.1 GW, and from family type biogas plants reached 4 GW installed capacity. Prior to 2019 India did not count large hydropower towards its renewable energy targets because large hydropower was under the jurisdiction of a different government ministry. The change in 2019, that reclassified the power generated from large hydropower plants under renewable sources, made it possible for large hydropower plants to be able to sell their power under the Renewable Energy Purchase Obligation. Under the Renewable Energy Purchase Obligation, the power Distribution Companies (DISCOMs) of the various states are obligated to source a certain percentage of their power from RES under two categories - solar and non-solar, with power from large hydropower plants falling under the non-solar renewable energy category.

It is worth noting that the government of India is scaling down on coal-based power generating capacity, with no intention for new coal-based capacity addition beyond the current 50 GW coal power plants that are at different stages of construction and expected to come online between 2017 and 2022.

Indonesia

The renewable energy profile of Indonesia needs to be considered in the context of the country's abundant energy resources. Indonesia's tropical rain forests and peat land areas have extensive coal storage. Indonesia has significant energy resources, including oil, natural gas and coal. It has 22 billion barrels of conventional oil and gas reserves, of which about 4 billion are recoverable, equivalent to about 10 and 50 years of oil and gas production respectively. It has about 8 billion barrels of oil-equivalent of coal-based methane (CBM) resources. It has 28 billion tonnes of recoverable coal and has 28 GW of geothermal potential.

Renewable energy potential in Indonesia is mainly from solar, wind, hydro and geothermal energy.

Renewable generation sources supplied 5 to 6 per cent of Indonesia's electricity in 2015. Indonesia has set a target of 26 per cent of electricity generation from renewable sources by 2025.

An estimated 55 per cent of Indonesia's population, i.e. 128 million people primarily rely upon traditional biomass (mainly wood) for cooking. Reliance on this source of energy by poor people in rural areas with little alternative, results in serious deforestation.

Indonesia has many Palm Oil Mills and has been piloting, since 2014, the use of effluents from these mills in a Palm Oil Mill Effluent (POME) Power Generator with a capacity of 1 MW, as a way to address the massive deforestation challenge.

Indonesia has set a target of 2 GW installed capacity in hydroelectricity, by 2025. With 1.3 GW installed capacity, Indonesia has the third largest installed generating capacity of geothermal energy in the world, trailing only the USA (3.4 GW) and the Philippines (1.9 GW), and ahead of Mexico (1.0 GW), Italy (0.9 GW), New Zealand (0.8 GW), Iceland (0.7 GW), and Japan (0.5 GW).

South Africa

Renewable energy in South Africa focuses on four core areas - electricity generation, air and water heating/cooling, transportation, and rural energy services – and drawing from sources such as, sunlight, wind, tides, waves, rain, biomass, and geothermal heat. The energy sector in South Africa is an important component of global energy regimes due to the country's innovation and advances in renewable energy, as well as, it's contribution to GHG emissions, with a per capita emission rate higher than the global average. Energy demand in South Africa is expected to rise steadily and double by 2025.

The geographic location of South Africa ensures that the country receives large amounts of radiative energy, considered very useful in the solar electricity sector, making solar power to hold the most potential in South Africa, among all the available RES. Wind is also another renewable energy source with high potential in South Africa. Multiple wind farms have been implemented in Cape Town, the taking advantage of the high wind velocity prevalent along the coastline of the country. These wind farms have been found to be successful in generating significant amounts of electricity for the residents of Cape Town. Notwithstanding the huge solar and wind potential that exists in the country, biomass is currently the largest renewable energy contributor in South Africa, with 9-14 per cent of the total energy mix.

The geographic location of South Africa ensures that the country receives large amounts of radiative energy.

South Korea

The renewable energy profile of South Korea is premised on the country being a major energy importer - importing nearly all of its oil needs and the second-largest importer of liquefied natural gas in the world. Electricity generation in South Korea mainly comes from conventional thermal power, which accounts for more than two thirds of production, and from nuclear power.

In order to reduce reliance on foreign oil imports, the government took a major decision in 2008 to increase investment in renewable energy. This provided the much-needed incentive for conglomerates to invest in solar power plants. South Korea continues to grow its market for large-scale PVs and in 2014, the country ranked among the world-leading top-ten installers of PV systems.

Mexico

Renewable energy in Mexico contributes 26 per cent of electricity generation in Mexico, coming mainly from hydro power, geothermal, solar power and wind. The country has established a long-term effort and ambition to increase the use of RES. It is anticipated that the percentage electricity generation from RES in Mexico will rise to 35 per cent by the year 2035.

As Mexico is located directly on the global solar belt, solar energy is considered the most efficient and convenient renewable energy source for Mexico. In addition, the large land mass, covering vast open spaces of the country, makes it very easy to construct solar panels in Mexico. In Mexico wind energy is concentrated within five major regions, allowing for funding and manpower for the development of wind to be readily allocated to where it could be most efficiently utilised. Mexico has also invested into a lot of time and effort in the development of biomass, which is the most common form of renewable energy in the country. However, energy from biomass has seen a steady decline, in the last few years, as the other forms of renewable energy become more used and researched.

The amount of geothermal energy used and harvested, places Mexico as number four in the world. As the importance of clean sustainable energy becomes more prevalent, the country and government officials continue to invest in research and innovations to enable Mexico, remain a leading example of renewable energy.

“The amount of geothermal energy used and harvested, places Mexico as number four in the world.”

Australia

Renewable energy in Australia includes wind power, hydroelectricity, solar PV, heat pumps, geothermal, wave and solar thermal energy. Australia produced 32 TWH of overall renewable energy (including renewable electricity) in 2018 which accounted for 6.2 per cent of Australia's total energy use. Renewable energy showed an annual average growth rate of 3.2 per cent in the ten years between 2007-2017 and by 5.2 per cent between 2016-2017. This contrasts to growth in coal (-1.9 per cent), oil (1.7 per cent) and gas (2.9 per cent) over the same ten-year period.

As at 2018 Hydropower supplied 35.2 per cent of Australia's renewable electricity generation. The Snowy Mountains Scheme, the largest hydropower system in Australia, was constructed between 1949 and 1974, and consists of 16 major dams and 7 major power stations, and has a total generating capacity of 3.8 GW, providing on average, 4,500 GWh electricity per year. Australia has plans to increase the Snowy Hydro scheme by 50 per cent or 2 GW. Hydro Tasmania operates 30 power stations and 15 dams, with a total generating capacity of 2.6 GW, and generates an average of 9,000 GWh of electricity per year. There are also plans to upgrade Tasmania's hydropower system to give it the capability to function as pumped hydro storage.

As at July 2018, total electricity sourced in Australia was wind power, representing 33.5 per cent of Australia's renewable electricity generation. Nine new wind farms were commissioned in 2018 and as at the end of 2018, 24 wind farms with a combined capacity of 5.9 GW were either under construction nationally, or financial committed have been made. Wind power in South Australia is the most developed, supplying 5,692 GWh, followed by Victoria with 4528 GWh, New South Wales (3124 GWh), Western Australia (1595 GWh), Tasmania (1093 GWh) and Queensland with 141 GWh. The Largest Wind farm in Australia is the Macarthur Wind Farm in Victoria, which opened in 2013 with a capacity of 0.42 GW.

Solar power is becoming a fast-growing industry in Australia, with solar accounting for 5.2 per cent (or 11.7 TWh) of Australia's total electrical energy production in 2018. As of March 2019, Australia's over 2 million solar PV installations had a combined capacity of 12,035 MW of which 4,068 MW were installed only during the preceding 12 months. Australia has developed world leading solar thermal technologies, but with only very low levels of actual use. Domestic solar water heating is the most common solar thermal technology. After a successful world leading research into flat plate solar water heaters, during the 1950s, by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), a solar water heater manufacturing industry was established in Australia and a large proportion of the manufactured product was exported. Four of the original companies are still in business and the manufacturing base has now expanded to 24 companies. Despite an excellent solar resource, the penetration of solar water heaters in the Australian domestic market was only about 5 per cent in 2006. With new dwellings accounting for most sales, around 14 per cent of Australian households had solar hot water installed by 2014.

Biofuels produced from food crops have become controversial as food prices increased significantly in mid-2008, leading to increased concerns about food vs fuel. Ethanol fuel in Australia can be produced from sugarcane or grains and there are currently three commercial producers of fuel ethanol in Australia, all on the east coast. Legislation imposes a 10 per cent cap on the concentration of fuel ethanol blends.

Denmark has a target to produce

30%

of all its energy needs from RES by

2020

Denmark

Denmark is a world leading country in the use of wind energy and production of wind turbine. In 2014 Denmark produced 57.4 per cent of its net electricity generation from RES.

The Danish wind company Vestas Wind Systems A/S, by 2015, had a revenue of EUR8.423 billion, with more than 18,000 employees globally and manufacturing plants in Denmark, Germany, India, Italy, Romania, the UK, Spain, Sweden, Norway, Australia, China, and the USA. Wind power alone produced 42.7 per cent of Denmark's electricity production in 2014 and is expected to increase its production to nearly 80 per cent by 2024.

Denmark has a target of producing 30 per cent of all its energy needs from RES by 2020, a considerable increase from the 17 per cent it attained in 2005. By 2014 this figure had already reached 29.2 per cent, making Denmark the fifth highest amongst the EU-28 countries. The country has ambitious renewable energy goals for the future, including using renewable energy for 100 per cent of its energy needs in all sectors including transport by 2050.

Japan

In 1950, coal supplied half of Japan's energy needs, hydroelectricity one-third, and oil the rest. By 2001, the contribution of oil had increased to 50.2 per cent of the total, with rises also in the use of nuclear power and natural gas. Japan now depends heavily on imported fossil fuels to meet its energy demand. The country lacks significant domestic reserves of fossil fuel, except coal, and must import substantial amounts of crude oil, natural gas, and other energy resources, including uranium. Japan relied on oil imports to meet about 84 per cent of its energy needs in 2010.

While Japan had previously relied on nuclear power to meet about 30 per cent of its electricity needs, following the Fukushima Daiichi nuclear disaster, there was strong opposition by the general public to the use of nuclear energy. After the 2011 Fukushima disaster, all nuclear reactors were progressively shut down for safety concerns, but some of the reactors have been progressively restarted since late 2015.

Japan currently produces about 10 per cent of its electricity from renewable sources. The Fourth Strategic Energy Plan set the renewable share goal to be 24 per cent by 2030. In the next 15 years, Japan intends to invest USD 700 billion in renewable energy.

The Japanese government has implemented an initiative of feed-in tariff scheme, in order to boost the amount of renewable energy produced and purchased in Japan. The scheme encourages companies to invest in renewable energy by providing set prices for various types of renewable energy.

> **“Japan currently produces about 10% of its electricity from renewable sources.”**

Norway

Norway is a heavy producer of renewable energy because of hydropower, which accounts for over 95 per cent of the electricity production in mainland Norway. The total production of electricity from hydropower plants amounted to 131 TWh in 2014.

Norway is Europe's largest producer of hydropower and the 6th largest in the world. The largest producer of hydropower in Norway is the state-owned Statkraft, which owns nine of the largest hydroelectric plants in the country, making it also a major player in the international energy markets.

Norway has a large potential for wind power, offshore wind power and wave power, as well as production of bio-energy from wood. Norway has limited resources in solar energy but is one of the world's largest producers of solar grade silicon and silicon solar cells. Renewables constituted 36 per cent of the average mix of electricity consumption by a Norwegian household in 2010.

As per the EU's 2009 Renewables Directive, Norway has established a national renewable energy goal of 67.5 per cent of gross final energy consumption coming from renewable sources by 2020.

In 2012 Norway had a wind power electricity production of 1.6 TWh, and the following year, the government approved a spending of 20 billion NOK to triple its wind power capacity of 0.7 GW to more than 2 GW by 2020.

In August 2016 construction of the 1 GW Fosen Vind project was commissioned. Increased production of power from wind turbines will allow Norway to curtail its domestic consumption of hydroelectricity, which due to being dispatchable is a valuable asset in the international power market. In order to further curtail its domestic consumption of hydroelectricity, Norway imports electricity when excess wind production in Denmark and the Netherlands drives prices down in those countries.

For the same reason, Norway is considering new transmission lines that would allow for similar trades with Scotland and Germany sometime after 2020.

Russia

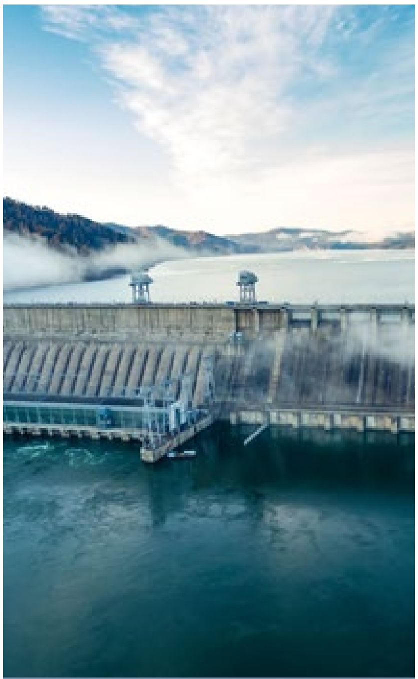
Renewable energy in Russia consists mainly of hydroelectric energy, accounting for 16 per cent of electricity generation, with all other RES generating less than 1 per cent combined.

The country is the sixth largest producer of renewable energy in the world, although it is 56th when hydroelectric energy is not taken into account. Some 179 TWh of Russia's energy production comes from RES, out of a total economically feasible potential of 1823 TWh.

Roughly 68 per cent of Russia's electricity is generated from thermal power plants and 16 per cent from nuclear power plants.

The abundance of fossil fuels in Russia resulted in little need for the development of other RES, until recently, when the Russian government is strongly supporting plans to develop all types of renewable energy and promoting having larger share of Russia's energy output coming RES.

The largest dams in Russia are the Sayano-Shushenskaya Dam, which has an installed capacity of 6,400 MW; the Krasnoyarsk Dam (6,000 MW); the Bratsk Dam (4,500 MW); the Ust-Ilimsk Dam (4,320 MW) and the Zeya Dam (1,330 MW). RusHydro is the largest hydroelectric company in Russia and the second largest hydroelectric producer in the world. Geothermal energy is the second most used form of renewable energy in Russia but represents less than 1 per cent of the total energy production. Half of the geothermal production is used to heat homes and industrial buildings, one third is used to heat greenhouses and 13 per cent is used for industrial processes. Russia's biofuel industry is new, but it has been developing rapidly in recent years. Russia is one of the largest grain producers, has a well-developed ethyl alcohol industry and has increasing rapeseed (often used to create biodiesel) production rates. Russia may become an active player in the global biofuel industry.



Russia is the sixth largest producer of renewable energy in the world.

Sweden

Within the context of the EU's 2009 Renewables Directive, Sweden was working towards reaching a 49 per cent share of renewable energy in gross final consumption of energy (electricity, heating/cooling, and transportation), by 2020. Sweden is reported to have already exceeded the Directive's 2020 target in 2014, reaching 52.6 per cent of total final energy consumption provided by renewables. This was a remarkable achievement compared to the level of just 38.7 per cent in 2004. At 52.6 per cent, Sweden was the leading country within the EU-28 group in terms of renewable energy use by share, followed by Finland and Latvia at 38.7 per cent, Austria at 33.1 per cent and Denmark on 29.2 per cent. The only two other signatories of the directive, but outside the EU-28, who were ahead of Sweden, were Iceland (77.1 per cent) and Norway (69.2 per cent).

The 2014, 52.6 per cent overall share of final energy consumption in Sweden breaks down as renewable energy providing the following shares to each sector: 68.1 per cent of the heating and cooling sector, 63.3 per cent of the electricity sector and 19.2 per cent of the transport sector.

Wind power accounted for 10 per cent of the electricity generated in Sweden in 2015, up from 5 per cent in 2012 and 2.4 per cent in 2010. Sweden has wind power potential of about 510 TWh. Consumption was 140 TWh of power in 2010.

Sweden is reported to have already exceeded the Directive's 2020 target in 2014, reaching 52.6% of total final energy consumption provided by renewables.

United Kingdom

Renewable energy in the UK can be divided into production for electricity, heat, and transport. In 2017, renewable production generated 27.9 per cent of total electricity; 7.7 per cent of total heat energy; and 4.6 per cent of total transport energy.

From the mid-1990s renewable energy began to contribute to the electricity generated in the UK, building on a small hydroelectric generating capacity. This has been surpassed by wind power, for which the UK has large potential resources. Interest has increased in recent years due to new UK and EU targets for reductions in carbon emissions and commercial incentives for renewable electricity such as the Renewable Obligation Certificate scheme (ROCs) and Feed in tariffs (FITs), as well as for renewable heat such as the Renewable Heat Incentive. The 2009 EU Renewable Directive established a target of 15 per cent reduction in total energy consumption in the UK by 2020.

Wind power delivers a growing fraction of the energy in the UK, consisting of 6,546 wind turbines with a total installed capacity of just under 12 GW: 8 GW of onshore capacity and 4 GW of offshore capacity by January 2015. The UK is ranked as the world's sixth largest producer of wind power, having overtaken France and Italy in 2012. Wind power is expected to continue growing in the UK for the foreseeable future, at an estimated rate of deployment of more than 2 GW of capacity per year for the next five years. Polling of public opinion consistently shows strong support for wind power in the UK, with nearly three quarters of the population agreeing with its use, even for people living near onshore wind turbines. Within the UK, wind power is the second largest source of renewable energy after biomass.

Notwithstanding the location of UK, suggesting that the country has great potential for generating electricity from wave power and tidal power, these technologies have not received much money for development and consequently have not yet been exploited on a significant commercial basis due to doubts over their economic viability in the UK. To date, the European Marine Energy Centre in Orkney operates a grid connected wave power scheme at Billia Croo outside Stromness and a grid connected tidal test site in a narrow channel between the Westray Firth and Stronsay Firth.

At the end of 2011, there were 230,000 solar power projects in the UK, with a total installed generating capacity of 0.75 GW. By February 2012, the installed capacity had reached 1,000 MW. Solar power use has increased very rapidly in recent years, albeit from a small base, as a result of reductions in the cost of PV panels, and the introduction of a Feed-in tariff (FIT) subsidy in April 2010. In 2012, the government said that 4 million homes across the UK will be powered by the sun within eight years, representing 22 GW of installed solar power capacity by 2020.

As of 2012, hydroelectric power stations in the UK accounted for 1.67 GW of installed electrical generating capacity, being 1.9 per cent of the UK's total generating capacity and 14 per cent of UK's renewable energy generating capacity. There are also pumped-storage power stations in the UK, and although, they are net consumers of electrical energy, they contribute to balancing the grid and help facilitate renewable generation elsewhere, by 'soaking up' surplus renewable output at off-peak times and release the energy when it is required.

United States of America

Renewable energy accounted for 12.2 per cent of total primary energy consumption and 14.9 per cent of the domestically produced electricity in the USA in 2016. Hydroelectric power is currently the largest producer of renewable electricity in the country, generating around 6.5 per cent of the nation's total electricity in 2016 as well as 45.7 per cent of the total renewable electricity generation.

In 2018, the share of electricity from hydroelectric power was 7 per cent of the nation's total electricity and 40.9 per cent of the total renewable power.

The USA is the fourth largest producer of hydroelectricity in the world after China, Canada and Brazil. The Grand Coulee Dam is the 5th largest hydroelectric power station in the world and another six U.S. hydroelectric plants are among the 50 largest in the world.

The next largest share of renewable power was provided by wind power at 6 per cent of total power production, amounting to 226.5 TWh during 2016. Wind power capacity in the USA tripled from 2008 to 2016. By January 2017, the USA generating capacity for wind power was 82 GW, with the State of Texas firmly established as the leader in wind power deployment, followed by Iowa and Oklahoma.

Solar power provides a growing share of electricity in the country, with over 50 GW of installed capacity generating about 1.3 per cent of the country's total electricity supply in 2017, up from 0.9 per cent the previous year. As of 2016, 43 States deployed net metering, where energy utilities bought back excess power generated by solar arrays. Many schools and businesses have building-integrated photovoltaic solar panels on their roof.

Most of these are grid connected and use net metering laws to allow use of electricity in the evening that was generated during the daytime. New Jersey leads the nation with the least restrictive net metering law, while California leads in total number of homes which have solar panels installed. The USA is credited with pioneering the solar thermal power technology in the 1980s.

In 2018, the share of electricity from hydroelectric power was 7% of the nation's total electricity and 40.9% of the total renewable power.

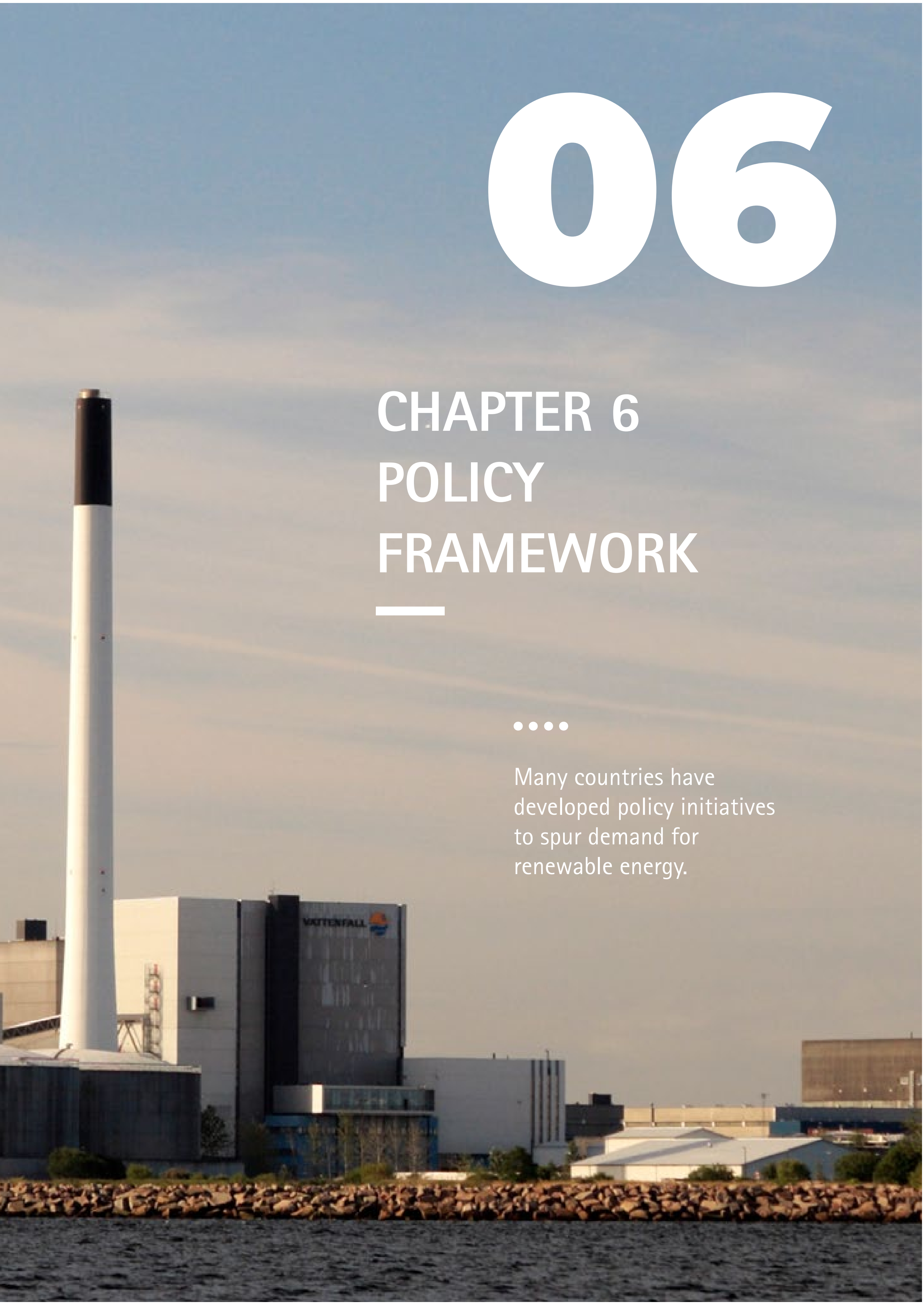
The country pioneered solar farms and many key developments in concentrated solar and photovoltaics came out of national research. Several solar thermal power stations have since been built, of which the largest are the Ivanpah Solar Power Facility (0.4 GW), southwest of Las Vegas, and the SEGS group of plants in the Mojave Desert, with a total generating capacity of 354 MW.

Other RES include geothermal, with The Geysers in Northern California the largest geothermal complex in the world.

Renewable energy in the USA, reached a major milestone in the first quarter of 2011, when it contributed 11.7 per cent of total national energy production (2.245 quadrillion BTU of energy), surpassing energy production from nuclear power (2.125 quadrillion BTU) for the first time since 1997.

The USA is credited with pioneering the solar thermal power technology in the 1980s

The USA is the fourth largest producer of hydroelectricity in the world after China, Canada and Brazil.



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CHAPTER 6 POLICY FRAMEWORK

Many countries have developed policy initiatives to spur demand for renewable energy.

A great deal of new and innovative techniques and ideas are being implemented globally, as the pursuit of green energy gains momentum. This trend began shortly after the United Nations Conference on Environment and Development (UNCED), also known as the Rio Conference, in 1992 and within the context of sustainable development and climate change, advances are primarily focused on promoting renewables and fading out fossil fuels.

Many countries have developed policy initiatives to spur demand for renewable energy. The rationale for renewables includes the need for energy that is secure, reliable, improves public health, protects the environment, addresses climate change, creates jobs, and provides opportunities to demonstrate technological leadership.

The two tables below provide a set of statistics and energy profiles for the G20 countries (20 of the world's leading economies). Some selected other countries outside of the G20 were included, allowing for regional balance. This information provides the context for the summaries of the main driving forces for the existing renewable energy policies, presented in this chapter, for the top 5 advanced economies and top 6 emerging economies, among the G20 nations (the world major developed and emerging developing countries, as ranked by 2019 GDP forecasts).

G20 NATIONS GDP - 2019 FORECAST

	GPD, current prices (billions of US dollars)	GPD Share
United States	21.482	31.2%
China	14.172	20.6%
Japan	5.221	7.6%
Germany	4.117	6.0%
India	2.958	4.3%
France	2.845	4.1%
United Kingdom	2.810	4.1%
Italy	2.113	3.1%
Brazil	1.930	2.8%
Canada	1.820	2.6%
South Korea	1.700	2.5%
Russia	1.649	2.4%
Australia	1.464	2.1%
Mexico	1.242	1.8%
Indonesia	1.067	1.6%
Saudi Arabia	796	1.2%
Turkey	631	0.9%
Argentina	408	0.6%
South Africa	386	0.6%
	Total GPD: $68.810 billions	Total GPD Share: 100%

Advanced Economies 63%

Emerging Economies 37%

Data Source: IMF World Economic Outlook, October 2018

Data Analysis by: MGM Research

Table 1: Country general profile*

Country	Population (Millions)	Surface (mmkm2)	GDP (billion USD)	Agricultural (%GDP)	Industry (%GDP)	Services (%GDP)	Unemployment Rate (%)
Argentina	44.5	2.7	408	10.9	28.2	60.9	10.1
Australia	25.2	7.7	1464	3.6	26.1	70.3	5.2
Brazil	210.4	8.5	1930	6.2	21.0	72.8	12.5
Canada	37.1	10.0	1820	1.7	28.1	70.2	5.4
China	1397.0	9.7	14175	8.3	39.5	52.2	3.7
France	65.1	0.6	2845	2.0	20.1	77.9	8.7
Germany	82.8	0.4	4117	0.6	30.1	69.3	3.2
India	1334.2	3.3	2958	12.5	45.1	42.4	7.2
Indonesia	265.3	1.9	1067	13.9	40.3	45.8	5.0
Italy	60.8	0.3	2113	2.1	24.0	73.9	10.2
Japan	126.4	0.4	5221	1.0	29.7	69.3	2.4
Mexico	124.7	2.0	1242	3.9	31.6	64.5	3.5
Russia	144.0	17.1	1649	4.7	32.4	62.9	4.7
Saudi Arabia	33.2	2.1	796	2.6	44.2	53.2	5.7
South Africa	57.4	1.2	386	2.8	29.7	67.5	27.6
South Korea	51.7	0.1	1700	2.2	39.3	58.5	4.0
Turkey	71.9	0.8	631	6.7	31.8	61.5	14.1
United Kingdom	66.5	0.2	2810	0.6	19.0	80.4	3.8
USA	328.1	9.4	21482	0.9	18.9	80.2	3.6
Qatar	2.8	0.001	355	0.2	50.3	49.5	8.9
Nigeria	195.9	0.91	1168	18.3	60.1		18.8
Algeria	42.2	2.41	657	13.2	36.1	50.7	11.2

*G20 plus selected other countries to give regional balance

Table 2: Country energy profile – 2018*

Country	Domestic Primary Energy Production (M toe)	Oil Generation (TWh)	Gas Generation (TWh)	Coal energy Generation (TWh)	Nuclear Generation (TWh)	Hydro Generation (TWh)	Solar Generation (TWh)	Wind Generation (TWh)	GHG Emissions (Million Tonnes CO2eq)
Argentina	85.1	6.4	85.3	2.0	6.9	41.6	0.1	1.4	180.3
Australia	144.3	5.3	50.2	156.6	-	17.3	12.1	16.3	416.6
Brazil	297.6	11.5	46.8	21.9	15.6	387.7	3.1	48.5	441.8
Canada	344.4	3.2	58.7	59.3	100.0	387.3	3.5	32.2	500.3
China	3273.5	10.7	223.6	4732.4	294.4	1202.4	177.5	366.0	9428.7
France	242.6	3.5	56.0	0	413.2	64.2	10.2	24.3	311.8
Germany	323.9	5.2	83.0	229.0	76.1	16.9	46.2	105.7	725.7
India	809.2	10.1	74.3	1176.3	39.1	139.7	30.7	60.3	2479.1
Indonesia	185.5	20.2	59.6	156.4	-	16.4	0	0.2	543.0
Italy	154.5	10.9	127.2	36.6	-	45.9	23.2	17.7	336.3
Japan	454.1	60.0	386.9	347.2	49.1	81.0	71.7	6.8	1148.4
Mexico	186.9	36.8	196.7	29.2	13.6	32.4	2.2	12.6	462.5
Russia	720.7	11.4	521.5	177.5	204.5	190.2	0.6	0.2	1550.8
Saudi Arabia	259.2	150.6	233.0	-	-	-	0.2	0	571.0
South Africa	121.5	0.1	1.9	225.0	11.1	0.9	4.9	6.9	421.1
South Korea	301.0	9.1	160.4	261.3	133.5	2.9	9.3	2.4	697.6
Turkey	153.5	0.6	92.2	111.7	-	59.5	7.9	19.8	389.9
United Kingdom	192.3	1.7	131.5	16.8	65.1	5.5	12.9	57.1	394.1
USA	2300.6	26.4	1578.5	1245.8	849.6	288.7	97.1	277.7	5145.2
Qatar	48.3	&	&	&	&	&	&	&	100.2
Nigeria		&	&	&	&	&	&	&	
Algeria	56.7	&	&	&	&	&	&	&	135.5

*G20 plus selected other countries to give regional balance

Policy Instruments

Before summarising the existing policy frameworks of the countries in the tables above, it is good to examine the policy instruments that are commonly used to promote the use of energy and the growth of economic activities, in general and renewable energy, in particular. Policy objectives can increase the attractiveness of renewable energy relative to other power sources. Policy instruments are means by which policy objectives are pursued. Policy instruments that are used for promoting the growth of renewable energy include:

01 Regulations and Laws

02 Economic or Pricing Instruments

03 Quantity Instruments

04 Performance standards

05 Public Procurement

06 Auctions

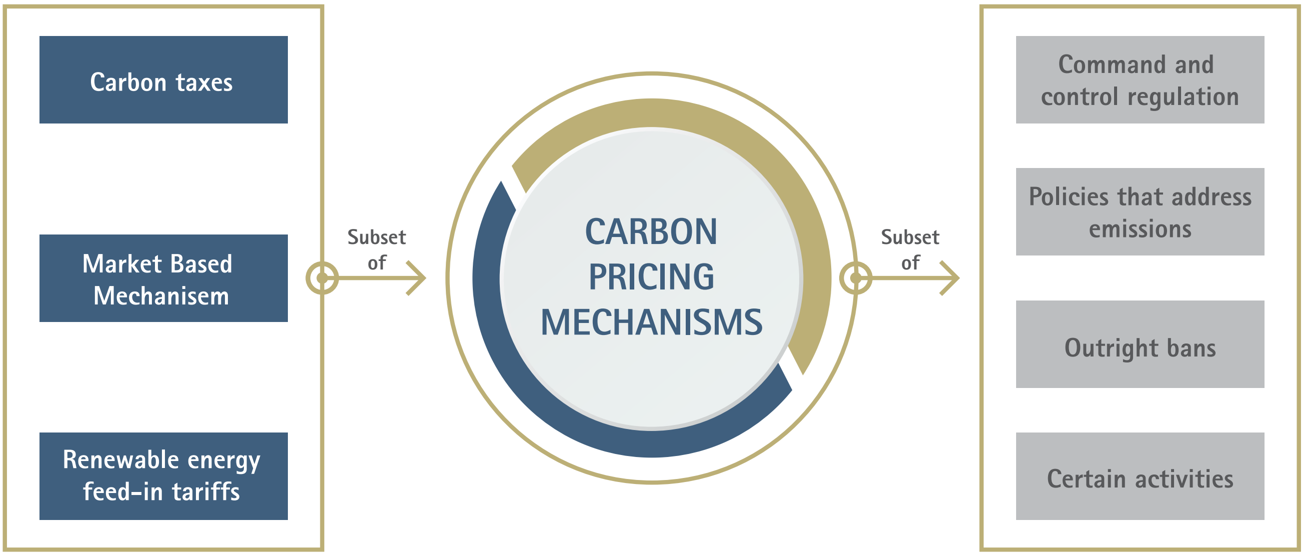
Regulations and Laws

Legal rules provide the fundamental infrastructure required for economic growth and stable societies. But the legal systems historically developed for industrialised nations are now under enormous pressure, due to the economic and social complexities tied to globalisation and technology advancements. Regulatory complexity is growing exponentially, and creating demand for clearer global standards, more agile governance, and legitimate private-sector alternatives. In the World Economic Forum's Global Competitiveness Index 2017-2018, half of the economies ranked in the overall top ten also took top spots in terms of the burden (or lack thereof) of government regulation, and transparency of government policy-making. Regulations can promote renewable energy directly through measures aimed directly at the removal of non-economic barriers and increase in demand for renewable energy, or indirectly through measures that place restrictions on the use of fossil fuels.

Economic Instruments

The global climate change discourse has particularly led to greater attention on carbon pricing mechanisms. Carbon pricing mechanisms comprise all policies that influence the cost of emitting. These include carbon taxes, market-based mechanisms and renewable energy feed-in tariffs. Feed-in tariff is a payment made to households or businesses generating their own electricity through the use of methods that do not contribute to the depletion of natural resources, proportional to the amount of power generated. Carbon pricing instruments are emerging as the policy tools of choice to address global emissions. Market-based mechanisms in particular have seen significant growth since 2002, when the three market-based mechanisms (the Clean Development Mechanism (CDM), Joint Implementation (JI), and Emission Trading (ET)) of the Kyoto Protocol came into operation. In the EU, for example, the Emissions Trading Scheme (EUETS) has grown in significance, and clearly demonstrated its effectiveness in catalyzing investment in mitigation activities. It now plays a vital role in the EU policy framework for renewables.

Carbon pricing mechanisms



Pricing Instruments help reduce cost and pricing-related barriers by establishing favorable price regimes for renewable energy relative to other sources of power generation. The two common forms of pricing instruments are:

- Fiscal Incentives such as; production/investment tax credits; capital subsidy, grant, or rebate; public investment, loans, or grants; increase in taxes on fossil fuels; reductions in sales, energy, CO2, VAT, or other taxes.
- Feed-in Tariffs (FIT) - FIT policies typically involve three key provisions: a preferential tariff; guaranteed purchase of the electricity produced for a specified period; and guaranteed access to the grid. A purchase obligation ensures that energy suppliers are obliged to buy the power generated by renewable energy projects. Ensuring guaranteed access to the grid so that the power produced by renewable projects enter the electricity market also helps reduce project development risks.

Quantity Instruments

Instruments that define a specific target or absolute quantity for renewable energy production. There are two main types:

- Renewable Portfolio Standards (RPS) that include renewable electricity standards, renewable obligations, or mandated market shares. RPS policies provide an explicit target for renewable energy (e.g., 20 per cent renewable energy by 2020;
- Renewable Energy Credits (REC) – These are usually in the form of a Renewable Energy Certificate. REC is a non-tangible, tradable commodity that represent proof that one MWh of electricity was generated from a renewable energy resource. Renewable Energy Credits can be bought and sold bundled with electricity or unbundled. They can be implemented in combination with RPS.

Pricing Instruments help reduce cost and pricing-related barriers by establishing favourable price regimes for renewable energy relative to other sources of power generation.

Performance Standards

A performance standard is a predetermined level of the performance threshold(s), requirement(s), or expectation(s) that must be met to qualify for some kind of incentives. Emission standards are the legal requirements governing air pollutants released into the atmosphere. Emission standards set quantitative limits on the permissible amount of specific air pollutants that may be released from specific sources over specific timeframes.

They are generally designed to achieve air quality standards and to protect human life. Vehicle emission performance standard, for example, is a limit that sets thresholds above which a different type of vehicle emissions control technology might be needed. An example of building standard is a solar hot water mandate that require a certain energy share or equipment requirement for a building to come from RES.

While emission performance standards have been used to dictate limits for conventional pollutants such as oxides of nitrogen and oxides of sulphur (NOx and SOx), this regulatory technique may be used to regulate GHGs, particularly CO2. Setting emission standards for energy use from different energy sources, has become a policy option for leveraging the use of low-emitting fuels.

Public Procurement

Since governments are often very large energy consumers, government purchasing, and procurement decisions affect the market. Procurement requirements are a tool for national and subnational governments to mature renewable energy markets. Governments could use procurement policies to lead by example, create demand, support initial markets, and build necessary capacity for growing the renewable energy sector.

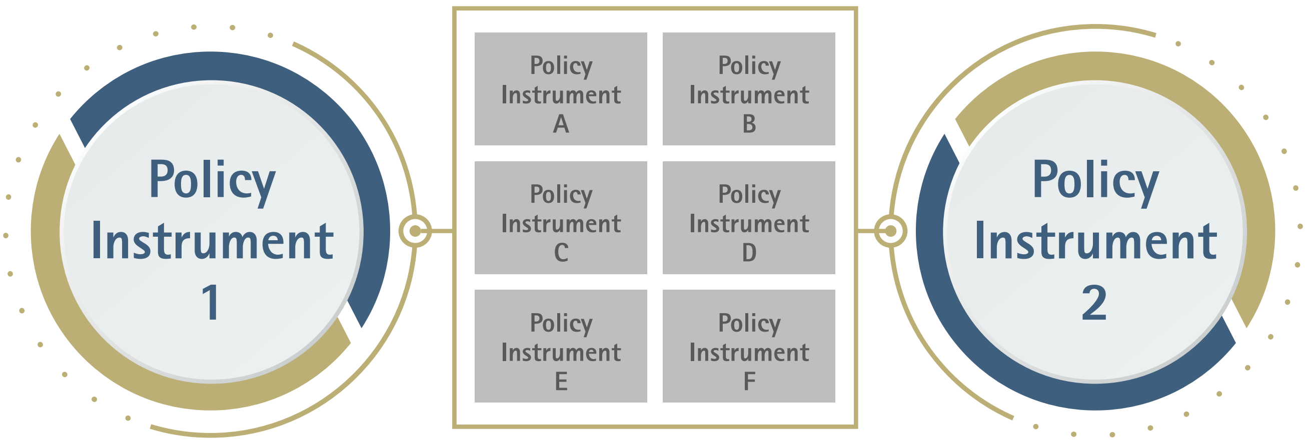
Electricity Auctions

An auction is a selection process to allocate goods and services competitively, based on a financial offer. In a 'reverse auction', electricity generators bid their supply to distribution companies and the process is designed to select the lowest price. Auctions can be used to discover appropriate tariff rate for FIT policy and could be a very attractive mechanism for attracting new renewable energy supply.

Renewable Energy Policy Design

In designing renewable energy policy, it should be noted that there is no universal policy prescription for supporting renewable energy. Because countries are typically unique, the most suitable policy instruments in one country may not be appropriate for another country. Instead of a single policy to achieve all of the policy objectives, it is useful to consider a policy portfolio approach or a policy tool kit.

Policy Portfolio



Multiple policy instruments functions in a complementary manner

Summaries of the main driving forces for the existing renewable energy policies for the Top 5 advanced economies and Top 6 emerging economies, among the G20 Nations (the world major developed and emerging developing countries, as ranked by 2019 GDP forecasts) are presented below.

United States of America

The USA is a country comprising 50 States, a Federal district, and five major self-governing territories, and various possessions.

The USA originated as a result of a revolution which separated it from the British Crown. The constitution, drafted in 1787, established a federal system with a division of powers which has remained unchanged in form since its inception.

With a population of over 327 million people, the U.S. is the third most populous country, after China and India.

The USA is a highly developed country, with the world's largest economy by nominal GDP, accounting for approximately a quarter of global GDP. The economy is largely post-industrial, characterised by the dominance of services and knowledge-based activities, although the manufacturing sector remains the second-largest in the world. The USA is the world's largest importer and the second-largest exporter of goods, by value. Although its population is only 4.3 per cent of the world total, the U.S. holds 31 per cent of the total wealth in the world, the largest share of global wealth concentrated in a single country.

Energy policy in the USA aims to provide reliable, affordable energy for consumers in a way that maintains environmental and health protections and minimises pollution and other negative environmental and health impacts.

The USA energy policy is determined by federal, state, and local entities, which address issues of energy production, distribution, and consumption, such as building codes and gas mileage standards. Energy policy may include legislation, international treaties, subsidies and incentives to investment, guidelines for energy conservation, taxation and other public policy techniques.

Several mandates have been proposed over the years, such as gasoline never exceeding USD 1.00/gallon, and the USA never again importing as much oil as it did in 1977, but no comprehensive long-term energy policy has been proposed. Thanks to new technologies such as fracking, the USA resumed in 2014, its former role as the top oil producer in the world.

67%

of Americans would be willing to pay more for their monthly utility bill if their utility company increased its use of renewable energy.

Three Energy Policy Acts have been passed, between 1992 and 2009, which include many provisions for conservation, such as the Energy Star programme, and energy development, with grants and tax incentives for both renewable energy and non-renewable energy. The Energy Policy Act of 2005 requires all public electric utilities to facilitate net metering. This allows homes and businesses performing distributed generation to pay only the net cost of electricity from the grid: electricity used minus electricity produced locally and sent back into the grid. For intermittent RES this effectively uses the grid as a battery to smooth over lulls and fill in production gaps. Some jurisdictions go one step further and have instituted feed-in tariff, which allows any power customer to actually make money by producing more renewable energy than is consumed locally.

The USA refused to endorse the Kyoto Protocol, preferring to achieve reduction in CO2 emissions through market instruments that include the requirement of CO2 emission taxation. The previous administration proposed an aggressive energy policy reform, including the need for a reduction of CO2 emissions, with a cap and trade programme, which could help encourage cleaner renewable, sustainable energy development. However, the current administration has ceased all participation in the 2015 Paris Agreement on climate change mitigation.

Energy technologies receive government subsidies. In 2016, federal government energy-specific subsidies and support for renewables, fossil fuels, and nuclear energy were USD 6,682 million, USD 489 million and USD 365 million, respectively. All but a few U.S. States now have incentives in place to promote renewable energy, while more than a dozen have enacted new renewable energy laws in recent years. The government also support several organizations within the academic, federal, and commercial sectors, that are conducting large scale advanced research in the field of renewable energy.

States have implemented funding and financial incentive programmes to subsidize or otherwise increase investment in renewable energy resources such as wind, solar, and hydroelectric power.

These programmes include renewable portfolio standards, grants, rebate programmes, tax incentives, loans, performance-based incentives, and more. The aim of the policies generally involves reducing the cost of renewable energy production for consumers, reducing regulatory compliance costs, reducing investment risks involving renewable energy, and/or increasing the adoption of RES by individuals and businesses. As of February 2017, 30 States have introduced Renewable Portfolio Standard (RPS); less than 26 States did not have state-run, utility-run, or locally run grant programmes for renewable energy; and more than 36 States have a state-run loan programme for renewable energy technologies.

Public opinion plays some role in ensuring that adequate consideration is given to the role renewables in US energy policy. A survey in 2010, conducted by Applied Materials shows that two-thirds of Americans believe solar technology should play a greater role in meeting the country's energy needs.

In addition, "three-quarters of Americans feel that increasing renewable energy and decreasing U.S. dependence on foreign oil are the country's top energy priorities". According to the survey, "67 per cent of Americans would be willing to pay more for their monthly utility bill if their utility company increased its use of renewable energy".

In a 2010, Chicago Council on Global Affairs public opinion survey, an overwhelming 91 per cent believed "investing in renewable energy" is important for the USAs to remain economically competitive with other countries. The same poll found strong support for tax incentives to encourage development of RES specifically as a way to reduce foreign energy imports.

China

The People's Republic of China is the second largest economy on Earth and the largest country by population, with 1.4 billion people. The country is highly diverse, both in geography and ethnography. Four of the ten largest cities on Earth can be found in China, all with metropolitan areas populated by well over twenty million people. As of 2017, the economy of China was led by the service sector (52.2 per cent) and industry (39.5 per cent), with agriculture contributing 8.3 per cent to national GDP. Since the introduction of economic reforms in 1978, China's economy has been one of the world's fastest-growing with annual growth rates consistently above 6 per cent. According to the World Bank, China's GDP grew from USD 150 billion in 1978 to USD 12.24 trillion by 2017.

Ensuring adequate energy supply to sustain economic growth has been a core concern of the Chinese government since 1949. Primary energy use in China was 26,250 TWh and 20 TWh per million persons in 2009.

According to the International Energy Agency, the primary energy use grew 40 per cent and electricity use 70 per cent from 2004 to 2009.

> **In a 2010, Chicago Council on Global Affairs public opinion survey, an overwhelming 91% believed "investing in renewable energy" is important for the USAs to remain economically competitive with other countries.**

Energy policymaking in China is largely decentralised. There has been no Ministry of Energy since it was dissolved in 1993, and it was only in 2002–2003 that serious governmental dialogue on re-centralising energy administration began. China's energy industries are governed by a number of ministries and commissions, and companies with varying levels of power and influence, such as the China National Petroleum Corporation (CNPC) and the China Petroleum and Chemical Corporation (Sinopec). Both of these companies originally comprised one ministry before being converted to state companies in the 1980s.

They have retained the same hierarchical rank as government ministries, putting them higher than the sub-ministerial bureau charged with supervising them. These complicated organisational structures and interrelationships complicate any efforts to change the way energy is priced and billed.

China is the world's leading investor in renewable energy and its commercialisation, with USD 52 billion invested in 2011 alone; it is a major manufacturer of renewable energy technologies and invests heavily in local-scale renewable energy projects. By 2015, over 24 per cent of China's energy was derived from renewable sources, while most notably from hydroelectric power: a total installed capacity of 197 GW makes China the largest hydroelectric power producer in the world. China also has the largest power capacity of installed solar photovoltaics system and wind power system in the world.

In recent decades, China has suffered from severe environmental deterioration and pollution. While regulations such as the 1979 Environmental Protection Law are fairly stringent, they are poorly enforced, as they are frequently disregarded by local communities and government officials in favor of rapid economic development.

Urban air pollution is a severe health issue in the country; the World Bank estimated in 2013 that 16 of the world's 20 most-polluted cities are located in China. And China is the country with the highest death toll because of air pollution.

There are 1.14 million deaths caused by exposure to ambient air pollution. China is the world's largest CO2 emitter.

The publication in 2007 of China's first National Action Plan on Climate Change, made China to become the first developing country to publish a national strategy addressing global warming. While the plan did not include targets for CO2 emission reductions, many observers estimated that, if fully implemented, China's annual emissions of GHGs would be reduced by 1.5 billion tons of CO2 equivalent by 2010.

The NDC submitted by China in terms of the Paris Agreement further enhanced the National Action Plan and showed indicative targets and direction of travel for the country's GHG emissions.

The National Action Plan and the consequent NDC, include increasing the proportion of electricity generation from RES and from nuclear power, increasing the efficiency of coal-fired power stations, the use of cogeneration, and the development of coal-bed and coal-mine methane.

In 2012, China signaled that carbon trading scheme will be an integral part of the country's policy framework.

The National Development and Reform Commission introduced a pilot carbon cap and trade scheme that would operate in a similar way to the EU Emission Trading Scheme (EU ETS).

The cities of Beijing, Tianjin, Shanghai, Chongqing and Shenzhen, and the provinces of Hubei and Guangdong were selected to be the first to participate in the pilot phase of the Regional ETS.

The introduction of a national emission trading scheme (National ETS) was set as the ultimate objective of the seven regional pilot schemes.

By 2015, over

24%

of China's energy was derived from renewable sources, while most notably from hydroelectric power.

China the largest hydroelectric power producer in the world.

> Japan ranks 20th in the 2018 Environmental Performance Index, which measures a nation's commitment to environmental sustainability.

Japan

Japan is the third largest national economy in the world, after the USA and China, in terms of nominal GDP. Japan has a large industrial capacity and is home to some of the largest and most technologically advanced producers of motor vehicles, electronics, machine tools, steel and nonferrous metals, ships, chemical substances, textiles, and processed foods.

Agricultural businesses in Japan cultivate 13 per cent of Japan's land, and Japan accounts for nearly 15 per cent of the global fish catch, second only to China. As of 2016, Japan's labour force consisted of some 65.9 million workers. Japan has a low unemployment rate of around four per cent.

Japan's exports amounted to USD 4,210 per capita in 2005, with main exports of transportation equipment, motor vehicles, iron and steel products, semi-conductors and auto parts. Japan's main imports are machinery and equipment, fossil fuels, foodstuffs (in particular beef), chemicals, textiles and raw materials for its industries. Japan ranks 34th of 190 countries in the 2018 ease of doing business index and has one of the smallest tax revenues of the developed world.

Since critical natural resources are scarce in Japan, the country is highly dependent on imported energy and raw materials. Japan's energy policy is therefore aimed at diversifying its sources and maintaining high levels of energy efficiency. As of 2011, 46.1 per cent of energy in Japan was produced from petroleum, 21.3 per cent from coal, 21.4 per cent from natural gas, 4.0 per cent from nuclear power and 3.3 per cent from hydropower.

Nuclear power produced 9.2 per cent of Japan's electricity, as of 2011, down from 24.9 per cent the previous year. However, by May 2012 all of the country's nuclear power plants had been taken offline because of ongoing public opposition following the Fukushima Daiichi nuclear disaster in March 2011, though government officials continued to try to sway public opinion in favor of returning at least some of Japan's 50 nuclear reactors to service.

Japan ranks 20th in the 2018 Environmental Performance Index, which measures a nation's commitment to environmental sustainability. In the period of rapid economic growth after World War II, environmental policies were downplayed by the government and industrial corporations; as a result, environmental pollution was widespread in the 1950s and 1960s. Responding to rising concern about the problem, the government introduced several environmental protection laws in 1970. The oil crisis in 1973 also encouraged the efficient use of energy because of Japan's lack of natural resources.

As the host and signatory of the 1997 Kyoto Protocol, Japan is under treaty obligation to reduce its CO2 emissions and to take other steps to curb climate change. In 2015, Japan submitted its NDC with aims to reduce its GHG emissions by 26 per cent from 2013 levels by 2030.

At the same time, more than 40 coal-fired power plants are planned or under construction in Japan, as of June 2015. This makes observers of global climate action to be skeptical about the commitment of Japan to its NDC target. Prior to the 2011 Fukushima nuclear disaster, Japan's emissions had been on the decline, largely due to nuclear power plants creating no emissions. However, since the 2011 Fukushima nuclear disaster leading to the switching-off of Japan's nuclear fleet and replacing some with coal-fired power plants, Japan's emissions has been on the increase again.

Japan signaled its strong commitment to the use of carbon market mechanisms by introducing a home-grown project-based bilateral mechanism (Japan Crediting Mechanism (JCM)), similar to the CDM in the Kyoto Protocol, to generate carbon offsets from projects funded and implemented by Japan in a participating developing country. However, several countries with the UNFCCC, as well as environmental NGOs, remain very skeptical about the environmental integrity of credits generated from JCM projects.

Germany

The Federal Republic of Germany includes 16 constituent States, covers an area of 357,578 square kilometres and with 83 million inhabitants, it is the second most populous state of Europe after Russia, as well as the most populous member state of the EU. Germany has a social market economy with a highly skilled labour force, a large capital stock, a low level of corruption, and a high level of innovation. It is the world's third largest exporter of goods, and has the largest national economy in Europe, which is also the world's fourth largest by nominal GDP and the fifth by PPP. The service sector contributes approximately 71 per cent of the total GDP (including information technology), industry 28 per cent, and agriculture 1 per cent.

In 2008, Germany was the world's sixth-largest consumer of energy, and 60 per cent of its primary energy was imported. In 2014, energy sources were: oil (35.0 per cent); coal, including lignite (24.6 per cent); natural gas (20.5 per cent); nuclear (8.1 per cent); hydro-electric and renewable sources (11.1 per cent). The government and the nuclear power industry agreed to phase out all nuclear power plants by 2021. Germany also enforces energy conservation, green technologies, emission reduction activities, and aims to meet the country's electricity demands using 40 per cent renewable sources by 2020. Although the country's total GHG emissions were the highest in the EU in 2010, Germany is committed to the Paris Agreement and continues to pursue greater commercialisation of renewable energy. The German energy transition (Energiewende) is recognized as a move towards sustainable economy by means of energy efficiency and renewable energy.

Germany is part of the European single market which represents more than 508 million consumers. Several domestic commercial policies are determined by agreements among EU members and by EU legislation. The German energy policy is framed within the EU, and the March 2007 European Council in Brussels approved a mandatory energy plan that requires a 20 per cent reduction of CO_2 emissions before the year 2020 and the consumption of renewable energies to be 20 per cent of total energy consumption (compared to 7 per cent in 2006).

The accord indirectly acknowledged the role of nuclear energy in the reduction of the emission of GHGs, allowing each member state to decide whether or not to use nuclear-generated electricity. Germany fully embraced the EC Directive, which resulted in a huge expansion of renewables, particularly wind power, with share of renewables increasing from around 5 per cent in 1999 to 22.9 per cent in 2012.

Subsidies aimed at stimulating the growth of renewables have driven up consumer energy prices by 12.5 per cent in 2013. So far, German consumers have absorbed the costs of the Energiewende, but the debate over the social and economic impacts of the new approach to energy transition, is gaining prominence as the growth in share of renewable energy continued to cause rising electricity prices.

The transition to a low-carbon energy sector requires public acceptance, and, therefore, retail electricity prices must remain at an affordable level. German electricity prices are among the highest in Europe, despite relatively low wholesale prices.

However, the new energy policy is considered to be based on long-term investment decisions, and there is still general consensus on a strong policy in favour of large-scale renewable energy commercialisation. In the court of public opinion, a national survey conducted for the German Renewable Energies Agency in 2017, showed that 95 per cent of respondents supported further expanding renewable energy. Almost two-thirds agreeing to renewable power plants located close to their homes.

Germany aims to meet the country's electricity demands using 40% renewable sources by

2020

India

India is the sixth-largest economy, the seventh largest country by area, and with more than 1.3 billion people, it is the second most populous country, in the world. With its average annual GDP growth rate of 5.8 per cent over the past two decades, and reaching 6.1 per cent during 2011–12, India is one of the world's fastest-growing economies.

Despite economic growth during recent decades, India continues to face socio-economic challenges. In 2006, India contained the largest number of people living below the World Bank's international poverty line of USD 1.25 per day, the proportion having decreased from 60 per cent in 1981 to 42 per cent in 2005; and 21 per cent in 2011.

India's capacity to generate electrical power is 300 GW, of which 42 GW is renewable. Climate change is a major challenge for developing nations like India, threatening to enhance risks already elevated by high levels of social vulnerability and climate variability. In its Nationally Determined Contribution (NDC), India sets out plans for a major transformation of its economy, committing to reduce the emissions intensity of its GDP by 33 per cent from 2005 levels by 2030. Furthermore, the nation aims to enhance investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, coastal economies, and health.

The energy policy of India is largely defined by the country's expanding energy deficit and increased focus on developing alternative sources of energy, particularly nuclear, solar and wind energy. In general, India's strategy is the encouragement of the development of renewable sources of energy by the use of incentives by the federal and state governments. Other examples of encouragement by incentive include the use of nuclear energy (India Nuclear Cooperation Promotion Act), promoting windfarms and solar energy through the use of Renewable Energy Certificate as a policy instrument. A long-term energy policy perspective is provided by the Integrated Energy Policy Report 2006 which provides policy guidance on energy-sector growth.

France

France is a sovereign State whose 18 integral Regions (five of which are situated overseas) span a combined area of 643,801 square kilometres and a total population of 67.02 million (as of July 2019). France is a developed country with the world's sixth-largest economy by nominal GDP and tenth-largest by purchasing power parity. In terms of aggregate household wealth, it ranks fourth in the world. France has a mixed economy that combines extensive private enterprise with substantial state enterprise and government intervention. The government retains considerable influence over key segments of infrastructure sectors, with majority ownership of railway, electricity, aircraft, nuclear power and telecommunications. As of 2016, France was ranked seventh largest exporter and the fourth largest importer of manufactured goods. Électricité de France (EDF), the main electricity generation and distribution company in France, is one of the world's largest producers of electricity. In 2003, it produced 22 per cent of the EU's electricity, primarily from nuclear power.

Although it is one of the most industrialised countries in the world, France is the smallest emitter of CO2 among the G8, and ranked only 17th in the world, behind less populous nations such as Canada or Australia. This is due to the country's heavy investment in less polluting nuclear power, following the 1973 oil crisis, for its electricity production. As of 2016, 72 per cent of the electricity produced by France is generated by 58 nuclear power plants. In this context, renewable energies are having difficulty taking off. France also uses hydroelectric dams to produce electricity, such as the Eguzon dam, Étang de Soulcem, and Lac de Vouglans. The outlook for renewable electricity in France received a boost following the publication in October 2016 of the "Programmation pluriannuelle de l'énergie", showing a commitment to re-balancing the electricity mix towards renewables. According to the report, renewable electricity capacity is planned to grow from 41 GW in 2014 to between 71 and 78 GW by 2023.

Under its commitment to the EU renewable energy directive of 2009, France has a target of producing 23 per cent of its total energy needs from renewable energy by 2020. This figure breaks down to renewable energy providing 33 per cent of energy used in the heating and cooling sector, 27 per cent of the electricity sector and 10.5 per cent in the transport sector. By the end of 2014, 14.3 per cent of France's total energy requirements came from renewable energy, a rise from 9.6 per cent in 2005.

According to the 2018 Environmental Performance Index conducted by Yale and Columbia, France was the second-most environmentally-conscious country in the world (after Switzerland), compared to tenth place in 2016 and 27th in 2014. Like all EU Member States, France agreed to cut carbon emissions by at least 20 per cent of 1990 levels by the year 2020. The country was set to impose a carbon tax in 2009 at 17 Euros per tonne of carbon emitted, which would have raised 4 billion Euros in revenue annually. However, the plan was abandoned due to fears of the burden this would impose on French businesses.

United Kingdom

The United Kingdom (UK) includes the island of Great Britain, Northern Ireland, and many smaller islands. Northern Ireland is the only part of the UK that shares a land border with another sovereign state, the Republic of Ireland. Apart from this land border, the UK is surrounded by water, with the Atlantic Ocean to the west, with the North Sea to the east, the English Channel to the south and the Celtic Sea to the south-west, giving it the 12th-longest coastline in the world. The UK's 242,500 square kilometres were home to an estimated 66.0 million inhabitants in 2017.

The UK consists of four constituent countries: England, Scotland, Wales, and Northern Ireland. The UK is a developed country and has the world's seventh-largest economy by nominal GDP and ninth-largest economy by purchasing power parity. It has a high-income economy and a very high Human Development Index rating, ranking 14th in the world. It was the world's first industrialised country and the world's foremost power during the 19th and early 20th centuries.

In 2006, the UK was the world's ninth-largest consumer of energy and the 15th-largest producer. The UK is home to a number of large energy companies, including two (BP and Royal Dutch Shell) of the world's oil and gas "supermajors".

In 2013, the UK produced 914 thousand barrels per day (bbl/d) of oil and consumed 1,507 thousand bbl/d. Production is now in decline and the UK has been a net importer of oil since 2005. In 2010, the UK had around 3.1 billion barrels of proven crude oil reserves, the largest of any EU member state. In 2009, the UK was the 13th-largest producer of natural gas in the world and the largest producer in the EU. Production is now in decline and the UK has been a net importer of natural gas since 2004.

In 2011, 40 per cent of the UK's electricity was produced by gas, 30 per cent by coal, 19 per cent by nuclear power and 4.2 per cent by wind, hydro, biofuels and wastes.

The Energy policy of the UK is a set of official publications and activities directed at the present and future production, transmission and use of various power technologies within the UK.

The current energy policy is set out in the Energy White Paper of May 2007 and Low Carbon Transition Plan of July 2009. The 2007 White Paper: "Meeting the Energy Challenge" sets out the Government's international and domestic energy strategy to address the long-term energy challenges faced by the UK, and to deliver four policy goals:

- To put the UK on a path to cut CO2 emissions by some 60 per cent by about 2050, with real progress by 2020;
- To maintain reliable energy supplies;
- To promote competitive markets in the UK and beyond, helping to lower the rate of sustainable economic growth and to improve productivity;
- To ensure that every home is adequately and affordably heated.

The policy also recognises that the UK will need around 30-35 GW of new electricity generation capacity over the next two decades as many current coal and nuclear power stations, built in the 1960s and 1970s, reach the end of their lives and are set to close. The UK Government's goal, set in 2006, for renewable energy production is to produce 20 per cent of electricity in the UK by 2020. Subsequently, the Low Carbon Transition Plan of 2009 made clear that by 2020 the UK would need to produce 30 per cent of its electricity. For Scotland, the Scottish Government has a target of generating 100 per cent of electricity from renewables by 2020.

The National Renewable Energy Action Plan adopted by the UK in accordance with Article 4 of the European Commission Renewable Energy Directive, provides details on a set of measures that would enable the UK to meet its 2020 target. The Plan further states that Ofgem, on behalf of DECC (now BEIS), administers schemes designed to promote the increased take-up of renewable generation (such as the Renewables Obligation scheme, the Renewable Energy Guarantees of Origin scheme and the FIT scheme). The UK renewables policy framework is made up of three key components: financial support for renewables; unblocking barriers to delivery; and developing emerging technologies.

The Action Plan provides for the establishment of a financial framework that provides long-term, comprehensive and targeted support for renewable technologies. The options include a system of feed-in tariffs in electricity, as well as the maintenance of banded Renewable Obligation Certificates in order to ensure that the country's greater ambitions for renewable energy are supported and have the required investment.

The UK is also looking into the possibility of a Green Investment Bank to help fund the introduction of renewable energy. As part of the creation of this bank, the government intends to create financial products to provide individuals with opportunities to invest in the infrastructure needed to support the new green economy. The benefits from higher levels of renewables will be extended to communities by providing opportunities for the promotion of community-owned renewable energy schemes. To ensure that local people benefit from the power they are producing, there would be thorough examination of the opportunity for communities that host renewable energy projects to keep the additional business rates they generate, as part of the financial support schemes.

The UK is taking steps to identify and address issues that affect the timely deployment of established renewable technologies such as: the planning system; supply chains; connection to the grid; and availability and use of sustainable bioenergy. The UK is taking positive steps to ensure that the grid is made smarter to enable efficient use of networks, and greater renewable and distributed generation. The country is also looking into ways to accelerate the rollout of the smart grid and smart meters.

With regards to developing emerging technologies, the government considers offshore wind to be a key area for development. The goal is to develop an offshore electricity grid that support the continuing commitment to make the UK a world leader in this technology. The new generation of offshore wind power is expected to play a key role in meeting the country's 2020 target. Marine energy is also considered a priority for development in the UK.

The UK is seen as a natural place from which to develop marine energy and the country considers itself lucky to have such a uniquely rich wave and tidal resource. The government intend to continue to encourage the development and commercialization of this industry over the coming decade. The world's first full-scale wave and tidal stream devices are British innovations, an indication that the required skills and know-how to develop a new world-leading UK-based energy sector, exist.

The UK public is largely supportive of renewable energy, driven primarily by concerns about climate change and dependence on fossil fuels. In a national survey of public attitudes towards energy in the UK, conducted in 2013, by the UK Energy Research Centre, 85 per cent of participants supported solar energy and 75 per cent supported wind energy.

The UK is on a path to cut CO2 emissions by some 60% by about 2050, with real progress by 2020.

Brazil

The Federative Republic of Brazil is the largest country in both South America and Latin America. At 8.5 million square kilometers and with over 208 million people, Brazil is the world's fifth-largest country by area and the fifth most populous. It is the largest country to have Portuguese as an official language and the only one in the Americas. It is also one of the most multicultural and ethnically diverse nations, due to over a century of mass immigration from around the world.

Brazil is considered an advanced emerging economy. Brazil is the largest national economy in Latin America, the world's ninth largest economy by GDP and the eighth largest in purchasing power parity (PPP) according to the 2018 estimates. It is one of the world's major breadbaskets, being the largest producer of coffee for the last 150 years. It is classified as an upper-middle income economy, with the largest share of global wealth in Latin America. Brazil has a mixed economy with abundant natural resources, particularly iron ore, that are highly prized by major manufacturing nations, including China. Active in agricultural, mining, manufacturing and service sectors Brazil has a labor force of over 107 million (ranking 6th worldwide) and unemployment of 6.2 per cent (ranking 64th worldwide). Over the past few years it has made major strides in its efforts to raise millions out of poverty.

After rapid growth in preceding decades, the country entered an ongoing recession in 2014. However, Brazil is still highly regarded as South America's most influential country, an economic giant and one of the world's biggest democracies. It is one of the rising economic powers - otherwise known as BRIC nations - together with Russia, India, China and South Africa. Thanks to the development of offshore fields, the nation has become self-sufficient in oil, ending decades of dependence on foreign producers.

The country's Amazon River basin includes a vast tropical forest, home to diverse wildlife, a variety of ecological systems, and extensive natural resources spanning numerous protected habitats. This unique environmental heritage makes Brazil one of 17 megadiverse countries and is the subject of significant global interest and debate regarding deforestation and environmental protection. The exploitation of the Amazon rainforest, much of which is in Brazil, has been a major international worry, since the wilderness is a vital regulator of the climate. It is also an important reservoir of plant and animal life. In 2005 the government reported that one fifth of the Amazon forests had been cleared by deforestation.

Brazil is the 10th largest energy consumer in the world and the largest in South America. It is an important oil and gas producer in the region and the world's second largest ethanol fuel producer. The first car with an ethanol engine was produced in 1978 and the first airplane engine running on ethanol in 2005. The government agencies responsible for energy policy are the Ministry of Mines and Energy (MME), the National Council for Energy Policy (CNPE), the National Agency of Petroleum, Natural Gas and Biofuels (ANP) and the National Agency of Electricity (ANEEL). State-owned companies Petrobras and Eletrobrás are the major players in Brazil's energy sector.

Brazil announced a big renewable energy plan in 2011. The new national 10-year plan shows that the country will triple its use of renewable energy by 2020 and that a lot of that energy will be wind energy. Going from 9 GW of wind, biomass and small hydropower in 2010, the country intends to hit 27 GW by 2020. It wants to have 16 per cent of its electricity supply coming from renewables in 10 years. Brazil plans to realize these ambitious targets by investing strongly in new renewable energy technologies and disinvesting in fossil fuels. The investment pattern shows the following breakdown of scheduled or anticipated investments:

- BRL70 billion for RES;
- BRL96 billion for large-hydro plants; and
- BRL25 billion for fossil projects.

Brazil is the 10th largest energy consumer in the world and the largest in South America.

The government of South Korea publishes every two years, a plan on the electricity supply and demand for the next

15

years

South Korea

South Korea has developed into one of Asia's most affluent countries since partition in 1948.

The Communist North invaded the country in 1950, just two years after the proclamation of the Republic. With backing from the UN and US, the Korean War ended in 1953 without a peace agreement, leaving South Korea technically at war for more than fifty years.

The following four decades were marked by authoritarian rule, during which government-sponsored schemes encouraged the growth of family-owned industrial conglomerates, including the Hyundai and Samsung groups. They helped transform South Korea into one of the world's major economies and a leading exporter of cars and electronic goods.

South Korea is a major energy importer, importing nearly all of its oil needs and the second-largest importer of liquefied natural gas in the world. South Korea is the world's eighth largest energy-consuming country, and its dependence on energy imports is 94.7 per cent, making the responsibility of securing stable energy, an important task for government. Therefore, as a country with limited energy reserves, setting up and implementing the nation's energy policy became a crucial task for its survival. In addition, the rate of increase in GHG emissions makes South Korea the second highest emitter among OECD countries.

The government is therefore, pursuing the energy transition, involving a reduction in nuclear power and coal-fired generation, and an expansion in renewable energies. In particular, the government is strongly implementing the so-called 2030 plan to increase the share of renewable energy generation to 20 per cent by 2030.

If the 2030 plan is fully implemented, the embedded reforms will see coal-fired power generation dropping from 40 per cent to 21 per cent of electricity generation capacity by 2030 and nuclear power declining from 30 per cent to 22 per cent. These power sources will be replaced under the plan by gas-fired power and renewable resources, with gas-fired power's share of the energy mix growing from 18 per cent to 27 per cent and renewables growing from the current mere 5 per cent to 20 per cent. This is an ambitious plan that will require the installation of 47.2 GW of new generating capacity from renewable resources in only 12 years.

In support of the development and implementation of its energy policy, the government of South Korea publishes every two years, a plan on the electricity supply and demand for the next 15 years. The 8th Basic Plan will cover from year 2017 to 2031. Peak power demand is estimated at 100.5 GW for year 2030, which is 12.7 GW (about 11 per cent) lower than that of the 7th plan. In other words, the South Korean government expects that the power demand will decrease so much so that it will be safe enough to stop the operation of nine nuclear reactors that could have been used to generate the reduced amount of 12.7 GW.

An interesting aspect of this anticipated change in energy mix is the effect it will have on liquefied natural gas (LNG) flows. In 2017, China overtook South Korea to become the world's second-largest LNG importer behind Japan, as China also looks to shift focus from coal-fired to gas-fired power generation. South Korea's pivot away from coal could see a rebound in LNG prices, which have been depressed in the Asia Pacific region by excess supply from Australia and the USA. South Korea is already working to develop the infrastructure necessary for such a shift, with the plan by Korea Gas Corporation (KOGAS) to begin construction of the country's fifth LNG-import terminal at Dangjin Port soon, with objective to make the facility fully operational by 2031.

Many people seem to be in favor of the energy transition even though the energy transition creates a certain amount of financial burden. However, renewable energy policy in South Korea, is still focused mainly on electricity and tends to neglect renewable heat. In order to achieve sizeable reduction in GHG emissions, the heating sector must also sharply switch from its use of conventional fuels to renewable sources.

Mexico

Covering almost 2,000,000 square kilometers, Mexico is the fourth largest country in the Americas by total area and the 13th largest independent state in the world. With an estimated population of over 129 million people, Mexico is the tenth most populous country and the most populous Spanish-speaking country in the world, while being the second most populous nation in Latin America after Brazil.

Mexico is the 15th largest economy in the world by nominal GDP and the 11th largest by purchasing power parity. It has the second-largest economy in Latin America, and is a major oil exporter. The Mexican economy is strongly linked to those of its 1994 North American Free Trade Agreement (NAFTA) partners, especially the USA, with its USD 2.2 trillion economy becoming increasingly oriented toward manufacturing since NAFTA entered into force. Mexico is the US' second-largest export market and third-largest source of imports. In 2016, two-way trade in goods and services between Mexico and the USA exceeded USD 579 billion.

In 1994, Mexico became the first Latin American member of the Organization for Economic Co-operation and Development (OECD). It is classified as an upper-middle income country by the World Bank. Mexico is an ecologically megadiverse country, ranking fifth in the world for its biodiversity. Mexico receives a huge number of tourists every year: in 2018, it was the sixth most-visited country in the world, with 39 million international arrivals. Mexico is a nation where affluence, poverty, natural splendour and urban blight rub shoulders. The socio-economic gap in Mexico is very wide, with prosperity remaining a dream for many Mexicans. Rural areas are often neglected, and huge shanty towns are visible around the cities. Many poor Mexicans have sought to cross the 3,000-Km border with the US in search of a job, but in recent years more Mexicans immigrants are returning to Mexico.

Agriculture has comprised 4 per cent of the economy over the last two decades, while industry contributes 33 per cent (mostly automotive, oil, and electronics) and services (notably financial services and tourism) contributing 63 per cent. Mexico accounts for one fifth of all energy use in Latin America, and demand continues to grow.

Energy production in Mexico is managed by the state-owned companies Federal Commission of Electricity and Pemex. Pemex, the public company in charge of exploration, extraction, transportation and marketing of crude oil and natural gas, as well as the refining and distribution of petroleum products and petrochemicals, is one of the largest companies in the world by revenue, making USD 86 billion in sales each year.

Mexico is the sixth-largest oil producer in the world, with 3.7 million barrels per day. Mexico had a plan to completely open its oil and gas industry to private investment from domestic and foreign companies across the value chain — from oil exploration to gas stations, by the end of 2018. Coincidentally, the Mexico's market for clean energy certificates (CECs) that was published in 2012, came on line in 2018. The introduction of the CEC was seen as a major step in the country's transformative and highly ambitious law on renewable energy. The law confirmed Mexico's intention to increase the amount of electricity generated from clean energy sources, including nuclear energy, to 35 per cent by 2024 and to 50 per cent by 2050. To put Mexico's renewable energy ambitions in context, the 2018 target required Mexico to build, in three years, the total wind farm capacity that Canada took 23 years to develop. Meeting even half the 2018 target requires the equivalent of the entire Danish fleet of wind turbines.

To enable Mexico to meet the goals, a system of auctions for energy, capacity and CECs that offer long-term contracts, was introduced. This provided the needed stability for foreign and domestic investors - 15 years in the case of energy and capacity; and 20 years for CECs. Notably, the auction system was designed to capture relative values of different generation technologies by both location and production profile. Projects in higher-price areas of the country or that deliver power at peak times could secure higher revenues and more investment through the auctions. This differentiated auction system was considered as one of the most sophisticated procurement mechanisms for renewable energy, with its reach and scope representing the most ambitious energy system transformation worldwide. Indeed, the IEA considers Mexico's electricity market reform as one of the most ambitious, comprehensive and well-developed reforms undertaken in the world since the 1990s.

The law confirmed Mexico's intention to increase the amount of electricity generated from clean energy sources, including nuclear energy, to 35% by 2024 and to 50% by

2050

Mexican law has certainly provided a template for others and inspired other nations to follow suit. It has demonstrated how thoughtful legislation and liberalisation can stimulate the market and reduces dependence on established fossil fuels. However, more recently, Mexico's latest auction has seen the world's lowest average price for solar in a regulated auction leading to fear of slowing down the development of renewables, as a result of the inevitable tightening of margins for developers.

Indonesia

The Republic of Indonesia is the world's largest archipelagic state, consisting of more than 17,500 islands and covering over 81,000 kilometers of coastline. Today, Indonesia is the world's fourth most populous nation, the world's 10th largest economy, and a member of the G-20. The country has abundant natural resources like oil and natural gas, tin, copper and gold.

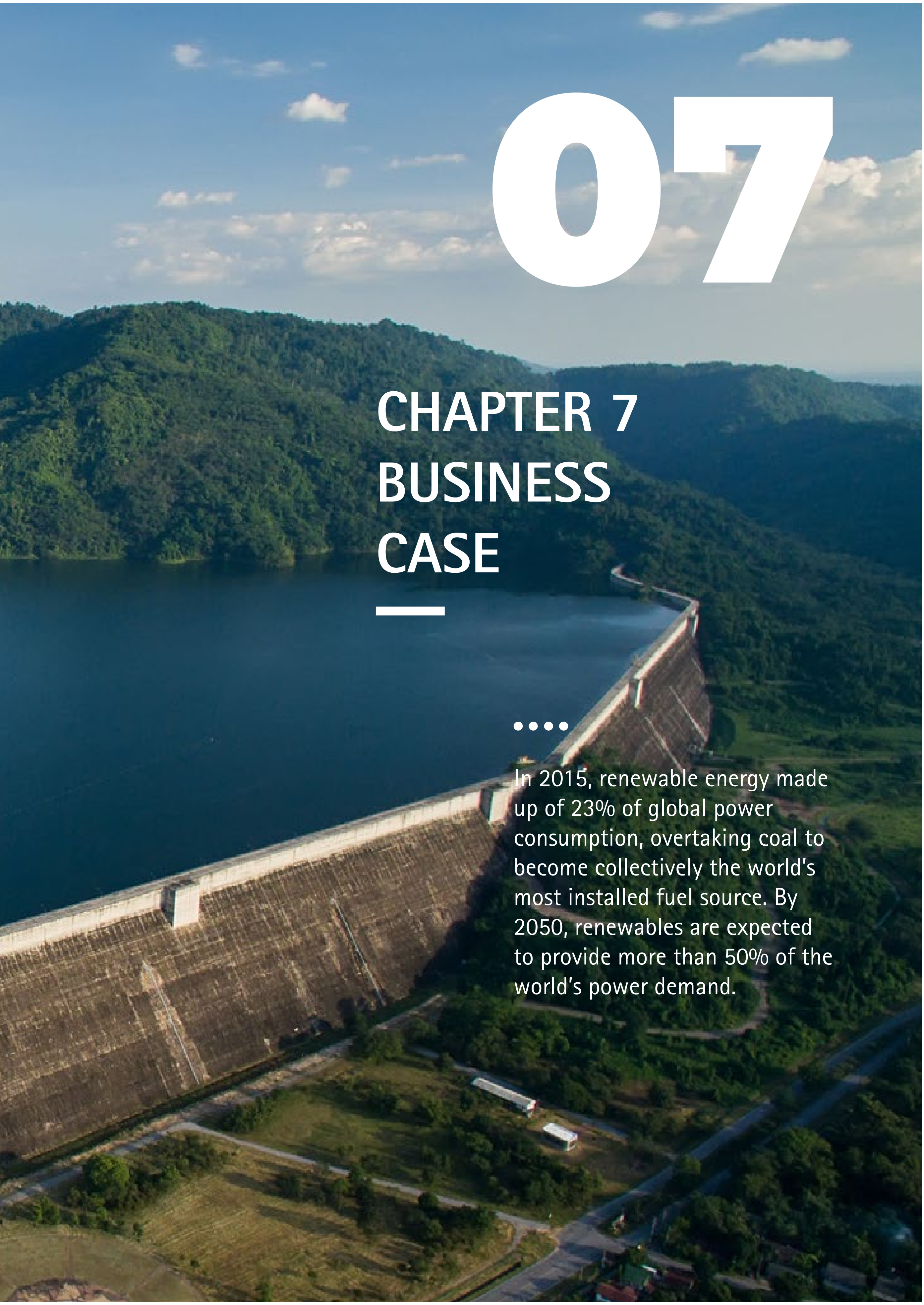
In 2016, Indonesia was the world's 9th largest energy producer with 16.8 quadrillion BTU, and the 15th largest energy consumer, with 7.5 quadrillion BTU. The country has significant energy resources, including 22 billion barrels of conventional oil and gas reserves (of which about 4 billion are recoverable), 8 billion barrels of oil-equivalent of coal-based methane (CBM) resources, and 28 billion tons of recoverable coal. While reliance on domestic coal and imported oil has increased, Indonesia has seen progress in renewable energy, with hydropower being the largest source, and has the potential for geothermal, solar, wind, biomass and ocean energy. Indonesia has set out to achieve 23 per cent use of renewable energy by 2025, and 31 per cent by 2050. As of 2015, Indonesia's total national installed power generation capacity stands at 55.5 GW.

Despite gains in poverty reduction over the past few decades, high population density and rapid industrialisation, coupled with strong dependence on the country's resource base, make Indonesia vulnerable to projected changes in climate. The Asian Development Bank estimates that by 2100, the impacts of climate change will cost between 2.5-7 per cent of the gross domestic product (GDP), and the poorest will bear the brunt of this burden.

The first national strategy on climate change was developed by the Ministry of Environment in 2007. The strategy aims to support economic activity through resilience measures for livelihoods, strengthen ecosystem sustainability and make urban and coastal areas more resilient to impacts of climate change. Indonesia is one of the top ten emitters of GHG emissions. In light of this, Indonesia ratified the Paris Agreement on October 31, 2016. In its Nationally Determined Contribution (NDC), the country pledges to unconditionally reduce emissions by 29 per cent by 2030 compared to a business-as-usual (BAU) scenario. The NDC highlights "improved land use and spatial planning, energy conservation and the promotion of clean and RES, and improved waste management" as priorities for adaptation.

Indonesia's large and growing population, and rapid industrialisation, present serious environmental issues. They are often given a lower priority due to high poverty levels and weak, under-resourced governance. Indonesia is poorly ranked at 133 out of 180 countries, in the 2018 Environmental Performance Index. Expansion of the palm oil industry that requires land reallocation as well as changes to the natural ecosystems is the major cause of deforestation in Indonesia. While the expansion of the palm oil industry can generate wealth for local communities, it also results in the degradation of ecosystems and many social problems. Indonesia is ranked the world's largest forest-based emitter of GHGs. In all GHG emissions including construction and deforestation in 2005, Indonesia was top-4 after China, US and Brazil.

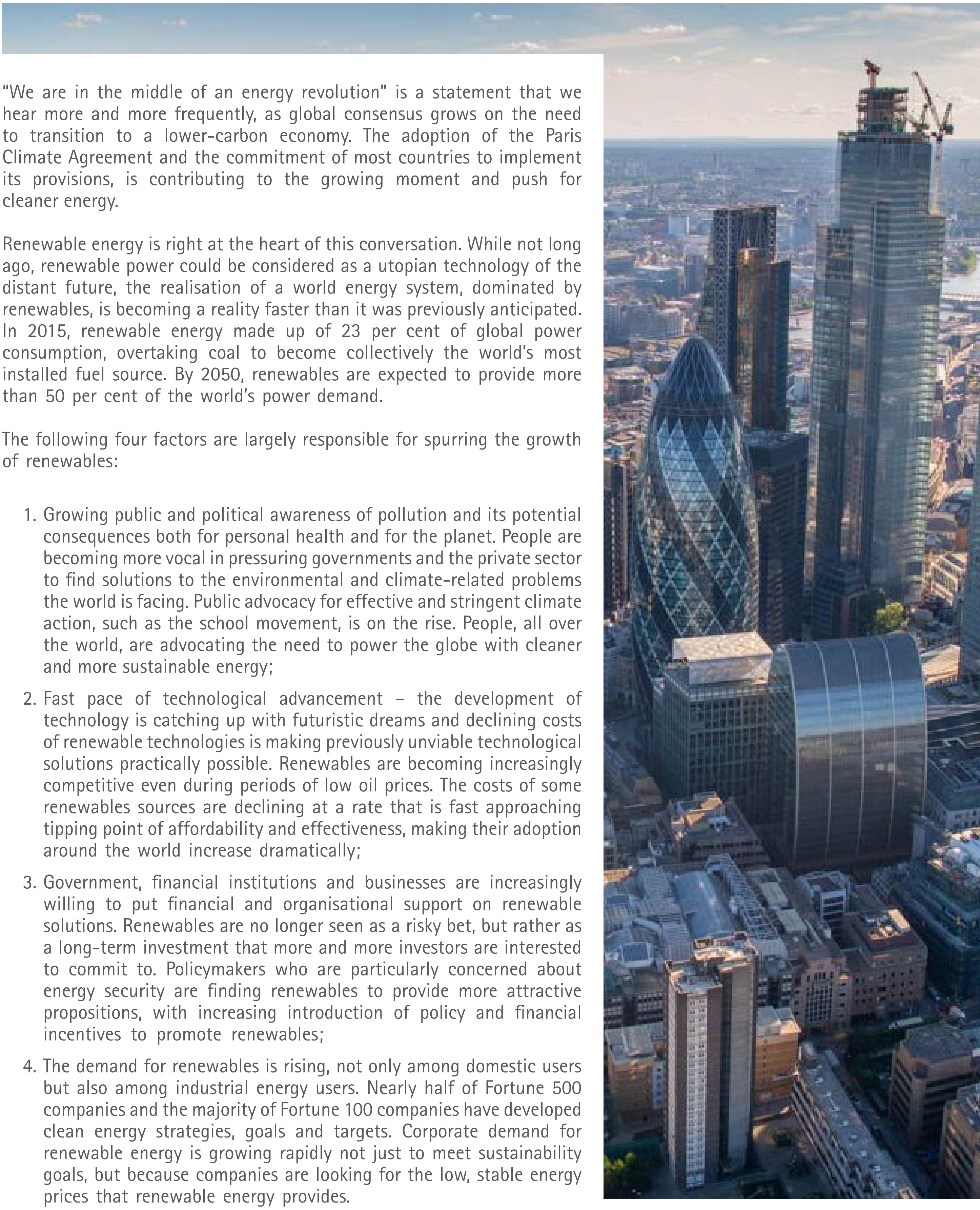
RES are gradually becoming the solution for energy development in Indonesia, as the country experience increased depletion of its fossil-based energy, as a result of growing population leading to increases in energy consumption and waste in fuel consumption. The national energy policy is set up as a guideline for national energy management, aimed at realising energy independence and energy security to support sustainable national development. In particular, the development of renewable energy is driven by the Indonesian government as the national energy of the future because the government sees potential for utilising renewable resources at high economic level.



07

CHAPTER 7 BUSINESS CASE

In 2015, renewable energy made up of 23% of global power consumption, overtaking coal to become collectively the world's most installed fuel source. By 2050, renewables are expected to provide more than 50% of the world's power demand.



“We are in the middle of an energy revolution” is a statement that we hear more and more frequently, as global consensus grows on the need to transition to a lower-carbon economy. The adoption of the Paris Climate Agreement and the commitment of most countries to implement its provisions, is contributing to the growing moment and push for cleaner energy.

Renewable energy is right at the heart of this conversation. While not long ago, renewable power could be considered as a utopian technology of the distant future, the realisation of a world energy system, dominated by renewables, is becoming a reality faster than it was previously anticipated. In 2015, renewable energy made up of 23 per cent of global power consumption, overtaking coal to become collectively the world's most installed fuel source. By 2050, renewables are expected to provide more than 50 per cent of the world's power demand.

The following four factors are largely responsible for spurring the growth of renewables:

1. Growing public and political awareness of pollution and its potential consequences both for personal health and for the planet. People are becoming more vocal in pressuring governments and the private sector to find solutions to the environmental and climate-related problems the world is facing. Public advocacy for effective and stringent climate action, such as the school movement, is on the rise. People, all over the world, are advocating the need to power the globe with cleaner and more sustainable energy;
2. Fast pace of technological advancement – the development of technology is catching up with futuristic dreams and declining costs of renewable technologies is making previously unviable technological solutions practically possible. Renewables are becoming increasingly competitive even during periods of low oil prices. The costs of some renewables sources are declining at a rate that is fast approaching tipping point of affordability and effectiveness, making their adoption around the world increase dramatically;
3. Government, financial institutions and businesses are increasingly willing to put financial and organisational support on renewable solutions. Renewables are no longer seen as a risky bet, but rather as a long-term investment that more and more investors are interested to commit to. Policymakers who are particularly concerned about energy security are finding renewables to provide more attractive propositions, with increasing introduction of policy and financial incentives to promote renewables;
4. The demand for renewables is rising, not only among domestic users but also among industrial energy users. Nearly half of Fortune 500 companies and the majority of Fortune 100 companies have developed clean energy strategies, goals and targets. Corporate demand for renewable energy is growing rapidly not just to meet sustainability goals, but because companies are looking for the low, stable energy prices that renewable energy provides.

In **2015** renewable energy made up of 23% of global power consumption, overtaking coal to become collectively the world's most installed fuel source.

In this chapter, these four factors are examined, with a view to assessing if there is indeed a strong business case for renewables – are there real business benefits for transitioning to renewable energy? To ensure a successful and sustained broad push for renewables, there should be money to be made, but to get to a state of profitability, there is need for a great deal of initial funding.

While governments are expected to continue to play a pivotal role in the development of renewables, by channeling public funding into renewable projects through subsidies, grants and tax breaks; the private sector has a bigger and more important role to play to ensure sustained investment in renewable energy.

Private sector stake in renewables

Investing in cleaner power by companies and institutional investors should not just be an exercise in corporate social responsibility, nor simply a way to pursue long-term return on investments.

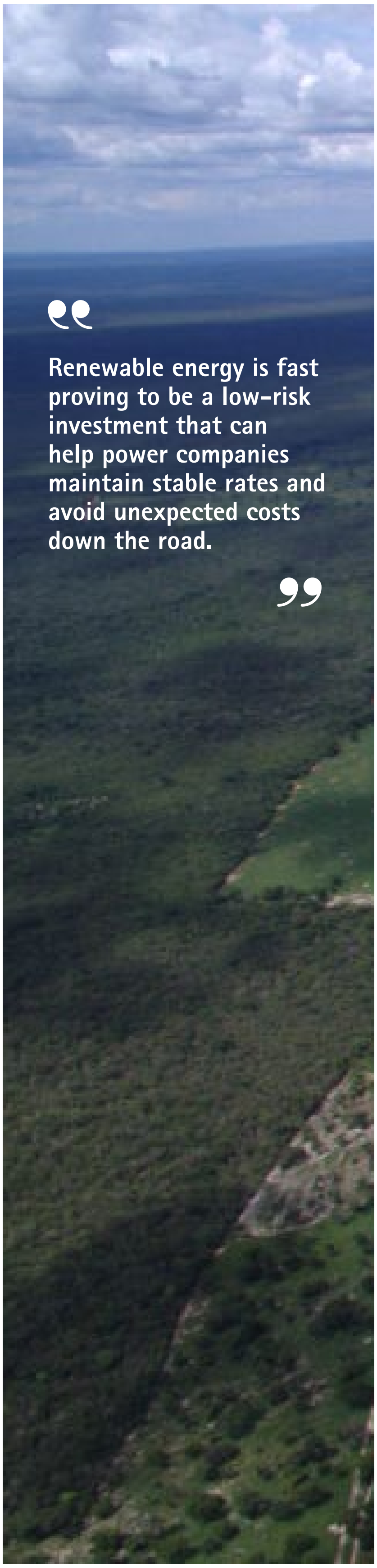
There are other serious business reasons for the private sector to make a strong push into renewables. Some of the compelling reasons underlining a strong business case for renewables include:

- Protecting natural resources and reducing environmental impact: In the face of mounting public scrutiny and stringent regulations, companies are embarking more on self-generation of power. Cheaper and more effective renewable energy solutions are providing far more viable options for self-generation of power and as a cost-effective way for managing impacts on climate change and the environment.
- Reducing exposure to energy price fluctuations: stability and predictability of energy prices are as important to many businesses, as the actual quantum of energy costs. With the usual volatility and fluctuations in oil price, most companies do find energy prices constitute one of the most significant and least-controllable elements of business and economic planning. Many companies are now committing to a sizeable portion of their energy requirements coming from renewables, with some setting near-term targets to become 100 per cent renewable, as a way of increasing energy independence and maintaining tighter control over their profit margins.
- Maximising the knock-on effect on other sectors: a push towards renewables will create increased demand in other sectors. Even though wind and solar, for example, may offer bottomless sources of energy, there is still a need to convert that energy into electricity, and to deliver that electricity when and where it's needed. Developing improved technologies to make renewable power generation and storage more effective is already becoming a significant growth market. Companies are investing billions of dollars in building factories for producing batteries for electricity storage. Better renewable services are also providing a boost for electric cars and more exotic projects like the Hyperloop, a vacuum tube transit service that is expected to rely heavily on solar power.

We are seeing examples of fossil-power plants that are already adapting to these new realities by converting their coal burners to renewables, like biofuels.

Investing by traditional power companies, as well as, non-traditional power companies in renewables and other associated economic activities, is proving to be an effective way for businesses to demonstrate their credentials as credible good corporate citizens.

- Creating new entrants and new investment opportunities in the energy sector: as methods for extracting power from renewable sources, and the infrastructure needed to deploy that power, become more sophisticated, technology players will increasingly become big players in energy too. This trend is likely to increase as more and more cutting-edge power generation technologies enter the picture, and in turn inspire new technological developments such as photovoltaic paint or nano-engineered solar panels. The Nanotech industry has been particularly highlighted as an important growth area in the development of renewables. Emerging potential applications of nanotech in the energy space include: nanofluids that capture more heat in geothermal plants; spherical core-shell nanoparticles that improve efficiency of hydrogen storage; nano-cells that capture energy out of paint, glass, concrete and brick walls; and superconducting cables based on carbon nanotubes.
- The inevitability of the pending change: the private sector realises that momentum is growing, and change is definitely coming. It is therefore in the interest of business to get on board. Many countries have not only set target dates to phase out coal entirely, most are on track to achieve this goal ahead of time. If power-generating companies are to remain viable as businesses, they will need to adapt to become producers of cleaner energy. We are seeing examples of fossil-power plants that are already adapting to these new realities by converting their coal burners to renewables, like biofuels. Government incentives and the imposition of taxes on more polluting industries, as a way to transition to renewables, are also playing a major part. This policy trend is expected to increase in post-Paris regulatory dispensations. Leaving the transition too late could leave organisations open to costly penalties that could have major dents on business profitability.
- Tapping on economic opportunities that provide some second-order benefits associated with renewable power: there are value-creating opportunities that may not be directly connected to energy generation, but indirectly. For example, a spread of domestic solar power and robust commercial battery systems could make urban power infrastructure much more resilient to power outages and natural disasters, offering potentially massive savings to city and national governments. Businesses across verticals should be eager to exploit these economic opportunities, and indeed some are already harnessing such opportunities.
- Rallying ground for collaboration and partnership: developing new businesses in renewables provides opportunity for cultivating, non-adversarial relationships between government, private sector and civil society. We now see some leading voices among policymakers, NGOs and industry executives; working across countries, multinationals, cross-vertical collaboration, and partnerships who are strong advocates of multi-stakeholder approach, as the most pragmatic way of confronting renewable energy issues and achieving real and sustained long-term solutions.



Investing by traditional power companies, as well as, non-traditional power companies in renewables and other associated economic actives, is proving to be an effective way for businesses to demonstrate their credentials as credible good corporate citizens. Companies are beginning to realize that simply making good returns on investments, is no longer the only measure to be used to demonstrate the business case for renewables. Even though all indicators are pointing to a competitive and profitable renewable energy sector in the very near future, there are other several important considerations that may not immediately translate into quantifiable monetary value, but play a significant role in any business decision to go into renewables.

Renewable energy is fast proving to be a low-risk investment that can help power companies maintain stable rates and avoid unexpected costs down the road, with wind and solar in particular, now being some of the lowest-risk options for meeting electricity demand. With wind and solar sources, there's no risk of higher-than-expected fuel prices. Wind and sun are free and there is little risk of costs to comply with unanticipated environmental regulations, because wind and solar power have relatively little environmental impact. There is also little risk of over-investing and being stuck with stranded assets, because wind and solar can be added in small increments and installed relatively quickly.

There is a broad, multilateral consensus on the value of the future of renewables. The tech sector is showing commitment to green innovation, and private sector financing is increasingly comfortable with investing in what was once seen as a high-risk area. While there are still some difficulties, huddles and challenges to overcome, the momentum is growing and the future is promising. The virtuous cycle of renewable power generation is turning, and if governments, companies and individuals can keep to the track, then the opportunities for business and for the world at large should be enormous.

In the context of UN Sustainable Development Goal 7 to "Ensure access to affordable, reliable, sustainable and modern energy for all", the world is still faced with the challenge of 1.3 billion people with no access to modern electricity, 3 billion people relying on wood, coal, charcoal or animal waste for cooking and heating, and less than half of the world's school population has access to electricity. Governments and the private sector are grappling with how to meet these energy needs through smart investments, in a very uncertain and politically unstable time. Some of the questions that the private sector, in particular, have to confront include: how much will fuel cost five or ten years from now?; what regulations will come and go?; how much demand for electricity will there be?; and where can companies invest to minimize the risks of an uncertain future? These and other questions are leading the world closer towards renewables.

Fortune 500 companies from a wide variety of industry sector, as well as, small business operators understand that sustainability isn't just about being green, but also about smart business practices. It is smart business to have reliable sources of energy that businesses and national economy can rely on for generations. Clean energy not only reduces carbon footprint, it is also beginning to make sound business sense and proving that sustainability and profitability are not mutually exclusive.

The hurdles and challenges to overcome

Renewable energy is experiencing some explosive growth which is shaken up the energy industry over the last decade. However, there are still some challenges to address, if the push for renewables is to be maintained, sustained and successful.

Infrastructural challenges

In places with rapid growth in the installation of renewable capacity, such as China and Germany, supply is beginning to overtake the ability of existing electricity grids to deliver. This is resulting in inefficiencies that require huge additional investments in infrastructure to address.

The high initial cost of installation is one of the major hurdles in the development of renewable energy. In addition, storage systems of the generated energy is expensive and represents a real challenge in terms of unit cost of MW production.

Technological challenges

The major technology-related challenges faced by renewables include: capital cost; siting and transmission; and market penetration. While most renewables are exceedingly cheap to operate because of free or low fuel cost and minimal maintenance, the building of renewable technologies is still relatively high compared to fossil fuel technologies. In the US, for example, the cost of installing solar systems in 2017 ranged from twice to three times the cost of a new natural gas plant. NRES are usually centralised while renewables, on the other hand, offer a decentralised model, in which smaller generating stations, spread across a large area, work together to provide power. Decentralisation offers a few key advantages (including, importantly, grid resilience), but it also presents siting and transmission challenges. In most cases, RES are dictated by location which can be off-putting to users. Locating things like wind turbines and solar farms on scattered pieces of land across wide areas, requires negotiations, contracts, permits, stakeholder consultations, and community relations, all of which can increase costs and delay or kill projects. Since renewables are relative newcomers, new transmission lines are often needed to move their generated power to where it's consumed as most existing transmission infrastructures were built to serve large fossil fuel power plants. While the push for clean energy is gaining momentum, renewables still have to compete with well-established and matured technologies that have hitherto enjoyed heavy investment by big players in the energy industry. Existing fossil fuel technologies are very mature, well understood, and still hold enormous market power, making market penetration by renewables an ongoing challenge.

Political and institutional challenges

In most developing countries, where the need to explore and exploit alternative sources of energy is most urgently needed, political instability, armed conflict, weak institutions, poor policy and regulatory framework, all constitute formidable barriers to global spread of renewables.

The fact that significant reserves of fossil fuels are still available, especially in developing countries, impedes the willingness to give sufficient importance to renewables. Fossil fuels still receive much more in subsidies than RES in many countries. In their competition with mature fossil fuel and nuclear technologies, renewables battle with regulatory challenges that are compounded by lack of economies of scale.

Intermittency

One of the biggest concerns in the field of renewable energy is power generation depending on natural resources that are uncontrollable by humans. For example, solar powered electricity is generated only when sunshine is available and turns off at night; wind energy also depends on the availability of wind, so if the wind speed is very low, the turbine will not turn, and this result in zero power flow to the grid. On the other hand, too much wind can damage the generator and therefore a delicate balance needs to be maintained in order to keep a consistent generation of energy.

Opponents of renewables like to highlight the variability of RES, such as the sun and wind, as a way of bolstering support for fossil fuel power plants, which can more easily operate on-demand or provide "baseload" (continuous) power. The argument is used to undermine large investments in renewable energy, presenting a rhetorical barrier to higher rates of wind and solar adoption. The perception of intermittency argument remains, but the reality is much more favorable for renewables. Operational experiences are showing that by pairing renewables with other complementary generation sources like natural gas, as well as, solar and wind are becoming highly reliable. Modern grid technologies like advanced and better storage batteries, real-time pricing, and smart appliances, are also helping solar and wind to be essential elements of a well-performing grid.

Leveling the playing field by internalising all externalities

The business case for renewable energy is been complicated by what economists term "externalities". In economics, an externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit. Externalities are impacts generated by one economic actor, which are felt by others, but the market doesn't bring these impacts back to affect the actor that originated them. They often occur when a product or service's price equilibrium cannot reflect the true costs and benefits of that product or service, and they can be both positive or negative.

These generally encompass "external economic, political or financial factors that may change the pure economics of a project. In the case of renewable and non-renewable sources of energy, these externalities may include: subsidies; taxes (specifically carbon taxes); emission taxes; local taxes or zoning rules; obligations in terms of international treaties; and costs that cannot be easily estimated, such as decommissioning costs or costs associated with relocating people to make room for projects. All these have impacts, in one way or the other, on the economics of the use of renewables.

In considering a 'business case' for renewables, as compared with other sources of energy, it is important to bear in mind the economic treatment of externalities as first postulated by the British economist Arthur C. Pigou, in 1920. Pigou argues that industrialists seek their own marginal private interest. When the marginal social interest cost diverges from the marginal private interest, the industrialist has no incentive to internalise the marginal social cost. Conversely, if an industry produces a marginal social benefit, the individuals receiving the benefit have no incentive to pay for that service. Pigou refers to these situations as incidental uncharged disservices and incidental uncharged services, respectively. The extent to which the incidental uncharged disservices and services are minimised or eliminated, thereby increasing the degree of internalisation of externalities; would improve the true cost of doing business.

Internalising the externality essentially means shifting the burden, or costs, from a negative externality, such as pollution, from outside to inside (outside the financial book to the internal accounting of the business). This can be done through taxes, property rights, tolls, and government subsidies. An example in the case of pollution would be pollution rights. Instead of placing the burden (the costs of higher pollution) on people breathing air, a government would place a monetary tax on pollution. The tax would be in the form of pollution rights that companies would bid on and purchase from the government.

So, if a company wants to pollute more, they would have to pay more money for more pollution rights. This shifts the burden (the costs of higher pollution) from outside the company to inside the company. In the context of energy companies, putting a price on carbon is particularly relevant as fossil fuels generate much more CO2 emissions than renewables.

Since the primary purpose of internalising an externality is to reduce the burden (or costs) of a negative externality by getting the people who are producing the externality to pay for the negative impacts, this helps to level the playing field for all energy sources.

Governments and institutions often take actions to internalise externalities, thus market-priced transactions can incorporate all the benefits and costs associated with transactions between economic agents. The most common way this is done is by imposing taxes on the producers of this externality, in this case pollution. This is usually done by establishing a threshold below which there is no tax imposed, but once the externality exceeds this point, there is a very high imposition of tax. However, since regulators do not always have all the information on the externality it can be difficult to impose the right tax. Once the externality is internalised through imposing a tax the competitive equilibrium is optimised.

The business case for renewables becomes much stronger when all externalities are internalised for all sources of energy (renewables and non-renewables). In other words, there should be no cost components for energy production that either the producers and consumers should assume that it is someone else responsibility to pay.

Making an appropriate decision and choice between sources of energy requires that capital, operational, technical, social, environmental costs, including the cost of managing carbon footprint, should be quantified and adequately considered.

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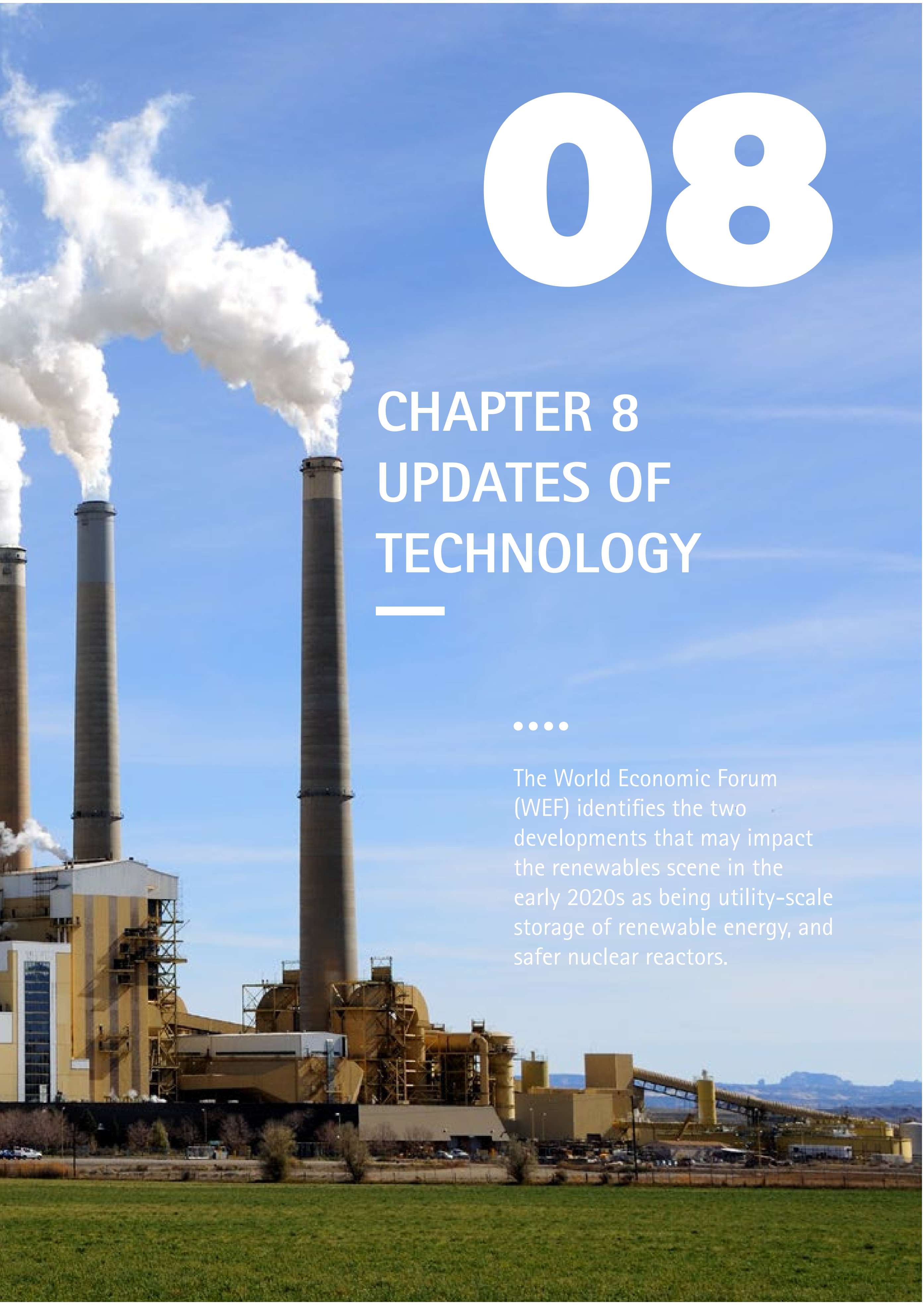

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CHAPTER 8 UPDATES OF TECHNOLOGY

The World Economic Forum (WEF) identifies the two developments that may impact the renewables scene in the early 2020s as being utility-scale storage of renewable energy, and safer nuclear reactors.

Technology in the sphere of renewables is continually developing. It is driven by incentives that seek to make technical developments viable sources of power, mainly due to concerns relating to climate change and energy security.

The World Economic Forum (WEF) identifies the two developments that may impact the renewables scene in the early 2020s as being utility-scale storage of renewable energy, and safer nuclear reactors.

We are seeing examples of fossil-power plants that are already adapting to these new realities by converting their coal burners to renewables, like biofuels.

Utility-scale storage of renewable energy

The way the world gets its electricity is undergoing a rapid transition, driven by both the increased urgency of decarbonising energy systems and the plummeting costs of wind and solar technology. In the past decade, electricity generated by renewables, primarily from wind and solar installations in the USA has doubled, according to the Energy Information Administration (EIA). In January 2019, the EIA forecasted that wind, solar and other nonhydroelectric renewables would be the fastest-growing slice of the electricity portfolio in the next two years. However, because of the intermittent nature of these renewable sources, electric utilities need a way to store energy when the sun is not shining, and the winds are calm. The need to store energy has increased the interest in energy-storage technology – in particular, lithium-ion batteries, which are poised to be more than just a minor player in the grid.

For decades, pumped-storage hydropower, a simple process that features reservoirs at different elevations, has been the dominant large-scale energy-storage method in the USA.

To store energy, water is pumped into the higher reservoir; when that energy is needed, the water is released into the lower reservoir, flowing through a turbine along the way. Pumped-storage hydropower currently accounts for 95 per cent of USA utility-scale energy storage, according to the EIA. But as efficiency and reliability have improved and manufacturing costs have dropped, there is a noticeable surge in the use of lithium-ion batteries. According to EIA, these batteries now account for more than 80 per cent of the USA utility-scale battery-storage power capacity, representing an increase from just a few MW a decade ago to 0.9 GW, as at February 2019.

In March 2019, an analysis by Bloomberg New Energy Finance reported that the cost of electricity from such batteries has dropped by 76 per cent since 2012, making them close to competitive with plants, typically powered by natural gas, that are switched on during times of high electricity demand.

While to date, batteries have largely been used only to make brief, quick adjustments to maintain power levels, utilities in several US states, including Florida and California, are now adding lithium-ion batteries, able to last between two to four hours. The energy research firm Wood Mackenzie estimates that the market for energy storage will double from 2018 to 2019 and triple from 2019 to 2020. According to experts, lithium-ion batteries are expected to be the dominant technology for the next five to 10 years. Continuing improvements will result in batteries that could store energy between four to eight hours – long enough, for example, to shift solar-generated power to the evening peak in demand.

However, arriving at the point where renewables and energy storage can handle the baseline load of electricity generation, would require the storage of energy for much longer timescales. This would mean moving beyond lithium-ion batteries, with potential candidates ranging from flow batteries that pump liquid electrolytes and hydrogen fuel cells, to simpler concepts, such as pumped-storage hydropower and gravity storage. These other options are still under development to make them sufficiently reliable, efficient and cost-competitive with lithium-ion batteries. By the end of 2017, there were only three large-scale flow-battery storage systems deployed in the USA, and utility-scale hydrogen systems are only still in demonstration stages.

The USA government is funding work in this area, particularly through the Advanced Research Projects Agency-Energy (ARPA-E) but is lagging far behind China and the Republic of Korea, where there is a ramping up of research and investment in flow-battery storage systems, utility-scale hydrogen systems and energy storage in general. It is uncertain whether, and how much, the costs of energy storage will continue to decline. Yet the accumulating pledges by governments, including at state and local level in the USA, to achieve carbon-free electricity production will provide a continued push to bring more and more storage online.

Safer nuclear reactors

While nuclear is strictly not considered a renewable, gradual improvements in the safety of nuclear reactors would have a significant impact on the demand for renewables. Improved resiliency of fuels and development of innovative reactors could enable a resurgence of nuclear power plants. Curbing carbon emissions from electricity generation will require a mix of energy technologies, including nuclear reactors that emit no carbon. Nuclear reactors are considered risky, as a result of a few major accidents, however, the risks associated with nuclear reactors could be reduced by the first half of 2020s, to a level that significantly changes the future landscape for renewables.

Small pellets of uranium dioxide, stacked inside long cylindrical rods made of a zirconium alloy, have been the fuel source used in commercial reactors for decades. Zirconium allows the neutrons, generated from fission in the pellets, to readily pass among the many rods submerged in water inside a reactor core, supporting a self-sustaining, heat-producing, nuclear reaction. The main challenge is, if the zirconium overheats, it could react with water and produce hydrogen, that could explode. This has occurred, causing two of the world's worst reactor accidents – the 1979 potential explosion and partial meltdown at Three Mile Island in the USA and the 2011 explosions and radiation release at Fukushima Daiichi, in Japan. It is important to point out that the Chernobyl disaster in 1986, on the other hand, was not caused by reactor fuel, but rather by faulty reactor design and operation.

Manufacturers such as Westinghouse Electric Company and Framatome are hastening development of so-called accident-tolerant fuels that are less likely to overheat and, if they do, would produce very little or no hydrogen. In some of the variations, the zirconium cladding is coated to minimize reactions. In others, zirconium and even the uranium dioxide are replaced with different materials. The new configurations could be slipped into existing reactors with little modification, so they could be phased in during the 2020s. However, thorough in-core testing, that is now ongoing, would have to prove successful and satisfy strict requirements from regulators, before such new accident-tolerant fuels could be deployed for wider use. In addition to reducing safety concerns, the new fuels could help nuclear plants to run more efficiently, further making nuclear power more cost-competitive, providing a significant motivation for manufacturers and electric utilities, who currently find natural gas, solar and wind energy as less expensive.

Although nuclear power has stalled in the USA and is being phased out in Germany and elsewhere, Russia and China are continuing to build nuclear reactors and manufacturers of new fuels could find lucrative markets in these jurisdictions. Russia is also deploying other safety measures, as seen in recent installations at home and abroad. The new installations by the state-run company Rosatom have newer "passive" safety systems that can squelch overheating even if electrical power at the plant is lost and coolant cannot be actively circulated. Westinghouse and other companies are also incorporating passive safety features into their updated designs.

Manufacturers are also experimenting with "fourth generation" models that use liquid sodium or molten salt instead of water to transfer heat from fission, removing the possibility of dangerous hydrogen production. China reportedly intends to connect a demonstration helium-cooled reactor to its grid this year.

In the USA, lack of a permanent, deep geological repository for spent nuclear fuel has long put a brake on industry expansion. Political sentiment may be changing. Recently, more than a dozen USA legislators proposed measures to restart licensing for the Yucca Mountain nuclear waste repository in Nevada, touted since 1987, as the country's leading storage site.

According to experts, lithium-ion batteries are expected to be the dominant technology for the next five to 10 years.

Solar technology

Solar technologies have evolved since they first made their debut in the 1960s. While previously solar PVs were seen as a technology of the future, technological breakthroughs have positioned the industry for huge growth. A series of new developments in solar PV technology also promises to contribute to the industry's success.

Researchers have long looked for ways to improve the efficiency and cost-effectiveness of solar cells - the life blood of solar PV systems. A solar PV array is comprised of hundreds, sometimes thousands, of solar cells that individually convert radiant sun light into electrical currents. The average solar cell is approximately 15 per cent efficient, which means nearly 85 per cent of the sunlight that hits them does not get converted into electricity. As such, scientists have constantly been experimenting with new technologies to boost this light capture and conversion.

Light-sensitive nanoparticles

Recently, a group of scientists at the University of Toronto (Canada) unveiled a new type of light-sensitive nanoparticle called colloidal quantum dots, that many believe will offer a less expensive and more flexible material for solar cells. Specifically, the new materials use n-type and p-type semiconductors that can function outdoors. This is a unique discovery, since previous designs weren't capable of functioning outdoors and, therefore, did not offer practical applications for the solar market. University of Toronto researchers discovered that n-type materials bind to oxygen, but the new colloidal quantum dots don't bind to air and therefore can maintain their stability outside. This helps increase radiant light absorption. Panels using this new technology were found to be up to eight per cent more efficient at converting sunlight.

Gallium arsenide

Researchers at Imperial College University in London (UK) believe they have discovered a new material, gallium arsenide, that could make solar PV systems nearly three times more efficient than existing products on the market. The solar cells are called "triple junction cells" and they are much more efficient, because they can be chemically altered in a manner that optimises sunlight capture. The model uses a sensor-driven window blind that can track sun light along with "light-pipes" that guide the light into the system.

Concentrated solar power (CSP)

CSP, also known as solar thermal energy, can be considered as the second arm of obtaining energy from the sun. This solar technology has been evolving to be used mainly for the industrial or utility purposes. The world's leading countries in application of this technology are the USA and Spain, where the available CSP capacity accounts for nearly 80 per cent of the world's total solar thermal capacity. Concentrated Solar Power is gradually becoming an advantageous alternative to the use of photovoltaics.

It is growing in popularity especially in Spain where the installed capacity on CSP was nearly 2.2 gigawatts (GW) in 2016. In the USA, it was 1.8 GW of available power capacity.

The system uses hundreds of heliostats (mirrors) that focus the sunlight onto a large heat exchanger, known as a receiver. The receiver is located on the top of a tower, which contains a pipe filled with heat transfer fluid. This fluid absorbs the heat obtained from the sunlight and carries it to the ground into a thermal energy storage tank. When the electricity is required, the heat transfer fluid flows through a pipe side-by-side with a pipe filled with water. The water-filled pipe goes into a steam generator, where water transforms into the steam by the use of the heat from solar. The resulting steam is directed to the turbine, which generates electricity. The remaining steam is then condensed and stored in a water tank. The heat transfer fluid is stored in a cool fluid tank that runs back to the receiver in order to repeat the cycle again. The latest development of CSP has led to the creation of four new types of CSP technologies. They are based on the same principle and share the same components (solar field, power block and storage system), but have different ways of reflecting or concentrating heat.

1. Solar Power Towers (SPT)

This technology offers flexibility in operating temperature up to 565°C and can store the heat for up to 15 hours. A particular advantage of this type of solar power scheme is that it does not only operate with molten salt (one of the best heat transfer fluids available) but can also operate with other alternatives like open air or superheated steam, that decrease the operating costs. The application of this technology is still in the development phase, with only a few Solar Towers currently in operation.

The main disadvantage of the technology is the significant water consumption for cooling process and cleaning of heliostats. Examples of successful utilisation of this technology are Solar Towers of Julich (Germany) and Solugas (Spain). These towers use pressurised air coupled to combined cycle turbines. This solution allows to generate up to 4.6 MW from air heated to 800°C.

Parabolic Dish Systems have a low application rate in commercial and utility scale projects, although some important projects like Orion project of 60 MW in China exist.

2. Parabolic Trough Collectors (PTC)

This is the most widespread technology type among CSP and the most commercially mature system as well. Parabolic trough collectors make up 3.5 GW out of the total 4.8 GW of installed CSPs worldwide.

In general, the heat transfer fluid used in this type of installation is the thermal oil that can achieve temperatures between 293°C and 393°C. However, the problem with the thermal oil lies in its high toxicity and flammability. Thus, to lower the risk, latest breakthroughs aim to increase efficiency by using alternative heat transfer fluids like molten salts and air. It is expected that these alternatives would allow the operating temperature to be raised even higher.

3. Parabolic Dish Systems (PDS)

Parabolic Dish Systems have low application rates in commercial and utility scale projects, although some important projects like Orion project of 60 MW in China exist. Despite having higher solar-to-electric conversion than other CSP systems, their downside is the low maximum power capacity of each parabolic dish. This makes them unattractive when compared with other CSP systems, especially in terms of costs and power performance. Furthermore, these systems typically lack storage system, making them unviable for large scale utility projects to be connected to the grid.

4. Linear Fresnel Reflectors (LFR)

LFR plants follow a similar trend like parabolic dish systems. LFR plants do not exceed more than 30 MW and use water as the heat transfer fluid.

This generally sets the inlet temperature values between 60°C and 190°C and exit temperature values between 257°C and 370°C. Although there are only a few applications in the commercial sector, current trends have proven the technical feasibility of this technology, for as long as optical efficiency issues keep improving. New LFR projects are planned in India, Australia, China, France and South Africa. While the CSP market is currently ruled by PTC, there is a good chance for LFR to become a strong competitor of this technology.

Wind Energy

Societies have taken advantage of wind power for thousands of years. The first known use was in 5000 BC when people used sails to navigate the Nile River.

Persians had been using windmills by 900 AD for pumping water and grind grain. Windmills may even have been developed in China before 1 AD, but the earliest written documentation comes from 1219.

Cretans were using literally hundreds of sail-rotor windmills to pump water for crops and livestock. Today, people recognise that wind power is one of the most promising new energy sources that can serve as an alternative to fossil fuel-generated electricity. Germany, the USA, Spain, Denmark, India and Australia are among the world's leading nations in the acquisition of wind energy.

Wind generated energy is growing in leaps and bounds across the globe. Wind power is now the world's fastest growing energy source and has also become one of the most rapidly expanding industries, with sales of roughly USD 3 billion in 2008. Major offshore developments will likely occur in northern European waters, in the early part of the next century.

The evolution of wind turbine technology from what it was just a decade ago to the new generation wind turbines, has been truly astounding. The production output has grown eight times from what it was in 2007.

Wind turbines continue to get larger and more efficient each year with the overriding objective of continuing to increase the competitiveness of wind energy. Below are the four main areas where wind turbines have been evolving to achieve higher performance.

1. Longer blades

Wind turbine blades extend to lengths of 50 meters. Wind farms get more efficiency out of longer blades because they sweep up more wind energy, resulting in improved economics for the wind farm. When the wind spins the turbine blades, the blades rotate the gearbox, the gearbox turns the generator, and the generator converts the wind energy into electricity. The electricity is sent down into the transmission lines to power homes and businesses. Longer blades make this process more efficient. Investing in longer blades makes business sense for a new wind farm looking to optimise profitability. However, longer blades are much heavier, and wind turbine manufacturers are continually testing new materials to make the blades lighter and to increase their velocity.

2. Taller wind turbines

Taller towers, many of which reach 100 meters or more, accommodate longer blades. New wind farms typically invest in larger turbines for maximum operational efficiency. The common practice is to run established wind farms with smaller turbines, to the end-of-life of the turbines, before replacing them with the newest taller and larger models.

3. Increased capacity

The capacity of the wind turbine is continually increasing with evolution of latest models. A 1.7MW turbine on the market, compared to its 1.5MW predecessor, has a 24 per cent increase in annual energy production, according to well-documented information from manufacturers. The average turbine capacity being deployed has increased significantly in the last ten years. Offshore wind turbines have capacities of up to 6-12 MW to capture the higher amounts of consistent wind over the ocean.

Wind power sales

3 Billion USD in 2008

4. Energy storage upgrades

As turbines get larger, they need more power for the emergency pitch control system, which rotates the blades out of the wind during an emergency shut-down situation. The pitch system is critical for protecting the wind turbine from severe damage in the case of high wind speeds that could spin the blades out of control. Most turbines with electric pitch control systems have been designed with lead-acid batteries for backup energy storage. The batteries provide the energy necessary to pitch the blades when grid power is down, and they recharge when grid power becomes available again. Wind farms experience many hours per week of turbine downtime due to the variety of maintenance tasks related to battery-based pitch control systems.

Batteries tend to perform poorly in very hot or cold temperatures and often do not serve their full lifetime due to demanding operational conditions. Premature failure requires wind technicians to shut down the turbines and climb to the nacelle with new batteries to make replacements. Batteries also require expensive chargers and, in some cases, take 20 to 30 minutes to recharge. Ultra capacitors have proven to be a more effective energy storage alternative to batteries for pitch control, providing increased operational efficiency. The ultra capacitor (or supercapacitor) is an electrostatic device that unlike the battery is less susceptible to cold and hot temperatures and has the special ability to deliver high power in fast bursts and recharge rapidly. Ultra capacitors are now commonly installed in thousands of onshore and offshore wind turbines. The switch from batteries to ultra capacitors for pitch control has accelerated significantly in several countries due to their reliability, minimal maintenance requirements, and the valuable time they save wind farm site personnel in terms of maintenance efforts as well as increased revenue hours. Many wind farms in the US have begun to retrofit battery-based systems with ultracapacitors to gain these advantages.

Challenges in offshore production

It is common knowledge, and simple fact of life, that there is more and cleaner wind offshore than onshore. Also, developing off-shore wind minimises the amount of land needed to be utilised for wind farms. Grid-connected offshore wind capacity additions reached almost 4.5 GW in 2018, 15 per cent higher than in 2017. Expansion shifted from the EU to China.

While, in 2018, new grid-connected offshore wind capacity additions in EU declined by 16 per cent, they more than tripled to 1.6 GW in China. For the first time, China installed more offshore capacity than any other country (1.6 GW), followed by the UK (1.3 GW) and Germany (0.9 GW).

Nevertheless, it is still estimated that offshore wind annual capacity additions need to more than quadruple by 2030. Notwithstanding positive developments and cost reductions of offshore wind technology, growth still needs to be accelerated for the technology to be fully on track with the Sustainable Development Scenario (SDS).

Recent EU auction results indicate cost reductions of 45-50 per cent, in the next five years due to expected advantages associated with economy-of-scale, standardisation and clustering. In 2018, manufacturers announced that turbines with record-level rated capacities ranging from 10 MW to 12 MW, would be available for plants commissioned after 2020.

These turbines are expected to deliver the record-low winning bids (USD 55-75/MWh) submitted since 2017 in Germany, the UK and the Netherlands.

Technology innovation gaps

Innovation is needed in installation processes and foundation designs. An improved understanding of the requirements of wind technology in offshore conditions, as well as the management of large numbers of wind farms, is necessary to design turbines, systems and farms. Changes in design architecture and an ability to withstand a wider array of design considerations, including hurricanes, surface icing, and rolling and pitching moments, are also critical considerations.

Improved alternative-current (AC) power take-off systems or the introduction of direct-current (DC) power systems are also promising technologies for internal wind power plant grid offshore, as well as, for connection to shore. Soft costs for offshore wind take up a substantial share of total installed costs, and together with interconnection they are a key challenge for reaching SDS cost goals.

Offshore wind farms also need to incorporate high levels of resilience to stronger wind regimes and meteorological conditions off shore, particularly to mitigate the impact of long-term exposure to seawater. System design needs tool development to minimise loads across the components to optimise for specific conditions including offshore, cold and icy climates, or tropical cyclone climates. The common standards and model tools used today are based on European sea and meteorological conditions. These will have to evolve through innovation so that they can continue to be relevant as wind power expands to new regions in the USA, Japan, Korea or emerging economies. Improving model tools requires measurement campaigns both in the field and in controlled test facilities.

Pre-commissioning of onshore wind turbines is a market-ready solution, where the rotor and turbine can be assembled onshore in the short term. In the medium-term, concepts for integrating structures could deliver further gains including joint installation of turbine and foundation.

An area of high priority is finding innovative ways to reduce the volume of high voltage AC (HVAC) infrastructure on the plant side. High voltage interconnections using DC are key in deep-water projects, and ways for minimizing further loss in capacity and reducing the cost of cabling equipment, are important consideration. Increasing voltages in offshore wind farm cabling and infrastructure to reach 400 kV would result in reduced losses. Low frequency transmission could further reduce losses, but only few of such initiatives are currently in place.

The richest offshore wind resources are in deep waters, where attaching turbines to the seabed is not practical. Several regions (e.g. the US or Japan) have a low share of their offshore wind resources in shallow waters. Floating offshore foundations, offer the potential for less foundation material, simplified installation and decommissioning, and additional wind resource at water depths exceeding 50m to 60m. Floating foundations, such as spar buoy, the tension leg platform and the buoyancy-stabilised semi-submersible platform, may also be attractive for mid-depth projects, where heavy-lift vessels to transport foundations are not required. However, new tools are required to capture the design criteria for floating platforms, which include the need to address weight and buoyancy requirements as well as the heaving and pitching moments created by wave action.

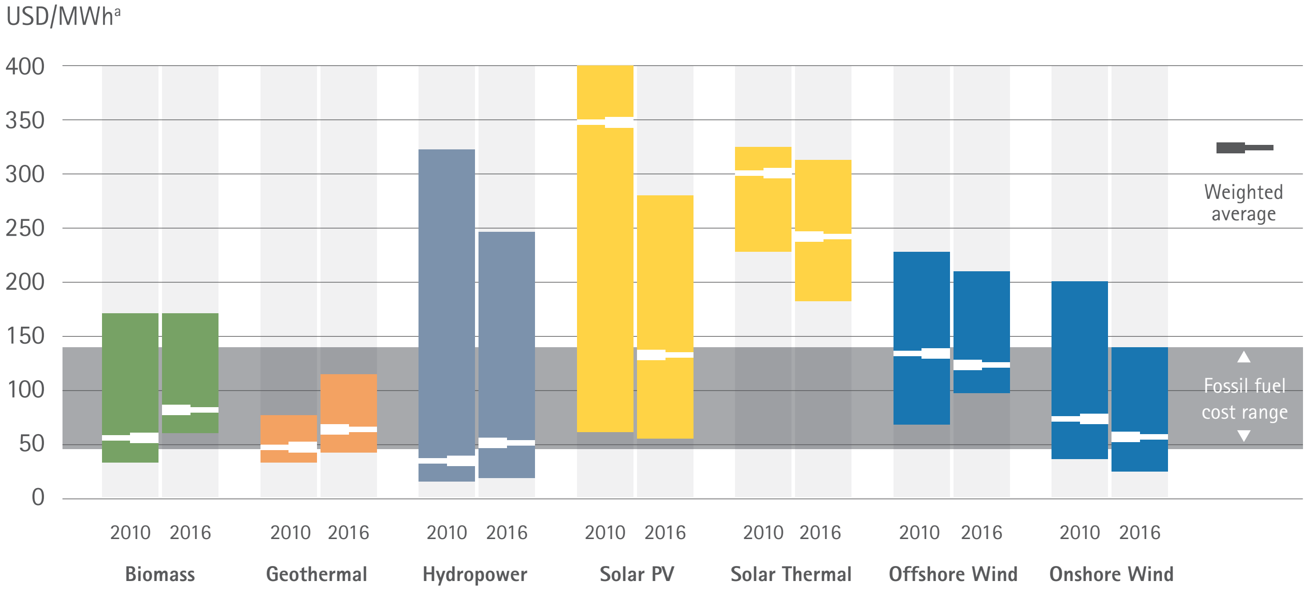
Cost history of renewables

Technological developments have contributed significantly to driving down the costs of renewables. Many governments and private companies have invested substantial amount of money in research and development of renewable energy technologies, over the last two decades. These investments are bearing fruits and having a positively impact on the competitiveness of renewable energy technologies, as compared to the traditional fossil fuel energy sources.

A report by IRENA indicates that prices do strongly influence people choices of energy sources, especially the relative costs between sources of energy. This is particularly true in higher-income countries, where the quest for low energy bills is profound, but it is increasingly true in low and middle-income economies as well. The key priority for many countries is to increase access to electricity and energy resources to more population, and to do this requires low-cost energy.

In the transport sector where the dominant energy source is liquid fuels (diesel and gasoline) the relative costs are less important than changes in price through time. Therefore, the focus is usually on the relative costs of energy sources in the electricity sector. In the electricity sector, the comparison of the relative cost of energy is done based on what is commonly referred to as the 'levelised cost of electricity' (LCOE). For renewable technologies to be truly competitive with fossil fuel sources, they need to deliver electricity at more cost-competitive rates. The chart below, sourced from IRENA's latest report on 'Rethinking Energy', shows the levelised cost of electricity (LCOE), measured in USD per MWh of electricity produced, across the range of renewable technologies in 2010 and 2016.

Levelised cost of electricity (LCOE) 2010 and 2016



Note:

a). MWh: megawatt-hour

b). All coasts are in 2016 USD. Weighted Average Coast of Capital is 7.5% for OECD andChina and 10% for Rest of Worla

It's important to acknowledge that the relative costs of energy are context-dependent and vary across the world. For example, the relative cost of solar PV is likely to be lower in lower latitude countries than at high-latitudes because they will produce more energy of their lifetime. This can result in very different LCOE figures by region, and indeed, the country-specific LCOE charts can vary significantly. For the global chart shown above, the range of costs is represented as vertical bars for each technology. The white line in each bar represents the global weighted average cost per technology. What the chart shows is that in terms of the 2016 weighted average cost, most renewable technologies are within a competitive range of fossil fuels. The key exception to this is solar thermal which remains about twice as expensive, although showing a falling trend between 2010 and 2016.

Apart from traditional biomass, hydropower, is the oldest and well-established renewable source. This fact is reflected in its low price, which can undercut even the cheapest fossil fuel sources. It should be noted however, that although the weighted average of most sources is competitive with the average fossil fuel cost, the wide range of potential costs means that this is not true for all countries. Therefore, it is important that the selection of particular technologies is considered on a local, context-specific basis.

09

CHAPTER 9
INVESTMENTS

This chapter examines the reason behind this growing trend and examines the major forces responsible for the changing investment landscape for renewables.

Investments in renewables have been growing rapidly in recent years. This chapter examines the reason behind this growing trend and examines the major forces responsible for the changing investment landscape for renewables, drawing heavily from publicly available reports by IRENA, Bloomberg New Energy Finance and studies carried out on behalf of the EU and IEA.

The chapter also outlines key global and regional trends of investment in the different technologies, examines the differing roles and approaches of private and public finance, highlights the important role of risk litigation instruments, and provides an outlook for renewable energy finance in 2019 and beyond.

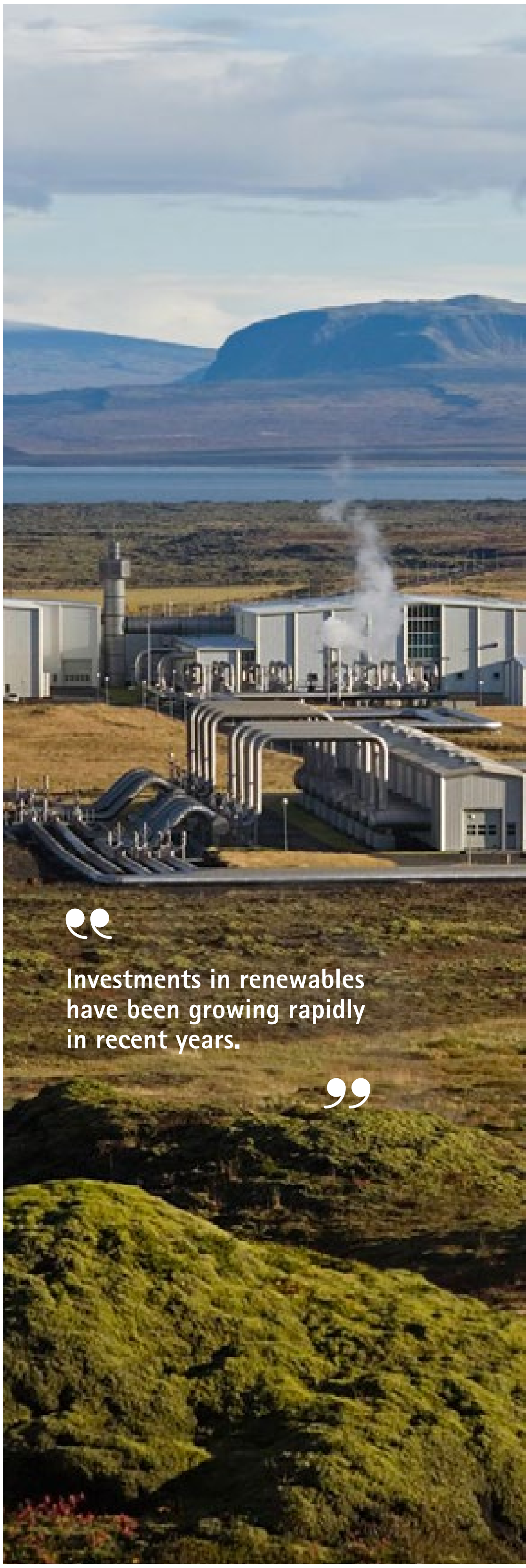
According to IRENA, since 2012, renewable power capacity installations have exceeded non-renewables by a rising margin, representing about 60 per cent of all new power-generating capacity added worldwide in 2016. Investment reached a comparable milestone in 2015, when renewable power technologies for the first time attracted more finance than non-renewable power technologies, a trend that has continued subsequently.

Global annual investment in renewable energy rose steadily from 2013 to 2015, peaking at USD 330 billion in 2015, before falling to USD 263 billion in 2016. While annual investment declined in 2016, capacity additions in the same year were up from 2015. The rise in capacity additions is partly due to declining costs and partly to the time lag between financial closure (the time of committing the investment) and the completion of construction, when the installation is fit and ready to be put into operation. For key renewable energy technologies, declining costs have significant influence on financial flows.

Lower solar and wind power costs reduced the total value of renewable energy investments in 2015 and 2016, as each dollar of investment was able to finance more capacity than in previous years. Policy changes also contributed significantly to global investment trends. The peak in 2015 was partially driven by a rush to complete projects before an expected fall in policy support in key markets (e.g. cuts in feed-in-tariffs in China, Germany, Japan and the UK).

Since 2004, cumulative renewable energy investment has been USD 2.9 trillion, the world installing a record 98 GW of new solar capacity, which is far more than the net additions of any other technology (e.g. renewable, fossil fuel or nuclear).

The cumulative USD 2.9 trillion investment in green energy sources since 2004, is a direct result of eight consecutive years (2010-2018) during which global investment in renewables exceeded USD 200 billion each year. This global level of investment in renewable energy resulted in increasing the proportion of world electricity generated by wind, solar, biomass and waste-to-energy, geothermal, marine and small hydro from 5.2 per cent to 12.1 per cent. The summary global spread shows that, between 2017-2018, China led with more than half of world's new solar capacity installed and global solar investment jumped by 18 per cent to USD 160.8 billion.



"Investments in renewables have been growing rapidly in recent years."

The amount of investment (USD 160.8 billion) attracted by the solar power sector in 2017-2018 was far more than any other technology. Solar power made up 57 per cent of the 2018 total investment in renewable (USD 279.8 billion), excluding large hydro. This made solar power tower costs above new investment in coal and gas generation capacity, which was estimated at USD 103 billion during the same time period. A driving force behind the 2018 surge in solar power was the development in China, where an unprecedented boom saw some 53 GW (more than half the global total) added at a whopping 58 per cent increase in investment to USD 86.5 billion.

The 2018 report titled 'The Global Trends in Renewable Energy Investment' published by the UN Environment, Frankfurt School - UNEP Collaborating Centre, and Bloomberg New Energy Finance, finds that falling costs for solar electricity, and to some extent wind power, is continuing to drive deployment. Overall, China was by far the world's largest investing country in renewables, at a record USD 126.6 billion, up 31 per cent as compared to 2016. There were also sharp increases in investment in Australia (up 147 per cent to USD 8.5 billion), Mexico (up 810 per cent to USD 6 billion), and Sweden (up 127 per cent to USD 3.7 billion). A total of 19 countries had investments of more than USD 2 billion each, including, for the first time, Ukraine and Vietnam.

Renewable energy investment in developed countries increased 11 per cent in 2018, to USD 136.1 billion, and by a record high 6 per cent to USD 61.6 billion, in the developing world, excluding China. This trend reflects a broadening of investment activity in wind and solar to more countries in Asia, Eastern Europe, the Middle East and Africa. Considering all financing of renewable energy (excluding hydropower larger than 50 MW) in 2018, China accounted for 32 per cent of the global total, followed by Europe (21 per cent), the USA (17 per cent) and Asia-Oceania (excluding China and India; 15 per cent).

In 2017, a record number of 157 GW of renewable power was commissioned, up from 143 GW in 2016 and far out-stripping the net 70 GW of fossil-fuel generating capacity added (after adjusting for the closure of some existing plants) over the same period.

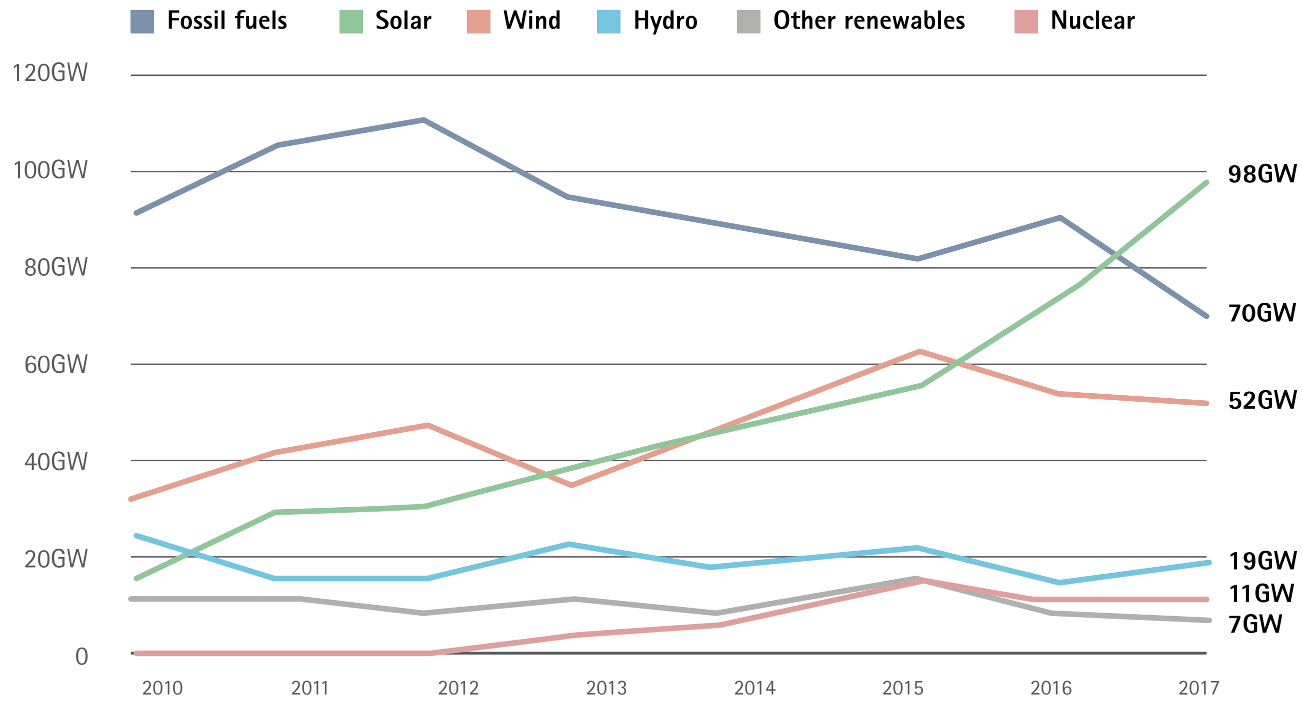
The chart below shows net capacity growth for different electricity sources, factoring in power plant closures.

The cumulative 2.9 trillion USD investment in green energy sources since 2004, is a direct result of eight consecutive years (2010-2018) during which global investment in renewables exceeded 200 billion USD each year.

Renewable energy investment in developed countries increased 11% in 2018, to

136.1 billion USD

Global growth in net electricity generating capacity



The explosive growth of renewable energy is shaking up the energy industry, since the last decade and, the trend is expected to continue. As the cost of solar and wind continues to fall and bottlenecks such as, storage capacity, are diminished, the IEA predicts that renewable energy will comprise 40 per cent of global power generation by 2040. The number of institutions divesting from fossil fuels has increased globally since 2011, although the funds are not necessarily reinvested in renewable energy projects.

The picture has not been upbeat all-round, as some big markets, saw declines in renewable energy investment during the same period. In the USA, for example, investment dropped 6 per cent to USD 40.5 billion. In Europe there was a fall of 36 per cent to USD 40.9 billion, with big drops occurring in the UK (down 65 per cent to USD 7.6 billion) and Germany (down 35 per cent to USD 10.4 billion). Investment in Japan slipped 28 per cent to USD 13.4 billion. According to Bloomberg New Energy Finance, the decrease in investment seen in these some of the countries, generally reflected a mixture of changes in policy support, the timing of large project financing, such as in offshore wind, and lower capital costs per MW.

Climate change considerations

In general, investment in renewables is booming, but the key question is whether the growing pace is fast enough to avert a global warming crisis by 2050, as predicted by science. The mounting pressure continues to be placed on the energy sector to address carbon emissions. It is less than four years since the Paris Agreement set the long-term goal to limit the rise in global temperature to well below 2°C.

Before then, the oil and gas industry had very little appetite to invest in decarbonisation. Paris now sits at the very heart of the strategic debate on the transformation of the energy industry.

The recent new target set by the UK, for net-zero emissions by 2050 is an indication of the ramping-up of pressure by governments on industries address climate change. Energy companies, particularly the big multinationals, are also facing agitation from investor, who are increasingly pressing corporate boards to address carbon emissions and build a sustainable business model. The sector's share of the global stock market indices has halved in the last few years, and the need to stay relevant and investable has never been so challenging for the energy sector.

Major oil companies, especially in Europe, are now leading the way in the development of robust climate change strategies. Total and Shell have gone further than others, in increasing exposure to renewables and other clean technologies, but Shell is out on its own in laying out a net-carbon neutral ambition. However, more and more International Oil Companies (IOCs) and National Oil Companies (NOCs) are recognising the need to signal clear intentions to investors, shareholders and stakeholders.

The major oil and gas companies have bought into much of the zero-carbon value chain, with biofuels and carbon capture and storage being integral parts of their portfolios for quite some time. The focus of these major companies, in the last four years, has shifted to renewables (solar PV, onshore and offshore wind); battery storage and electric vehicle (EV) charging; and forestry (carbon sinks), capitalising on the similarities in scale and complexity between development of the biggest renewables and traditional upstream projects.

The power market remains highly fragmented and zero-carbon businesses are typically small or held within a regional or local utility. Some observers in the energy sector, are of the view that mergers and acquisitions (M&A) could be the key for taking the current trends in energy revolution to another level. Big oil companies with any ambition to be a major or big player in the new green energy revolution, will need to scaleup their investments in renewables.

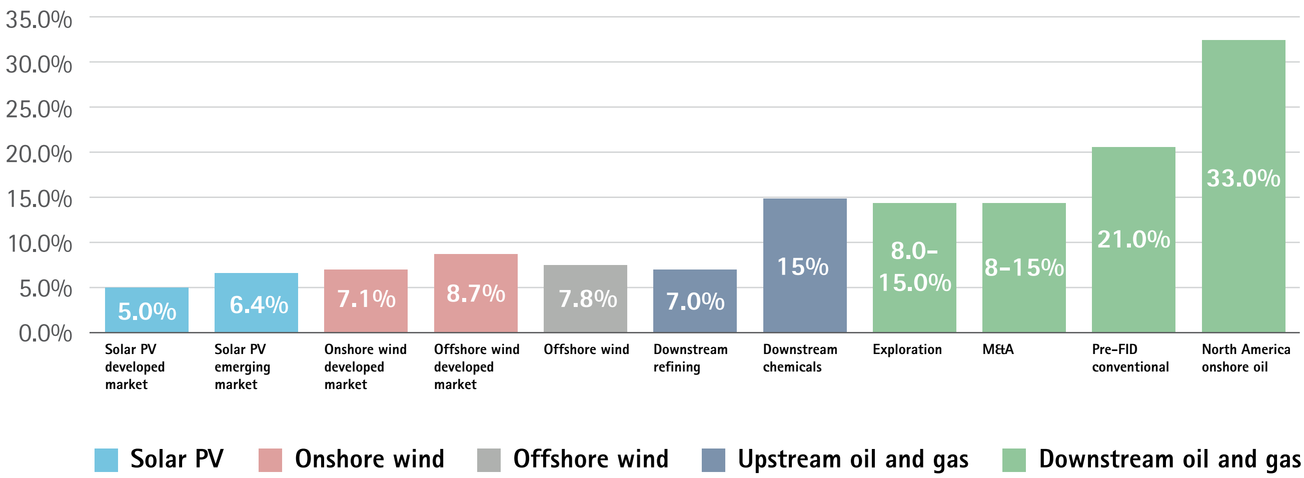
M&A have proven effective in growing businesses to operate at scale. While it may still be some years away yet, there is growing realisation that transformational M&A will come and accelerate further buildup of the renewable energy sector.

So far, the major oil companies have spent relatively little, with only just USD 6 billion on M&A in four years, representing a tiny fraction of investment in the core business. However, this is expected to grow in time, as companies move from the trial and formative stages of positioning and testing, into full-blown M&A.

It seems that companies are still trying to assess technologies and timing to find where they can create value. Both Total and Shell are planning to invest up to USD 2 billion a year, and Total has committed to having 20 per cent of assets in renewables by 2030.

Currently, many companies find the returns on investment for renewable energy projects to be too low, making it difficult to justify a business case for investing big on renewables. Returns on investment are typically at single digits, 5 per cent to 9 per cent Internal Rate of Return (IRR), depending on the technology, market, and other factors. These figures don't stack up well against pre-Final Investment Decision (FID) upstream oil and gas project returns, though there is not a huge difference on full-cycle comparisons. It is also worth bearing in mind that oil and gas returns are expected to shrink as the energy transition gains momentum. This will ultimately drive a ramp-up in exposure to zero-carbon assets, as renewable energy returns are further boosted through innovative financing models and direct and indirect government interventions.

Returns from zero-carbon assets tend to lag those in oil and gas (IRR)



The interconnectedness of renewables and climate change was discussed in Chapter 5. However, it is important to point out in this chapter, that without the growing considerations for climate change, the drivers of investment in renewables would not have been so strongly pronounced. These drivers include: subsidies and tax breaks; trends in technology for electricity generation; and conservation of energy in other industries.

Subsidies and tax breaks

According to OECD, subsidy can be defined as any measure that keeps prices for consumers below market levels, or for producers above market levels, or that reduces costs for consumers or producers. In the context of promoting investment in renewables, especially as a way of mitigating against climate change, it is prudent to consider the broader sense of all energy-related financial supports and interventions that include: tax expenditures, direct transfers, indirect transfers and research, development and demonstration (RD&D) budgets.

Tax expenditures are the amount of tax benefits, or preferences, received by taxpayers (in this case, consumers and producers of energy from renewable sources) and forgone by governments.

In reality, tax expenditures are often directed to final consumers, as in the case of granting favourable excise tax or energy tax rate for use of diesel for agriculture or other specified purposes. Direct transfers, mainly in the form of grants and soft loans, are direct expenditures by governments to recipients, which could be either consumers or producers. Indirect transfers, on the other hand, encompass various types of economic mechanisms that consist of transferring amounts of money from groups of people or entities to a specific group or entity.

Most often, such measures are financed through final tariffs or prices, using cross-subsidy mechanisms. Examples of indirect transfers include: biofuels blending mandates; capacity mechanisms; differentiated grid connection charges; energy efficiency obligations; feed-in tariffs or premiums; interruptible load schemes; PPA; price guarantees (cost support or price regulation); RES quotas with tradable certificates. Energy RD&D budgets cover various types of interventions such as fiscal instruments (e.g. taxes), financial instruments (e.g. loans, grants), market-based mechanisms, direct investment (e.g. public procurement), education and information campaigns, or technology replacement programmes.

In 2017, Thomson Reuters released its inaugural report on the top 100 global energy leaders, which evaluated companies in the sector (both traditional and renewable) based on eight criteria, including innovation, environmental impact, social responsibility, and risk management.

According to the report, the top companies go beyond the balance sheet, by ensuring that they created advanced sustainability programme, developed groundbreaking technologies, and benefited their surrounding communities; in addition to having solid financials.

The report contained a sub-list of the top 25 renewable energy companies, which are generally smaller and younger than the energy giants in the main ranking. Eight of those leading renewable energy companies are based in China, Hong Kong or Taiwan.

Types of renewable energy financing

In 2018, renewable energy financing mainly took the form of asset finance, small-scale distributed capacity investment, global research and development (R&D), public market investment, and venture capital and private equity.

Asset finance accounts for the clear majority of total investment in renewable energy – including the financing of utility-scale wind farms, solar parks, biomass and waste-to-energy plants, biofuel production facilities, small hydropower dams, geothermal plants and ocean power stations.

The estimated total of financial flow through asset financing in 2018 was USD 236.5 billion. This was the lowest level since 2014 and represented a drop of 12 per cent from 2017 levels. New asset finance deals were led in USD dollar terms by a USD 3.3 billion (950 MW) offshore wind farm in the UK and a USD 2.4 billion (800 MW) plant in Morocco that combines solar PV and concentrating solar thermal power.

Small-scale distributed capacity investment, which is mainly investment in solar PV systems smaller than 1 MW, was USD 36.3 billion in 2018, down 15 per cent from 2017. In the USA, which was the biggest market for small-scale solar, investment was down 15 per cent to USD 8.9 billion. Germany, Australia, India, Japan and the Netherlands (in descending order) remained significant markets at over USD 1 billion each. In total, capacity investment in asset finance and small-scale distributed installations (excluding large hydropower) came to USD 272.8 billion in 2018.

Other types of renewable energy financing that contributed to the investment total in 2018 included global R&D, public market investment, and venture capital and private equity, as well as USD 4.8 billion in re-invested equity. Both corporate and government R&D increased in 2018, with a 12 per cent rise to a record USD 7.5 billion for corporate R&D and 8 per cent increase to USD 5.5 billion in government R&D.

The largest percentage increases in R&D overall came in China and in the Asia-Pacific region. Total R&D for solar power and wind power increased by 12 per cent and 9 per cent from 2017, respectively.

Public market investment in new equity issued by specialist renewable energy companies was up 6 per cent, to USD 6 billion, but remained well below the double-digit billions reached in 2007 and 2014. The biomass and waste company China Everbright International led the way in public market investment, by raising a whapping USD 1.3 billion in equity in 2018.

Venture capital and private equity investment (VC/PE) in renewable energy reached USD 2 billion in 2018, up 32 per cent, with the US biofuels company World Energy leading the list of VC/PE deals, with a USD 345 million expansion capital round. The USD 2 billion investment in 2018 was still far below the record USD 9.9 billion VC/PE investment attained a decade earlier.

Investments by Types in 2018

Asset finance	Small-scale distributed capacity investment	Corporate and government R&D	Public market investment	Venture capital and private equity
237 billion USD	36.3 billion USD	13.0 billion USD	6.0 billion USD	2.0 billion USD

Fossil fuel divestment trends

Investment patterns in renewables would not be complete without a look at the trend in divesting in fossil fuels. Since 2011, a growing number of institutions have divested from or sold off their financial interests in fossil fuel companies. Different approaches are taken in divesting from fossil fuels. Some institutions divest by making binding commitments to exclude any fossil fuel company (coal, oil and natural gas) from either all or part of their managed asset classes. Investors could also selectively exclude companies that derive a large portion of their revenue from coal and/or tar sands companies. Others divest based on criteria that may include a company's willingness to engage in meaningful efforts to curb emissions.

By 2018, around 1,000 institutions spanning 37 countries had committed to divesting from fossil fuels, with estimates of total asset values ranging from USD 6.2 trillion to USD 8 trillion. These divested funds range from insurance companies (approximately 55 per cent of total assets divested), pension funds (approximately 33 per cent), banks (approximately 6 per cent), to smaller shares from governments, non-governmental and faith-based organizations, and health, cultural or educational institutions, amongst others.

Insurance companies are increasingly divesting from coal company equities and bonds and, in some cases, are ceasing to underwrite coal projects. Around 20 per cent of the insurance industry's global assets were covered by divestment policies in 2018, up from 13 per cent in 2017. This includes at least 19 major insurance companies worldwide, many of which are based in Europe.

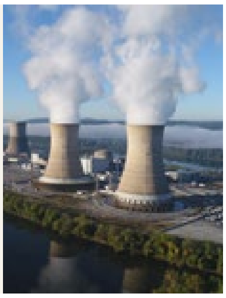
By the end of 2018, 144 self-managed public pension funds had committed to divesting from fossil fuels, including those of major cities such as Berlin (Germany), Copenhagen (Denmark), Dunedin (New Zealand), Paris (France) and Sydney (Australia). The mayor of New York City (USA) announced plans in 2018 to divest around USD 140 billion of the city's pension funds within five years, and the mayor of London (UK) pledged to divest the London Pension Fund Authority of its remaining fossil fuel investments by 2020. Ireland became the first country to pass legislation divesting all public funds (around USD 355 million) from fossil fuels.

Estimated Global Investment in New Power Capacity, by Type (Renewables, Fossil Fules and Nuclear Power), 2018

33 billion USD

Nuclear power

7.9%



95 billion USD

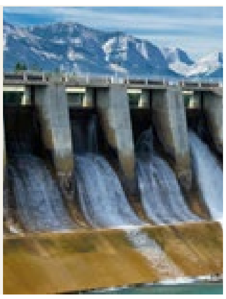
Fossil power

22.8%

16 billion USD

Hydropower >50MW

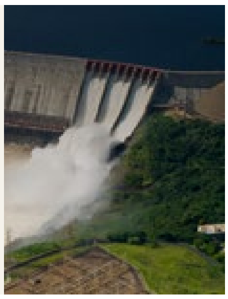
3.9%



272 billion USD

Renewables (excluding hydropower > 50 MW)

65.4%



Note:

Renewable investment data in figure exclude biofuels and some types of non-capacity investment

It is important to point out, however, that funds divested from fossil fuel companies are not necessarily reinvested in companies associated with renewable energy. (Tell the reader more here, this is interesting).

Conclusion

The world is experiencing an energy revolution, and gradually moving towards a low-carbon green economy, characterised by increasing proportion of the global energy mix being generated from renewable sources.

This book highlights some widespread examples of countries setting specific quantitative targets for renewable energy in their energy mix. Large energy corporations are increasing their renewable energy portfolio, as well as, investments in research and development of renewable energy technologies.

An increasing number of jurisdictions worldwide, at country, city, and municipality levels, are even aiming for aggressive targets of 100% renewable energy.

Some examples of emerging and developing countries aiming for specific renewable energy targets, include: China has plans to increase the share of non-fossil fuels in primary energy consumption to about 15% in 2020 and 20% by 2030.

India intends to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. Chile has set a national target of 20 per cent renewable electricity by 2025. Israel has a target of generating 17% of its electricity from renewable by 2030.

An increasing number of jurisdictions worldwide, at country, city, and municipality levels, are even aiming for aggressive targets of 100 per cent renewable energy. While most of these are primarily targeting the power sector specifically, increasing numbers are also including heating, cooling, and transport.

Denmark, for example, has a strategy to move toward 100 per cent renewable energy in the power and heat sectors by 2035, and fossil fuel-free economy-wide by 2050.

The Danish city of Frederikshavn has set a more ambitious target of 100 per cent renewable energy by 2030.

Iceland already realizes almost 100% of its electricity production and heating from renewable energy.

The African island nation of Cape Verde aims for 100 per cent renewable energy, largely to eliminate its high dependence on imported fossil fuels. Sumba Island in Indonesia, with a population of 650,000, has adopted a local government plan that aims to achieve 100 per cent renewables by 2020.

The US state of Hawaii adopted binding legislation in 2015 to aim for 70 per cent renewable electricity by 2030, and 100 per cent by 2045.

East Hampton in New York state decided to meet 100 per cent of the community's electricity needs with renewables by 2020.

The countries whose economies are traditionally dependent on the production, export and consumption of fossil fuels are not left behind in the growing push for renewable energy sources.

The Kingdom of Saudi Arabia, for example, is paying great attention to the development of renewable energy, launching several projects and initiatives under the country's Vision 2030 and related National Transformation Programme, to produce 4% of its total energy from renewable sources by 2020, and 10% by 2030. Egypt aims to generate 20% of its power from renewable sources by 2022 and 37% by 2035.

Qatar is committed to increasing the share of renewables in supplying the country's energy needs, setting a realistic target of reaching the goal of 20% of total energy to be produced by solar generation by 2030. Algeria has a national programme for renewable energy that involves large scale deployment of photovoltaic, wind power and solar energy, to reach a target of 27% of total electricity generation by 2030.

Under Australia's Renewable Energy Target scheme, over 23 per cent of Australia's electricity was expected to come from renewable sources by 2020. Indonesia adopted a mixed energy use policy to achieve renewable energy target of at least 23% in 2025 and 31% in 2050.

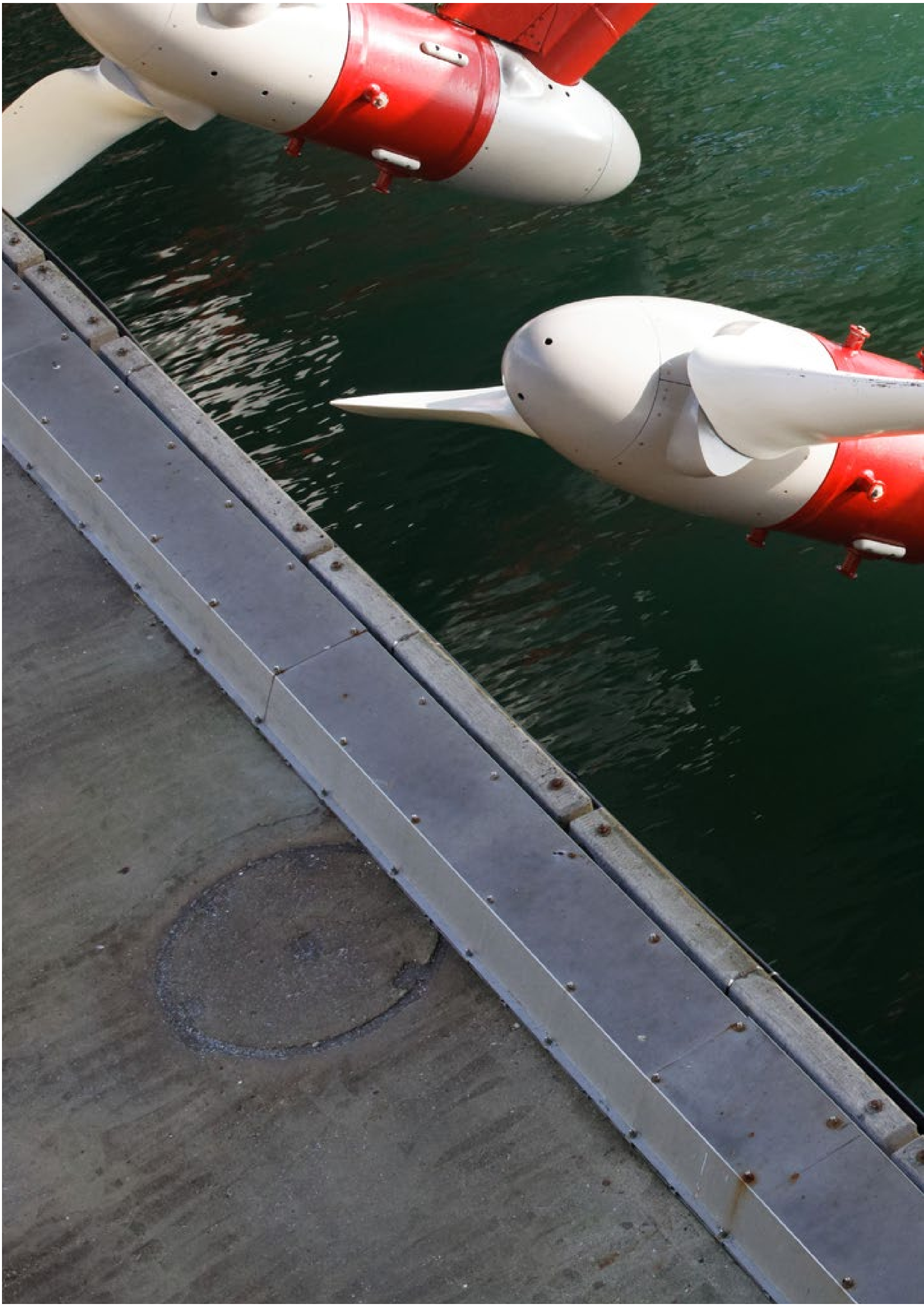
Noting examples of wide spread initiatives by many countries to promote and develop renewable energy, it is asserted that the private sector, and more specifically energy industries, occupy a unique place in the constellation of organizations that can shape the development and growth of renewables.

Furthermore, there is a compelling business case for energy companies to pursue significantly bolder and sophisticated measures that can attract large-scale flows of private finance in support of development of renewable energy technologies. These assertions are guided by the following premises:

- The momentum on renewable energy is unstoppable;
- The pressure on investors to disinvest from fossil fuels will continue to increase, in the face of mounting climate challenge;
- The Paris Agreement recognises the need for active participation of all sectors of society, including the different tiers of government, in the widest possible cooperation by all countries, to implement climate actions;
- Unlike the era of the Kyoto Protocol, the predecessor to the Paris Agreement, there is now some acceptance that the private sector should become part of the solution rather than remaining as culprits to be continually castigated for climate change problems;
- It is in the interest of the energy industry, that the traditional energy companies step up to be counted among the leading actors in the new paradigm shift presented by the Paris Agreement;
- Nobody understands what it would take to transform the energy sector more than the players within the sector;
- There are many opportunities for the traditional energy companies to use their business expertise to address the challenges facing the development of renewable energy technologies; and
- Harnessing such opportunities make good business sense and helps the contribution of the energy sector to sustainable development.

The pressure on investors to disinvest from fossil fuels will continue to increase, in the face of mounting climate challenge.

"Qatar is committed to increasing the share of renewables in supplying the country's energy needs, setting a realistic target of reaching the goal of 20% of total energy to be produced by solar generation by 2030."



INVITED PAPERS

Paper 1: Renewable Energy in Trinidad and Tobago.
Paper 2: Examples of Renewable Energy Financing.
Paper 3: Wood Mackenzie Whitepaper on Energy Transition.
Paper 4: Electricity Demand in Qatar: Opportunities for Demand Response.
Paper 5: Agricultural and urban microgrid systems and architectures for Qatar.
Paper 6: Environmental and Economic Impacts of PV Adoption in Qatar.

PAPER 1
RENEWABLE ENERGY IN TRINIDAD AND TOBAGO

> Almost 100% of electricity in Trinidad and Tobago is generated through power plants fueled by natural gas.

The need for Renewable Energy in Trinidad and Tobago

Trinidad and Tobago (T&T) is a small island developing state in the Caribbean but has a sizeable hydrocarbon-based economy, which includes the production of oil and gas along with significant petrochemical and LNG capabilities. T&T is one of the largest exporters of methanol and ammonia in the world and was once one of the top ten exporters of LNG in the world. However, there was a time when natural gas was considered a nuisance product of the oil industry, and in many cases it was vented or flared. In the 1980s, the government at the time decided to monetise the resource. As a result of this decision a petrochemical industry including methanol and ammonia production began and in 1999 the first LNG facility was developed. The county at the time also began using the resource to produce electricity.

However, since 2010, there has been significant gas curtailment in Trinidad and Tobago since then production of natural gas has not met the demand of installed capacity. This current situation of curtailment means that it is essential that the government extracts the most value from every molecule of natural gas that is produced. At 2019 rates, the country produces approximately 3.6 bcf/d. However, demand for gas exceeds 4 bcf/d.

The demand for electricity is typically about 8000 Gwh per year of power. At present, nearly all of this is produced using natural gas. The production of electricity consumes about 8% of the total natural gas produced, around 250mmscf/d.

The Energy Chamber has recognised that there are areas where inefficiencies exist within the electricity sector which has impacted on the natural gas supply and therefore the revenues earned by the government. The Energy Chamber of Trinidad and Tobago has been supporting the government and encouraging reform in many areas to ensure that the links between the electricity sector and the gas sector are efficient and transparent. The Energy Chamber is also endeavouring to highlight these issues to a broad array of stakeholders to ensure that the situation is understood and can be addressed through a supportive policy framework and fiscal structure.

If electricity was generated using renewable energy, the gas consumed could be diverted to higher-value operations in the petrochemical sector or for LNG. In addition, reducing the demand for electricity through energy efficiency would reduce the demand for natural gas in this subsector.

The Situation

Currently, almost 100% of electricity in Trinidad and Tobago is generated through power plants fueled by natural gas. The Trinidad and Tobago Electricity Commission (T&TEC) purchases gas from the National Gas Company (NGC) and subsequently pays independent power producers to convert the natural gas to electricity. T&TEC then earns income through distribution of electricity to end-users.

T&TEC purchases gas from the NGC at a rate that is below the prevailing market rate for gas in Trinidad and Tobago.

Fig 1. Market price for gas vs the price of gas for electricity

The low price of gas (the main input into electricity generation) also leads to the low electricity rate (which is the lowest in the region and among the lowest in the world). However, the difference between the actual price of gas and the price that T&TEC pays represents significant losses of revenue to the National Gas Company and therefore to the government of Trinidad & Tobago. This can be referred to as an opportunity cost subsidy.

The diagram below illustrates the values that are forgone due to this current arrangement. In 2017, the resultant loss was approximately USD$508m.

Natural Gas used for power generation represents approximately 17% of NGC sales. What exacerbates the situation is that reportedly T&TEC has not paid the NGC for the gas it has consumed in over 5 years. This volume of gas is equivalent to 4 average-sized petrochemical plants to be operational or enough gas to generate 26 cargoes of LNG.

The production of electricity consumes about

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of the total natural gas produced, around 250mmscf/d.

Energy Efficiency in Trinidad and Tobago

In many instances, the lowest hanging fruit to reduce the amount of gas used in power generation would be to reduce the demand for electricity. This can be achieved through energy efficiency.

At present there is some legislation that supports the development of energy efficiency.

However, there are some problems in the implementation of the legislation, and thus no one has been able to access incentives to develop any energy efficiency projects.

In 2010, Parliament passed legislation creating a tax allowance that provides a 150% tax credit on expenditure relating to energy efficiency audits and subsequent upgrades. The tax credit can only be accessed once the work is carried out by an Energy Service Company (ESCO) certified by the Ministry of Energy. However, the Ministry of Energy, to date, as no system for certifying ESCOs so no one has been able to access the tax credit.

There was a committee established in the former Ministry of Energy and Energy Affairs to determine how they could certify ESCOs, but no decision has been taken on the issue in the over 8 years since the incentive was announced.

The Energy Chamber of Trinidad & Tobago has lobbied the Ministry of Energy repeatedly on the issue of ESCO certification.

Many small businesses were established in 2010 and 2011, anticipating that there would be significant business opportunities generated because of this tax allowance. The inability for the government to implement a simple system to certify ESCOs frustrated many business people, most of whom have not seen any return on the investments they made in increasing their capacity in energy efficiency and related renewable energy systems.

We understand the difficulty that the Ministry of Energy has with this issue as they are simply not set up to conduct this sort of certification system. However, there are other bodies in the country who are, including organisations like the Energy Chamber and the Green Building Council.

In most countries, these sort of industry certifications are run by trade associations and there is no reason it should be different in Trinidad and Tobago. The Energy Chamber is already running a company certification system on behalf of the industry, called Safe to Work, where we already have over 500 certified companies.

In lieu of having the supporting legislation being operational, the Energy Chamber has developed an Energy Efficiency Declaration to encourage member companies to be inward-looking at their operations and to endeavour to increase the levels of energy efficiency and conservation. The Declaration was launched at the 2019 Trinidad and Tobago Energy Conference and since then 60 companies have signed the declaration, including all of the major upstream energy companies and many downstream and energy services companies.

The companies have committed to improving efficiency in the following areas:

Facilities:
By examining the integration of energy-efficient technology, programmes and policies into existing operations;

Natural gas utilisation, electricity generation and electricity consumption:
By exploring and deploying opportunities to optimize the use of natural resources, raising the awareness of employees, contractors and partners and where applicable examining the use of renewable and sustainable sources of energy;

Transportation:
Through further collaboration in aviation, land & marine transportation logistics and where applicable the use of energy-efficient technology.

In 2019 as well The Parliament has established a National Energy Efficiency Committee. The committee, which comprises representatives of several Government Ministries and agencies, is mandated to develop an Energy Conservation and Energy Efficiency Action Plan for Trinidad and Tobago for the period 2019 – 2024, that covers all sectors of the economy involved in the use of energy.

The Energy Chamber also sits on this committee and is supporting the activities under this group. The output from this committee is expected to be completed in September 2019.

Social Media

To highlight these issues in the public sphere, the Energy Chamber continuously writes and publishes articles for social media and print media.

In 2018 the Energy Chamber partnered with a local NGO, the IAMovement to develop an animated three-part video series which illustrates the hidden opportunity cost subsidies that exist in the electricity sector. The Energy Chamber provided the data and information in an unbiased way to the NGO which turned the information into a thought-provoking series which gathered significant attention on social media.

There has been very positive feedback from the video series and the videos have collectively had approximately 100 thousand view and hundreds of likes and shares on Facebook and other social media.

Education & Events

The Energy Chamber has developed the first two-day conference in Trinidad and Tobago dedicated to low carbon initiatives, it is titled the Trinidad and Tobago Energy Efficiency and Renewables Conference. The conference attracts high quality speakers from all over the world and gives participants the opportunity to understand international best practices but also discuss how implementation can take place at a local level.

Over the three years, the conference has seen over 600 participants and 120 speakers.

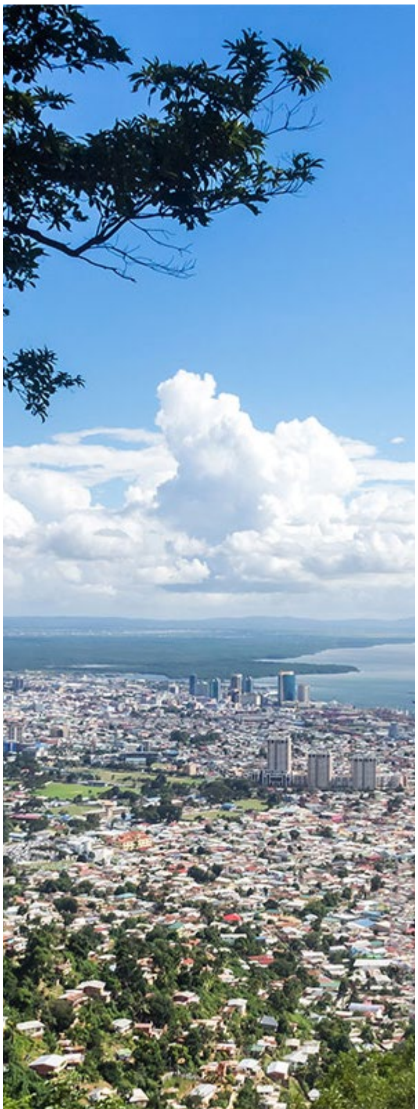
This conference also gives companies the opportunity to exhibit their capabilities at the Trade Show and Exhibition Area where they can network and create opportunities for business.

The Energy Chamber has also been hosting several smaller educational sessions to encourage wider participation with academia. Since 2017, the Energy Chamber has worked with the University of Trinidad and Tobago to host 7 mini symposia to discuss a wide array of issues including; a roadmap to renewable energy, alternative fuels and the future transport, and battery storage.

Moving Forward

The Energy Chamber has been focusing on advocacy around Energy Efficiency and Renewable Energy in Trinidad and Tobago for several years. The Chamber has been working with many stakeholders in the country to ensure that everyone understands the context and the urgency to bring renewable energy onto the grid and also to be more mindful of the energy that is used.

To date the government has put out a request for proposals for utility-scale renewable energy projects to generate up to 130mw of electricity. The Energy Chamber understands that the government has received significant interest and has received 11 bids. These bids are currently under review which will be completed by October 31st 2019. We are encouraged by this, and we hope to see the first major renewable energy projects in Trinidad and Tobago in 2020.



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2020

PAPER 2
EXAMPLES OF RENEWABLE ENERGY FINANCING

This paper consists of a compilation of three case studies by Qatar National Bank (QNB)

Case study 1
Renewable energy project financing in Turkey

Over the past four years QNB Group subsidiary, Finansbank, has financed twelve renewable energy projects worth over USD350 million to support Turkey's transition to a more environmentally sustainable and diverse electricity supply.

We financed the development and construction of six solar, three wind and three hydroelectric power plants that have helped to shift the country's energy mix, significantly reducing greenhouse gas emissions.

These projects produce approximately 2.8 million MWh per year and reduce greenhouse gas emissions by 1.4 million tonnes of CO2e per year.

The solar and wind projects, specifically, have contributed to Turkey's aim of establishing a non-hydro renewable generation capacity of 27GW in the next five years. Of this, 5GW is expected to be solar and 20GW wind.

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Case study 2
Green Economy Financing Facility in Egypt

QNB Group subsidiary, ALAHLI, is playing a leading role in the Egyptian solar energy market by encouraging small & medium scale solar developments. Particular focus is given to integrating renewable energy in the industrial sectors, where QNB ALAHLI is proud to be the first bank in Egypt to finance an industrial roof top solar installation, generating 1MW at the Coca Cola bottling plant in Sadat City.

The solar power plant has a significant environmental impact, expected to offset 1,180 tonnes of CO2 annually, the equivalent of planting ~1,000 trees.

The transaction was financed under the Green Economy Financing Facility (GEFF), a sustainable financing programme that encourages green & sustainable investments. This is offered by the European Bank for Reconstruction & Development (EBRD) and backed by resources from the European Union. QNB ALAHLI is the first bank in Egypt to participate in this programme.

The solar power plant has a significant environmental impact, expected to offset 1,180 tonnes of CO2 annually, the equivalent of planting ~1,000 trees.

Case study 3
Installation of Solar Panels at QNB ALAHLI Branches

QNB Group subsidiary, ALAHLI, was one of the pioneering Banks in Egypt to adopt fitting branches with solar energy panels, thus promoting carbon saving technologies and increasing the energy resilience of its operations.

Energy savings are estimated at around 28% of the annual energy consumption at the locations fitted solar energy panels. In addition to reducing QNB's direct environmental footprint, the roll out of solar energy also leads to reduced costs over the life cycle.

Energy savings are estimated at around 28% of the annual energy consumption at the locations fitted solar energy panels.

PAPER 3
WOOD MACKENZIE WHITEPAPER ON ENERGY TRANSITION

Energy Transition Outlook 2019
A call to action to the global energy industry

Wood Mackenzie President Neal Anderson introduces our 2019 Energy Transition Outlook and examines why the energy mix is not changing nearly as quickly as the world needs it to.

I'd like to introduce you to our 2019 Energy Transition Outlook – an assessment of how the next two decades may play out across the entire energy and natural resources value chain. We have drawn this integrated analysis from across all of Wood Mackenzie's commodity, technology, markets and segments coverage.

A number of things leap out

First and foremost, there's resistance to achieving the aspirational targets to reduce global carbon emissions set in Paris four years ago. The energy mix is not changing nearly as quickly as the world needs it to. Despite sincere intentions, there is still no carbon price in many major consuming countries or market segments.

In addition, the technologies essential for decarbonisation remain nascent; policy and regulation lack global coordination; and investment in the production of hydrocarbons and in the sectors that consume them persists at a high rate because money can be made.

Finally, we're witnessing a trade war between the two largest global economies and a go-it-alone approach driven by populists and protectionist agendas. I see that as at odds with the collaborative, can-do spirit that emerged from Paris at the end of 2015.

The scalability challenge

I call this situation the scalability challenge. While some of the technologies required for a 2 degree future are economic, proven and scalable, many others are not.Optimists look at solar and wind costs and say we have all we need to achieve our targets. The reality is that significant additional investment and political will are needed to get them to a material scale globally. And the huge challenges that remain in sectors beyond power and road transport are often downplayed.

Our latest view – based on a bottom-up, asset-based, investor-led perspective – is something nearly no other company can do. It is based on fundamentals and objective thinking. It is supplemented by our relationships across every major asset class, government and demand segment. It is a result of our teams pushing the cost technologies and adoption rates as much as we think possible, given the inertia already embedded within multiple business cycles. What emerged is a conservative outlook: one in which the current pathway looks more like 3 degree of warming than the 2 degrees or lower advocated in Paris.

It's easy to produce a bullish forecast on the pace of the energy transition when you use a top-down approach that doesn't model at the asset level or is solely focused on renewables. Or when you don't have the proprietary data and analytics. But, because of the depth and volume of data available to us, it's clear that lack of proper incentives and regulations is resulting in each asset class operating independently to maximise its returns.

What is the energy transition?

How we define the energy transition at Wood Mackenzie?

Rapid technological advancement across a variety of industries is enabling society's quest for sustainability at an unprecedented pace. The resulting energy transition is causing an epochal shift in how the world's population consumes energy and natural resources, driven by a range of factors:

- Decarbonisation
- Economics and equity
- Energy access
- Efficiency
- Political and regulatory expectations
- Emerging Technologies
- Societal expectations around environment and climate

Our full integrated natural resources value chain

> Rapid technological advancement across a variety of industries is enabling society's quest for sustainability at an unprecedented pace.

Our integrated view of three possible energy transition scenarios:

Energy Transition Outlook

Our base case view across all global commodity and technology verticals. It does not represent business as usual; it reflects an evolution of current policies and technology advancement playing out as we can foresee, expressing some degrees of business and consumer inertia. The following insights reflect this outlook and it is valid for all commodity outlooks synced with our H1 2019 research. It is broadly consistent with a ~3 degree Celsius global warming view.

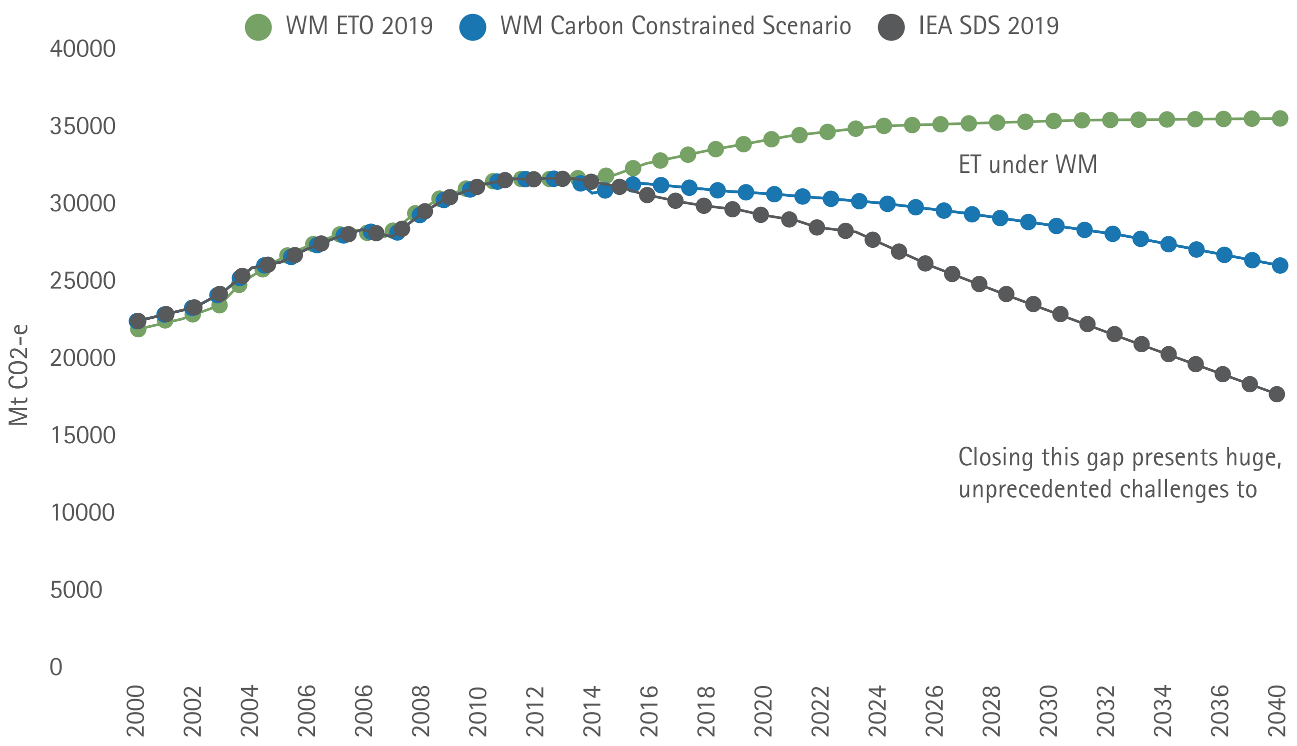
Carbon Constrained Scenario

A scenario leveraged from our base case representing an accelerated view of the Energy Transition, published in 2018. It is a much deeper view on decarbonisation and electrification, best efforts on technology, policy, and cost reduction acceleration. It also reflects heightened societal preference to rapidly meet the challenges presented today by the quest for sustainability. It is what we think could conceivably happen over the long-term, if there is more radical change in the short-term. It is broadly consistent with a ~2.5 degree Celsius global warming view. We will refresh in Q4.

2 Degree Scenario

Quantifies the impact of successful implementation of major climate goals limiting global warming to 2 degree Celsius. The IEA's Sustainable Development Scenario (SDS) is the most common and standardised framework for quantifying a "2 degrees or lower" outlook. We ascribe a very low degree of confidence that 2 degrees can be achieved due to the challenges across technology, policy, regulation and cost; intergovernmental constraints; trade and consumer choice; and what is built into the current energy systems of today. However, we will release an assessment of what it would mean for commodities and the technologies required to attain that trajectory later in the year.

How emissions differ by scenario, 2000 to 2040



Source: Wood Mackenzie Energy Transition Outlook

Key Takeaways

1. The global energy system faces a scalability challenge

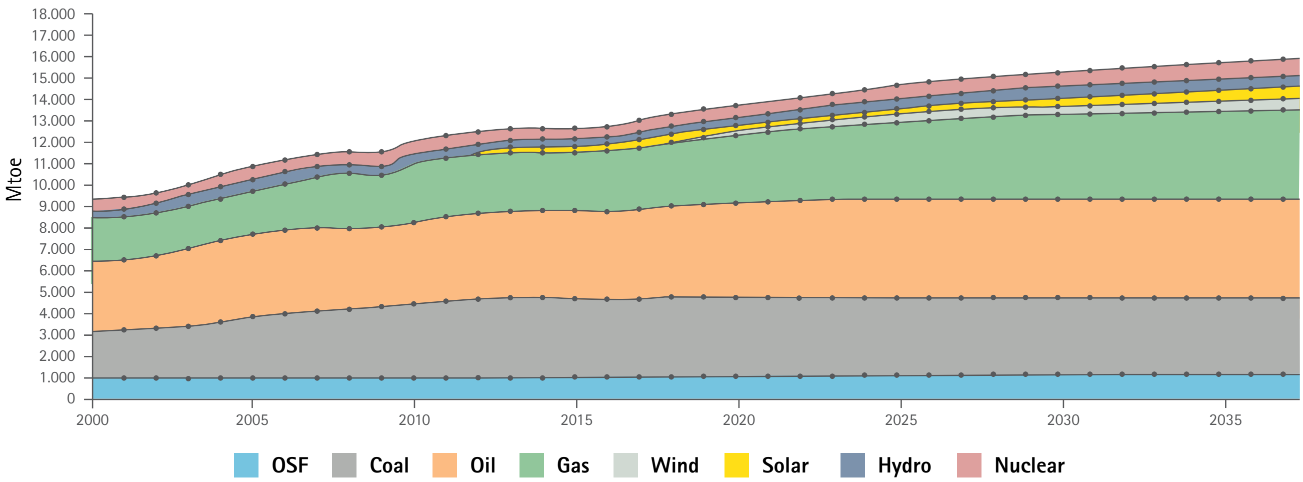
It needs to move sharply towards a global warming pathway limited to 2 degree Celsius or lower. But despite great efforts to reduce costs in renewables electricity, zero-carbon technologies and advanced transportation – not to mention burgeoning support in governmental policies – it is not enough.

What's changed since COP21?
The global backdrop has become more challenging and polarized – with less cooperation. The ongoing trade war is also impeding progress. Policies being promoted in the EU and smaller economies are helpful. But larger, energy-dense countries and energy-rich segments lack any serious progress.

2. Energy demand will keep rising through to 2040

With rising population but moderating intensities, global energy demand will slow. It increases from 13 Btoe in 2018 to 16 Btoe in 2040. That's a growth rate of just 1%, half the rate of the past decade. Since 2010, the growth in Asia Pacific has been ~35% while it has been nearly flat in North America and Europe. We do see progress in energy access through off-grid solar programmes in Sub-Saharan Africa. But in other economies, like India's, large populations will be connected to the grid using a coal- heavy fuel mix.

Total Primary Energy Demand: Hydrocarbon and zero carbon supply



Source: Wood Mackenzie Energy Transition Outlook

3. World risks relying on fossil fuels for decades to come

The energy mix is changing only gradually and the world risks relying on fossil fuels for decades to come.

We forecast coal, gas and oil will still contribute around 85% of primary energy supply by 2040, compared with 90% today.

Availability of resource, infrastructure and cost competitiveness (absent a carbon price) keeps fossil fuels resilient.

We also see the potential for protectionism to creep in to other areas of the economy, hastening the need to focus on domestic resources; including fo fossil fuels.

4. Renewables are the fastest-growing source of energy supply by far

The accelerating capacity build-out is changing the power sector landscape. Wind and solar will contribute 24% of power supply by 2040 compared with 7% today. Although the competitiveness is improving, there are practical limitations to reaching a fuelmix comprised of 50% or greater share for solar and wind. We see growth in energy storage to almost 600 GW. But without long-duration storage, on a much higher scale, high solar and wind yields negative prices and grid shape, design and stability issues.

Where is value captured in 'zero carbon' economies when marginal power prices collapse? Can design change solve this? Possibly. Beyond capacity markets and auctions, value creation in renewables still doesn't look as remunerative as the best oil and gas developments. This may prompt an existential crisis for those seeking to generate comparable returns in new energy investments, although there are interesting opportunities emerging in retail models for distributed generation and grid edge technologies.

The accelerating capacity build-out is changing the power sector landscape. Wind and solar will contribute 24% of total global power supply by 2040 compared with 7% today.

We are seeing annual capacity additions of the order of ~70GW per year for wind, and ~120GWdc per year for solar for the next few years. Reductions in costs for wind, solar and energy storage keep coming, although the rate of reductions in critical markets like APAC will continue to slow.

We assess, for instance, that onshore wind and solar cost reductions will continue at between 2-3% per year over the next few decades, rather than 5-14% per year in the last decade in Asian markets. APAC represents the critical market because we still see strong energy demand and power-led growth, tied to domestic fossil-based resources.

Although the competitiveness is improving, there are practical limitations to reaching a fuel mix in the power market comprised of 50% or greater share for solar and wind. What we've observed is that marginal prices of power begin to collapse, as substantial growth in renewables additions cannibalize prices. Where is value captured in 'zero carbon' economies when marginal power prices collapse? Can market design change solve this? Possibly.

Beyond capacity markets and auctions, value creation in renewables still doesn't look as remunerative as the best oil and gas developments. This may prompt an existential crisis for those seeking to generate comparable returns in new energy investments, although there are interesting opportunities emerging in retail models for distributed generation and grid edge technologies.

> **"Wind and solar will contribute 24% of total global power supply by 2040 compared with 7% today."**

The often quoted "silver bullet" of energy storage is of course an enabler to greater renewables penetration. Although we see growth in energy storage to almost 600 GW, a very limited amount is in 'long-duration' storage. The vast majority is in Lithium-Ion, which typically can capture up to 4-6 hours of storage time. Long-duration storage (from 20-24 hours and upwards) is still very nascent and yet to be commercialized. And to balance and optimize the grid, with representative prices that can encourage investment, you'd need to start seeing storage time-periods in the multi hours-to-days variety – not much of which is happening at the ground level. Subsequently, high solar and wind without that balance, can yield to negative prices and grid shape, design and stability issues.

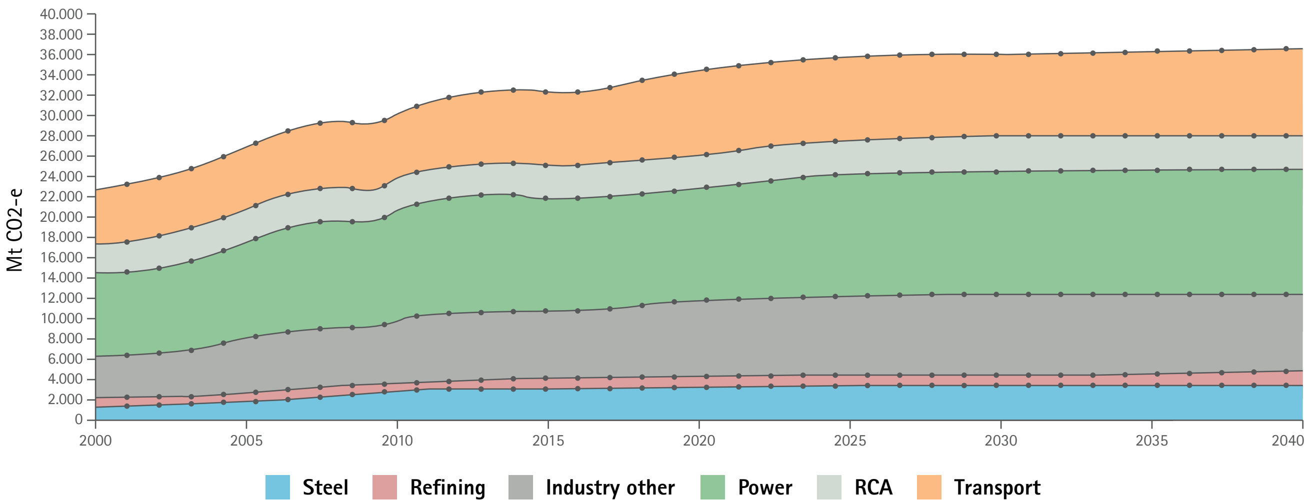
5. Electrification is the emerging transformational theme – both for power and for the transport sector

Electric vehicles pose a significant threat in the light-duty transport sector and to oil demand within the next few years. But gains in fuel efficiency will mirror the amount of fuel lost due to substitution – in the 5-6 mb/d range. Mining has a critical role to play with much growth expected in raw materials for batteries, motors and infrastructure in transport, as well as grid infrastructure and equipment in power.

6. Decarbonisation is only slowly taking hold beyond the power sector

The obstacles presented in industry, manufacturing, housing, aviation, shipping, agriculture and heat dwarf those in power and road transport. Little to no progress has been made in commercialising technologies in those segments and hopes are turning to hydrogen and carbon capture and storage (CCS) as the panacea. But those large industrial segments also face geopolitical problems. Take decarbonisation of an industry like steel, which is highly competitive and has 'national champions' in China, South Korea and Japan. Steel has also been at the core of trade disputes since 2014. Who will be willing to create 'green steel' first when the returns are not visible?

Emissions by key segment



Source: Wood Mackenzie Energy Transition Outlook

7. Carbon emissions will continue to rise, with growth slowing only in the 2030s

Both our Energy Transition Outlook (3 degree Celsius) and Carbon-Constrained Scenario (2.5 degree Celsius) fall outside 2 degree Celsius or lower trajectories. Zero- carbon needs to be on a pathway to 40% of the total energy mix by 2040, compared with the 20% we forecast in our Energy Transition Outlook.

Yes, policy is becoming supportive in some markets (the UK just legislated an economy-wide zero-carbon pathway by 2050) but other markets represent large, energy-dense segments with little-to-no progress.

8. Reducing emissions to below 2 degrees is a huge global challenge

Achieving it requires urgent policy and regulatory initiatives in both laggard OECD but also non-OECD countries, too. These must include tax policy and subsidies that incentivise R&D and capital allocation into the zero-carbon technologies.

It will need continued support for investment in renewables, as well as transforming existing technologies – carbon capture, utilisation and storage, batteries and long-duration energy storage, hydrogen and alternatives in non-power – into commercial propositions. That is the scalability challenge we see.

Risks that could threaten the pace and scale of the energy transition:

Source: Wood Mackenzie Energy Transition Outlook

* Relative to base case.

What's inside the full 100-page energy transition outlook?

1. Key Takeaways and Implications
2. Macro Economic Climate & Trade
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5. Individual Commodities/Fuels/Technologies
6. Key Segments: Power
7. Key Segments: Transport
8. Emissions, New Technologies, Emerging Themes
9. Investment and Corporate Strategies
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The UK just legislated an economy-wide zero-carbon pathway by

2050

but other markets represent large, energy-dense segments with little-to-no progress.

PAPER 4
ELECTRICITY DEMAND IN QATAR:
Opportunities for Demand Response

Qatar's electricity demand has increased more than twofold due to the fast-growing population, the yearlong demand for air-conditioning, and the quest for higher standard of living.

Introduction

The reduction of electricity demand in Qatar is a paramount concern that has important economic and environmental implications with reference to the reduction of energy generation costs and carbon emissions. Due to the abundance of solar resources, Qatar has a unique opportunity to attain substantial reductions in electricity demand through the enactment of demand response measures in smart grids that include distributed energy production through photovoltaic systems and energy storage. However, to understand where and how reductions in electricity demand may be achieved, it is necessary to collect and analyze electricity demand data. This chapter focuses on this need through a review of the work on electricity demand data analysis carried out at QEERI with reference to cooling loads.

Background

Qatar has one of the highest per capita electricity consumption in the world and the residential sector accounts for nearly two-thirds of the overall demand. Over the last decade, Qatar's electricity demand has increased more than twofold due to the fast-growing population, the yearlong demand for air-conditioning, and the quest for higher standard of living. Highly subsidized electricity prices and the availability of disposal household income have facilitated this trend. To meet growing demand, the government of Qatar has been investing in multi-billion-dollar infrastructure projects to introduce new generation, transmission, and distribution capabilities.

At the same time, a higher commitment to the reduction in carbon emissions and the need to compensate for recent revenue losses from hydrocarbon imports and budget deficit have created a pressing need to lower electricity consumption. As an initial step to reduce consumption, Kahramaa, the national electricity and water utility company, has introduced energy efficiency programme called "Tarsheed" which is Arabic for "awareness". It is estimated that the programme succeeded in reducing the per capita consumption of electricity and water in Qatar by 17% and 18%, respectively, by the end of 2017. The programme works through the enforcement of regulations that target household appliance energy efficiency.

Another potentially rewarding strategy in reducing the economic and environmental impacts of electricity demand is the use of demand response to help meet demand at peak times. Even with its strong grid capacity, the Qatar electricity system can come under stress at time of peak electricity demand. For example, in summer 2017, the system utilization exceeded 90% and customers experienced several power outages. The use of demand response to manage distributed energy from residential and commercial photovoltaic (PV) systems can help address such time of critical peak usage by storing energy at time of low consumption and use the stored energy to address demand at peak times.

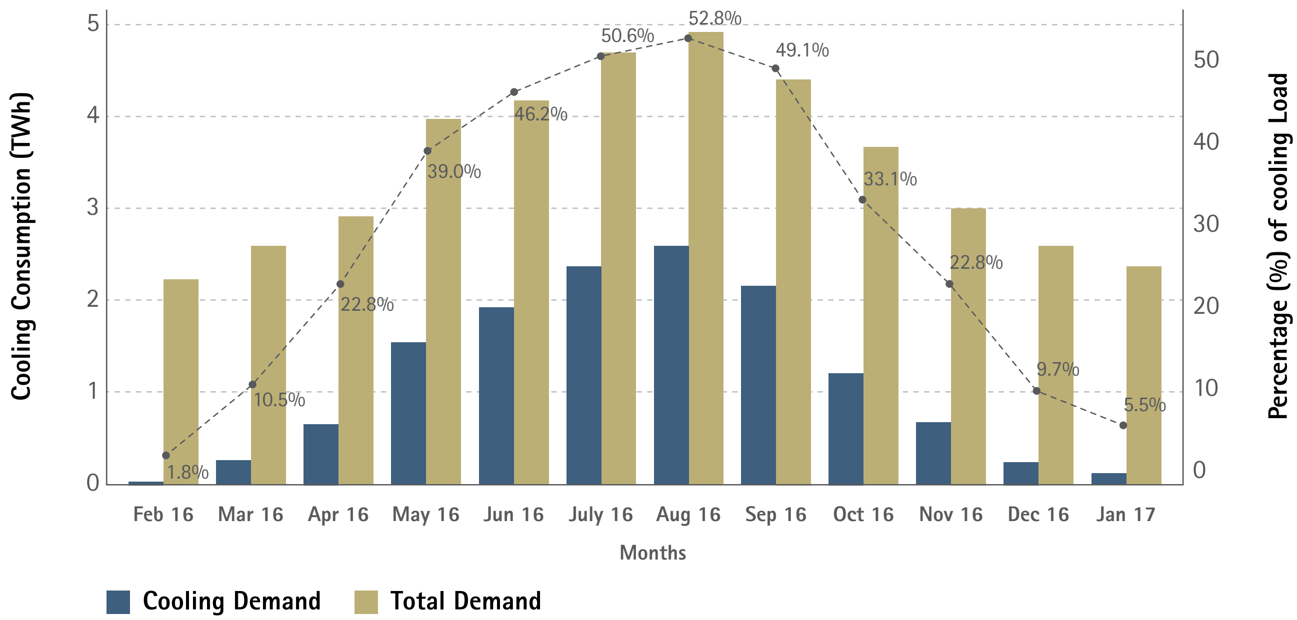
As an initial step to reduce consumption, Kahramaa, the national electricity and water utility company, has introduced energy efficiency programme called "Tarsheed" which is Arabic for "awareness".

In the remaining part of this paper, we will provide an analysis of electricity demand with specific reference to cooling loads that provides an indication of what the most rewarding areas of demand response application may be in Qatar.

Electricity demand at country level

Electricity demand in Qatar has unique characteristics due to the factors discussed above. For instance, due to subsidies and a high disposal income, daily load profiles are smoother compared to other countries and there are no visible peaks during the day. Moreover, weekend and weekday profiles are very similar, while in many countries weekend consumptions are considerably lower than weekdays. In other way, due to cooling needs and excessive ambient temperatures, the summer demand is 2-3 times higher than the winter load as it is shown in Figure 1. This electricity consumption patterns are very specific and an opportunity to develop innovative demand response solutions.

Figure 1: Electricity and cooling demand



Using load profiles, national cooling load can be estimated by differentiating a typical cooling day from a non-cooling one. As shown in figure 1, cooling load represents more than half of the load during summer months and nearly 37% of the annual load. This indicates that national demand response programmes should focus on cooling load to achieve higher impacts. Moreover, summer peak demand occurs between 1 and 3 pm due to high cooling load, while winter peak demand takes place around 6-7 pm due to lighting load[1] as it is shown in Figure 2.

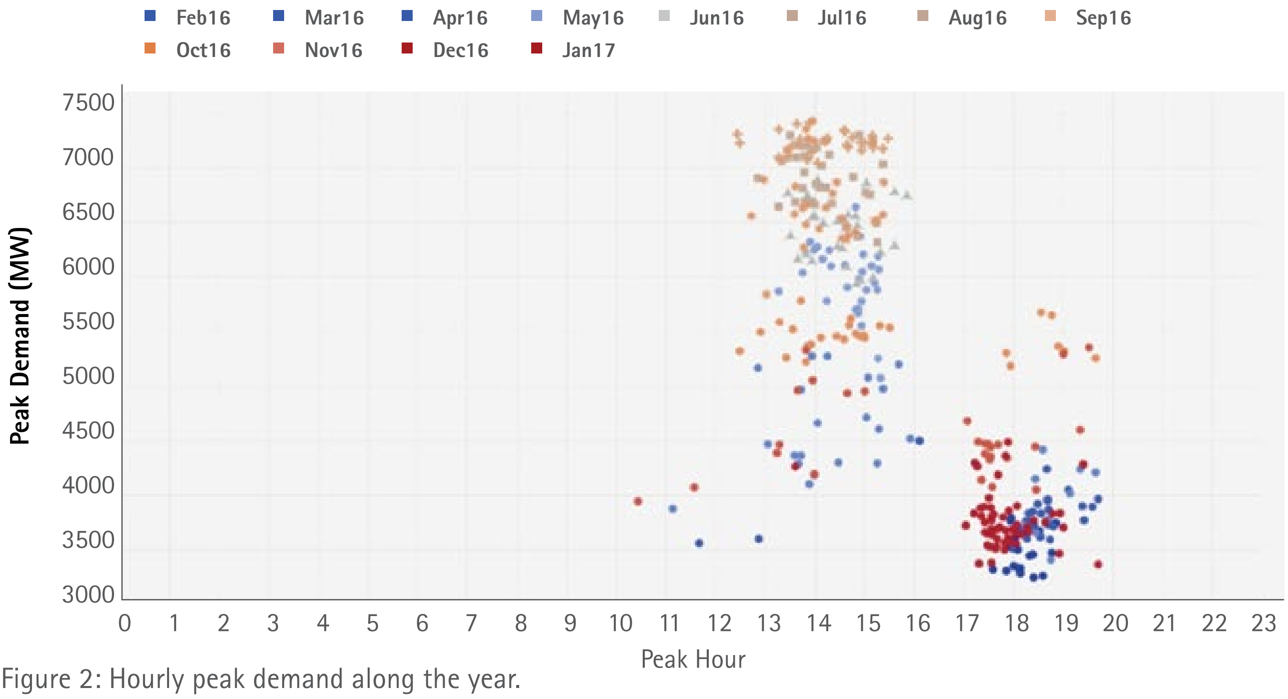


Figure 2: Hourly peak demand along the year.

Electricity demand at household level

Household load profiling is an important step towards identifying socio-economic and seasonal factors that influence power consumption patterns. To achieve residential profiles, smart meters or energy monitors are used to capture profiles typically at every 15 minutes or at higher resolutions. To gain insights, we have conducted a measurement study compromising of ten households of different sizes for a period of one year to gain insights[2].

Houses were selected based on Qatari census data and compromised of villas and apartments with occupant numbers varying from 1 to 10.

At household level, the major factors determining the electricity consumption are as follows. First, the size and the physical properties (e.g., thermal capability) of the dwelling is an important determinant as the entire living space needs to be cooled. Second, residents who do not pay electricity bills tend to consume more electricity than the ones that do not pay. Third, central AC units consume less energy than split type AC units. Fourth, units with higher number of occupants consume more energy due to more frequent use of appliances.

Another noteworthy point is that sizable portion of the population takes extended summer Vacations and leave their AC units running. Even though this is a recommended practice to prevent the houses from overheating, a significant amount of energy is being wasted. On the other hand, this situation presents an opportunity for a demand response application which is presented next.

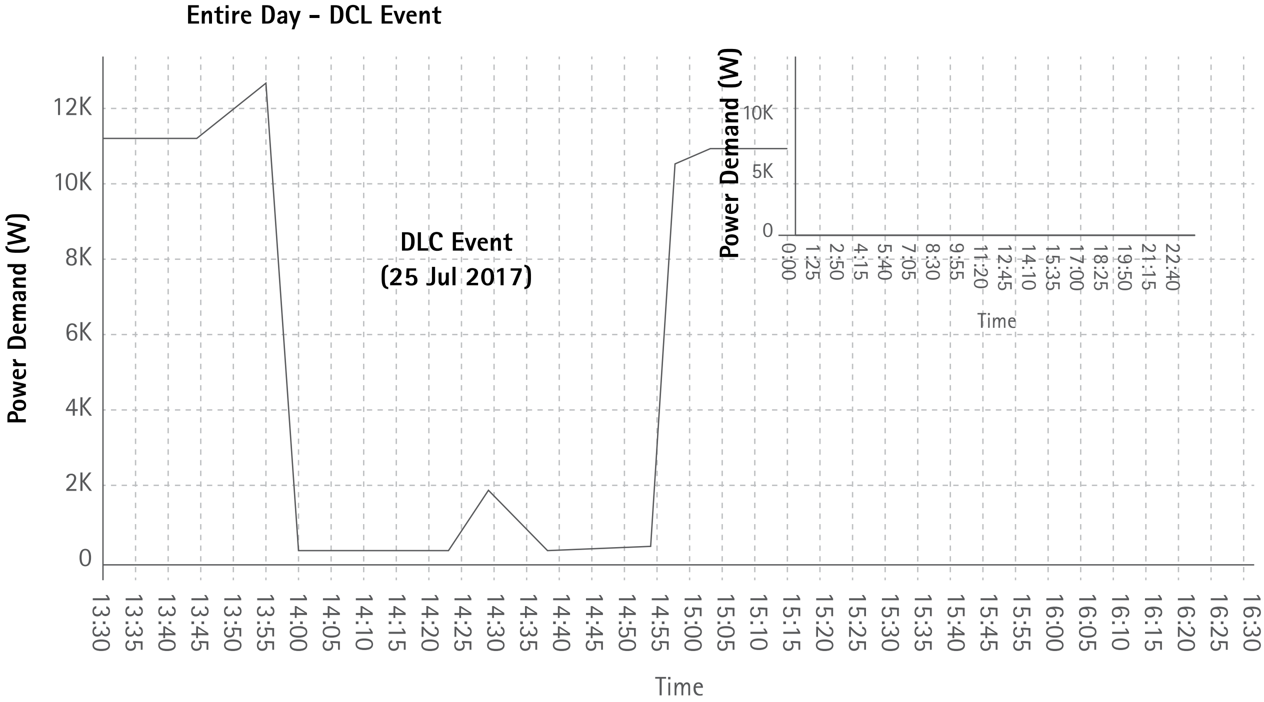
Direct-load Control of AC Units

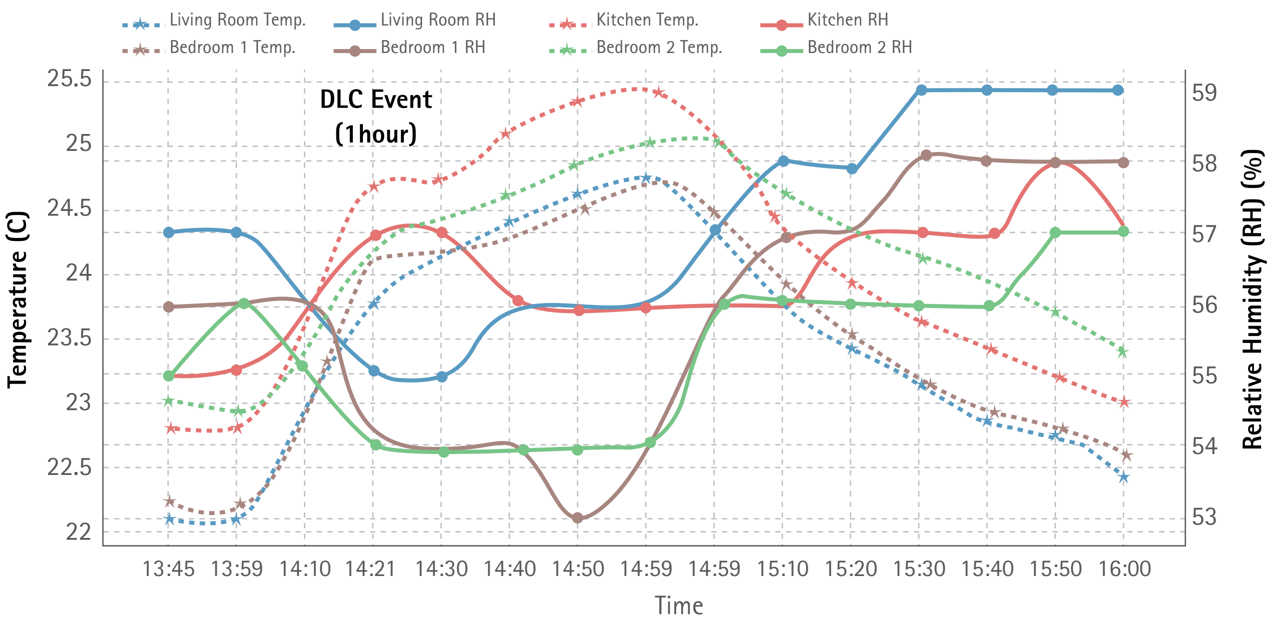
Direct load control programmes, however, can be a practical solution to shave Qatar's peak electricity consumption. The aim of the DLC programmes is to remotely control specific appliances such as AC unit, heat pump, water heater, pool pump, or plug-in electric vehicle during peak hours or emergency cases. DLC programmes for air conditioning units have already gained mainstream acceptance in the United States, notably in states like California, Texas, and Florida where there is a high AC load intensity during summer months3.

Direct load control experiments are conducted in a typical two-bedroom two story Qatari villa with a total physical space of 219 square meters.

The villa is located at the Al- Rayyan district of Qatar and was built in 2002. During summer 2017, AC unit of the house was turned off for various durations (1 hour DLC event is shown below) and indoor temperature and power savings were recorded.
As presented in the figure 3, nearly 11 kW of power can be dimmed at the expense of 1.5-2 Celsius indoor temperature rise. Practically, DLC can be applied for short durations (e.g., 15-30 min) for households when residents are present and longer DLC durations can take place at house whose residents are on vacation.

1. Bayram, I. S., Saffouri, F., & Koc, M. (2018). Generation, analysis, and applications of high resolution electricity load profiles in Qatar. Journal of cleaner production, 183, 527-543.
2. O. Alrawi, I. S. Bayram, S. Al-Ghamdi, M. Koc, High-Resolution Household Load Profiling and Evaluation of Rooftop PV Systems in Selected Houses in Qatar, Energies, 2019
3. Bayram, Islam Safak, et al. "Direct load control of air conditioners in Qatar: An empirical study." 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA). IEEE, 2017





Conclusions

The integration of distributed PV generation in Qatar through residential and commercial PV systems would help curtail infrastructural investments needed to keep the national power system in lockstep with ongoing economic and population grow. From 2010 to 2017, electricity demand in Qatar has grown at an annual average of about 6%, with peak loads going from 5,090 to 7,855 MW. To ensure that electricity demand be met at peak load times, the capacity of the grid needs to be constantly increased, even though maximum demand occurs only sporadically, at predictable times. Costs to upgrade the national electricity generation, distribution and transmission network in Qatar may reach $9bn by 2020, to add an additional 4.3 GW to the current 8.8 GW grid capacity[4], and continue to increase thereafter. These costs can be eliminated through the introduction of smart grids that integrate distributed PV generation, incorporate storage technologies to manage variable renewable energy, and use demand response to reduce demand during periods of peak consumption.

4. Sources: Arab Petroleum Investments Corporation (http://www.apicorp.org).

PAPER 5
AGRICULTURAL AND URBAN MICROGRID SYSTEMS AND ARCHITECTURES FOR QATAR

Overview

Qatar has large number of scattered farms and animal barns that are not connected to the central grid and hence act as off-grid loads. The use of microgrid for these loads represents an effective mean to supply and manage the needed operational energy. Microgrids enable the integration of renewable energy sources while its control system manages the demand and storage to optimize system operation and resources utilization.

Besides serving off-grid loads, microgrids also play an important role for urban grid-connected loads. Urban microgrids in Qatar can help providing services such as peak-shaving, uninterruptable power supply and optimized utilization of combined cooling, heating and power supply CCHP systems.

Moreover, urban microgrids in Qatar can be very useful to meet the ambitious plans for rapid increase in renewable energy integration in the utility grid. Being a country with relatively low absolute power capacity, the addition of few GWs of renewable energy sources represents a significant share of the power supply in the country and thus an increased grid stress. The use of microgrids allows managing renewable energy sources, energy storage and demand management to mitigate any disturbance or power flow fluctuation.

When considering microgrids in Qatar, several aspects need to be considered. Some of these aspects are related to the nature of the used loads, while others are related to certain atmospheric challenges. This article addresses the main aspects that need to be considered for microgrids for farm and urban systems successful deployment in Qatar.

Nature of loads in farms and off-grid power system and its impact on microgrid requirements

There are more than 1,300 agricultural farms in Qatar, and most of them are far from the utility network and usually scattered geographically [1]. These desert-based farms are mostly powered as off-grid systems [2].

Moreover, farms in desert areas are expected to increase in the near future to meet the increasing needs in food supply, not only in Qatar, but internationally. Besides that, the energy demand in these farms in continuously increasing with time as farmers are moving toward increased greenhouses utilization to extend the farming season and introduce new types of crops. Similar to agricultural farms, large numbers of animal barns can be found in desert areas with grid power supply. Up to 5,000 off-grid barns exist in Qatar. The electrical power need in these barns is very different depending on the type of animals hosted, for example, camels need power to get a supply of water while horses also need properly air conditioned spaces. Having a continuous supply of reliable and regulated power generation is very critical for this type of loads. Power interruption in such an environment might jeopardize the animal lives [3]. Figure 1 shows a typical farm with animal barn in Qatar, similar to the one QEERI (Qatar Environment and Energy Research Institute) is using as research test bed for microgrid usage optimization.

Figure 1. An Aerial view of typical dessert farm.

In these desert farms we find a specific variety of types of loads that define the kind of microgrid that need to be engineered.

Water Pumps

Desert areas usually suffer a lack of water supply and, in most cases, underground water represents the main source for water. In this sense, water pumps are among the most common load in these areas. Pumps can run thanks to combustion engines, which are based on burning fuel, or by electrical motors fueled with electrical energy. Solar PV based water pumps are also common in off-grid systems, where the system complexity determines its effectiveness. In the simplest case, PV modules operate the DC motor directly without any intermediate power conversion. These systems have the lowest cost, but they have poor performance as the DC motor consumption needs to be aligned with the PV maximum power point. Moreover, DC motors require frequent maintenance and replacement for the brushes, which increases the operational costs. Another type of PV based pumps are based in induction motors run by PV modules connected to 50/60 Hz inverters without maximum power point tracking. A more efficient system uses AC motors with an inverter that uses variable frequencies to track the PV maximum power point all the time. This last system has the highest efficiency and it can also be integrated with batteries to store any surplus energy generated by the PV modules to be used later when needed.

Water Desalination

Beside the need for energy for water pumping, in some cases, energy is needed to improve the water quality. Water desalination represents the major energy consumption in this context. Despite being reserved inland, underground water could suffer from salinity levels that are higher than the existing in sea water [4]. The salinity could be due to sea water trapped on the landscape or due to minerals dissolved into underground fresh water. In either case, there is a need for water desalination, especially if the water salinity level exceeds 500 mg/L [5].
Table 1 [6], shows the energy needs of the various water desalination techniques. Capital and maintenance costs need also to be considered for the different technologies.

Table 1. Typical energy consumption of different desalination techniques

Desalination Technique	Multistage Flashing	Multi-Effects	Vapor-Compression	Reverse Osmosis	Electro-dialysis
Total Equivalent Energy Consumption (kWh/m3)	13.5 - 25.5	6.5 - 11	7 - 12	3 - 7	2.6 – 5.5

HVAC Systems

Harsh weather condition in desert environments is a major challenge for human, plants and animals lives. Therefore, the need to acquire and operate systems to provide heat, ventilation and air conditioning (HVAC) is essential in such environments.

Evaporative cooling systems can be used for this application. These systems have low cost and require relatively low electrical energy to operate and work perfectly in a dry climate in areas with sufficient water availability. However, in some desert environments, these conditions might not be met during the hot season and in these cases, compressing cooling systems are usually deployed.

On the other hand, compression cooling systems work effectively in all climates, but they consume more electrical energy than evaporative cooling systems. However, in the context of off-grid power systems, compression cooling systems have a distinctive advantage. Unlike evaporative cooling, since the generated cooling effect can be used to produce chilled water or ice that can be stored to be used later when needed. The ability to store chilled water can have great value to reduce the need for battery storage in off-grid systems that are supplied by renewable energy sources.

Other Loads

Besides the ones mentioned above, a number of loads are usually found in a desert environments such as lamps, fans, electronic devices and home appliances. Most of these loads do not have an energy storage capability and their operation depends on the user needs, some of which are mainly needed during the night times. Therefore, battery storage is essential to operate these systems in off-grid systems that are supplied solely by renewable resources. Typical power consumption for various loads within a farm in Qatar is listed in Table 2.

Table 2. Typical load in the farm

Load type	Power consumption	Quantity	Hour per day	Total consumption	Comments
Pump	4 kW	2	2-6	16-48 kWh	well pumping and Irrigation
Lighting	60 W	30	6	10.8 kWh	For the farm
Air conditioners	2.4 kW (2 tons)	3	6	43.2 kWh	For animals
Fans	75 W	6	6	2.7 kWh	For animals

Microgrid control in grid connected and islanded modes

In the control stage, centralized or decentralized control of the microgrid aims to optimize the production and consumption of electricity to improve the overall efficiency. Local controls are the basic category of microgrids control. The challenge is that several sources must be able to connect or disconnect from the distribution grid whenever and wherever needed. Moreover, controlling a large number of different sources having different characteristics is very challenging due to the possibility of conflicting requirements and limited communication.

Furthermore, the intermittent generation of certain microgrids' sources coupled with the unpredictable nature of the consumers demand implies that, at certain points in time, it becomes more convenient to exchange energy among microgrids instead of consuming it from the main grid. Hence, it has become an issue of great urgency that grid operators attempt to devise an excellent supply-and-demand management framework and reduce the amount of power that is wasted during the transmission over the distribution lines. Such requirement, together with the recent developments in electric power systems and the interconnections between neighboring electric power systems to achieve a more economic and secure operation, has led to tremendous difficulties in monitoring, controlling and managing electric power systems [7].

In the presence of microgrids, hierarchical distributed control is employed to provide a coordinated strategy for the distributed energy resources together with the storage devices and flexible loads. In hierarchical distributed control, the microgrid is divided into a number of areas where each area can include distributed energy sources, loads, and power lines. The primary motivation behind the implementation of a distributed control structure is the inability of the different areas operators to share information and data [8]. Hierarchical control architecture can be divided into three control levels based on the required time frame: primary, secondary, and tertiary.

“Hierarchical control architecture can be divided into three control levels based on the required time frame: primary, secondary, and tertiary.”

The primary control level is the first control known as "internal control". This control level works on the system variables such as voltage and frequency components to ensure that these variables track their set points. The primary control techniques in microgrids can be divided into two main categories: communication-based and droop characteristic based [9]. The main advantage of communication-based control techniques is that the amplitude and frequency of the inverter output voltage are close to their reference level without using additional control level. Concentrated control [10], master/slave control [11], and distributed control [12] techniques are good examples for the communication-based control. Although communication-based control techniques provide proper power sharing among the DG inverters, these control strategies bring some drawbacks such as the requirement for communication lines, which increases the overall system cost especially for large systems and reduces the system reliability. On the other hand, droop characteristic based control techniques ensure voltage regulation and power sharing without communication medium [13]. These control techniques are suitable for long distance DG inverters to ensure proper power sharing while achieving good voltage regulation. These techniques also eliminate the complexity and high cost of the communication-based control techniques. The droop-based control can be divided into three main categories: 1) traditional droop control [14]; 2) virtual framework structure-based method [15]; 3) the hybrid droop/signal injection method [16].

Droop-based control

The basic idea of the droop control technique is to imitate the behavior of a synchronous generator whose frequency is reduced as the active power increases [7]. Figure 2 depicts the simplified single-line diagram of the microgrid with two DG units. The active and reactive power of nth converter connected to the AC microgrid can be defined as:

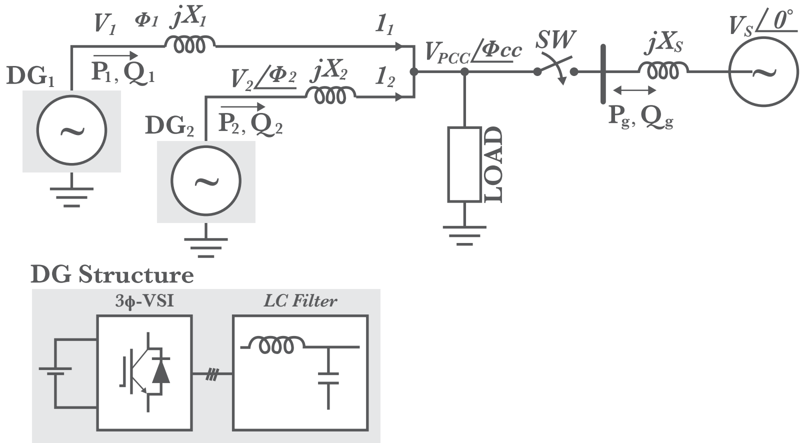


Figure 2. The simplified single-line diagram and DG structure of microgrid.

$$\left.\begin{aligned} P_n &= \frac{VE_n}{X_n}\sin\varphi_n \\ Q_n &= \frac{VE_n \operatorname{Cos}\varphi_n - V^2}{X_n} \end{aligned}\right\}$$

(1)

where En is the inverter output voltage, V is the point of common coupling (PCC) voltage, Xn is the inverter output reactance, ϕn is the phase angle between the inverter output voltage and PCC voltage and these equations apply when the inverter output impedance is relatively inductive. The reactive power depends on the En, whereas the active power is dependent on the ϕn. Using this information, the P/ω and Q/E droop characteristics can be drawn, as shown in Fig. 3.

These characteristics can be explicated as follows: when the frequency decreases from $\omega 0$ to ω, the DG is allowed to increase its active power from P0 to P. A falling frequency is evidence of an increase in the active power demand of the system. In other words, parallel connected units with the same droop characteristic increase their active power outputs to handle the fall in frequency. Increasing active power of the parallel units will prevent the fall in frequency.

Thus, the units will settle at active power outputs and frequency at a steady-state point on the droop characteristic. To sum up, the droop characteristic based control technique allows parallel connected units to share load without the units affecting each other.

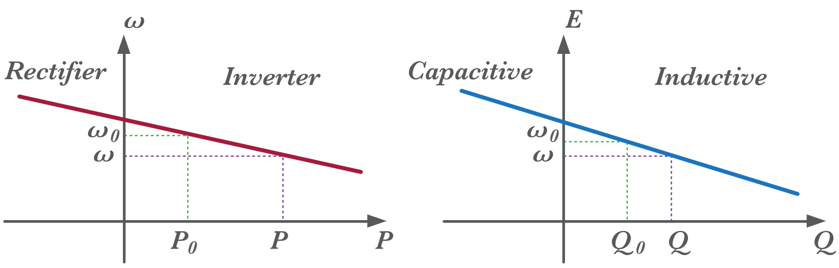


Figure 3. P/ω and Q/E droop characteristics

The droop characteristics are inherent behavior in synchronous generator control, but it can also be extended for controlling power electronics based voltage source inverters (VSIs). The P/Q droop technique is expressed as:

$$\left.\begin{aligned} \omega_n &= \omega_0 - k_p\left(P_n - P_0\right) \\ E_n &\quad E_0 - k_Q\left(Q_n - Q_0\right) \end{aligned}\right\}$$

(2)
where n is the index representing each VSIs, $\omega 0$ and E0 are the base frequency and voltage, respectively, Pn and Qn are the active and reactive power of the units, respectively. P0 denotes the base active power while Q0 denotes the reactive power. kP and kQ are the droop coefficients that directly affect the performance of the system.

The selection of kP and kQ affects the stability of system, so these parameters should be designed appropriately. Each DG unit generates power proportional to its capacity with appropriately selected parameters. The active and reactive proportional droop coefficients (kP and kQ) can be expressed by:

$$\left.\begin{aligned} k_p &= \frac{\Delta\omega_{\max}}{P_{\max}} \\ k_Q &= \frac{\Delta E_{\max}}{Q_{\max}} \end{aligned}\right\}$$

(3)
where, $\Delta\omega$max is the maximum allowed voltage frequency droop; ΔEmax is the maximum allowed voltage amplitude droop; Pmax is the maximum allowed active power; and Qmax is the maximum allowed reactive power.

The traditional droop control technique is depicted in Fig. 4. The power stage consists of input power source such as PV panel, DC to AC converter, and LC filter with line inductor. The control structure consists of three control loops; (1) power sharing loop; (2) voltage control loop; and (3) current control loop.

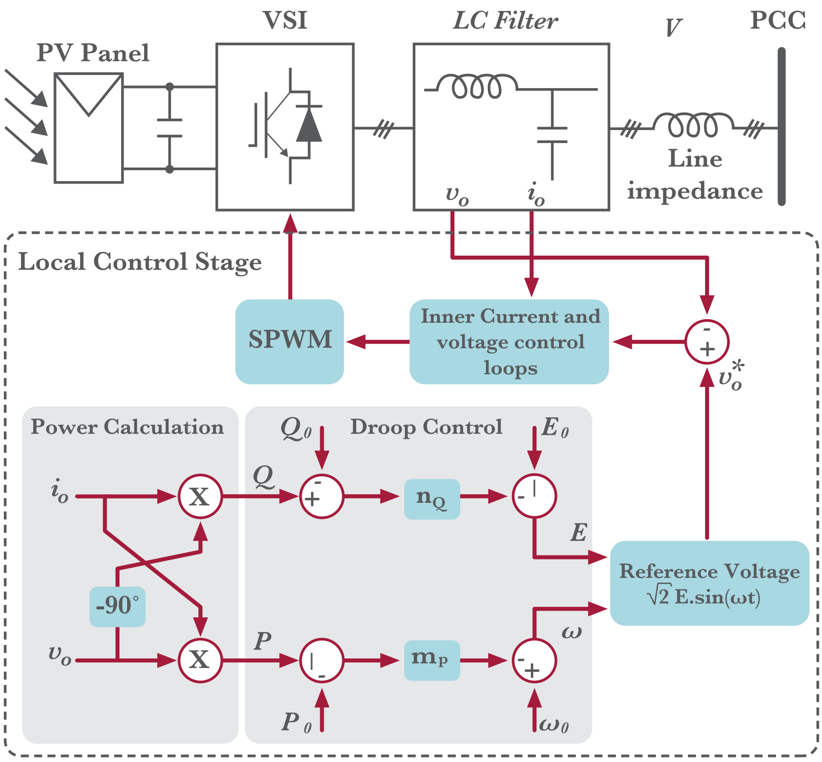


Figure 4. The simplified control scheme of traditional droop control for DG [7]

Although the traditional droop control is easy to implement in the microgrid applications, this technique has several disadvantages. Due to the use of average active and reactive powers there is a slow transient response and instability during fast load change. This leads to a slow and oscillating dynamic response and steady state deviations. In choosing the droop coefficients, there is a tradeoff between the amplitude of the droop and the system stability. Large droops speed up the load sharing but can cause instability. Smaller droops slow down the control but are more stable. Additionally, because the proportional controllers are without integral terms, the frequency and voltage in the microgrid are not constant but load-dependent. It also has an inability to provide accurate power sharing among the DG units due to output impedance uncertainties as it does not account for current harmonics in the case of non-linear loads. Figure 5 summarizes the effect of the type of distribution network on this base relationship between the voltage, frequency, active power and reactive power. When the impedance is highly inductive or resistive, the power angle δ is assumed to be small and therefore the following approximations are assumed, sin$\delta \approx \delta$ and cosδ≈1.

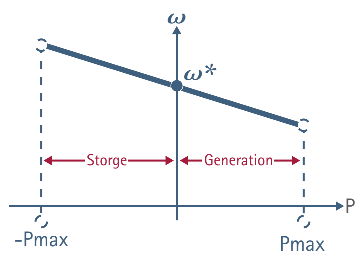
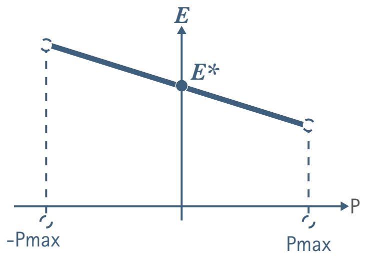
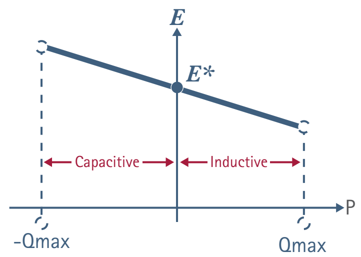
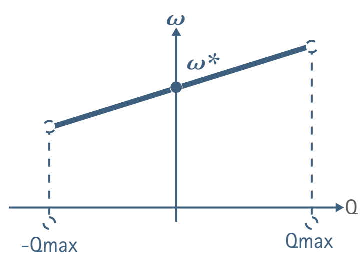
	Conventional Drop	Unconventional Droop
Type of line	High and medium Voltage	Low Voltage
Assumptions	$Z = jX, R = 0 \delta = 0$	$Z = R, X = 0 \delta = 0$
Droop Equations	$\omega = \omega^* - m (P - P^*)$ $E = E^* - n (Q - Q^*)$	$\omega = \omega^* - n (Q - Q^*)$ $E = E^* + m (P - P^*)$
Active Power Characteristics		
Reactive Power Characteristics		

Figure 5. Comparison of traditional and opposite droop characteristics

It can be seen from Fig. 5 that the ω/P characteristic changes to ω/Q droop, and the V/Q droop shifts to one with V/P as the line impedance changes from high voltage lines to lower voltage lines. The impedance therefore has to be carefully tracked in order to ensure the droop control is working in the required mechanism. To resolve this issue, the implementation of virtual impedance has been explored in [16].

Topologies of DC and AC microgrid for Qatar applications

Globally and in Qatar, diesel generators have dominated off-grid market until recently. However, high operating costs and environmental impacts of diesel generations offer space for renewable energy source technologies to have larger share among existing off grid system. Therefore, off-grid market offers path for renewable energy to be deployed as grid-connected market have not yet grown as expected.

Being intermitted in nature, renewable energy sources cannot be solely used to power off-grid systems. Energy storage elements and other dispatchable sources need to be operated in conjunction with renewable sources to ensure continuous and reliable power supply. For that purpose, microgrids can be formed to manage power supply for off-grid systems where a central controller unit monitors the system status and manage various loads and sources to optimize system operation and resources utilization. Figure 2 shows a microgrid system diagram under installation within a farm in Qatar.

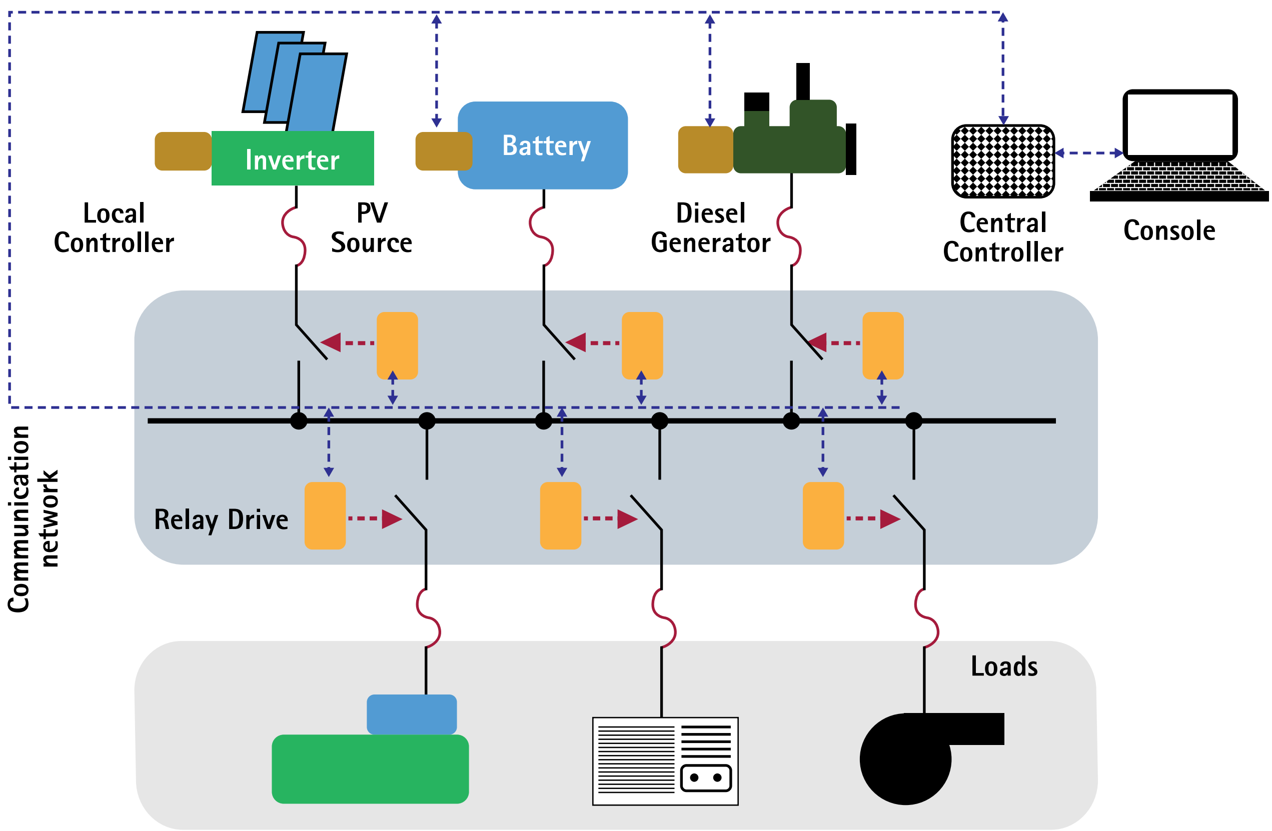


Figure 6. Microgrid system within a farm in Qatar to be implemented by QEERI

The system has 30 kW of solar PV, diesel generator and batteries. In the load side, 2 units of 2.5 kW water pumps, air conditioners and water desalination unit are included. The central controller monitor the power supplied by the PV and operate the water pumps and the desalination unit based.

The ability to pump water into tank and to desalinate more water when there is surplus solar energy reduces the needed size of battery. Additionally, ice storage could be used for cooling the thing that minimizes the battery size to serve lights and electronic systems during night time operation.

As indicated above, farm based microgrid are expected to benefit significantly from renewable energy sources and the use of variable speed pump and air conditioners can be very helpful to match the load with the available amount renewable energy. In the AC microgrid, PV power is converted from DC to AC to match the voltage at the microgrid lines. At the loads side, the AC power is converted into DC form to operate variable speed motors for the pumps and air conditioners. Therefore, it is more efficient, effective and economic to form a DC microgrid as shown in Fig. 7.

In the DC microgrids number of DC to AC and AC to DC converters will be eliminated which leads to reduction in the losses as well as the system cost. Moreover, easier and more effective control for the system can be implemented since fixed line voltage is monitored by all components within the microgrid.

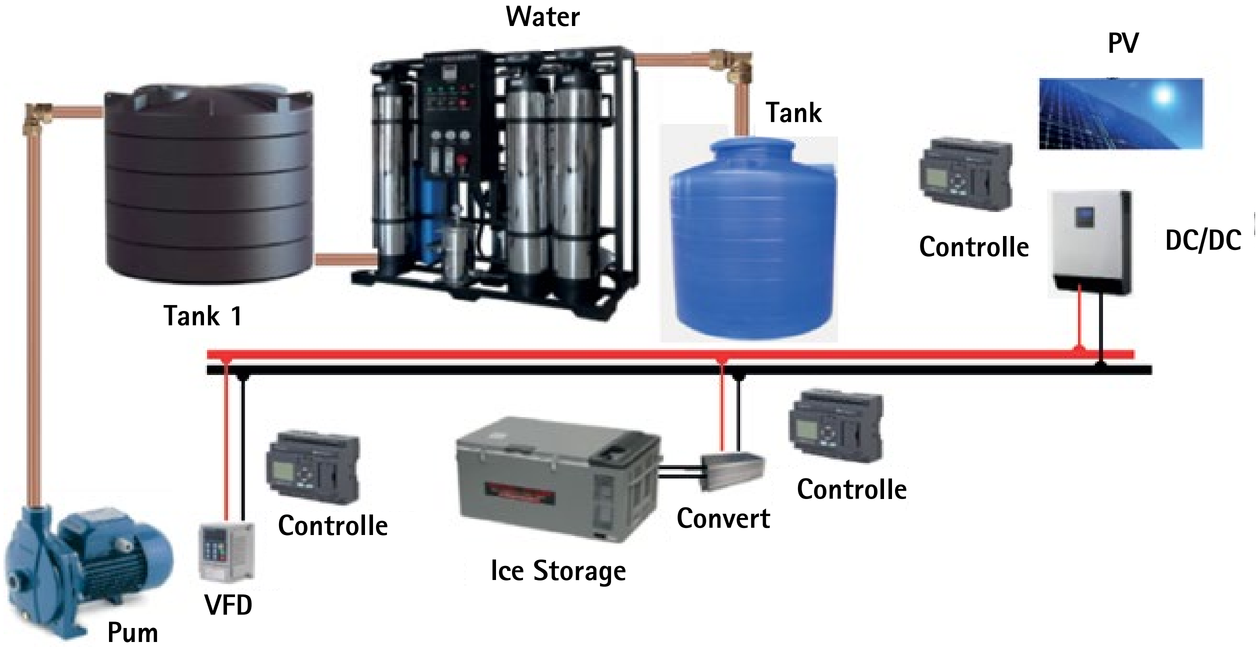


Figure 7. DC microgrid for off-grid agricultural farms

Part of research conducted in QEERI is size the DC microgrid for the farm application such as the required DC bus capacity such that stable operation is ensured all the time even when these is major change in the load. Being served by the same DC bus, loads and sources can coordinate their activities based on the DC bus voltage such that autonomous activity coordination is supported with any need for inter-sources communication as shown in Fig. 8.

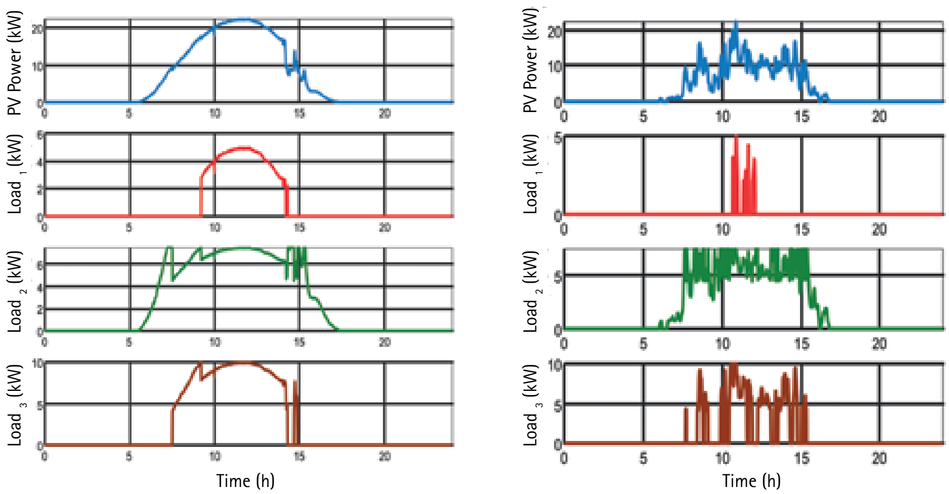


Figure 8. PV source supplied power and loads consumption for (a) sunny and (b) cloudy days for DC microgrid with loads with coordinated control

Calendar aging of a 250 kW/500 kWh Li-ion battery deployed for the grid storage application

The introduction of Li-ion batteries for grid applications has become evidence as the cost per kWh is continuously decreasing. Although the Li-ion battery is a mature technology for automotive applications and portable electronics, its use for stationary applications needs more validation due to lack of sufficient data and studied for the degradation of these types of battery in such applications.

The Li-ion technology is considered safe enough for grid storage application, but its lifetime is generally evaluated to be around 10 years. However, many factors affect the degradation like the intended application which could be being frequency regulation, peak shaving or proving an uninterruptable power supply UPS.

Higher market penetration will be achieved if a longer lifespan could be demonstrated. Therefore, aging evaluation of the batteries becomes crucial.

Based on the developed hybrid solar power generation/storage micro-grid system by Qatar Environment and Energy Institute, the effects of aging after a three years' standby field deployment of a 250 kW/500 kWh Li-ion battery integrated with the grid and solar farm under the harsh climate conditions of Qatar, are investigated.

The development of tools for acquisition and analysis of data from the battery management system (BMS) allows the assessment of the battery performance at the battery stack, string and cell levels shown in Fig. 9.

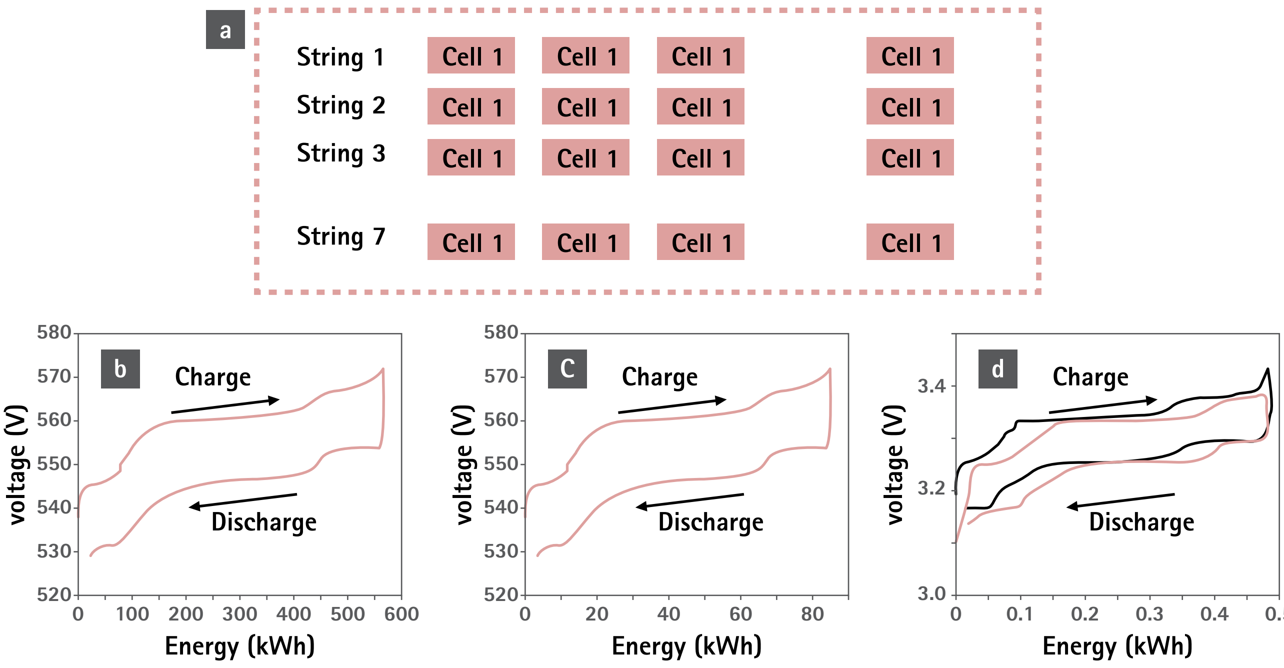


Figure 9. (a) Scheme of the 250 kW/500 kWh Li-ion battery, discharge curves of (b) the full battery, (c) the string, (d) individual cells.

The focus of the studies is battery diagnostic. The Study has been conducted at the cell level which shows that most problems of big battery originate from cell imbalance. One faulty cell in the string is enough to strongly decrease the apparent useable battery capacity.

The failure in the system could be due to heat and/or dust as discussed below. Moreover, the impact of keeping the battery at standby mode is also studied and included at the end of this section.

Heat Impact on Battery performance and degradation

The high temperature during the summer time in Qatar can have damaging impact on battery systems. In addition to the heat from the atmosphere, significant heat can be produced from the battery cells and the power electronic circuits. In some cases, the heat impact on the electronic, mechanical and electrical components can be more significant than its impact on the battery cells since they are not as well insulated as the cells. This can lead into situation where battery failure raises more from fatigue of the mechanical and electronic parts than from the electrochemical cells themselves which is supported by some studies conducted at QEERI.

The use of air-conditioner provides a solution for the heat issue. Air conditioners in these applications need to be sized such that they eliminate the heat due to external atmospheric condition as well as the heat generated from the cells and electronic components. The use of air conditioner impacts the total system cost and the overall efficiency since the energy utilized by the air can be treated as losses. For the 100kW system deployed at QEERI, 5kW air conditioner is installed. When the battery and air conditioner operate at rated power the impact of the latter represents 5% power loss in the system. However, air conditioner is not needed all the time and thus it should have less impact on the overall system efficiency.

Dust Impact on Battery performance and degradation

Dust and soiling are very common all-around Qatar. For the battery system, dust can have negative impact on the performance of the electronic components. Some studies at QEERI show that there is parasitic current on some of the battery strings which creates uncertainty on the battery SOC determination. Dust can also lead to Connector aging, inefficient heat dissipation electric/electronic components and fatigue for some mechanical parts like the compressor/fan of air conditioners.

Battery degradation at Standby mode

The analysis of the residual capacity after aging showed that the stack suffered from a low decrease of capacity, whereas some inconsistencies have been found between the strings. These inconsistencies are caused by misalignment of a small number of cells that underwent self-discharge during standby at high state of charge. A diagnostic of a grid-connected 250 kW/500 kWh Li-ion battery has been made after 3-years storage at high state of charge. The battery that is made of 1176 cells has been investigated at different levels: battery stack, string of cells in series and individual cells.

The overall look at the battery shows that it suffered only limited damages from the storage. Its residual capacity was evaluated to 93% of its initial available capacity. A deeper analysis of the string and cell performance shows that a few per cent of the cells have suffered damages that result in shift of electrode balancing in the most affected cells. Only 0.42% of the total cells have been found to cause correction in the SOC estimation. These cells have been found in 2 among the 7 string. The damages due to calendar aging are suspected to be caused by self-discharge, possibly related to the maximum 40 °C temperature storage. The relatively observed aging effects also suggest that Li-ion batteries might have longer useful life than previously estimated for single cell studies, when deployed as back-up for solar energy farms, even in harsh field deployment conditions.

Demonstration study of hybrid solar power generation/storage micro-grid system under Qatar climate conditions

The ultra-strong solar irradiance conditions in Qatar area have natural benefits for large-scale solar photovoltaic (PV) farm deployment. However, climate issues such as soiling, extremely high temperatures and sand storms are real challenges for stable performances of solar PV farms. The integration of an energy storage system to the solar farm can be used to smooth the intermittency of the PV power generation. A 500 kW/500 kWh hybrid solar power generation/storage micro-grid system, shown in Fig. 10, has been installed in the Solar Test Facility (STF) near Doha, Qatar.

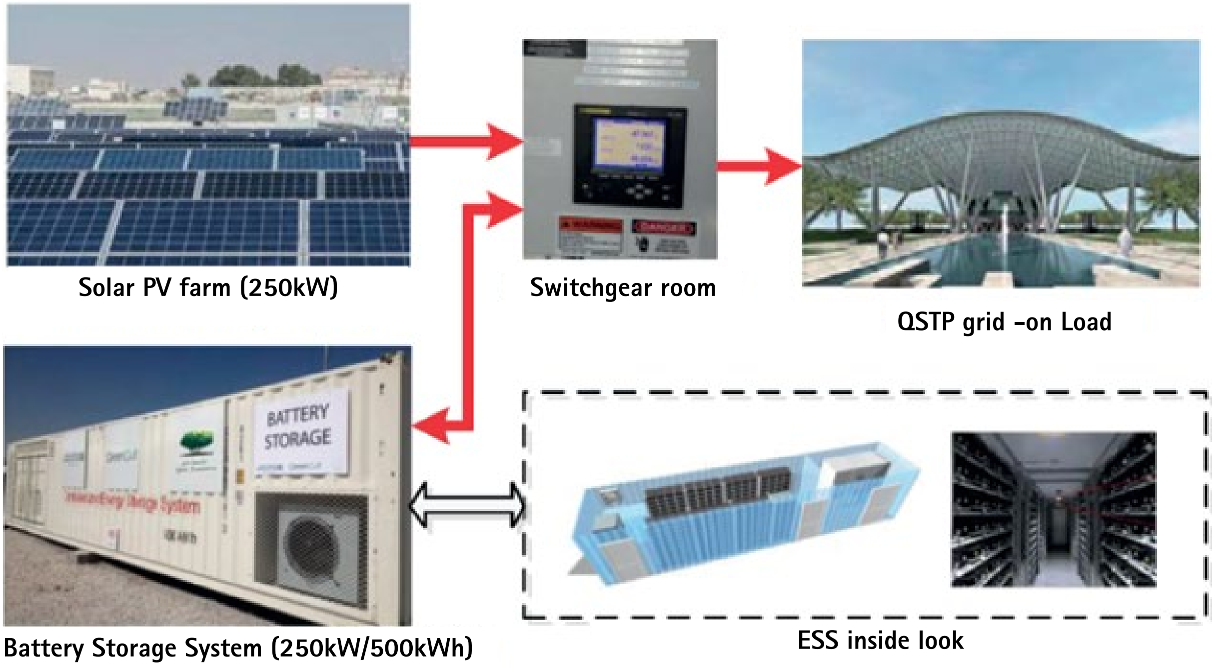


Figure 10. Overview of the hybrid solar/Energy Storage System micro-grid

In this project, the Supervisory Control and Data Acquisition (SCADA) system, shown in Figure 11, that has been developed to monitor the different elements of the micro-grid. We give a brief summary of the solar PV performance, analyze the impact of power fluctuations on the quality of the grid and present the data generated from the micro-grid system. We demonstrated a significant improvement of the power quality of the grid with the introduction of an energy storage system to the micro-grid.

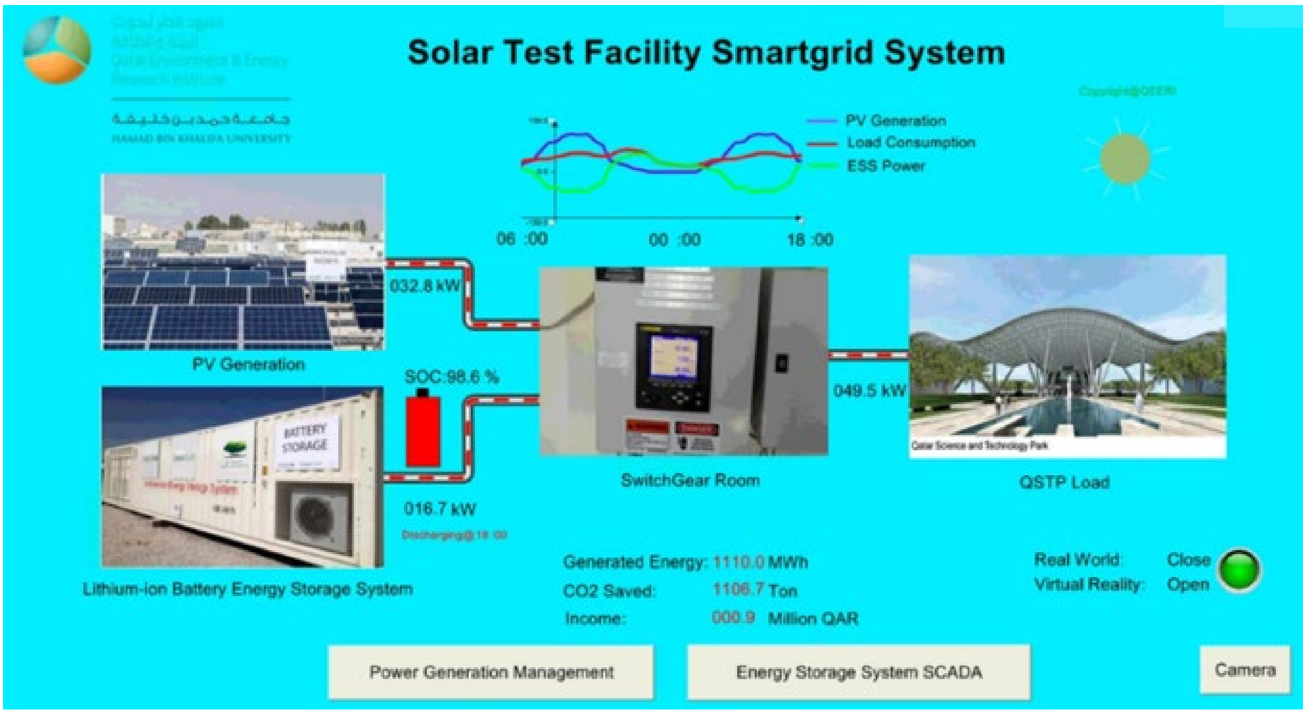


Figure 11. developed SCADA system for the micro-grid

Two research areas are covered in this project which are:

1. Battery Control and management related topics in integration with PV and micro-grid.
2. Battery aging and diagnostics from cell level to full-stack level under Qatar weather conditions.

These studies are needed to evaluate the battery performance and degradation under heavy workload for different grid application scenarios as there is lack of studies and data in this area.

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PAPER 6 ENVIRONMENTAL AND ECONOMIC IMPACTS OF PV ADOPTION IN QATAR

Introduction

Qatar enjoys strong Global Horizontal Irradiation (GHI) with long winter days and it is therefore ideally suited for applications of solar energy based on photovoltaic (PV) systems. Qatar's plans for PV adoption include an ongoing effort to achieve 700 MV PV capacity by the end of 2021 and the intention to exceed 20% in dependency on solar energy by 2030. The prospected use of solar energy for the production of electricity will yield significant natural gas savings, which is currently the primary source of electricity production. These gas savings can be repurposed for additional trade, or left untapped to extend the lifetime of the country's natural gas reserves and lower extraction costs, with ensuing reduction of CO2 emissions. The objective of this chapter is to explore and quantify these environmental and economic impacts in the light of the changing demand for electricity in Qatar.

Solar Resources and PV Adoption in Qatar

Qatar has a yearly average of 5.8-6 peak sun hours per day, which is among the highest worldwide[1]. The total yearly yield of GHI, which is the relevant irradiation component for PV applications (Pelland et al. 2013), is also very high at 2163 kWh per m2 (Martín-Pomares et al. 2017). Qatar is therefore ideally suited for PV applications of solar energy based on photovoltaic (PV) systems, as shown in Figure 1.

Currently, Qatar has only a few megawatts (MWs) of solar PV installed, mostly in Education City. KAHRAMAA, Qatar's electricity and water distribution company, has recently issued a tender for a 700MW solar PV plant to be fully operational by the end of 2021. Qatar's commitment to a path of PV adoption is further corroborated by the announcement made by Qatar's Ministry of Municipality and Environment at the meeting on Climate and Sustainable Development for All convened by the UN General Assembly on 28 March 2019 in New York that "Qatar's dependency on solar energy will exceed 20% by 2030".

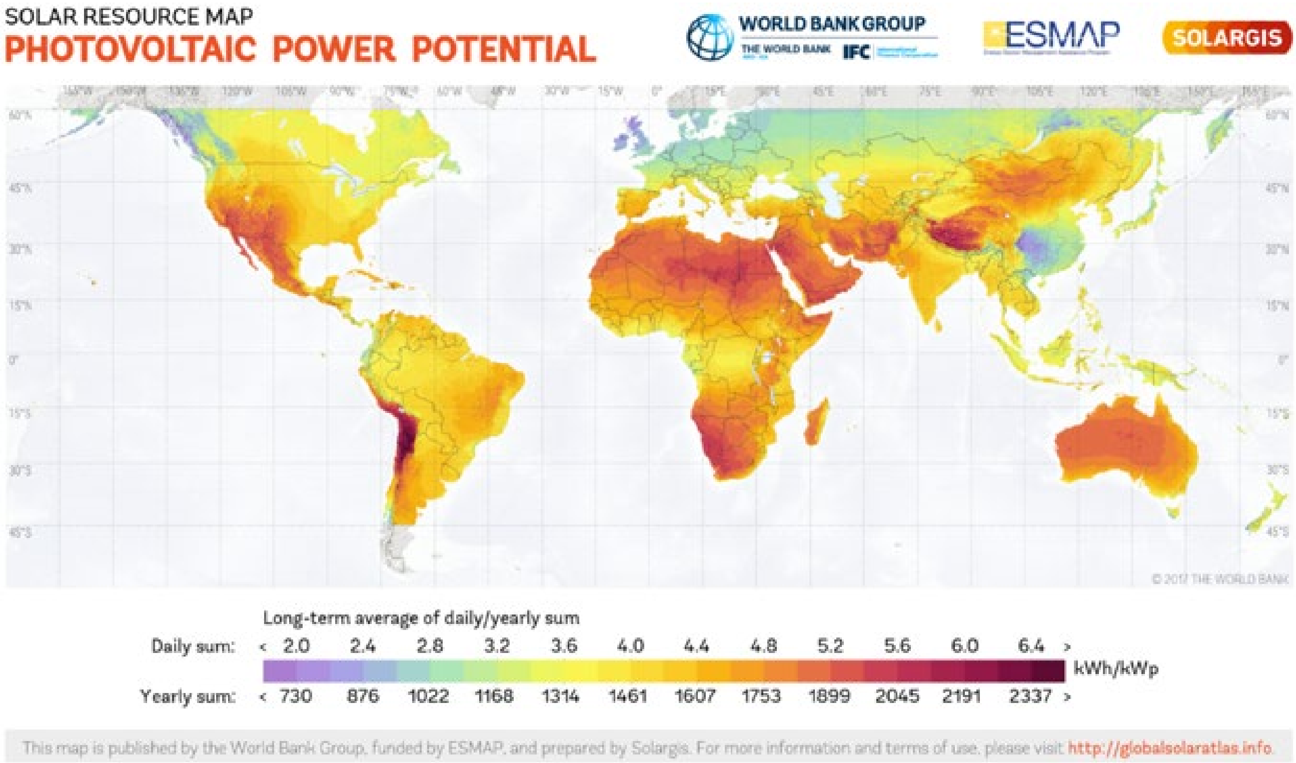
In 2017, the power grid in Qatar reached a total capacity of

10,170

MW as the sum of contracted capacity from the local independent water and power producers (Kahramaa Statistics Report 2017).

1. The term peak sun hours refers to the solar insolation reaching a given location with the sun shining at its maximum value (1 kW/m2) for a certain number of hours. For details about peak sun hours across world locations see https://www.gaisma.com.
2. Source: Gulf Times (https://www.gulf-times.com/story/515040/Qatar-power-capacity-tipped-to-reach-13-000MW-by-2).

In 2017, the power grid in Qatar reached a total capacity of 10,170 MW as the sum of contracted capacity from the local independent water and power producers (Kahramaa Statistics Report 2017). As anticipated in 2016 by Fahad al-Mohannadi[2], managing director and general manager of Qatar Electricity and Water Company, grid capacity may soon reach 13,000MW to meet the demands of the FIFA World Cup in 2022. The expected PV plant capacity of 700MW in 2021 will therefore represent about 7% of total grid capacity. Plans by KAHRAMAA to promote distributed solar energy generation through the adoption of residential and commercial PV systems may increase the PV share of total grid capacity.



Estimating Natural Gas Savings from PV Adoption

In order to estimate natural gas savings from PV adoption, we need to establish the amount of gas needed to generate a given unit of electricity. This can be done using the estimated average thermal efficiency of Combined Cycle Gas Turbine (CCGT) plant, which is the standard for electricity production in Qatar. Assuming a thermal efficiency of 60% (Robb 2010), and taking into account that 1 megawatt hour (MWh) of electricity is equivalent to 0.086 Toe (metric ton of oil equivalent) on an energy basis (IEA Unit Converter), we can establish that it takes 0.12 Toe of natural gas to generate 1 MWh of electricity.

We estimated the electricity generated yearly by the planned 700 MW PV plant in Qatar at 1,252,177.78 MWh using the NREL PVWatts Calculator (PVWATTS) with the following settings:

- Solar Resource Data Site: Abu Dhabi, United Arab Emirates
- Distance from reference location: 205 miles
- Module Type: Standard
- Array Type: Fixed (open rack)
- Tilt: 20 degrees

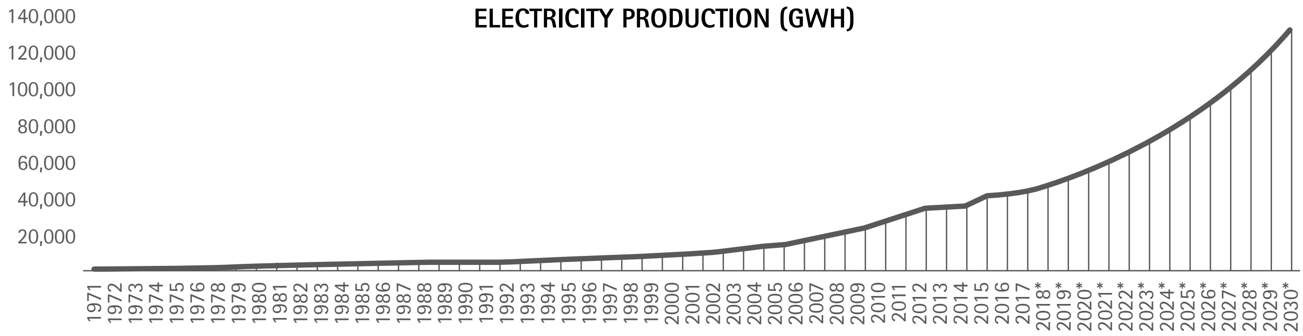
- Azimuth: 180 degrees
- DC to AC Size Ratio: 1.2
- Inverter efficiency: 96%
- Ground Coverage Ratio: 0.4
- Losses due to Soiling: 10%
- Light-induced degradation: 1.5%.

This estimation is close to the one presented in Martín-Pomares et al. (2017), where the annual PV output for a 500 kW PV plant is pegged between 89 and 93 gigawatts hour (GWh), which equals 1,246,000 to 1,302,000 MWh for a 700 MW PV plant. The estimated amount of natural gas saved each year of operation for the 700 MW plant will therefore be 150,261.33 Toe (1,252,177.78 MWh * 0.12 Toe).

To estimate the amount of natural gas saved a given year when 20% of total electricity production is achieved through solar PV, we need to establish the electricity production for that year. To do so, we used yearly data about electricity production and population growth in Qatar from IEA, KAHRAMAA and the World Bank for the period 1971-2017 to train a multivariate forecasting model that provides electricity production and population growth forecasts (Figure 2) through 2030, when at least 20% of total electricity production through solar PV is expected. The forecasting model is based on a linear regression algorithm (Hyndman & Athanasopoulos 2013) where the current term x, of a time series $x_i,\ldots,x$ for $N \geq t \geq i \leq n$, is estimated as the linear weighted sum of previous terms $x_i,\ldots,x$ in the series, as shown in (1) where c is a constant, ε_t is white noise, and $a_i, \ldots, a_n$ are the auto-regression coefficients that function as the weights in the sum and are derived using regression techniques such as least squares estimation or maximum entropy.

$$x_t = c + \sum_{i=1}^{N} a_i x_{t-i} + \varepsilon_t$$

1



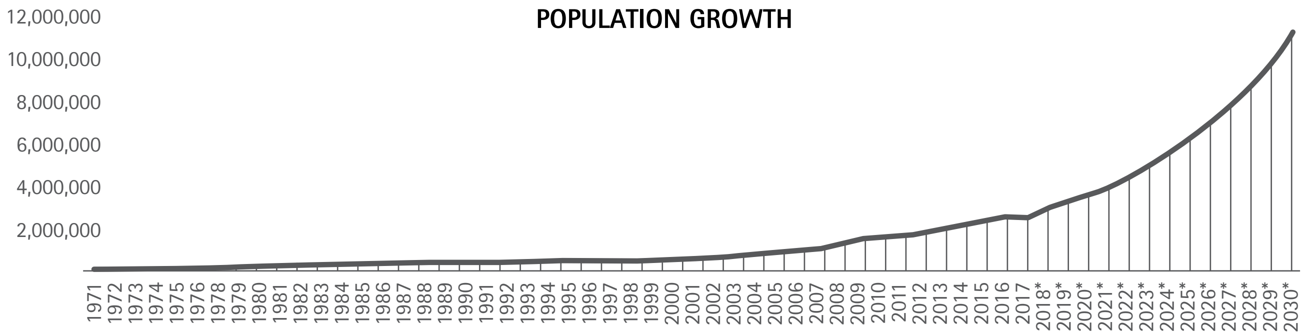


Figure 2: Electricity production and population growth in Qatar 1971-2030. Forecasted years are marked with an asterisk.

The model provides an estimated total electricity for 2030 of 133,277,854.9 MWh, which is about three times the total electricity generated in 2017, with a Compound Annual Growth Rate (CAGR) of 8.2% for the period 2018-2030, as compared to the GAGR of 8.9% for the previous thirteen years (2005-2017).

The model is evaluated by training on 70% of the data and testing on the remaining 30% using the Normalized Root Mean Square Error (NRMSE) in (2) as metric. As shown in Table 1, the evaluation results indicate that the model has a low error rate for both electricity production (>6%) and population growth (>3%).

$$NRMSE = \frac{\sqrt{\frac{\sum_{t=1}^{n}(x_{predicted_t} - x_{observed_t})^2}{n}}}{average\ (observed_{1,\dots,n})}$$

2

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Electricity Production (%)	0.52	0.54	2.22	1.33	1.99	1.79	1.21	3.28	2.54	2.95	3.98	4.20	5.45
Population Growth (%)	1.61	1.14	1.79	1.40	1.75	1.88	1.72	2.04	2.04	2.15	2.52	2.60	2.86

Table 1: Evaluation results (NRMSE) for electricity production and population growth forecasts.

According to these electricity production forecasts, 20% of total electricity production through solar PV in 2030 would be 26,655,570.98 MWh, with an ensuing natural gas saving of 3,198,668.52 Toe.

Environmental and Economic Impacts

Table 2 shows the prospected yearly natural gas saving from 2022 through the 700 MW PV plant, and in 2030 as a function of 20% of the forecasted electricity production.

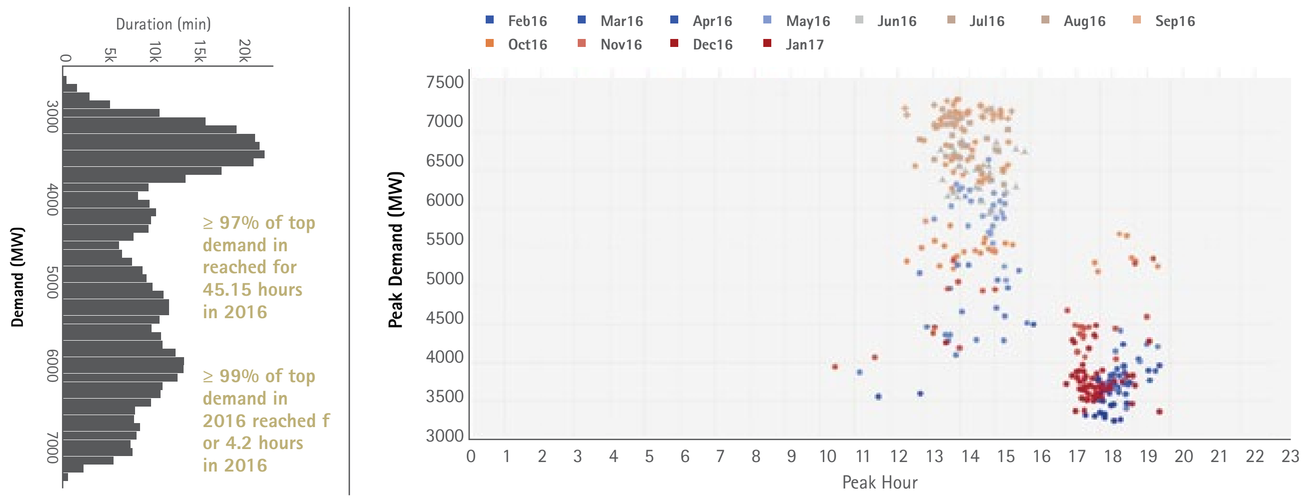


Table 2: Prospected yearly natural gas savings in 2022 and 2030 from PV adoption.

In all likelihood, PV capacity will grow somewhat gradually from 2022 through 2030, so that the yearly natural gas savings in the intervening years will be incrementally higher. We can use interpolation to estimate this incremental trend in natural gas saving, as shown in Table 3, keeping in mind that this is just an abstraction, as PV adoption need not follow such a regular course of development. Taking into account that 1 Toe is equivalent to 39.68 Million British thermal units (MMBtu), each Toe of saved gas sold on the international market at the Aug 2019 Henry Hub Natural Gas Spot Price of $2.26/MMBTU would yield USD 89.68. If the natural gas saved through PV adoption were sold on the international market at the same price, the total revenues for the period 2022-2030 would yield over 1.35 billion, as shown in Table 3.

With reference to power grid infrastructure, the integration of distributed PV generation in Qatar through residential and commercial PV systems would help curtail infrastructural investments needed to keep the national power system in lockstep with ongoing economic and population grow. From 2010 to 2017, electricity demand in Qatar grew at an annual average of about 6%, with peak loads going from 5,090 to 7,855 MW, as shown in Table 4. To ensure that electricity demand be met at peak load times, the capacity of the grid needs to be constantly increased, even though maximum demand occurs only sporadically, at predictable times, as shown in Figure 3. Costs to upgrade the national electricity generation, distribution and transmission network in Qatar may reach $9bn by 2020, and continue to increase thereafter. These costs can be significantly decreased through the introduction of smart grids that integrate distributed PV generation, incorporate storage technologies to manage variable renewable energy, and use demand response to reduce demand during periods of peak consumption.
Figure 3: Duration of demand levels and distribution of electricity peak demand by day in 2016 (Bayram et al. 2018).

Overall, the growth of the PV market in Qatar would help diversify the national economy through innovation and entrepreneurship, and accelerate the transition from a carbon-based to a knowledge-based economy, as mandated by Qatar National Vision 2030. The main environmental impacts of PV adoption is the reduction of CO2 emissions. Each MMBtu of natural gas burned to generate electricity generates 117 pounds of CO2 (EIA FAQ). Given the Toe-MMBtu equivalence (1 to 39.68), each Toe of natural gas burned will therefore generate 4642.56 pounds of CO2. The expected CO2 emission reductions emerging from PV adoption for the period 2022-2030 are shown in Table 3 (in metric ton). The reduction of CO2 emissions is a crucial outcome, since Qatar's ambient air has one of the world's highest annual concentrations of particulate matter, which is known to increase the risk of acute lower respiratory infection in children, chronic obstructive pulmonary disease, ischemic heart disease, stroke, and lung cancer.

Year	Gas Savings (Toe)	Potential revenues from trade (USD)	CO2 emission reduction (Ton)
2022	150,261.33	$13,475,436.07	316,424.79
2023	531,312.23*	$47,648,080.79*	1,118,853.12*
2024	912,363.13*	$81,820,725.50*	1,921,281.46*
2025	1,293,414.03*	$115,993,370.21*	2,723,709.80*
2026	1,674,464.93*	$150,166,014.92*	3,526,138.14*
2027	2,055,515.82*	$184,338,658.74*	4,328,566.45*
2028	2,436,566.72*	$218,511,303.45*	5,130,994.79*
2029	2,817,617.62*	$252,683,948.16*	5,933,423.13*
2030	3,198,668.52	$286,856,592.87	6,735,851.47
Totals	**15,070,184.33**	**$1,351,494,130.71**	**31,735,243.15**

Table 3: Prospected yearly natural gas savings from PV adoption and ensuing potential revenues from trade at $2.26/MMBTU and CO2 emission reductions for the period 2022 through 2030 – interpolated values are marked with an asterisk.

Year	Total demand (GWh)	Max demand day (MW)	Date	Min demand day (MW)	Date
2010	28,144	5,090	14-Jul	1,570	8-Feb
2011	30,730	5,375	1-Aug	1,785	13-Jan
2012	34,788	6,255	6-Aug	1,840	26-Jan
2013	34,668	6,000	18-Jul	2,046	16-Jan
2014	36,125	6,740	7-Sep	2,154	12-Feb
2015	41,499	7,270	1-Sep	2,320	24-Feb
2016	42,306	7,435	3-Sep	2,410	19-Jan
2017	43,800	7,855	14-Aug	2,600	25-Feb

Table 4: Maximum and minimum load of the electricity network in Qatar GW (source: KAHRAMAA).

Conclusions

Qatar is committed to a path of PV adoption punctuated by the installation of a 700 MW solar plant by the end of 2021 and the plan to generate at least 20% of total electricity by solar energy in 2030, including utility scale and residential/commercial systems. Some distributed solar energy capacity is already operational and more is expected through residential and commercial installations aided by mechanisms such as the feed-in tariff and net metering or direct trade via blockchain technology. PV adoption will save significant amounts of natural gas that can be repurposed for additional trade, or left untapped to extend the lifetime of the country's natural gas reserves and lower extraction costs, with ensuing reduction of CO2 emissions. In addition, the adoption of distributed solar energy capacity, in the form of residential and commercial PV systems, will help reduce the need for costly upgrades to the national electricity generation, distribution and transmission network.

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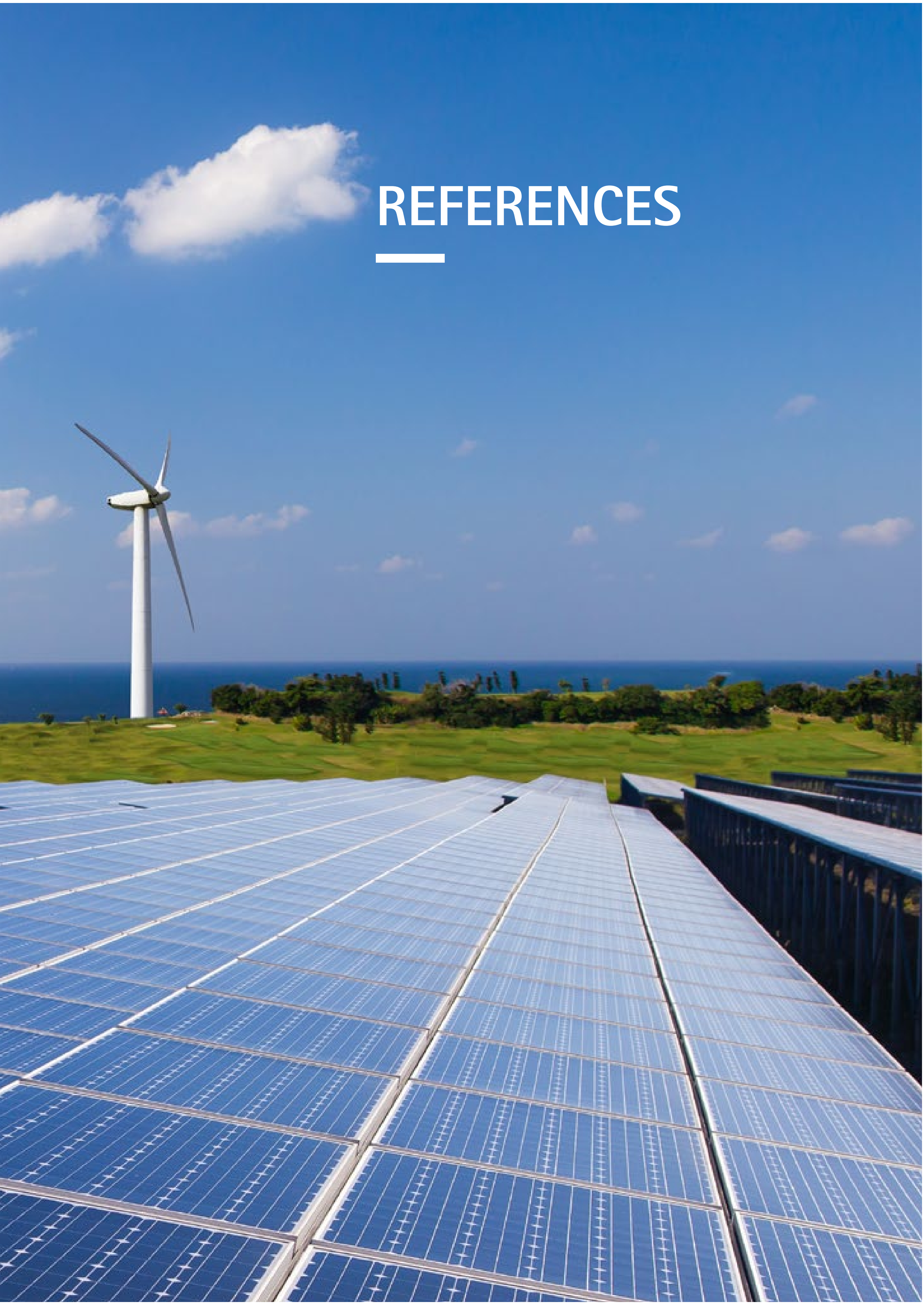

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