CHAPTER

5 Global energy production and its sustainability

Energy drives economies, sustains livelihoods and enables individuals to power the technologies to support and enhance their wellbeing. Currently, the world gets 85 per cent of its commercial energy from fossil fuels. These energy resources have underpinned sustained economic growth and improved the quality of life for those benefitting from such development. However, it is evident that this dependence on fossil fuels has adversely affected the environment, as global energy production is the main driver of climate change. What is needed is a transition from fossil-based fuels to a mix of low-carbon renewable technologies. A smooth and secure energy transition will require political will and higher clean energy investment flows from both governments and the private sector. It must be inclusive so that developing countries are supported and are part of the transformation. The challenge ahead this century is to establish universal access to a more sustainable energy system of low-carbon energy sources that are efficient and reliable.

In this chapter, students study the nature and spatial patterns of global energy production, the factors influencing this activity, the current trends and future directions of energy production and its sustainability, as well as challenges and responses.

> **Once you got a solar panel on a roof, energy is free. Once we convert our entire electricity grid to green and renewable energy, the cost of living goes down.**
>
> **Elizabeth May, Canadian politician, environmentalist and author**

5.0.1 A wind farm over the sea, North Holland, Netherlands

Chapter glossary

bioenergy energy produced from organic material, known as biomass, which contains the energy captured by plants; most commonly made from forest waste and crops such as corn and sugarcane

carbon capture the process of removing carbon dioxide from large power and industrial plants and injecting it into deep geological formations

charcoal a lightweight black residue of charred wood

coal a solid carbon-rich material that formed 300 to 360 million years ago in the Carboniferous period when vast swampy forests were buried under sediments

coal seam a layer of combustible sedimentary rock containing coal deposits.

conventional oil liquid oil that can flow through a wellbore

crude oil a naturally occurring black, viscous liquid composed mainly of hydrocarbon

firmed renewables energy sources such as wind or solar, where the output is maintained to ensure that enough energy is always available

fossil fuels fuels such as coal, oil and natural gas formed from the fossilised buried remains of plants and animals that lived hundreds of millions of years ago

fracking a method of capturing natural gas by widening cracks in rocks by injecting high-pressure water laced with chemicals and sand; the sand props open the cracks enabling gas to escape

geothermal energy energy generated from reservoirs of hot water below the Earth's surface; its original source is the internal energy of the Earth, as magma heats nearby rock and underground water

green hydrogen a clean energy source as it only emits water vapour and leaves no residue in the air

hydropower any technology that uses the kinetic energy of flowing water to generate electricity; it most commonly involves building a dam to store water, then releasing it down pipes to turn turbines

non-renewable resources resources including coal, oil, gas and nuclear energy; they are in limited supply and once they are used up, they are gone forever in a timescale relevant to humans

nuclear fission the breaking of the nucleus of an atom into two or more parts, releasing energy

nuclear fusion the joining atoms together to form a single nucleus, releasing energy

renewable resources resources including solar, wind and hydropower that can replenish themselves through natural processes; they are sustainable if they are not used faster than they are replaced

shale oil oil that is bound up tightly in impermeable rock and requires mining, crushing and heating the shale to extract the oil

solar photovoltaic where solar cells made of thin transparent wafers of silicon capture sunlight and turn it into energy

solar thermal usually large-scale solar projects where an array of mirrors tracks the sun and focuses the reflected sunlight on a central tower which generates electricity using steam and turbines

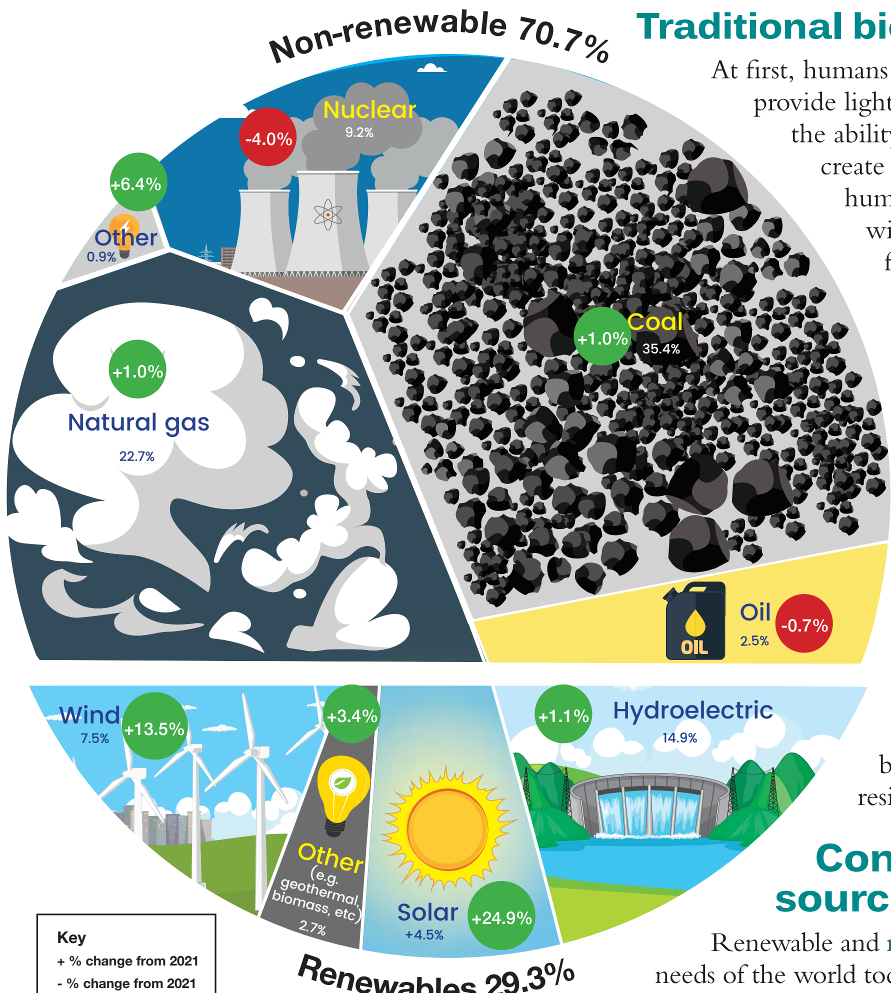
tar sands sticky deposits of bitumen mixed with sand and clay; extracting and converting these deposits into useable crude oil requires excessive amounts of energy and water

unconventional oil thicker oil that cannot be feasibly accessed using conventional vertical drilling techniques because the oil is trapped in rocks or stuck to sand and is hard to access

UNIT 5.1

The nature and spatial patterns of global energy production

The ways in which societies secure the energy they need have changed throughout history. There have been major shifts in the types of fuels used over time and each transition has underpinned major geographical changes in the distribution of production and consumption of resources, and in many cases spurred developments, which have improved standards of living. Figure 5.1.1 shows the sources of the world's electricity by fuel type in 2022.



5.1.1 Electricity generation by fuels, 2022

Did you know?

The longest-lasting known fire in the world is Burning Mountain in the Upper Hunter region of NSW. It has been burning for 6000 years, fuelled by a coal seam under the mountain.

Traditional biofuels

At first, humans relied on the Sun as a source of energy to provide light and warmth during the day. Then, with the ability to control fire, humans burned wood to create energy for heating, cooking and lighting. So, humans have used biofuels for a very long time, with evidence suggesting it could have been as far back as 1 million years ago. Wood remained the main source of energy for the world's population until the late nineteenth century.

The first energy source created by humans was **charcoal**, a lightweight black residue of charred wood, probably first discovered in the remains of a wood fire. Charcoal is a better fuel than wood as it produces twice the heat but gives off less smoke and is easily transportable. It has been intentionally produced since prehistoric times.

Until the middle of the nineteenth century, traditional biofuels were the dominant source of energy used throughout the world with the burning of wood and charcoal, as well as crop residue and even animal dung.

Contemporary energy sources

Renewable and **non-renewable resources** meet the energy needs of the world today. Non-renewable resources include **coal**, oil, gas and nuclear energy. They are in limited supply and once they are used, they are gone forever in a timescale relevant to humans. This is of increasing concern as the world relies on these finite resources for most of its energy needs. **Renewable resources** such as solar, wind and **hydropower** can replenish themselves through natural processes and are sustainable if they are not used faster than they are replaced.

Non-renewable energy

Carbon-based **fossil fuels**, such as coal, oil and natural gas, were formed from the fossilised buried remains of plants and animals that lived hundreds of millions of years ago. These fuels are sources of energy because the plants captured energy from the sun before they were buried. This energy drove photosynthesis to convert carbon dioxide and water into the building blocks they needed to grow. By using predominantly carbon and hydrogen atoms, these ancient organisms stored the energy in hydrocarbon compounds. Over geologic time this organic material remained buried and thereby protected from oxidation and was subjected to immense heat and pressure. The organic remains were slowly converted to fossil fuels with their hydrocarbon compounds serving as fuel when burned.

Fossil fuels are sought for this trapped energy. With the Industrial Revolution came the need for energy and the rise of coal, followed by oil and natural gas. Industrial economies built their wealth using fossil fuels, as they provided electricity and powered both machinery and transportation.

5.1.2 Underground coal mining at Longyearbyen in Norway's Svalbard archipelago

Coal

Coal is an abundant but dirty fuel. It is a solid carbon-rich material that formed 300 to 360 million years ago when vast swampy forests were buried under sediments. As a combustible sedimentary rock, it is found underground in **coal seams**. These are found on every continent. Coal is mined both above the ground in open-cut mines and underground (see Figure 5.1.2). The three largest coal producers are China, India and Indonesia, with each of these countries producing record amounts of coal in 2022 (see Figure 5.2.5, page XXX). In contrast, the United States, once the largest global producer of coal, has more than halved its production since 2008.

Coal has been a critical energy source and the mainstay of global energy production for centuries. It's the world's most affordable fuel and is used in thermal power plants to generate electricity. Coal is also used in industrial plants and is crucial to raising the temperature of blast furnaces to smelt metal and make steel. Global coal consumption has been increasing and hit a fresh record high of 8.3 billion metric tons in 2022, largely in response to continued strong growth in Asian economies. China and India lead the world in coal consumption, together accounting for two-thirds of the market.

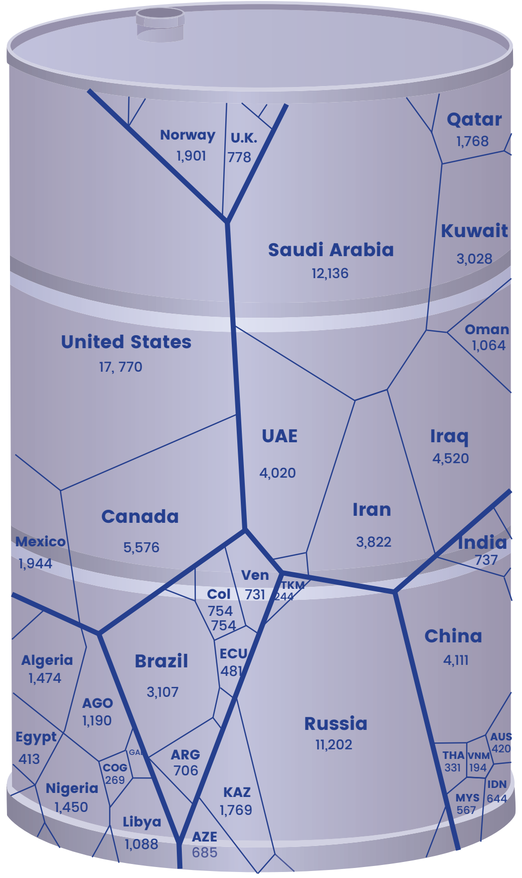
However, coal is the most polluting energy source in terms of the amount of carbon dioxide it produces per unit of energy, so moving away from coal energy is vital in tackling climate change.

5.1.3 A pumpjack on an oilfield that mechanically lifts the oil out of the well if there is not enough pressure for it to flow up to the surface from the reservoir below.

Oil

Crude oil is a naturally occurring black, viscous liquid composed mainly of hydrocarbons. Crude oil was formed over millions of years from the decayed remains of ancient organisms sinking to the bed of shallow seas. Oil is usually trapped in reservoirs between layers of impervious rock. Crude oil is known as **conventional oil** if, as a liquid, it can flow through a wellbore. It is extracted by drilling down vertically into the reservoir and pumping the oil out (see Figure 5.1.3).

The planet's reserves of conventional oil are in decline. As a result, unconventional sources are being exploited. **Unconventional oil** is thicker oil that cannot be feasibly accessed using conventional vertical drilling techniques. This is because the oil is trapped in rocks or stuck to sand and is hard to access. Technological advances have made them economically viable to recover, where they were once too costly to tap. **Shale oil** is bound up tightly in impermeable rock and requires mining, crushing and heating the shale to extract oil. **Tar sands** are sticky deposits of bitumen mixed with sand and clay. Extracting and then converting these deposits into useable crude oil requires enormous amounts of energy and water.



5.1.4 Oil production in barrels per day by country, 2022

Saudi Arabia, Iran, Iraq and Russia have the largest reserves of conventional oil. As illustrated in Figure 5.1.4, the United States and Saudi Arabia dominate production. Russia also has the largest recoverable reserves of shale oil, followed by the United States and China. The main producers of shale oil are China and Estonia. The largest tar sands deposits are in Canada (mostly in Alberta) and Venezuela. Canada dominates global production and it provides more oil to the United States than any other country. Exports to Asia of oil from tar sands reached record levels in 2022, with India the leading destination, followed by China and South Korea.

Oil is the world's largest energy source today. It is the dominant source of energy for the transport sector and powers global industry. The value of the oil market is evident in Figure 5.1.6, as it clearly dwarfs all other commodity markets by value. The United States is the largest consumer of oil, followed by China and India.

Natural gas

Natural gas is a fossil fuel energy source. It is a naturally occurring mixture of gaseous hydrocarbons, consisting mainly of methane. Natural gas is often found lying above reservoirs of conventional oil and in permeable material between layers of impermeable rock. Stores of natural gas can be accessed by standard drilling. If the gas is tightly trapped in hard rock formations such as shale, it is not easy to extract and **fracking** is performed. This process involves widening cracks in the rock by injecting high-pressure water laced with chemicals and sand. The sand props open the cracks enabling the gas to escape. Fracking requires large quantities of water and can radically lower the hydrology of an area. It also releases highly toxic wastewater that may leak into and contaminate groundwater.

SPOTLIGHT

The dirtiest project on Earth

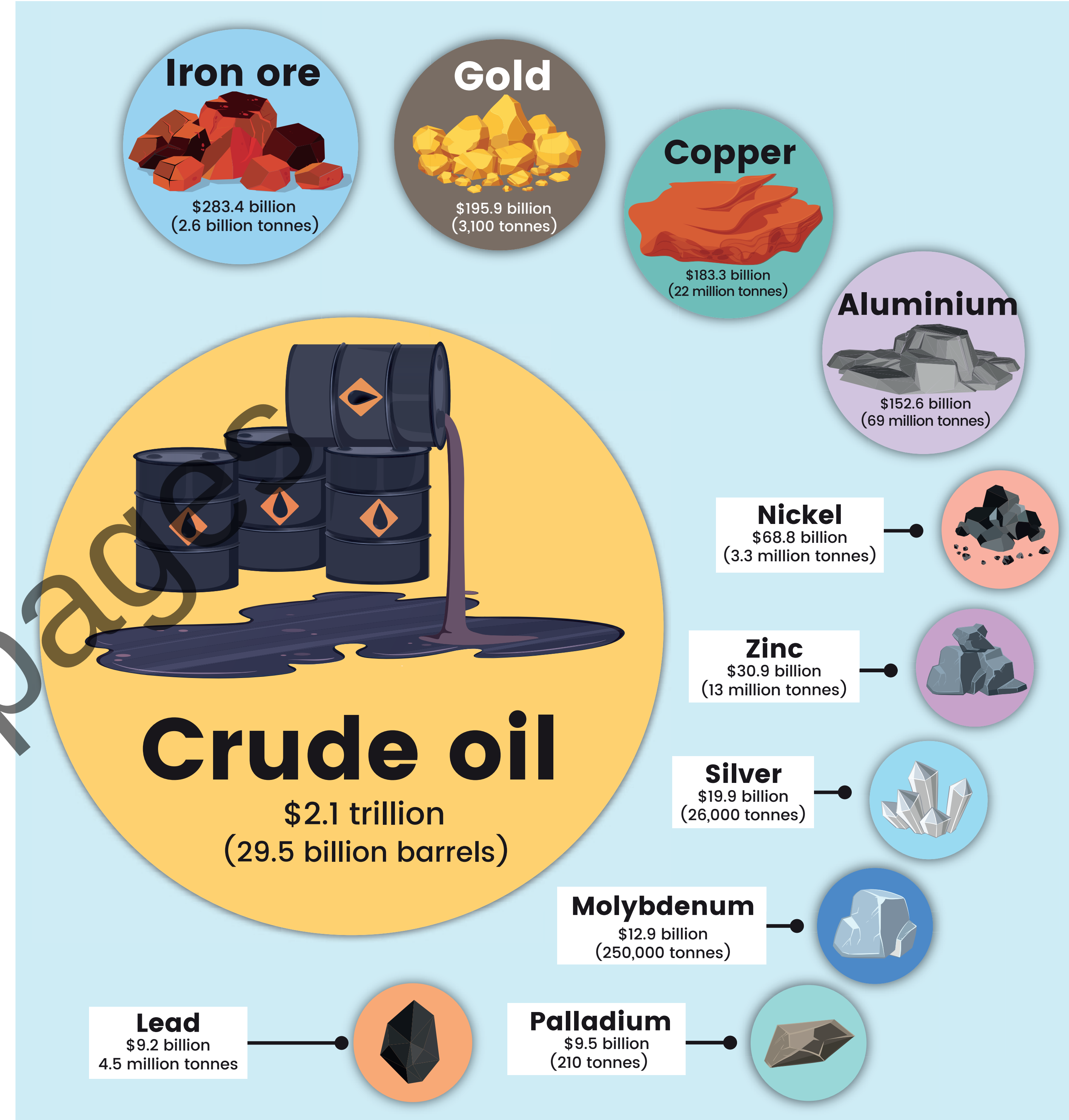
Extracting the tar sands in Alberta, Canada, is the one of world's largest industrial projects. It has been judged by many as the most destructive in human history. Canada has the world's third-largest proven oil reserves with the capability of producing 1.8 trillion barrels of crude bitumen. The tar sands are found under 140 000 square kilometres of ancient boreal forest. Vast swathes of the forest have been removed and replaced by a treeless toxic swamp with open pit mines, toxic waste ponds, pipelines and roads (see Figure 5.1.5). The landscape is punctuated by over 300 000 oil and gas wells.

The two extraction methods used are both environmentally disastrous. Strip mining involves removing the overlying mineral deposit, then digging down 75 metres and shovelling up the deposits. The entire ecosystem is lost. Removing four tonnes of soil only yields one barrel of oil. As half of the deposits are too deep for strip mining, steam is pumped down to melt the bitumen embedded in the sand so it can be brought to the surface.

The mines use huge amounts of energy and water in the extraction process and the water must be retained in open, unlined tailings ponds. These now cover 260 square kilometres and they swell each day with millions of litres of new waste. The ponds are highly toxic as they are heavily contaminated with mercury, lead and other carcinogenic heavy metals. They are so poisonous that in 2008, 1600 ducks died after landing on a Syncrude tailings pond north of Fort McMurray, Alberta.

The sands pump out more than three million barrels of oil a day, making Canada the world's fourth-largest oil producer. Despite the growing need for countries to shift away from fossil fuels, both the Canadian government and the oil companies expect the output will continue to rise into the 2030s. Canada's tar sands are amongst the world's most climate-polluting sources of energy.

5.1.5 The Athabasca oil sands near Fort McMurray, Alberta, Canada



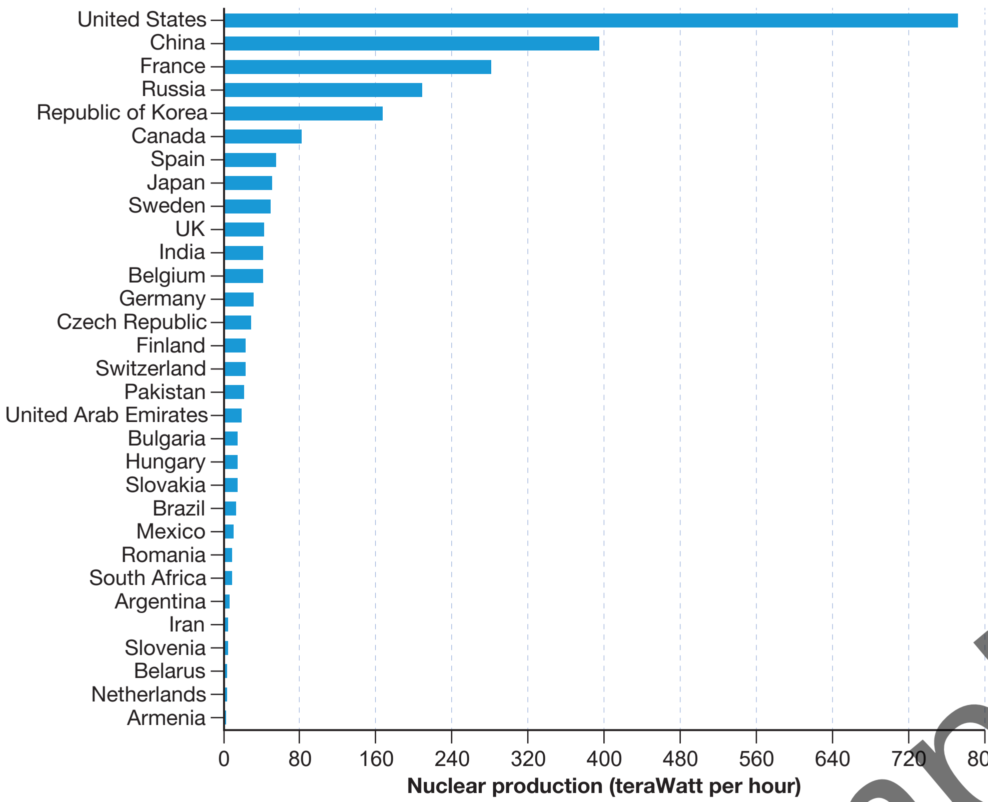
5.1.6 By value, crude oil dominates the commodities markets. The crude oil itself is simply the raw product. Before it can be used, it is processed into different components ranging from plastics to gasoline, from diesel to jet fuel, and from lubricant oils to asphalt.

Natural gas has, for decades, lagged behind coal and oil as an energy source. However, today its consumption is increasing rapidly as it is seen as a replacement for coal in the energy mix (see Figure 5.1.7). Gas is the cleanest burning fossil fuel, as it releases few by-products. Gas is a major provider of electricity production and is an alternative fuel in vehicles. It is a key source of heat and power in homes and in industrial settings. Natural gas is also used in a variety of processes such as waste treatment, food processing and refining metals. The United States and Russia dominate the global production of natural gas.

5.1.7 Coal, liquefied natural gas and crude oil account for most fossil fuel usage.

Nuclear power

Nuclear power uses nuclear reactions to produce electricity. The energy is in the nucleus of an atom and through **nuclear fission** the nucleus is split into several parts, releasing the energy. The nuclear fission of uranium and plutonium in nuclear power plants produces the world's nuclear energy. Initially, the technology was developed during World War II for making bombs, but in the 1950s, attention turned to using it to generate power. Nuclear power plants are now operational in 32 countries worldwide and approximately 440 nuclear reactors provide about 10 per cent of the world's electricity (see Figure 5.1.8).



5.1.8 Nuclear power generation by country 2022. Thirteen countries produced at least one-quarter of their electricity from nuclear. France gets up to 70% of its electricity from nuclear energy, while Slovakia, Belgium and Hungary get about half from nuclear.

Nuclear power is a low-carbon source of energy. However, the initial capital required, and the ongoing maintenance costs are much higher than for other energy projects.

There is also the issue of safely managing the waste generated by nuclear reactors as it remains radioactive for hundreds of thousands of years. Although uncommon, accidents in nuclear reactors can have devastating and long-lasting consequences for both humans and the environment. The Chernobyl (Ukraine) and Fukushima (Japan) nuclear disasters are often cited in arguments against nuclear power.

Did you know?

Nuclear energy can also be produced through **nuclear fusion** or joining atoms together. The Sun is constantly undergoing nuclear fusion as hydrogen atoms fuse to form helium. Nuclear power plants currently cannot safely produce energy from nuclear fusion, but research into this continues.

Renewable energy

As the global population rises and existing fossil fuel supplies diminish, countries will need to move to other sources of energy. More importantly, the world needs to steer away from fossil fuels to tackle climate change and move towards low-carbon renewable resources.

Solar power

Solar power is generated when energy from the sun is converted directly into electricity or used to heat air, water or other fluids. There are two main types of solar energy technologies.

- **Solar photovoltaic**: where solar cells, made of thin transparent wafers of silicon, capture sunlight, and turn it into energy. They are wired together in a panel, and many panels can be connected to produce energy for a household or, on a much larger scale, a solar power plant. These systems can store the energy in batteries until needed or send it to the electrical grid. The largest solar power plants operate in Spain, Portugal, Germany, China and the United States.
- **Solar thermal**: usually large-scale solar projects where an array of mirrors tracks the sun and focuses the reflected sunlight on a central tower which generates electricity using steam and turbines (see Figure 5.1.9).

5.1.9 This solar thermal power station is in north-west China. The total reflection area of the power station's mirror field is 1.4 million km². When the sun shines down, the heliostat will reflect and concentrate the light on the top of the heat absorption tower.

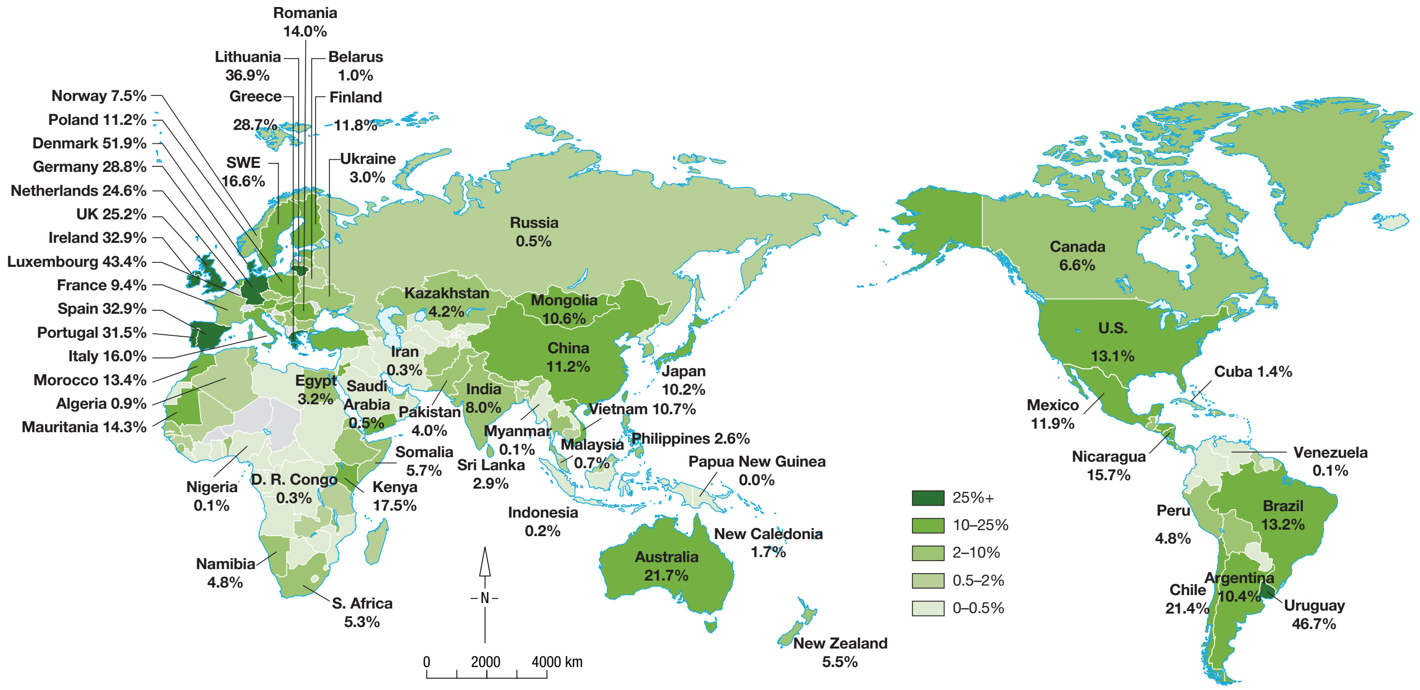
Wind energy

Wind energy is an indirect form of solar power as differential heating across the Earth's surface is what causes winds to blow. The kinetic energy of the wind can be converted into electricity by wind turbines. As the turbines' three blades spin in the wind, they drive a generator that produces the electricity. Wind turbines, as tall as an 80-storey building, are able to access winds that are stronger and steadier. The blades themselves are over 100 metres long. Groups of wind turbines in wind farms transmit their electric energy to the grid.

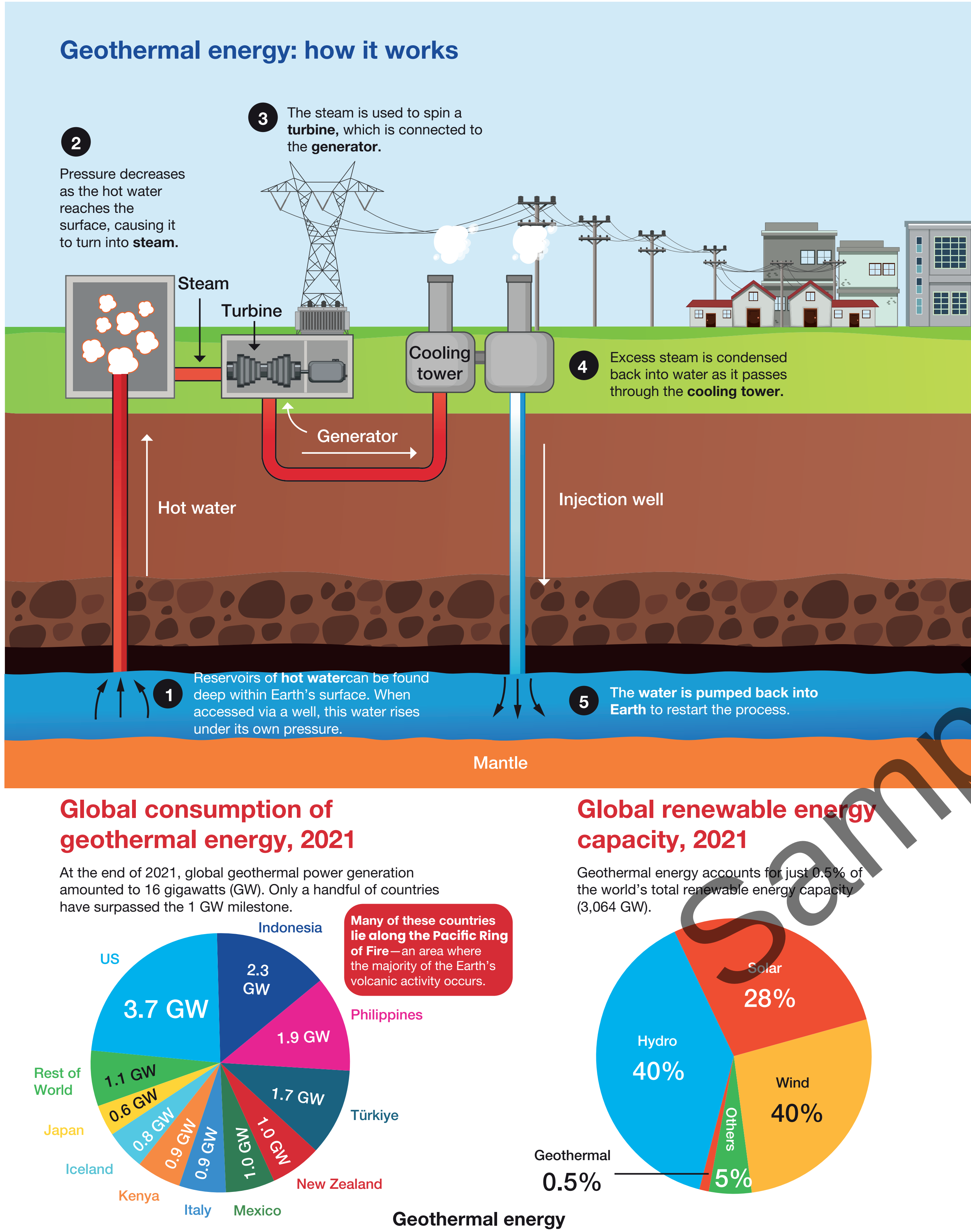
Most of the world's wind farms have been built on land in the United States, Europe and China, but increasingly, offshore locations are favoured where the winds are stronger and more consistent. Figure 5.1.10 illustrates the global wind and solar share.

Hydropower

Just like wind power, hydropower is another indirect form of solar energy as the Sun powers the water cycle. Hydropower is any technology that uses the kinetic energy of flowing water to generate electricity. This most commonly involves building a dam to store water and then releasing it down pipes where turbines at the bottom of a gradient are turned to produce electricity. Hydropower is the most widely used renewable



5.1.10 Solar and wind power generation by country



5.1.11 Geothermal energy

resource, providing 6.4 per cent of the world's energy. China, Canada, Brazil and the United States are the leading producers and consumers. It also has the greatest potential for further development as according to the UN, only 13 per cent of the world's hydropower has been utilised. India and several countries in Central Africa and South America are suitable for such developments.

Geothermal energy

Geothermal energy is renewable energy generated from reservoirs of hot water below Earth's surface. Its source is Earth's internal energy, as magma heats nearby rock and underground water. Geothermal power plants harness the steam that forms when this water comes to the surface, which rotates turbines to generate electricity. While this energy source is reliable and takes up less space than other types of renewable energy sources, it is expensive to build these plants and geothermal energy plants can only be built on reservoirs with temperatures above 100°C. Figure 5.1.11 shows how this works as well as where geothermal energy is being used and compares it to other types of clean energy.

Bioenergy

Bioenergy is produced from organic material, known as biomass, which contains the energy captured by plants. This is converted into heat, electricity, biogas and liquid fuels. Liquid biofuels have been used since the beginning of civilisation. One of the first biofuels was simple vegetable oil to light pottery lamps. Modern biofuels help underpin efforts to move away from fossil fuels and cut carbon emissions. At the end of the twentieth century, the value of bioenergy was linked to the recognition of pollution from fossil fuels. Countries such as the United States responded and now generate 26 per cent of ethanol in the world that is used for fuel.

There is a real push to bring together the energy, forestry and agricultural sectors to create technologies to advance the use of biofuels. Bioenergy most commonly consists of forest waste and crops such as corn and sugarcane. It has the potential to supply significant amounts of energy, but it comes at a cost as it takes land away from food production.

Activities

Acquiring and processing geographical information

1 Name the first two sources of energy used by humans.
2 Explain why charcoal is a superior fuel to wood.
3 Distinguish between renewable and non-renewable resources.
4 Explain why coal, oil and natural gas are referred to as fossil fuels and why they contain energy.
5 Explain why coal has been such a critical source of energy for the world.
6 Justify why coal is considered a dirty fuel.
7 Distinguish between conventional and unconventional oil.
8 Describe shale oil and tar sands.
9 Describe the problems caused by the process of fracking to extract natural gas.
10 Describe how power is produced from nuclear fission and the extent of global use of this energy source.
11 Distinguish between the solar photovoltaic and solar thermal generation of electricity.
12 Explain how wind turbines work.
13 Describe the global use of hydropower.
14 Describe how the use of biofuels has evolved.

Applying and communicating geographical understanding

15 Study Figure 5.1.1. Write a report summarising the sources of electricity by fuel type.
16 Study the text in this unit and write a paragraph on the importance of incoming solar radiation for the variety of energy sources used by humans.
17 Using the internet, investigate the occurrence of coal in Antarctica and what this reveals about the continent's former climate.
18 Study Figure 5.1.4. Determine which country is the biggest oil producer in Asia, North America, Africa and South America.
19 Study Figure 5.1.10. Compare the generation of wind and solar energy in North America to South America. Use the Internet to investigate the difference. Write a paragraph summarising your findings.
20 Study Figure 5.1.11. Write a paragraph on the advantages and disadvantages of geothermal energy.

UNIT 5.2

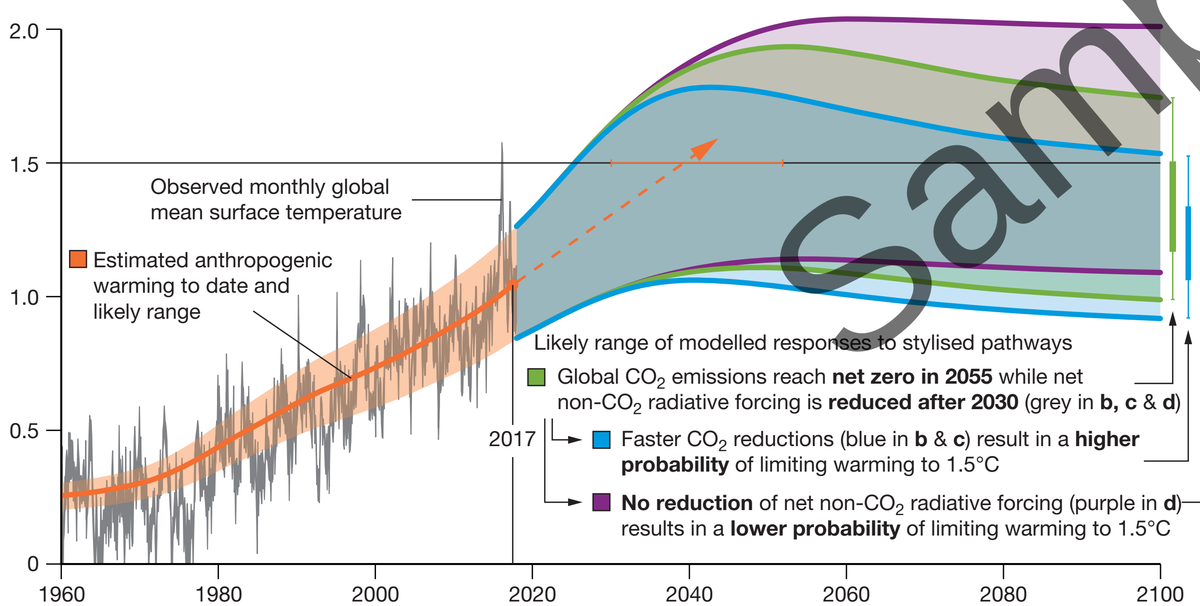
Factors influencing global energy production

There is an urgency to move away from fossil fuels as the effects of climate change continue to show, with record-high temperatures and more extreme weather events. Despite the best intentions, many nations have faltered in their energy transition as several factors have influenced the decisions of their policymakers. Over the last decade there certainly has been progress, with the production of renewable energy more than doubling. However, the use of fossil fuels has similarly expanded to meet the growing demand for energy. Global coal demand rose to an all-time high of over 8.3 billion tonnes in 2022. The share of energy generated from fossil fuels has remained unchanged and global carbon emissions have increased 5 per cent.

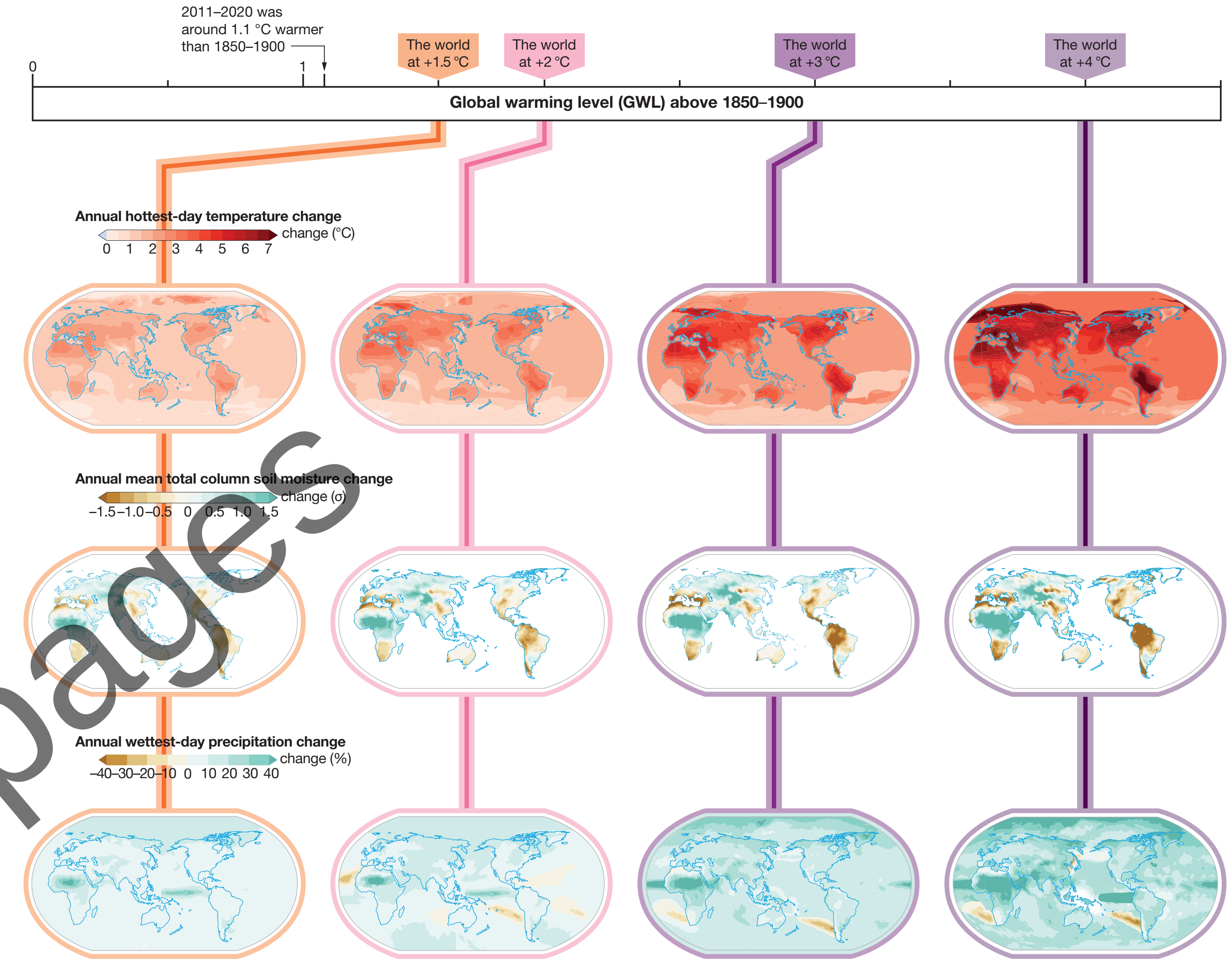
The call to action by the IPCC

An international treaty, the 2015 Paris Agreement, was signed by 193 nations and the European Union in response to the urgent and potentially irreversible threat of climate change to the planet. The signatories agreed to cut greenhouse gas emissions to keep the global rise in temperature this century below 2°C above pre-industrial levels and pursue the goal of limiting the rise to 1.5°C. This will require reaching net zero emissions by 2050.

The IPCC was assembled by the United Nations to conduct regular scientific assessments on climate change and inform policymakers of current trends and associated potential risks, as well as give them technical guidance. The IPCC has concluded that human activities are estimated to have been responsible for approximately 1°C of global warming above pre-industrial levels. If it continues to increase at the current rate, global warming is predicted to reach 1.5°C in the 2030s and perhaps as early as 2027. The IPCC has indicated that by 2030, global carbon dioxide emissions need to be 45 per cent lower than 2010 levels to reach net zero around 2050. The importance of reducing carbon dioxide emissions is clear in Figures 5.2.1 and 5.2.2.



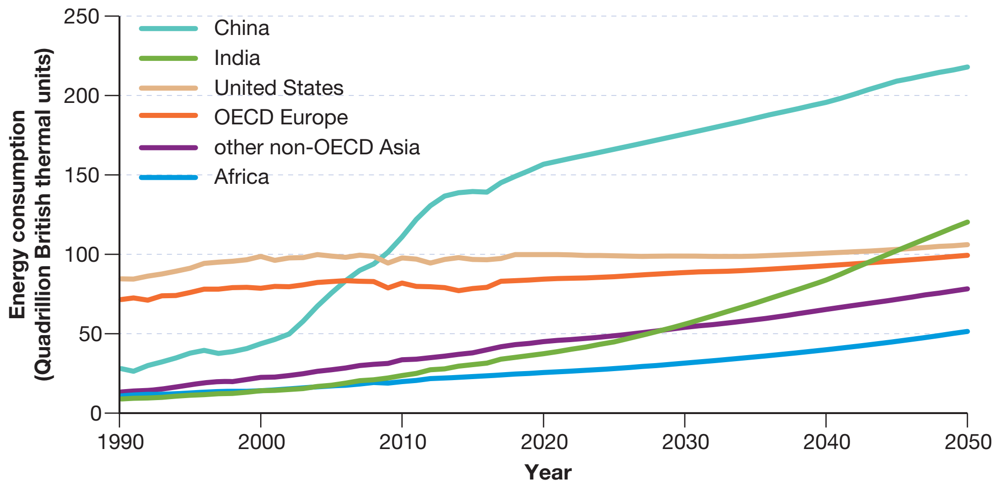
5.2.1 This graph shows observed temperature changes to 2017, and the predicted continued changes in temperature based on whether carbon dioxide emissions are reduced a quickly, slowly or not at all.



5.2.2 Projected changes of annual maximum daily maximum temperature, annual mean total column soil moisture and annual maximum 1-day precipitation at global warming levels of 1.5°C, 2°C, 3°C and 4°C, relative to 1850–1900

India and China: The big users

The two most populous nations in the world, India and China, are both competitively pursuing economic growth. As they do, their use of fossil fuels increases to meet their increased need for energy (see Figure 5.2.3). The middle-class expansion that is happening in these countries will be the largest in history. As people enjoy a better standard of living, there is a higher demand for energy. Electricity consumption per capita in China increased to 5.728 kilowatt hours in 2022, doubling in the last decade. India's per capita consumption is only a quarter of China's. As more people are lifted out of poverty in India, consumption will rise and it holds the most potential for an increased demand for energy in the future.



5.2.3 Total energy consumption in selected countries and regions 1990–2050

Source: U.S. Energy Information Administration, *International Energy Outlook 2019*

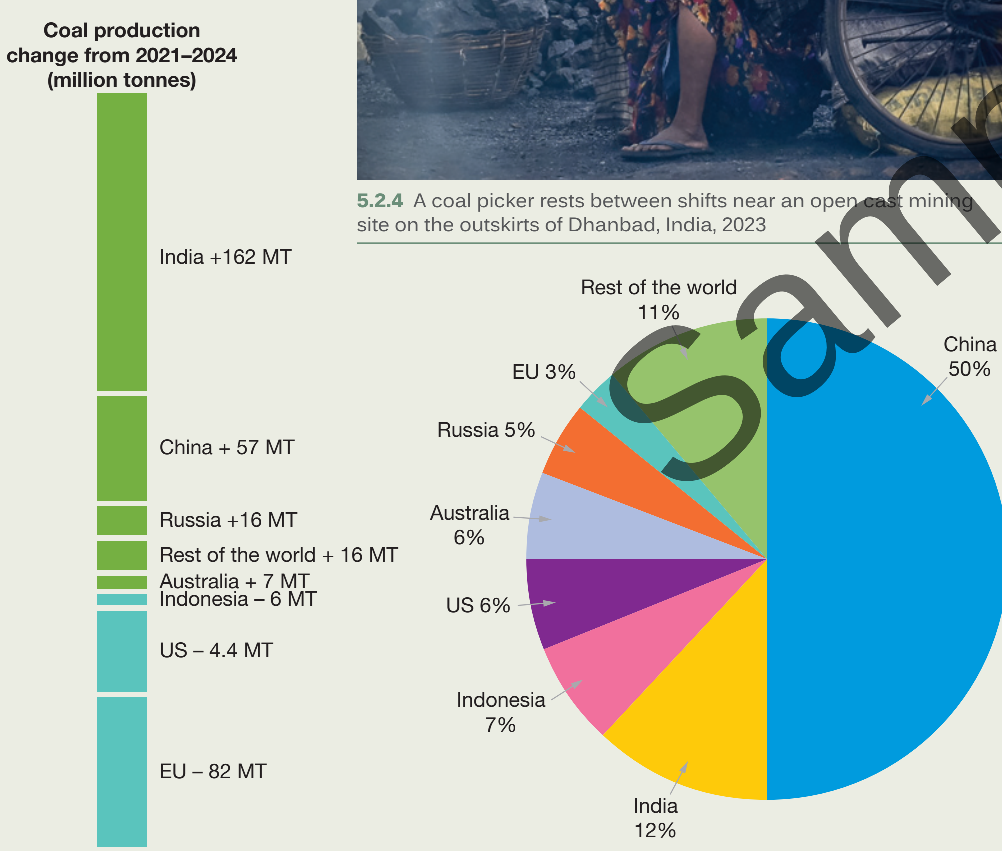
● **SPOTLIGHT**

Coal fuels China and India

China and India produce almost 60 per cent of the world's coal (see Figures 5.2.4 and 5.2.5). They are expected to raise their combined production by more than 200 million tonnes each year. The demand for coal in both nations is driven by their need to produce electricity for industry and their large populations. China has pledged to start reducing coal consumption in 2026. In the meantime, they intend to build 43 coal-fired power stations to satisfy demand. Some of this extra production is to cover a lower reliance on imports, which are forecast to drop by 16 per cent or 51 million tonnes by 2024.

By 2024, China's coal consumption is expected to increase by 3.3 per cent and India's by 12.2 per cent, to support economic growth. This would mean that their combined consumption would take two-thirds of the world's coal.

5.2.4 A coal picker rests between shifts near an open cast mining site on the outskirts of Dhanbad, India, 2023



5.2.5 Global coal production 2021–2024

Domestic consumption of energy in both countries is driven by the pursuit of economic growth by their policymakers, which has most dramatically expanded their energy needs. China maintained decades of rapid economic growth, reaching 10 per cent in the 2000s and 7 per cent in the 2010s. China's industrial sector still accounts for two-thirds of its total energy consumption. Similarly, India's growing demand for energy is tied to the twin processes of urbanisation and industrialisation. Over the next two decades, its import bill for fossil fuels is expected to double, with oil being the biggest component.

Geopolitical factors

Given that energy underpins the operation of national economies, geopolitics can put acute strains on the energy market. One of the most severe disruptions in modern energy history was the OPEC crisis (Organization of the Petroleum Exporting Countries) in the 1970s. Overnight, the price of oil was quadrupled, and the Arab states prohibited oil exports to the United States and Western Europe in retaliation for their support of Israel in the Arab–Israeli conflict.

The global energy crisis of 2022 was of unprecedented depth and complexity. It had multiple dimensions across all energy markets and occurred at a crucial time in history when the focus needed to be on tackling climate change by transitioning to clean energy. Whilst there were shortages and increased prices after the COVID-19 pandemic, the situation escalated following the 2022 Russian invasion of Ukraine. Europe has been the main stage in which this crisis has played out as Russia sought to gain political leverage over nations opposing its actions, by withholding gas supplies. The price of gas soared, reaching record highs. The immediate response to the crisis was more reliance on fossil fuels which increased their prices. Oil hit its highest level in four years. The rise in prices for energy and food resulted in hardship for families, businesses suffered and economic growth slowed.

The global energy market shifted dramatically, as in many parts of the world energy has become more expensive. It has brought into sharp focus the global dependence on fossil fuels, where production is dominated by a few producers, where supplies may be insecure and prices volatile. This has galvanized action in developing renewable resources.

Activities

Acquiring and processing geographical information

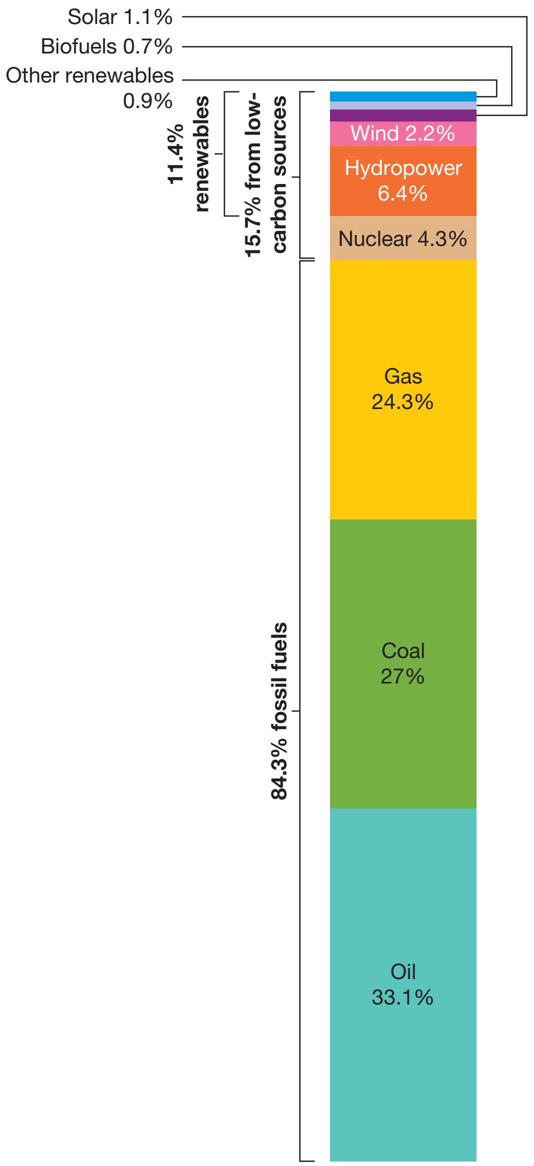
1 Explain why there is an urgency to move away from fossil fuels.
2 Describe the Paris Agreement and explain why it was put into place.
3 Explain why China and India are the biggest consumers of fossil fuels in the world.
4 Describe how China and India dominate the production of coal.
5 Describe the 2022 global energy crisis. Why it was more complex than the OPEC crisis of the 1970s?

Applying and communicating geographical understanding

6 Study Figure 5.2.1. Determine what the rate of anthropogenic warming was between 1960 and 2017.
7 Study Figure 5.2.2. Compare the impact of a 4°C warming on Africa to the rest of the world.
8 Study 5.2.3. Calculate the projected percentage increase in carbon dioxide emissions in China between 1990 and 2050.

UNIT 5.3

Current trends and future directions in global energy production



5.3.1 Global primary energy consumption by source, 2020

Fossil fuels have been the main source of global energy for over a century, and vast amounts of coal, oil and natural gas are still extracted and consumed every year (see Figure 5.3.1). Their dominance in the energy market is evident, despite the adoption of the Paris Agreement in 2015, in which many countries committed to reducing their energy emissions. While there has been growth in renewable energy sources in recent years, there has been little change in the consumption of fossil fuels for power generation in the last two decades (see Figure 5.3.2).

An energy transition

An energy transition involves a change in an energy system, usually from one fuel source to another. Historically, major global energy systems that moved the world from wood to coal and then to oil slowly, each taking 50 to 60 years (see Figure 5.3.2).

The current energy transition is driven by the realisation that if Earth is to avoid the catastrophic effects of climate change, there must be a radical reduction in greenhouse gas emissions. Given the alarm of what is unfolding today, a rapid shift from fossil fuel energy production to renewable resources is crucial. Decarbonisation of the energy sector requires urgent action, and a renewable energy transition is important now, not sometime in the future. This is what is needed in the twenty-first century: to transition to a more sustainable energy system that provides universal access to a reliable supply of efficient low-carbon energy. The speed and scale of the energy transition needed today is a new challenge, one very different from the past and certainly much more important.

Transitioning to a renewable energy-based economy will provide resilient, low-cost, sustainable energy for all. However, if the world is to avert a climate catastrophe, and meet the pledges of the Paris Agreement, investment in renewable energy will need to triple by 2030. Fulfilling the commitment to reduce carbon emissions and shifting to renewable technologies has been uneven across the world (see Figures 5.3.3 and 5.3.4).

In Europe, Iceland generates 79 per cent of its energy from hydropower (55%) and geothermal power (24%). Other countries also sourced most of their energy from low-cost carbon sources such as renewables or nuclear:

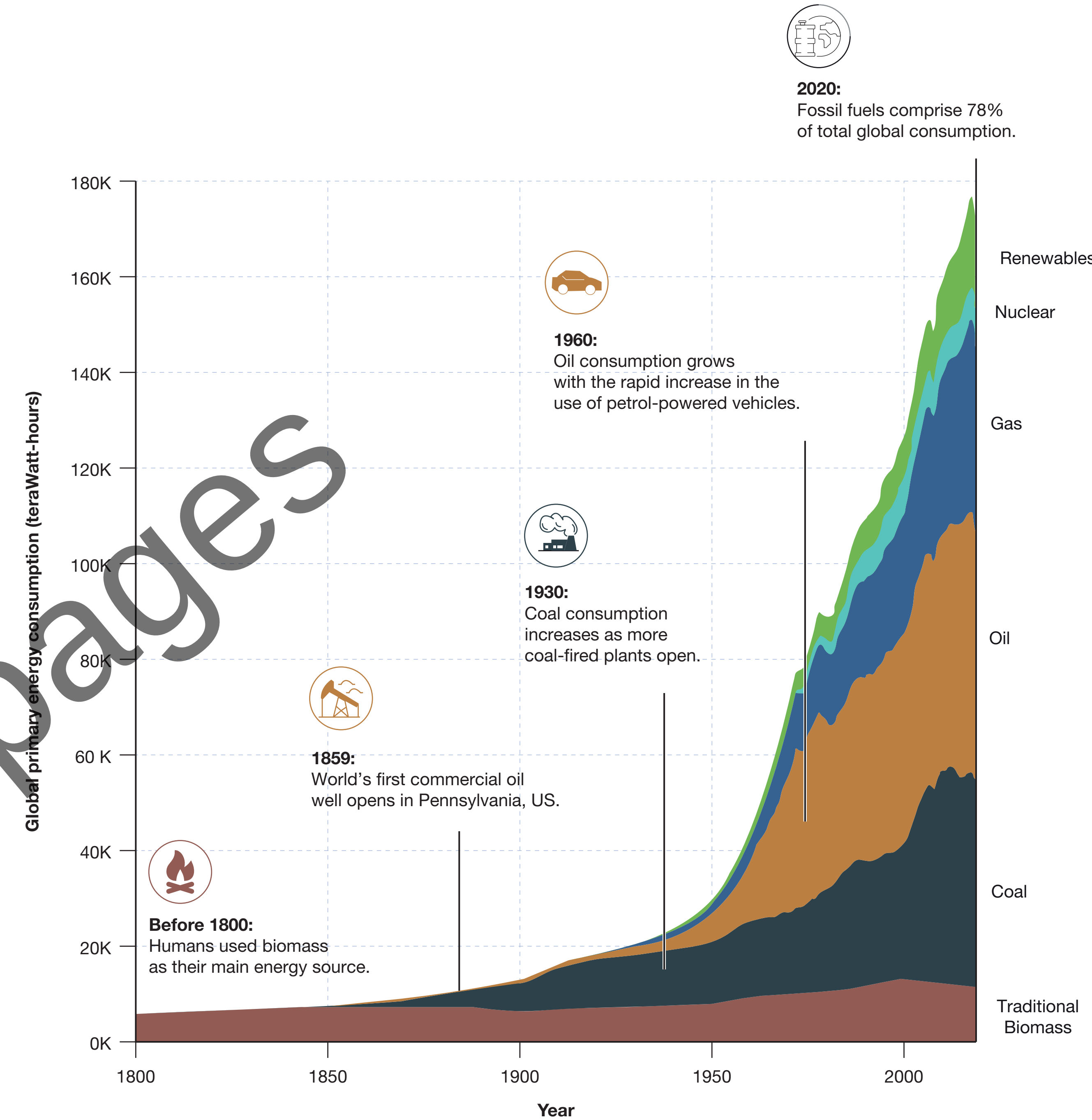
● SPOTLIGHT

Highway to climate hell

The UN Secretary-General, Antonio Guterres, issued a stark warning at a climate change summit in 2021, that the world was losing its fight against climate change while repeating his call to phase out coal by the year 2040.

We are in the fight of our lives, and we are losing. Greenhouse gas emissions keep growing, global temperatures keep rising, and our planet is fast approaching tipping points that will make climate chaos irreversible. We are on a highway to climate hell with our foot still on the accelerator.

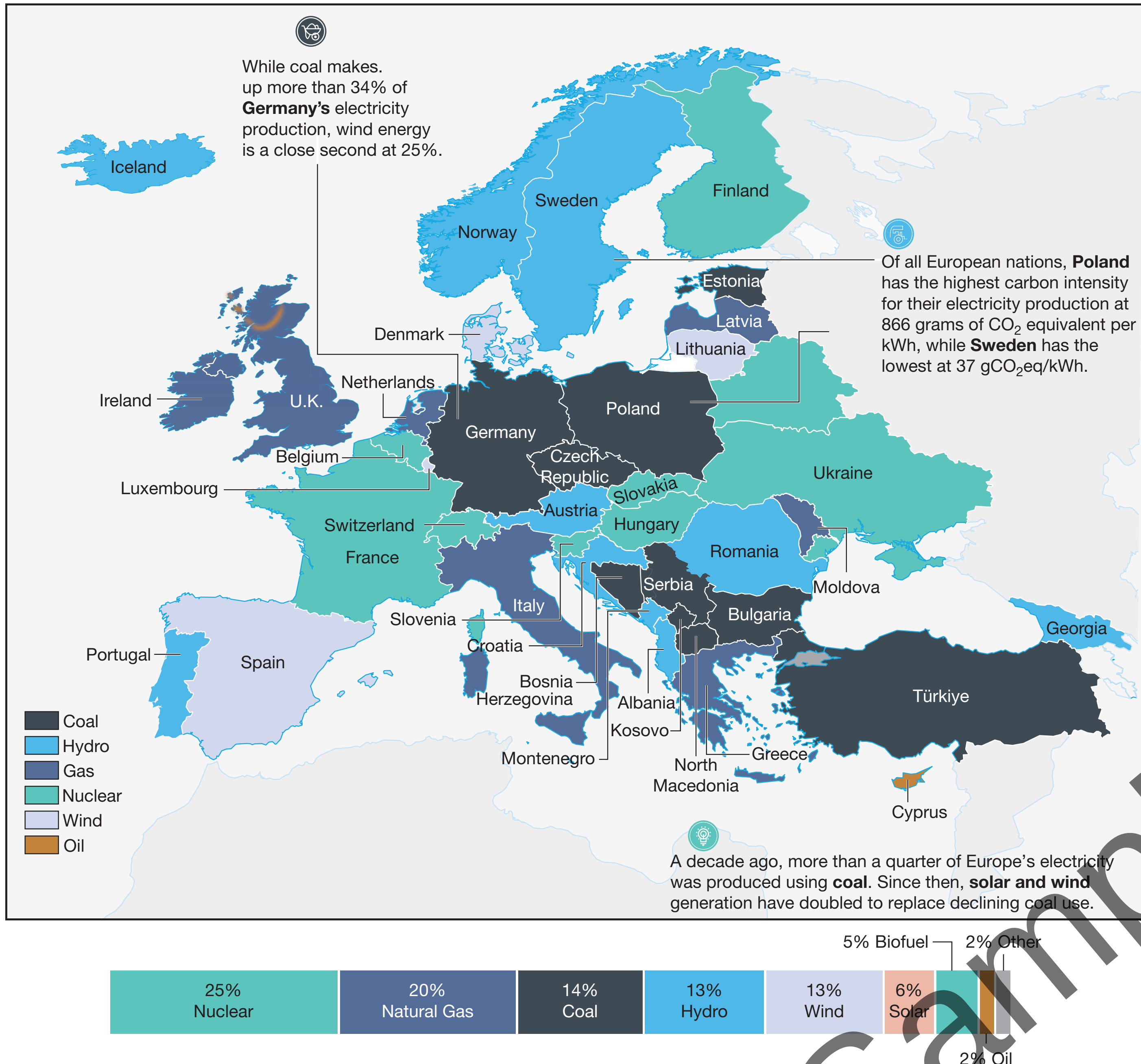
António Guterres, UN Secretary-General



5.3.2 The history of energy transitions, 1800–2020

Sweden (69%), France (49%) and Switzerland (49%). Many of these countries have the advantage of a suitable physical environment to generate hydroelectricity or geothermal power. They are also wealthy developed countries with the capital to invest in new renewable technologies and infrastructure.

Though clean energy has gained momentum in Asia, coal still made up over half of the continent's electricity generation in 2023. Asia is also the region that relies most heavily on coal for energy, so decarbonisation will be a challenge with continued rises in population and economic growth. No country in Asia uses solar, wind or nuclear energy as their primary source of energy, even though their combined share of these renewables has doubled in the last ten years. Asia is expected to increase the share of renewables in power generation in the future. Initially, solar energy installations will be more heavily funded, but after 2031 wind power capacity will accelerate. Nuclear power is also being considered by several countries in Asia to reduce their reliance on imported energy.

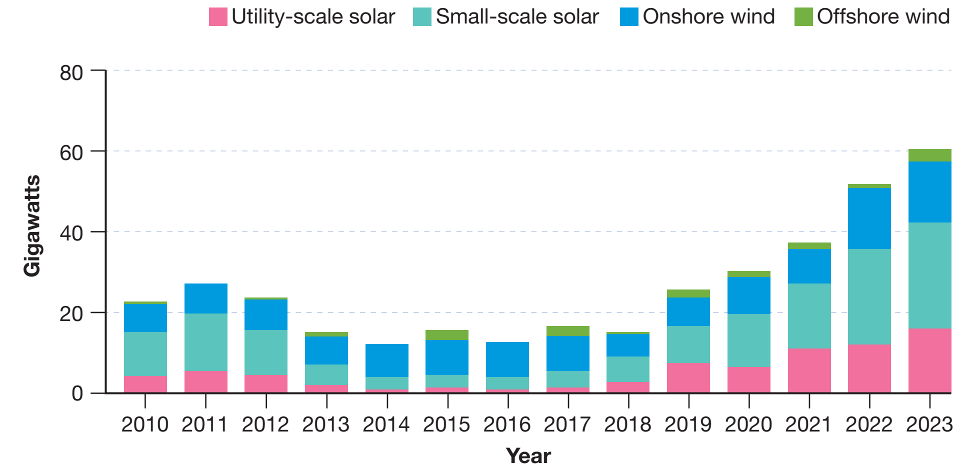


5.3.3 Europe's biggest sources of energy 2022

Trends in renewable energy investment

The 2022 global energy crisis laid bare the vulnerability of energy systems heavily dependent on fossil fuels. The crisis made clear that there had not been enough investment in renewables. Global investment into such technologies reached a record high of US $1.3 trillion in 2022, but this will need to triple to limit global warming to 1.5°C. The only way to tackle climate change effectively is to invest in clean power and infrastructure.

Solar photovoltaic systems and onshore wind farms are the cheapest options for clean energy generation in most countries. Solar investment has been increasing by 38 per cent each year. China led the world in renewable energy investment in 2022, spending $164 billion on new solar farms and $109 billion on new wind farms. The United States also invested $50 billion in solar and wind technologies and the European Union $39 billion. The European Union's mix of investments in renewable energies is illustrated in Figure 5.3.4.



5.3.4 Annual increase in renewable energy production, showing another record year for renewable additions in Europe, 2023

The world energy outlook

The International Energy Agency (IEA) is a Paris-based intergovernmental organisation, that provides policy recommendations, analysis and data on the entire global energy sector. It works with governments around the world to shape their energy policies for a secure and sustainable future. The IEA plays a crucial role as it realistically assesses the current situation to alert policymakers to what needs to be done to limit global warming to 1.5°C. Each year it publishes the World Energy Outlook (WEO).

In the 2022 WEO, the IEA released its Stated Policies Scenario (STEP) to provide a more conservative benchmark for the future of the global energy industry. This is because it does not take for granted that governments will reach all the goals that they have announced. Instead, it looks at what has been put in place to reach these energy objectives, considering not just existing policies and measures, but those under development. What is most important is that a realistic assessment of the energy system is made, predicting where it might end up without interference from policymakers to ensure that 1.5°C is not exceeded. The WEO does not assume that aspirational targets are met, unless they are backed up with the details of exactly how they are going to be achieved.

Figure 5.3.5 provides an insight into the energy transition underway:

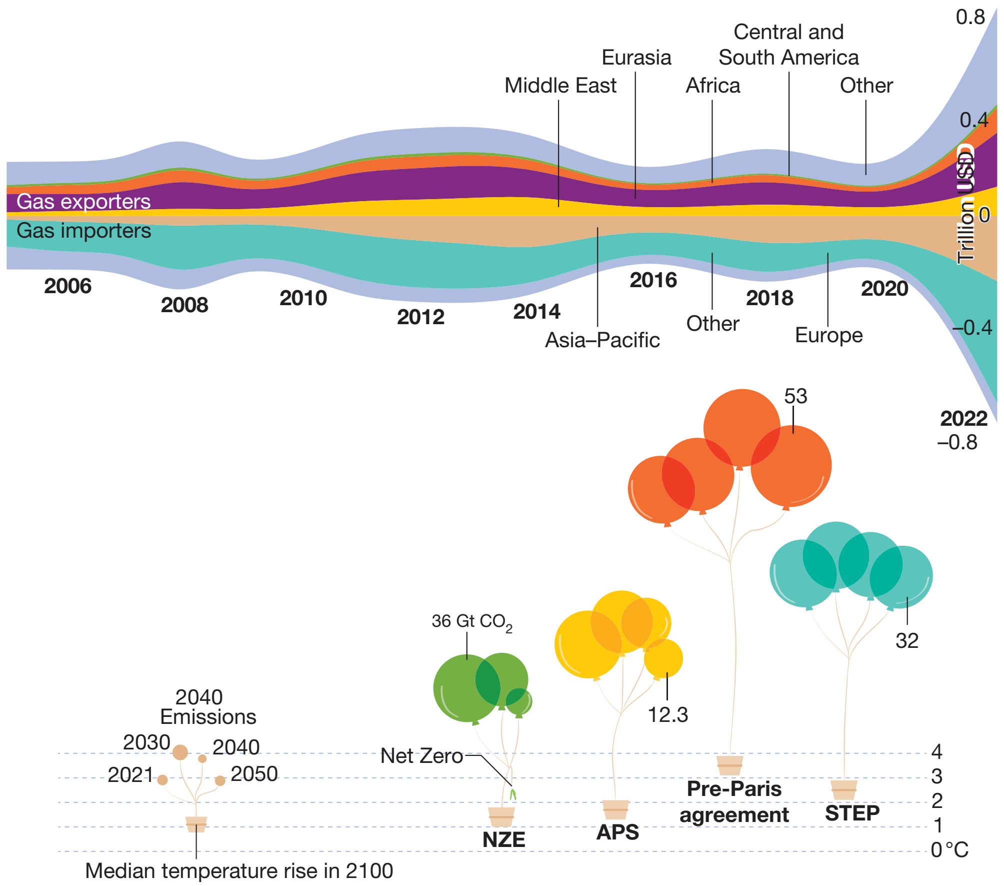
- **Pre-Paris agreement:** the scenario if there had been no reduction in greenhouse gas emissions
- **STEP:** how the energy system will evolve if current policy settings are retained, but they must be substantiated with detail on how it will be done
- **Announced Pledges Scenario (APS):** where governments are given the benefit of the doubt that they are going to achieve their targets in full and on time. This scenario represents the extent of the world's collective ambition when it comes to tackling climate change
- **Net zero Emissions (NZE):** the main goal of capping global warming at 1.5°C.

What is evident from Figure 5.3.5 is that the even world's collective ambition to limit global warming falls short, it is even more worrying that many nations are already not meeting their targets.

It was the IEA that warned in 2022, that the world's energy system was vulnerable and there needed to be a major increase in clean energy investment flows to secure a smooth energy transition. It also advised that this needs to happen alongside a shift towards support for and much higher investments in developing countries and emerging markets.

Did you know?

Asia is and will continue to be the world's largest market for renewable energy investment, with the most investment in developing new installations in China, India, Japan and South Korea.



5.3.5 The cost of global gas imports from 2006 to 2022 when the energy crisis occurred. The various scenarios of the impact of policies tackling climate change from 2021 to 2050. The Pre-Paris agreement is the red bubbles indicating the highest carbon emissions and temperature rise. STEP is the blue bubbles showing a modest drop in carbon emissions and global temperatures are not as high. APS is the yellow bubbles show a greater drop in carbon emissions limiting the temperature increase further, but still above 1.5°C. NZE scenario shows what is needed to keep the increase in temperature below 1.5°C.

Activities

Acquiring and processing geographical information

1. Describe the changes in the generation of power from fossil fuel sources and renewable sources over the last two decades.
2. Define an energy transition.
3. Name the main energy transitions that have already happened in the world.
4. Describe the current energy transition and justify the urgent need to accelerate it.
5. Explain what is needed to avert a climate disaster.
6. Describe the trends in renewable energy investments and assess whether they are adequate.
7. Explain the significance of the Stated Policies Scenario.

Applying and communicating geographical understanding

8. Study Figure 5.3.2. Estimate how many terawatt hours were consumed from each of the following sources in 2000:
   - traditional biomass
   - coal
   - oil
   - gas
   - nuclear
   - renewables.
9. Study Figures 5.3.3 and 5.3.4 and the text under the headings, An energy transition and Trends in renewable energy investment. Write a paragraph comparing Europe's and Asia's biggest sources of energy. Account for your findings.
10. Study Figure 5.3.5. Complete the following table.

Scenario	Emissions	Median temperature rise
Pre-Paris Agreement		
Announced Pledges Scenario		
STEP		
Net Zero Emissions		

UNIT 5.4

Sustainability in global energy production: Challenges and responses

The energy sector holds the key to averting the worst effects of climate change. The transition to a net zero world by 2050 is one of the greatest challenges humankind has ever faced, and it must meet it to ensure that the planet remains liveable. It requires a complete transformation of how we produce and consume what we need, and how we move around. Across the world, there is a growing coalition of countries, businesses and institutions pledging to get to net zero emissions. However, the commitments made by governments by 2023 fell far short of what is necessary to avert a climate disaster. The energy transition must be accelerated, and quickly. Policymakers must shoulder the challenging task of tackling the seemingly opposing agendas of energy security needed for economic growth against the need to transition to low-carbon energy resources. In the face of conflict and uncertainty, the overarching goals must be halting climate change and achieving sustainable development.

Almost 200 countries committed to reducing carbon emissions but their commitment and has varied. Some have reduced their emissions, while others have continued to grow their emissions, despite promises of further decarbonisation. Global regulatory bodies responsible for energy transition have been uneven in their policy positions across the world, with some more interested in change, particularly the speed of change, than others.

Costa Rica leads the charge

Costa Rica, a small nation in Central America, is well known for its commitment to environmental sustainability with a strong record in tackling deforestation. It has set ambitious goals to become carbon neutral, with 100 per cent of its energy generated from renewable sources such as hydroelectricity, wind, solar and geothermal power. Since 2014 it has successfully produced 98 per cent of its power from these renewable sources.

In the 1970s the government started investing in hydroelectric power, recognising the suitability of the country's physical environment with its high rainfall and many rivers. Hydroelectric power now provides 70 per cent of the country's electricity. Concerned that climate change might disrupt rainfall patterns, Costa Rica added other renewable sources to its energy mix such as wind, geothermal and solar. The mountainous terrain and consistent trade winds suit wind farms and, as the country sits on a tectonic plate boundary, geothermal power can be tapped. One obstacle Costa Rica faces is transport and reliance on oil, so it has promoted public transport and electric vehicles.

Costa Rica provides an excellent model to other countries on how to transition to sustainable renewable resources. It also collaborates with neighbouring countries and exports energy to them, assisting these countries to lower their fossil fuel dependence.

The European Union's Green Deal

In 2023 the EU launched the Green Deal, a package of policies on the path to a sustainable green energy transition. The EU set itself a legally binding target of achieving net zero carbon emissions by 2050, with an immediate target of reaching a 55 per cent reduction of 1990 levels, by 2030. As only 22 per cent of the EU's total energy consumption came from renewables in 2021, this is an ambitious project. Under the new laws, countries that fail to add enough renewable resources in the form of solar or wind installations will be fined by the EU. To reach the target by 2030, the share of renewables in each country must rise by 0.8% annually by 2025 and after that by 1.1% each year. This should generate more than 100 gigawatts of new clean energy each year across the bloc. More specifically, the transport, industrial and housing sectors will have their own targets to meet.

The US Inflation Reduction Act

In a sign that the climate crisis has galvanised policy support, the landmark *Inflation Reduction Act 2022* (IRA), commits more than US$370 billion to accelerate the transition to net zero in the United States. It provides new support and long-term visibility of decarbonisation to address climate change and provide energy security. This will bolster efforts to lower greenhouse gas emissions in the United States to less than 40 per cent of 2005 levels. This comes on top of the US$190 billion *Infrastructure Investment and Jobs Act 2021* for cleaner energy and mass transit. With the IRA, the United States is the first country to approach the challenge with incentives, rewriting the rules of industrial policy and changing the politics of climate change. It will continue to have a significant impact on incentivising investment in the transition to net zero (see Figure 5.4.1).

Did you know?

Carbon capture is the process of removing carbon dioxide from large power and industrial plants and injecting it into deep geological formations.

The IRA will:

- supercharge renewable energy and transform energy demand in the United States, thereby achieving industrial decarbonisation
- provide incentives to reduce the cost of clean manufacturing from solar and wind to batteries and hydrogen
- invest in technologies that will dramatically lower the costs of clean energy and green finance.

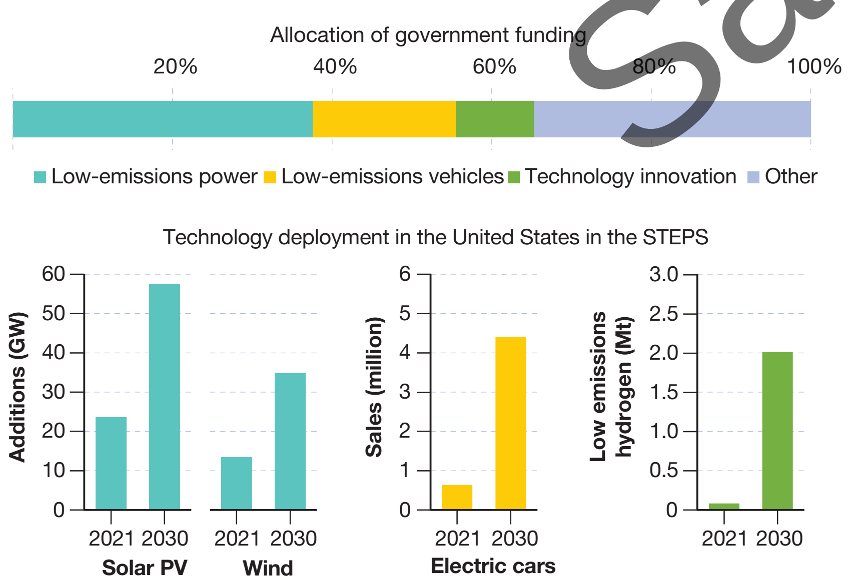
With the IRA committing to years of support for green technologies, including solar, hydrogen, wind, **carbon capture** and storage, efficient heating and appliances, and electric vehicles, there are many challenges and opportunities. The big winners are likely to be new and developing technologies of carbon capture and **green hydrogen**. These technologies are being provided with bigger subsidies so are more likely to attract investors.

The IRA has had a significant global impact, increasing the production of renewable energy sources. As it is heavily subsidised by the United States government, other countries are putting pressure on their own governments to do the same, to kickstart the production of new renewables. Of course, this is fraught with political problems and conflict, as governments grapple with many issues, national and global.

The IRA has also impacted global supply chains as the United States moved quickly to secure necessary supplies. This may cause problems for other nations seeking the same supplies and will increase geopolitical complexities globally. The IRA is an ambitious approach to clean energy and manufacturing in the United States but there are concerns about the availability of crucial inputs, such as graphite and lithium, holding back progress. Gaining permits and approvals could also slow the speed of rolling out crucial infrastructure. While there is plenty of funding to upgrade industrial facilities, there is little available to improve the American electricity transmission network and this presents a key risk to the transition to net zero.

Did you know?

Green hydrogen is a clean energy source as it only emits water vapour and leaves no residue in the air. This gas has long been used as a transport fuel.



5.4.1 Government funding in the IRA, the *Infrastructure Investment and Jobs Act* and technology deployment in the United States, 2021–30

China's 2025 renewable energy targets

China is leading emerging economies in its efforts to improve energy access and sustain economic development while transitioning to cleaner resources with a renewable-dominated power system in the country's future. China's renewable energy targets are listed in Figure 5.4.2.

Did you know?

South Korea and Japan have announced an intention to move to a partial 'hydrogen economy' to decarbonise.

Indicators	Unit	2020 level	2025 target
1 Renewable electricity utilisation			
■ Renewable energy consumption share	%	28.8	33
■ Non-hydro renewable energy consumption share	%	11.4	18
■ Renewable electricity generation	trillion kWh	2.21	3.3
2 Renewable non-electric utilisation (geothermal heating, biomass heating and fuel, and solar heating)	million tonnes of standard coal	–	>60
3 Total renewable consumption	billion tonnes of standard coal	0.68	1
4 Non-fossil fuel power generation share	%	33.9	39
5 Electrification rate	%	27	30
From 2021 to 2025, more than 50% of the country's incremental electricity and incremental energy consumption shall come from renewables.			

5.4.2 China's 2025 renewable energy targets

Australia's 2022 Integrated Systems Plan

The future of Australia's energy is a matter of great national urgency. The Integrated Systems Plan (ISP) supports Australia's net zero emissions ambitions to address climate change. In 2022, the Australian government formalised its 2030 emissions reduction target at 43 per cent of 2005 levels by 2030, to align with the Paris Agreement. Both the federal and all state governments have confirmed their objectives of a net zero emission economy by 2050 or sooner.

The ISP is to transform the National Energy Market (NEM) from fossil fuel energy to a greater mix of **firmed renewables** and provide a reliable, secure and affordable energy supply to the eastern and southern states of Australia. With the transition to renewables, people will be able to draw on low-emission electricity for their transport and to run their homes and businesses. This will require levels of investment in the generation, storage and transmission of energy exceeding the combined total of all previous investments in Australia. The IPS provides a clear roadmap for each decade through to 2050.

Did you know?

Firmed renewables are energy sources such as wind or solar, where the output is maintained to ensure that enough energy is always available. Technological developments in large battery storage supporting this, need to be increased (see Figure 5.4.3).

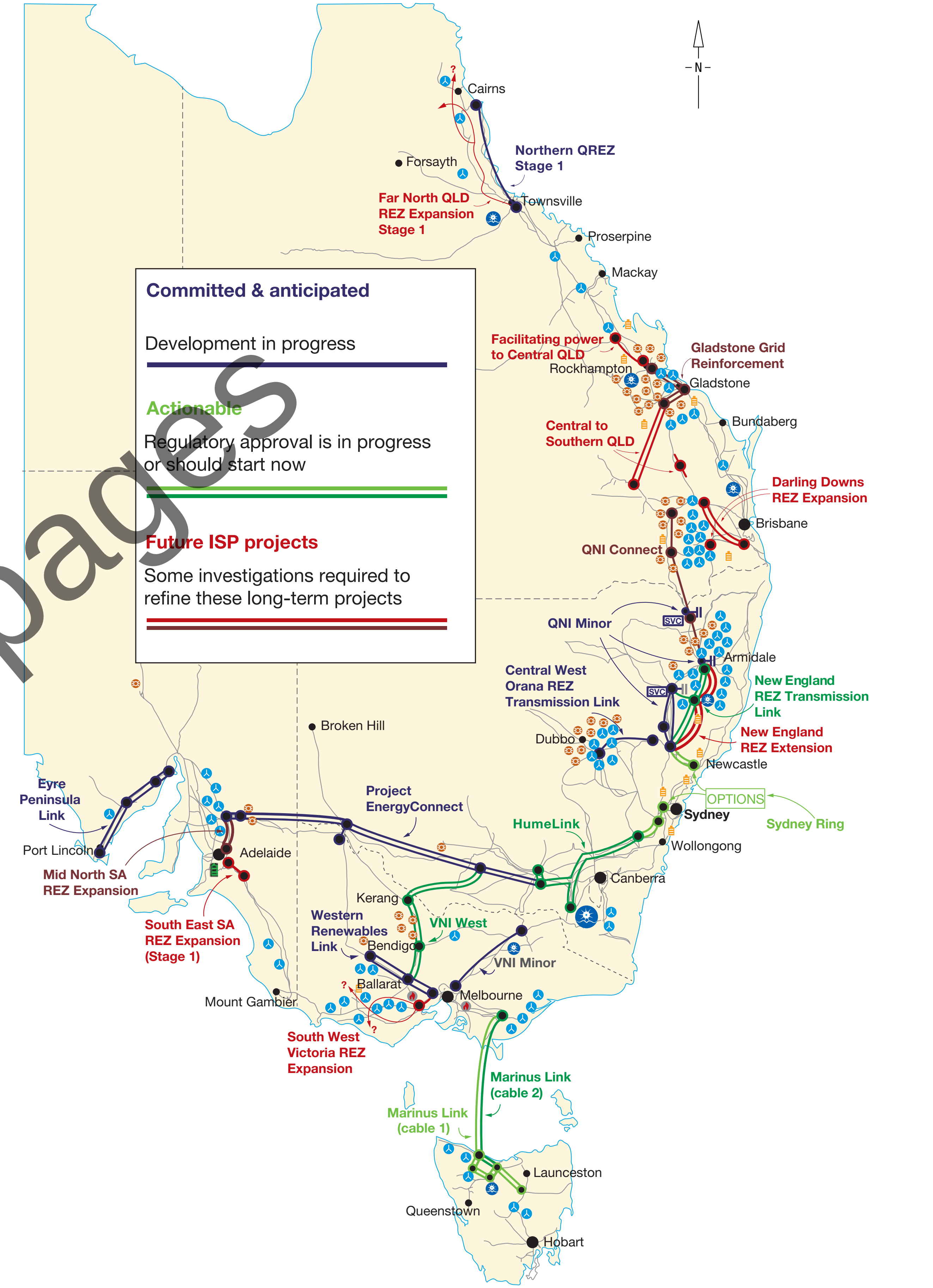
5.4.3 The Tesla 100MW 'big battery' at the Hornsdale Wind Farm, South Australia

The energy transition in Australia is accelerating in line with what is happening globally, strengthening the shift to renewable energy sources. Investment in these resources and the infrastructure that transmits the power is the key strategy. Australia has some of the best renewable resources in the world, especially solar and wind power. To take advantage of these opportunities there needs to be substantial investment in modernising the electricity system, including building transmission lines and providing long-duration storage. The new transmission towers that will connect the geographically spread renewable sources to consumers need to start working on the earliest planned schedule. A firm commitment from all stakeholders is crucial if Australia is to secure a sustainable energy future and reach net zero by 2050.

The energy transition in Australia requires a double transformation: electrification of the economy while switching to firmed renewables. This will require:

- doubling the amount of energy delivered from 180 terawatt hours in 2023 to 360 terawatt hours in 2050, to power the electrification of transport, industry, offices and homes, thereby replacing petrol, gas and other fuels
- lowering coal-fired thermal generation capacity by 60 per cent by 2030
- tripling the amount of wind and solar energy generated by 2030, doubling again by 2040, and then doubling again by 2050. Much of this will be built in renewable energy zones, including offshore wind farms
- harnessing the generation and feed-in capability of millions of individual consumer-owned solar photovoltaic systems exporting power back into the grid
- as weather-dependent wind and solar sources start to dominate, the NEM must effectively match when and where the power is generated, with when and where needed. Over the next decade, there is an urgent need to develop effective storage such as grid-scale batteries to manage daily and seasonal variations in the output from solar and wind generation and ensure their reliable availability.

The successful transformation of the NEM involves many projects linked by 10 000 kilometres of new transmission lines to connect these developments and efficiently deliver firmed renewable energy to consumers. The extent of such developments in Eastern Australia is evident in Figure 5.4.4.



5.4.4 Energy generation and transmission projects planned for Eastern Australia

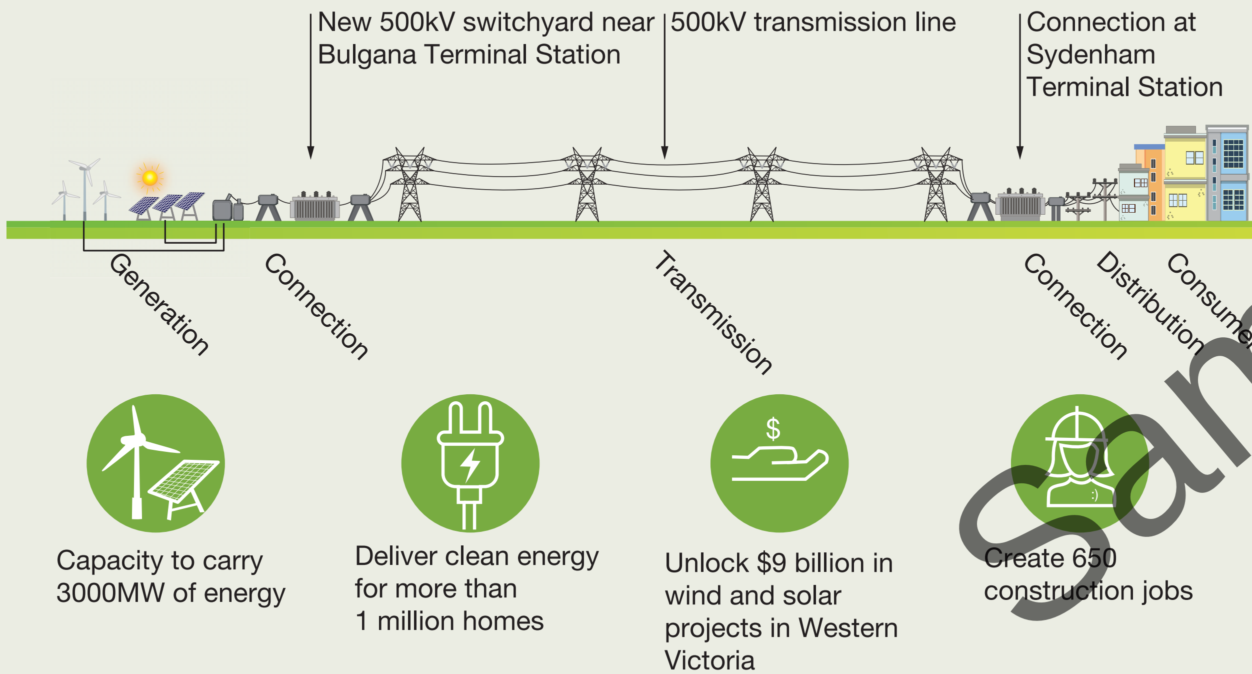
● SPOTLIGHT

The Western Renewables Link

The Western Renewables Link is a crucial infrastructure project designed to provide Victoria with cleaner, more sustainable energy. The state's richest wind and solar resources are in its west and north, and given their potential, the region has been declared a key Renewable Energy Zone. The Western Renewables Link is the key to enabling Victoria to meet its renewable energy targets. Having achieved 20 per cent by 2020, it aims for 40 per cent by 2025 and 50 per cent by 2030. However, the existing transmission network in Western Victoria is already at capacity, meaning only limited power can be transported out of the region into the wider grid network. This will likely impact energy security and electricity prices for consumers over the long term. The Western Renewables Link is a proposed new 190-kilometre overhead high-voltage electricity transmission line that will provide the crucial connection to carry renewable energy from Bulgana in Western Victoria to the Sydenham Terminal Station in Melbourne's north-west (see Figure 5.4.5). This will reduce the extreme congestion of the existing transmission network and unlock up to 900 megawatt hours of renewable energy capacity.

There have been objections from landholders and communities along the route of the Western Renewables Link, wanting it to be buried underground, but the costs of doing so are high. Farmers rallied outside Parliament House in 2023, bringing their tractors and horses in protest of restrictions on machinery and irrigation near easements and under transmission lines. For these projects to be successfully delivered, a social licence needs to be created and maintained in the interest of all stakeholders.

Accessing the vast reserves of renewable energy in Victoria and making them available to the national electricity market will play a key role in energy security and place downward pressure on energy prices. The Western Renewables Link is a vital project in helping Australia to transition to a low-carbon future in line with the Paris Agreement.



5.4.5 The Western Renewables Link is a project where a proposed 500kV double circuit transmission line will run from Bulgana to Sydenham in Western Victoria.

An inclusive global energy transition

While wealthy countries grapple with the energy transition, poorer developing countries face a far bigger challenge. They are trying to grow their economies, alleviate poverty, give their populations access to the basics and provide energy—all while needing to avoid the carbon-intensive pathways that the rich countries previously took to achieve these outcomes. This challenge is made more difficult by the cost of capital for renewable resources in developing countries where solar photovoltaics are two to three times more expensive than in advanced economies. Developing countries need cheap, clean energy which is more cost-effective for them than fossil fuel alternatives.

Many countries are sliding into energy poverty because of COVID-19 and the global energy crisis. Seventy-five million people were unable to pay for electricity in 2022. Poor households consume a tenth of the that energy wealthy households do, yet it takes a much larger proportion of their income. Developed countries need to collaborate to bring down the cost of capital and give poor communities a lift into the new energy economy. Worsening energy poverty trends need to be turned around for a successful global energy transition that is inclusive. A global threat demands a global response.

Activities

Acquiring and processing geographical information

1 Describe the energy mix of Costa Rica. Assess its sustainability.
2 Describe the EU's Green Deal as a path to achieving net zero emissions by 2050.
3 Describe what the United States has put in place to accelerate its transformation to net zero.
4 Explain what may hinder the progress of the United States in achieving this goal.
5 Outline the plan put in place by Australia to address climate change.
6 Define a firmed renewable.
7 Explain what needs to be done to assist developing countries in the energy transition process. Why this is important?

Applying and communicating geographical understanding

8 Hold a class discussion on the punitive approach of the EU and the incentives approach of the United States. Decide which is more likely to be successful. Write a paragraph justifying your answer.
9 Using the internet, investigate carbon capture and green hydrogen technological advancements. Prepare a report on the role that they may play in the global energy transition.
10 Study Figure 5.4.4. Select two planned energy projects and undertake internet research on them. Present your findings as a slideshow presentation.