CLIMATE BOX

An interactive learning toolkit on climate change

TEXTBOOK

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Acknowledgements
The project team thanks all advisors and scientific consultants who helped to prepare the Climate Box interactive learning toolkit, particularly: Alexey Kokorin for valuable advice on the sections 'Climate change' and 'How climate change affects the Arctic region', Yulia Kalinicheva for assistance in preparing the wall map and climate mitigation poster, UNDP in Armenia for preparing the climate adaptation poster, Alexey Soldatov (BSH Home Appliances LLC) and Olga Pegova for their assistance in preparing materials on 'Energy efficiency and energy saving'.

The Climate Box textbook is part of an interactive learning toolkit on climate change aimed at primary and secondary school students and teachers specializing in natural sciences and environment studies. The toolkit was prepared by the United Nations Development Programme (UNDP) with financial support provided for different phases of the Climate Box programme from the Global Environment Facility, the Government of the Russian Federation, and the Coca-Cola Company. Climate Box continues a series of environmental toolkits for students, which includes the Black Sea Box and Baikal's Little Treasure Chest.

Climate Box: An interactive learning toolkit on climate change. / V. Berdin, E. Gracheva, Y. Dobrolyubova et al. United Nations Development Programme, 2024.

UDC 373.3 (5): 551,583
BBK: 74.26:26.237 K49
ISBN 978-5-9902971-2-8

About the CLIMATE BOX

Climate change is universally recognized as the most important global priority today. The problem is global because the effects of climate change are felt in all countries and regions of the world, and because each one of us, in varying degrees, bears responsibility for the changes occurring on our planet. We are the ultimate consumers of goods and services that require resources and energy, i.e., fossil fuels (oil, coal, and natural gas), for their production. The production and consumption of fossil fuels cause emissions of greenhouse gases (GHGs), which increases their concentration in the atmosphere and the associated greenhouse effect and global air temperatures. The production of cement and metals, as well as other human activities on land, such as agriculture activities and forest management, also increase GHG emissions in the atmosphere. This is the carbon footprint we leave on Earth.

The imperative of climate change demands that we gain all the knowledge and tools we need to protect our environment and reduce our carbon footprint. It is important that such knowledge and habits are instilled in us from an early age, so that everyone understands by the time they leave school how important it is to take care of our natural environment and resources.

The United Nations Development Programme (UNDP), with the support of the Global Environment Facility (GEF), the Government of the Russian Federation, and the Coca-Cola Company, has developed the Climate Box as an interactive learning toolkit on climate change for students. It seeks to provide students with key facts on issues related to global climate change in an engaging and entertaining way, and teachers with recommendations on use of the toolkit in the school curriculum.

"To all those working, marching and championing real climate action, I want you to know that you are on the right side of history and that I am with you."

António Guterres
United Nations Secretary-General
19 September 2023

The Climate Box consists of:

- an illustrated textbook for students with educational materials and a variety of questions and tasks for individuals and groups, as well as guidelines for teachers on use of the toolkit in lessons for students in different age groups (as a chapter in the textbook and a standalone supplement)
- the Climate Quiz, a set of game cards
- a wall map illustrating the possible effects of climate change on nature and humanity in various parts of the world by the end of the 21st century
- a poster with recommendations on how to resist and adapt to climate change impacts that are hard to mitigate;
- a poster with tips on how to reduce your carbon footprint;
- climate-box.com – a website with all toolkit materials

Designed specifically for school students, the textbook is like an illustrated encyclopaedia about climate, presenting important and sometimes difficult issues in an accessible way. Readers learn how the Earth's climate has changed from the earliest geological epochs, what climate changes are happening now, how these changes affect nature and humanity, whether we can adapt to the inevitable impacts, how to prevent the most dangerous consequences of global warming, and what is already being done in different regions of the world. A separate section of the book explains the concept of the carbon footprint and how to reduce it.

The textbook and other materials in the Climate Box have been designed in a way that lets young readers use them independently. Some topics focus on younger children, and others on secondary school students. Some readers will find the entire book of interest while others will be attracted by specific intriguing facts, illustrations, or ideas for experiments. Everyone will find something new and interesting in the Climate Box.

The success of the pilot phase of the Climate Box, the appreciation of climate change experts, teachers, and schoolchildren inspired UNDP to make it a truly international educational kit uniting children and teachers across borders.

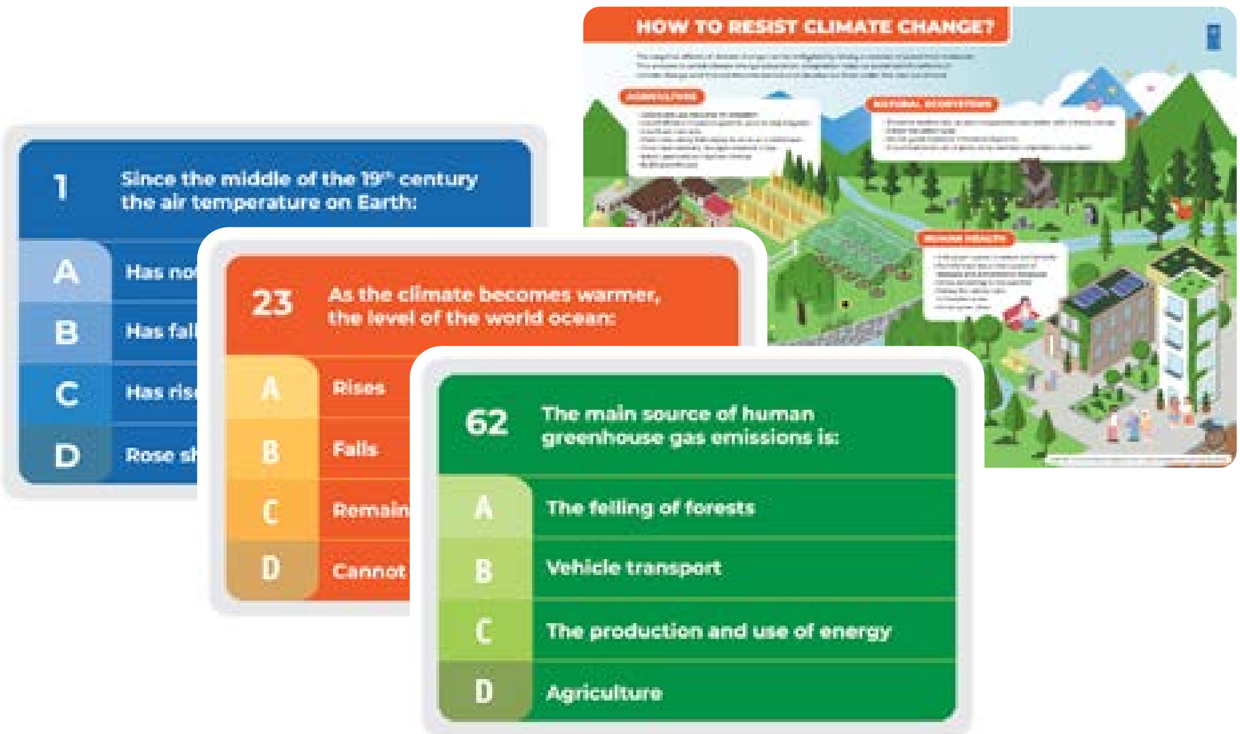
By 2019, UNDP had scaled up implementation of the Climate Box project across nine countries in Eastern Europe, the Caucasus and Central Asia, and the number of new countries continues to grow. Digital versions of the toolkit are available in different United Nations languages and national languages of the participating countries on **www.climate-box.com**.

This revised 2024 English version of the Climate Box toolkit contains the most up-to-date information on climate change, including key findings from the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) and case studies of recent initiatives on climate change mitigation and adaptation from around the world. It also includes feedback and recommendations received from teachers and experts in the participating countries based on their experience in applying the Climate Box programme and toolkit.

A big team of authors has worked on the Climate Box, including leading experts in climatology, geography, biology and economics, and professional writers of books for children. Experienced schoolteachers made invaluable contributions by helping to develop guidelines on classroom use of the toolkit by teachers.

We hope that the Climate Box will continue to be an engrossing and useful source of information on climate change for schoolchildren and help them to learn how to protect the natural world.

Learn more about the Climate Box project at www.climate-box.com.



Preface

Prof. Thomas Stocker

Professor of Climate and Environmental Physics, University of Bern, Switzerland

Co-Chair IPCC Working Group I, 2008 - 2015

Think 2030, 2050, 2100. These are the years most mentioned when we talk about climate change and its impacts, and how we must adapt to the inevitable transformation they will bring about in the future.

Such times appear far away for most people, and especially for young people. But for you, the next generation, these waypoints on the time axis are critical. What will I work on in 2030? Where will I live in 2050? How will my children find a happy life in 2100? These questions are fundamental for today's students, from school to university.

Our generation is used to seeking answers to such questions by looking at ourselves, by getting the best education, by working hard, and by being creative and inventive. However, climate change caused by human activity will change not only the living conditions on Earth – our only home – but will also more than ever influence the options for our own lives, and the wellbeing of our families and our neighbours, close, far, and wide. Climate change will become the factor that most determines our living conditions in the coming decades.

This is why the Climate Box is so timely. We need to know what shapes our future, and understand how our decisions today not only affect us in our own lifetime, but influence the lives of our children and grandchildren in multiple and complicated ways. Scientific knowledge of the human influence on Earth, on its climate and on all its resources must be taught at the earliest stage, so that sensitivity to these issues is nurtured as early as possible.

Instruction comes in many forms. The Climate Box offers a fresh and dynamic entry to this complex topic. By presenting the most up-to-date scientific facts in clear language, with simple graphics, quizzes, and stories, students can digest the knowledge through multiple channels. The tasks in the Climate Box help to recall, assess, and focus their understanding.

Globalization has brought us many benefits, but we are ill-equipped to live, work and function in a globalized world. Our brains have been trained over millennia to react and adapt to the changes that happen in our immediate environment. This has been essential for our survival. Our personal sensors do not go beyond what we see and hear. However, today, our actions, foremost the consumption of energy from fossil fuels and the squandering of land reserves through deforestation and other activities, have global consequences which threaten the survival of us all.

Our survival kit, therefore, is in dire need of an upgrade. This upgrade comes from the science that provides us with an understanding of the changing climate and enables us to estimate the possible futures emerging from our choices today.

Will we live in a world that is different from the one we know today, a warmer world with a changed climate, but still a home where most people on Earth are able to adapt, and live comfortably in? Or will we, as a consequence of unchecked climate change, experience a fundamentally different world, much warmer than anything that humans and ecosystems can cope with, with sea level at least one metre higher, vast expanses of coastal land submerged and unlivable, glaciers melted, and the Arctic irreversibly altered? This will also be a world in which extreme weather events will harm the most vulnerable people, and many ecosystems will have ceased to be useful. This other world is projected to result from 'business as usual', a most inappropriate and treacherous term, as it innocuously suggests that in 2050 or 2100, business as we know it today will still be carried out 'as usual'. The informed citizen already knows that this will not be the case in such a scenario.

The Climate Box helps students to learn about these life-threatening consequences of a changing climate through science and instruction and increase their sensitivity to the results tomorrow of their actions today. I hope that, with this innovative learning material, being made available at all levels of teaching, we prepare the next generation, so that they do not lose as much time as we did and take the right decisions.

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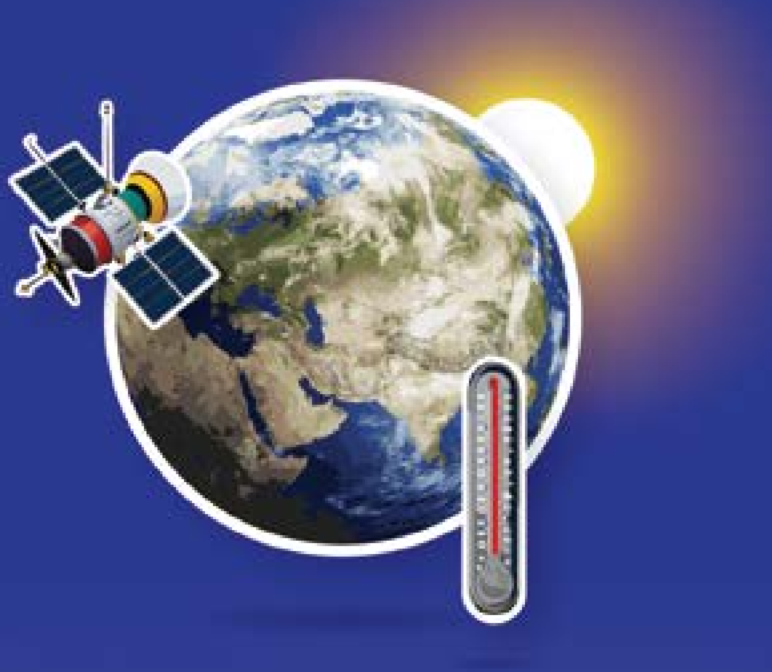


1

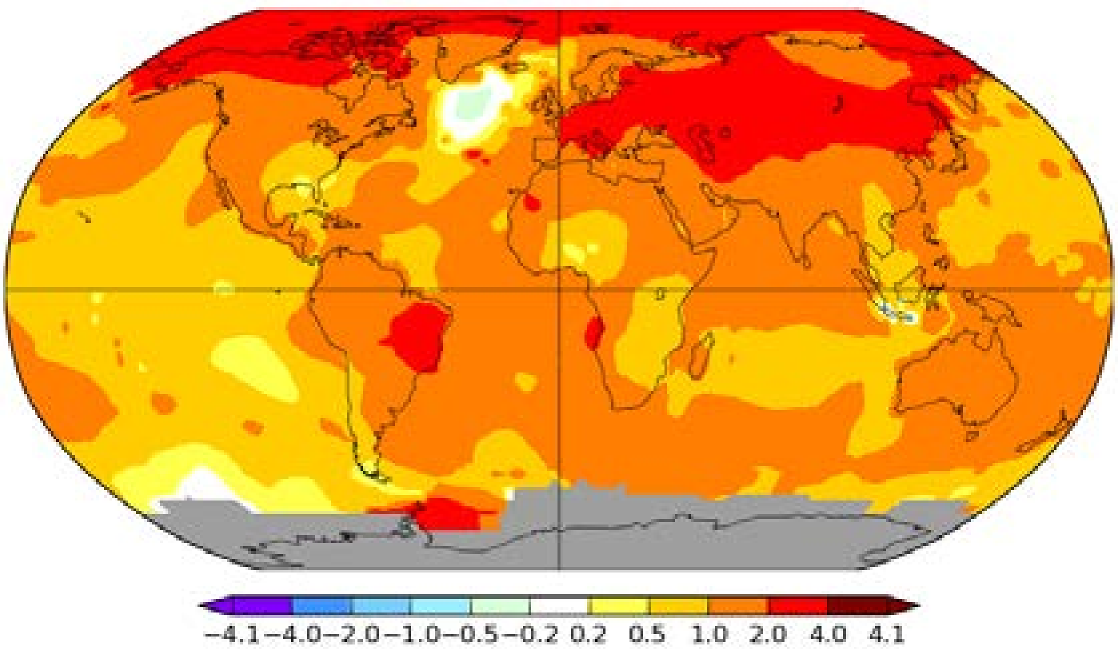
The problem of climate change

1 The problem of climate change

Climate change is one of the most urgent global issues of our time. Thirty years ago, only scientists talked about climate change, but today it concerns most of us. We notice that the weather has become warmer and is increasingly hard to predict at any time of the year. We also notice the increased frequency and severity of extreme events, such as storms, hurricanes, heatwaves, precipitation, and droughts.

The fact that our planet's climate is changing, and changing rapidly, is clear beyond doubt. Judge for yourself: since the second half of the 19th century till this decade, the average temperature on Earth has risen by nearly 1.2°C. That may not seem like much, but on a global scale it poses a serious threat to all life on our planet, from plants to animals and to ourselves. And keep in mind that nearly 1.2°C is the world average, but warming is stronger over land than in ocean, and strongest in the Arctic. Warming is also stronger in the northern hemisphere than in the southern hemisphere, whose larger surface area absorbs more solar radiation and ocean circulation. Warming has also occurred at a faster rate after the 1970s than in the first half of the 21st century.

Figure 1.1 **Map of observed changes in surface temperature on Earth between 1901 and 2022**



Note: Gray areas signify missing data

The Earth is getting hotter

According to the World Meteorological Organization, the global average temperature on Earth in 2023 was about 1.4°C above the 1850-1900 average. This means that 2023 was the warmest year since record-keeping began in 1850.

The Greek philosopher Heraclitus coined the phrase '*panta rhey*' (everything flows) to express the concept of change. This also applies to the climate, which has been constantly changing for millions of years. Even 125 million years ago, global average temperatures were higher by about 1°C than they are today.

But the rapid rate of climate change in recent decades has perilous consequences for the planet and all its inhabitants.

'Climate change' is a more accurate term than 'global warming' because higher temperatures are only a part of what climate change means for Earth. Changes in climate lead to a loss of equilibrium throughout the natural world: glaciers and permafrost are melting, sea levels are rising, floods, droughts and hurricanes are more frequent, and the weather is harder to predict. Climate change leads to the extinction of many animals and plants, which cannot adapt to the new conditions, it hurts countries' economies and threatens the health and the lives of people.

There are different theories of why these changes are happening. Some researchers say they are due to the impact of astronomical processes (increased solar activity and changes in the slope of the Earth's axis), while others say that climate problems are a result of excessive human consumption of natural resources. What is certain is that solar activity and changes in the slope of the Earth's axis are beyond our control, while excessive consumption and the climate-harming greenhouse gases it causes are things we can do something about.

There is no country that is not experiencing the drastic effects of climate change. Greenhouse gas (GHG) emissions in the atmosphere are more than 50% higher than in 1990. Increasing GHG emissions are causing long-lasting changes to our climate system, which threatens irreversible consequences if we do not act.

13 CLIMATE ACTION

The climate action goal (Goal 13), one of the 17 Sustainable Development Goals adopted by the United Nations in 2015, aims to address the need to both adapt to climate change and invest in low-carbon development.

The Intergovernmental Panel on Climate Change and its most recent findings

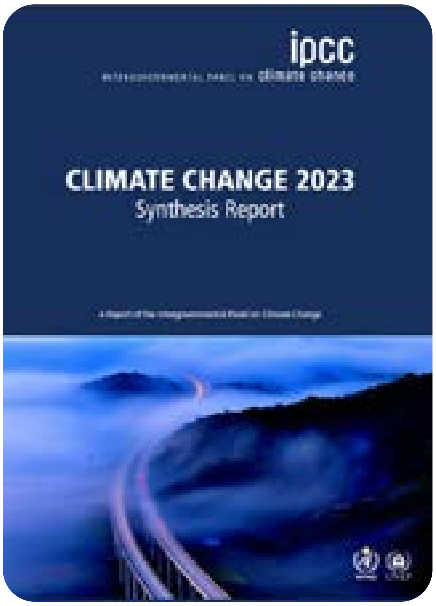
The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations. The IPCC was created in 1988 by the World Meteorological Organization and the United Nations Environment Programme to advance scientific knowledge and understanding of climate change, its drivers, and consequences, and how to deal with it.

The IPCC provides governments with the most updated scientific information on climate change. It does not conduct its own research but assesses all relevant scientific literature. This includes the observed changes in the climate system and their projections; natural, economic, and social impacts and risks stemming from climate change, and options and opportunities to mitigate climate change and adapt to its consequences. Thousands of scientists and other experts volunteer to review huge volumes of publications and reflect their findings in 'Assessment Reports' for policymakers and the public.

The IPCC is the most authoritative source of scientific information and assessment on climate change as leading climate scientists and governments endorse its findings. IPCC reports play a key role in the annual climate Conferences of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) that are known as COPs. Each of the six Assessment Reports (AR) published by the IPCC has led to major advances in UNFCCC negotiations. The First Assessment Report was critical to the negotiations that led to the adoption of the UNFCCC in 1992, the Second Assessment Report to negotiations of the Kyoto Protocol in 1997 and the Fifth Assessment Report to negotiations of the landmark Paris Agreement in 2015.

The most recent report by the IPCC is its Sixth Assessment Report (AR6) published in 2021-2023. Many of its findings are in this edition of the Climate Box (Fig. 1.2).

Figure 1.2 **Highlights of key messages from the IPCC AR6**



"It is indisputable that human activities are causing climate change, making extreme climate change events, including heat waves, heavy rainfall, and droughts, more frequent and severe."

"The evidence is clear: the time for action is now."

You can find more at:
https://www.ipcc.ch/assessment-report/ar6/

So, what is really happening to our weather and climate? How did the Earth's climate change in the past and how is it changing now? What is to blame for the changes that are happening? What are greenhouse gases and what can we do about them? Let's try to find some answers to these questions.

1.1 Climate and weather

People often complain about the weather, but they hardly ever complain about the climate. For example: "October extinguished itself in a rush of howling winds and driving rain and November arrived, cold as frozen iron, with hard frosts every morning and icy drafts that bit at exposed hands and faces." (J.K. Rowling, *Harry Potter and the Order of the Phoenix*). Writers and poets don't write about the climate. And it's easy to understand why. You can see the weather just by looking out of the window. We must deal with the weather every day. But the climate is something much harder to grasp. Yet, everyone – from scientists to politicians and businesspeople – talks about how the climate is changing.

When you get back from a holiday with your parents somewhere far from home, the first thing people want to know is how the weather was. But when you recommend the same place to friends for a holiday, you will probably tell them: "The climate there is very good." So, what is the difference between weather and climate?

WEATHER

is the state of the atmosphere at a particular place at a particular time or for a limited period (for example, a day or a month).

The weather is the momentary state of what we call 'meteorological elements', things that we hear about every night on the TV weather forecast: temperature, humidity, atmospheric pressure, cloud cover, etc. When it turns cold for a week in the summer and rains so hard that you don't even want to poke your nose out of doors, that's bad weather.

CLIMATE

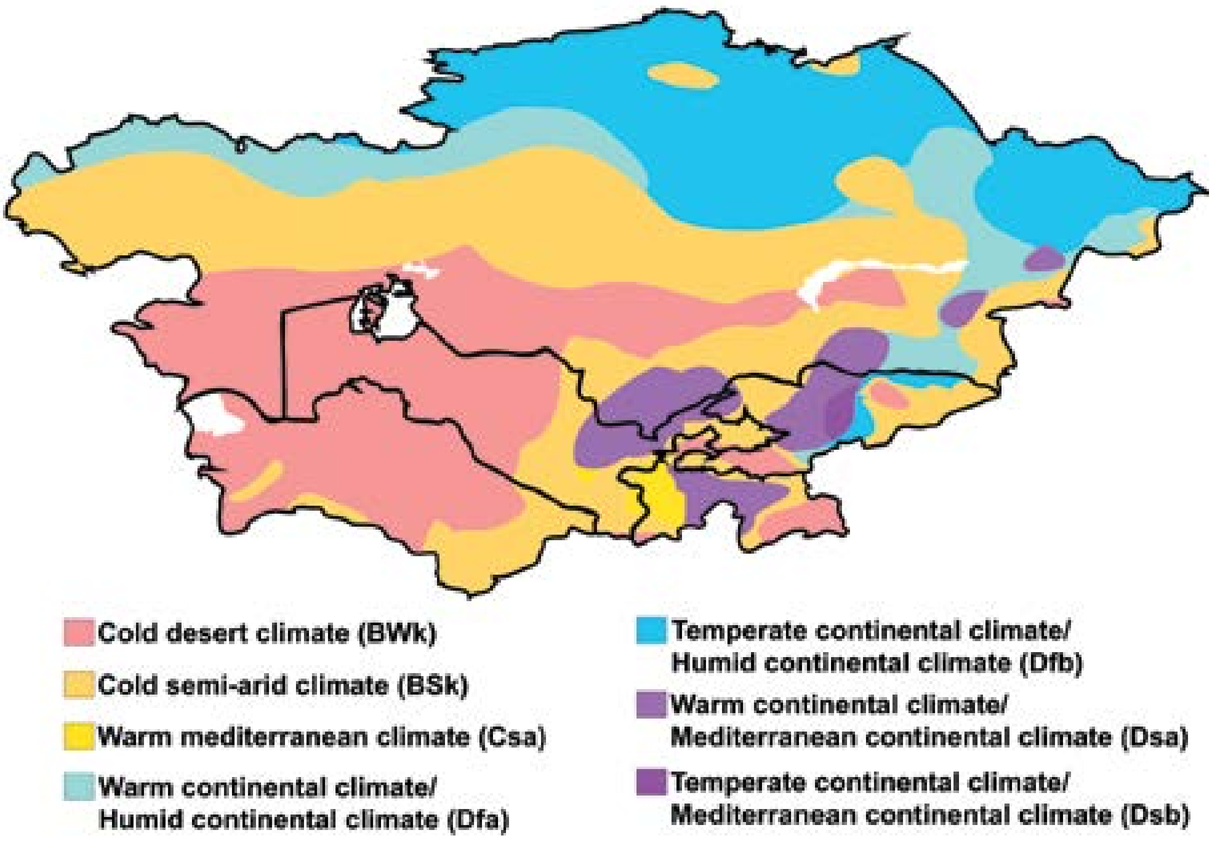
is the average state of the weather at a particular place over a long period (several decades).

For example: summers are hot and dry, while winters are cool and wet with very rare snowfalls. That is a brief description of the Mediterranean climate. As the proverb says: 'Climate is what we expect, weather is what we get'. You can't see the climate just by looking out of the window!

The main features of climate are:

- air temperature and its changes depending on the season;
- the amount and the time of precipitation (rain and snow) during the year;
- how air masses move;
- prevailing and other winds.

Figure 1.1.1 **Example of a climate map of Central Asia (by W. Köppen)**



AIR MASS

is a large piece of the atmosphere with roughly the same air temperature, pressure, and quantities of water vapour throughout.

The observation, study and forecasting of the weather is the subject of a branch of atmospheric sciences, called **meteorology**. **Climatology** is another branch of atmospheric sciences concerned with the description of the climate, the analysis of the causes of climatic differences and changes and their practical consequences.

People who live in Ireland say jokingly, “Ireland has a wonderful climate, but it’s spoilt by the weather.” Ireland is a country on a large island off the coast of Western Europe. Its weather is very changeable, but winters are mild, and the grass is green all year round. Because of this, Ireland is often called the ‘Emerald Isle’.

What meteorological elements determine the weather?

Air temperature may be positive or negative. The dividing point between positive and negative air temperature is 0°C when water freezes and turns to ice.

Air humidity depends on the amount of water vapour in the air. When humidity is higher in the winter, we feel colder. But when humidity is high and the air temperature is high, it feels stuffy.

Clouds are a cluster of tiny water droplets or ice crystals in the atmosphere.

Precipitation varies depending on whether it falls from clouds (rain, snow, frozen rain, hail) or forms on the surface of the ground and on objects (dew, frost, hoar frost, ice).

Visibility is the maximum distance beyond which an observed object blends into the distance and cannot be distinguished.

Fogs are a cluster formed by the condensation of water vapour close to the ground.

Atmospheric pressure is the pressure of air at a certain level in the atmosphere.

Wind is the horizontal movement of air caused by differences in atmospheric pressure.

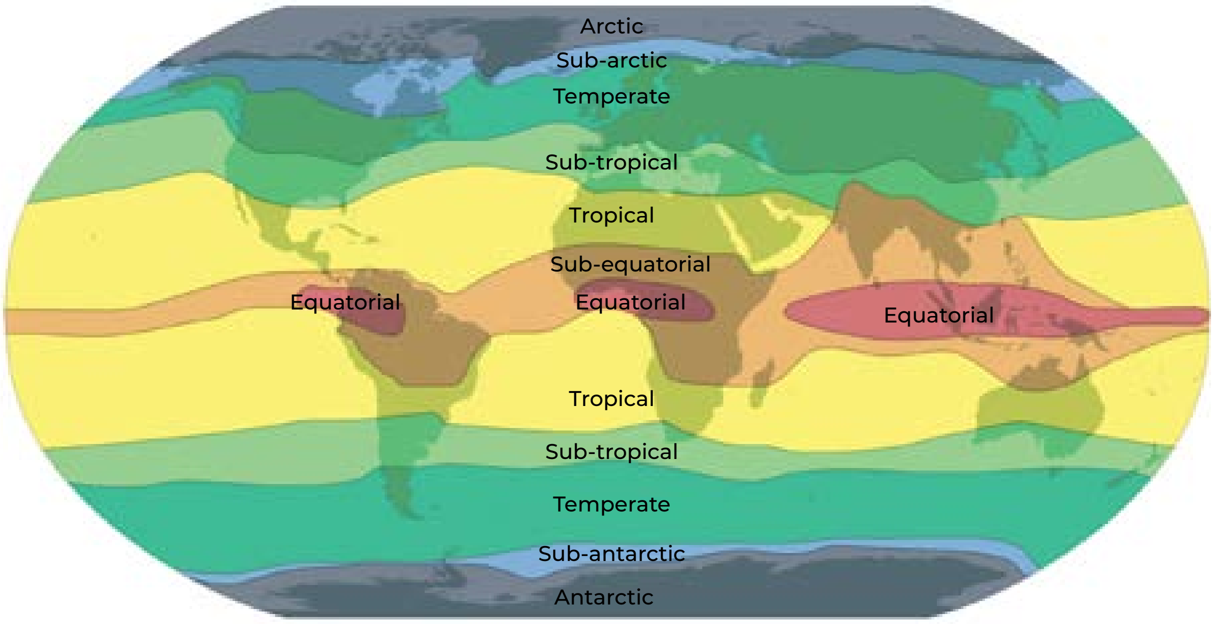
1.2 Types of climate and climate zones

Different parts of the globe have different climates. In northern countries, when people look out of the window during winter and see snow everywhere, they are keen to go on holiday to tropical countries, where one can enjoy hot weather and swim in the warm sea all year round.

Since ancient times, scientists have divided Earth into climate zones depending on the height of the sun above the horizon and the length of the day. The word 'climate' comes from the Greek language, in which it refers to the angle of inclination of the sun. Differences in the climate are primarily because the sun's heat is distributed unevenly over the Earth's surface. Proximity to the sea, atmospheric circulation, patterns of precipitation and other so-called 'climate-forming factors' also have a major role in determining climate, and they, in turn, depend much on geographical latitude and on the height above sea level.

Areas with similar climates are like broad stripes encircling the globe. They are what scientists call 'climate zones' and they turn colder the further away they are from the equator (Fig. 1.2.1).

Figure 1.2.1 The Earth's climates (by Boris Alisov)



CLIMATE ZONES

are areas with a relatively uniform climate.

The most well-known classification of climates was introduced by a German Russian climatologist Wladimir Köppen in 1884 (Fig. 1.1.1). He divided the climates into five main types: **A** – Tropical, **B** – Dry, **C** – Temperate, **D** – Continental, **E** – Polar and Alpine.

Another system of climate classification, commonly used in Eastern Europe, was created in the 1950s by the Russian scientist Boris Alisov (Fig. 1.2.1). It defines four main climate zones in each hemisphere and three transitional zones.

The main climate zones are **equatorial, tropical, temperate, and polar (Arctic in the Northern Hemisphere and Antarctic in the Southern Hemisphere)**. They are the main climate zones since each is dominated throughout the year by the same air masses.

Between the main climate zones are the transitional zones: **sub-equatorial, sub-tropical and sub-polar (sub-Arctic in the Northern Hemisphere, and sub-Antarctic in the Southern Hemisphere)**. All the names of transitional climate zones have the prefix 'sub', which in Latin means 'under'.

The air masses in transitional climate zones change with the seasons, entering them from neighbouring zones at various times of the year. For example, in a sub-tropical climate the summer is hot, like in the tropics, but the winter is cool, since the tropical air mass is displaced by an air mass from the temperate zone.

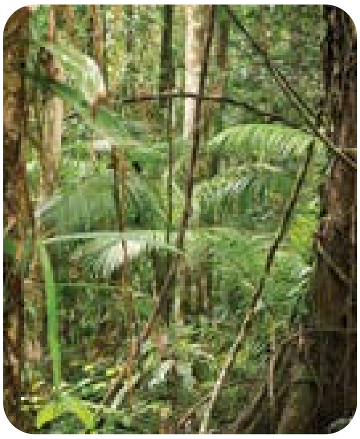
Some climate zones contain specific climate regions with a **continental, maritime or monsoon** climate (See Table 1.2.1).

The seasons in the southern and northern hemispheres are directly opposite: from December to February, when it is winter in the Northern Hemisphere, the Southern Hemisphere is in the midst of summer, and when the Northern Hemisphere is at its coldest, the Southern Hemisphere is at its hottest.

Table 1.2.1 Climates of Earth (by Boris Alisov)

Climate zone	Climate type	Average temperature		Time and amount of atmospheric precipitation	Circulation of the atmosphere and predominant winds	Territory
		Winter	Summer			
Equatorial	Equatorial	+26°C	+26°C	Throughout the year, 2000 mm	Warm, moist equatorial air masses are formed in a region of low atmospheric pressure	Equatorial regions of Africa, South America and Oceania
Sub-equatorial	Tropical monsoon	+20°C	+30°C	Mainly during the monsoon, 2000 mm	Monsoon	Southern and South-East Asia. West and Central Africa, Northern Australia
Tropical	Tropical dry	+12°C	+35°C	Throughout the year, 200 mm	Trade winds	North Africa, Central Australia
Sub-tropical	Mediterranean	+7°C	+22°C	Mainly at the cold time of the year, 500 mm	In summer, anticyclones with high atmospheric pressure; in winter, cyclones	Mediterranean, South Africa, South-West Australia, Western California
	Sub-tropical dry	0°C	+40°C	Throughout the year, 120 mm	Dry continental air masses	Interior of continents between 30 to 45° north and south of the equator
Temperate	Temperate maritime	+2°C	+17°C	Throughout the year, 1000 mm	West winds	Western parts of Eurasia and North America
	Temperate continental	-15°C	+20°C	Throughout the year, 400 mm	West winds	Interior of continents from 40–45° latitude to the polar circles
	Temperate monsoon	-20°C	+23°C	Mainly during the summer monsoon, 560 mm	Monsoon	Eastern fringes of Eurasia
Sub-polar (sub-arctic and sub-antarctic)	Sub-arctic	-25°C	+8°C	Throughout the year, 200 mm	Cyclones predominate	Northern fringes of Eurasia and North America
	Sub-antarctic	-20°C and below	About 0°C	Throughout the year, up to 500 mm	Cyclones predominate	Seas of the Southern Hemisphere from 60° southern latitude
Polar (Arctic or Antarctic)	Polar (Arctic or Antarctic)	-40°C	0°C	Throughout the year, 100 mm	Anticyclones predominate	Seas of the Arctic Ocean and the mainland of Antarctica

A brief description of different climates

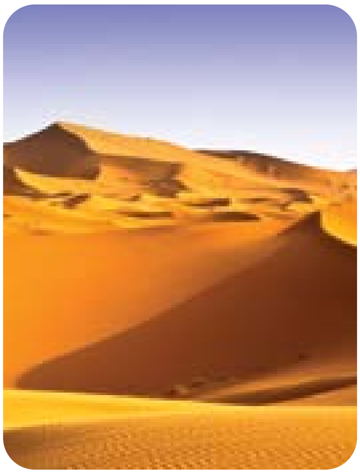


Equatorial climate

An equatorial climate is marked by hot and moist equatorial air masses. Air temperature is constant (+24–28°C) and there is much rain throughout the year (from 1500 to 5000 mm). Rain falls faster than water can evaporate from the ground, so the soil in an equatorial climate is waterlogged and covered by a dense and high rainforest. An equatorial climate is found in northern parts of South America, the coast of the Gulf of Guinea, in the Congo River basin and the headwaters of the Nile in Africa, over the greater part of the Indonesian archipelago and the adjacent parts of the Indian and Pacific Oceans in Asia.

Sub-equatorial climate

A sub-equatorial climate is marked by a rainy season in the summer, followed by a cool and dry season in the winter. Rainfall in a sub-equatorial climate is very uneven throughout the year. For example, Conakry (the capital of Guinea) receives just 15 mm of rain from December-March, but 3920 mm from June-September. This type of climate is found in some parts of the Indian Ocean, the western Pacific Ocean, as well as in South Asia and the tropical regions of Africa and South America.

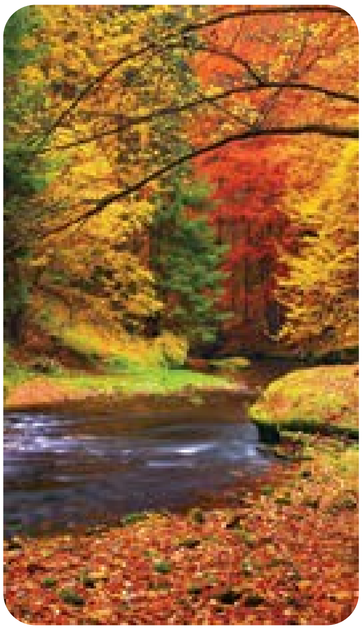


Tropical climate

A tropical climate is dominated by anticyclones with high pressure, giving clear weather nearly all the year round. There are two seasons: warm and cold. Temperatures can vary from +20°C on the coast to +50°C in the interior. The temperature can also vary greatly within a single day: on a summer afternoon the air heats up to +40–45°C but cools down at night to +10–15°C. Deserts are often found in tropical climates, and the largest is the Sahara Desert in Africa. Deciduous forests (forests that lose their leaves in the winter) and savannas are common in wetter regions. Mexico, North and South Africa, Central Australia and the Arabian Peninsula have a tropical climate.

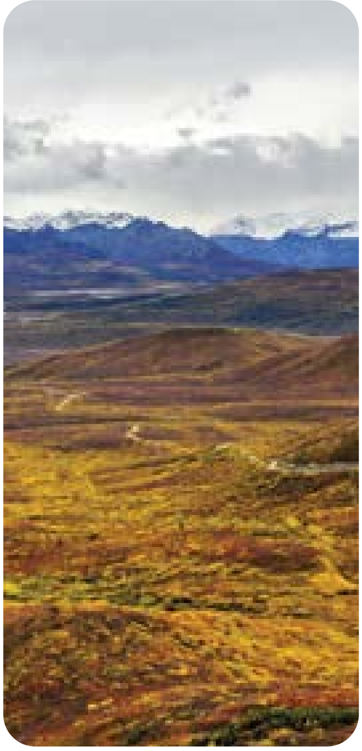
Sub-tropical climate

A sub-tropical climate is found in regions between tropical and temperate latitudes, from about 30° to 45° north and south of the equator. They are marked by hot, tropical summers and cool winters. The average temperature in summer is above +22°C and in winter above -3°C, but the arrival of air from polar regions in wintertime may cause temperatures to drop to -10 to -15°C, and occasionally even as low as -25°C. This type of climate is typical for the Mediterranean, South Africa, Southwestern Australia and Northwestern California.



Temperate climate

A temperate climate is found in so-called temperate latitudes (from 40°–45° north and south of the equator as far as the polar circles). In the northern hemisphere more than half of the temperate zone is occupied by land rather than the sea. But 98% of the temperate zone in the southern hemisphere consists of ocean. A temperate climate is marked by frequent and severe weather changes due to cyclones. A temperate climate is characterized by four seasons, of which one is cold (winter), one is warm (summer) and the other two (spring and autumn) are transitional. The average temperature in the coldest month is usually below 0°C, and in the warmest month it is above +15°C. The ground is covered with snow in the winter. Prevailing westerly winds bring rain and snow throughout the year, with rainfall and snowfall varying from 1,000 mm in coastal areas to 100 mm deep inland.



Sub-polar (sub-Arctic, sub-Antarctic) climate

A sub-Arctic climate is found between Arctic and temperate climate zones in the northern hemisphere. This climate is marked by air masses at moderate temperature in the summer and cold air masses from the Arctic in the winter. The summers are short and chilly, with air temperature in July rarely above +15°C by day and dropping to 0°–+3°C at night, and frosty nights likely through the summer. In winter the temperature by day and night is -35°–45°C. The landscape in a sub-Arctic climate consists of tundra and forest tundra, the soil is marked by permafrost, and there are few plants and animals. The north of Russia and Canada, Alaska (USA), South Greenland and the far north of Europe have a sub-Arctic climate.

A sub-Antarctic climate is found in the southern hemisphere between the temperate and Antarctic zones. The greater part of the sub-Antarctic zone consists of ocean, with annual rain and snowfall up to 500 mm.

Polar (Arctic, Antarctic) climate

A polar climate is found to the north of 70° latitude in the northern hemisphere (Arctic climate) and to the south of 65° latitude in the southern hemisphere (Antarctic climate). Polar air masses are dominant all year round. The sun does not appear above the horizon for several months (this period is called the ‘polar night’) and during some other months it does not set beyond the horizon (‘midnight sun’ or ‘polar day’). Snow and ice reflect more heat than they absorb, so the air is very cold, and the snow never melts. Atmospheric pressure is high all year-round (anticyclone), so winds are weak and there are almost no clouds. There is very little snowfall, the air is full of small icy needles and a water haze often occurs in the summer. The average temperature in summer is below 0°C, and between -20°C and -40°C in winter.

Where are the coldest and hottest places on Earth?

The coldest place on Earth is the eastern plains of Antarctica. In August 2010, the US NASA Aqua satellite registered a new record low temperature there of -93.2°C (Figs. 1.2.2 and 1.2.3). However, this record is unlikely to be officially recognized because by current scientific standards air temperature must be measured on the Earth's surface, and not from outer space, to be declared accurate. More recent analysis by NASA scientists shows that temperatures at the same location fell lower, to -98°C. So, the internationally recognized low temperature record remains -89.2°C, registered at the Soviet (now Russian) Vostok research station in Antarctica on 21 July 1983 (Fig. 1.2.4). The village of Oymyakon in eastern Siberia is the coldest permanently inhabited place on Earth, with average winter temperatures of -50°C. The city's coldest day on record was in 1924, when temperatures plunged to -71.2°C.

The hottest place on our planet is Death Valley in the USA where an absolute record air temperature in the shade of +56.7°C was registered on 13 July 1913 (Fig. 1.2.5). WMO is currently verifying two temperature measurements of +54.4°C, recorded at the same place, on 16 August 2020 and on 9 July 2021. If validated, this would be the highest temperature on Earth since 1913.

Figure 1.2.2

The American satellite NASA Aqua was launched in 2002 to study physical processes on Earth.

Figure 1.2.3

Surface air temperature in Antarctica: data from the US satellites NASA Aqua in 2003–2013 and Landsat 8 in 2013.

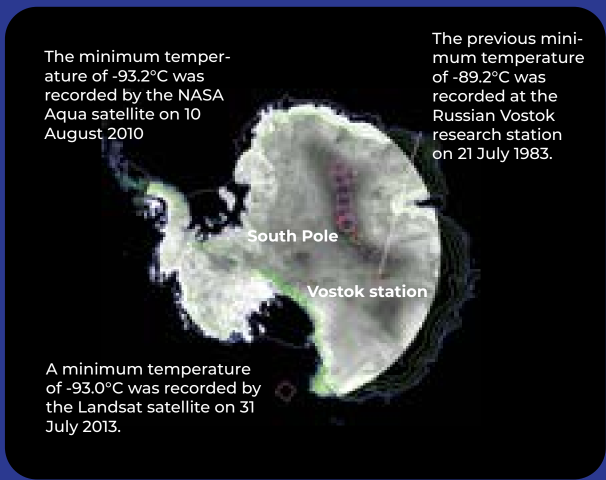


Figure 1.2.4 **Russian research station Vostok in Antarctica**

Figure 1.2.5 **Death Valley, USA**

QUESTIONS

1. When it is winter in the Northern Hemisphere, what time of year is it in the Southern Hemisphere?

2. What is wind? What types of winds do you know? What are the differences between them? In which climates do they predominate and why?

3. In which climate zone do you live? What do you know about the weather at different times of the year in your climate zone?

4. In which climate zones is it hardest for plants and animals to survive?

5. Where is it colder, at the North Pole or at the South Pole?

6. How fluent are you in climate terminology? Test yourself with the UNDP Climate Dictionary: https://www.undp.org/publications/climate-dictionary

TASKS

1

GAME

Materials: Cards showing various features of different types of climate: equatorial, tropical, temperate, polar. This is a game for 12–24 people. Each player receives one card with one climate feature.

Talk with other players and bring together all the features of one climate in one group of players. Mime to show the other groups what sort of climate you have.

2

The famous American writer Mark Twain once joked: “If you don’t like the weather in New England, just wait a few minutes.” What was it about the climate and weather in New England that the writer was making fun of?

Find New England on a map of the USA. Which climate zone is it in?

3

What are ‘favourable’ and ‘unfavourable’ climatic conditions?
Divide into groups and choose one type of climate.
Make up play-acting and jokes about the type of climate you choose.

4

GAME

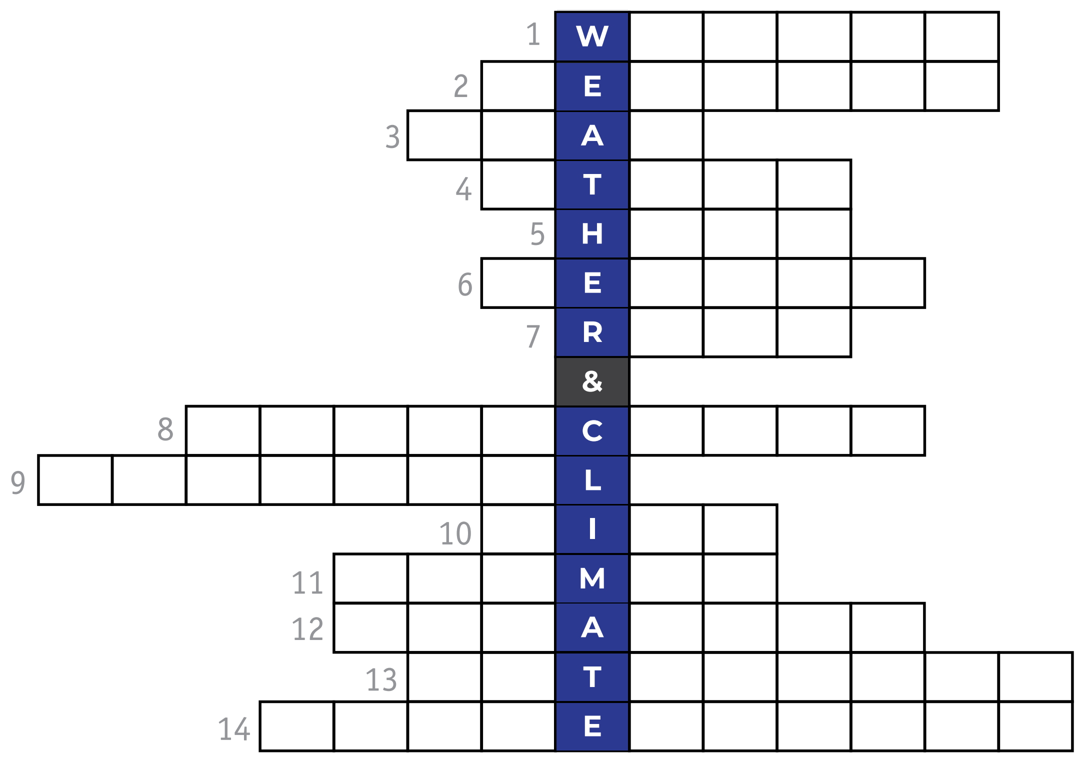
Point of the game: To feel as if you are in an equatorial climate and experience daily tropical rain.
How to play: Stand in a circle, with a leader in the centre. As the leader, you must show your movements to all the other players, turning slowly on your axis with each one. Begin a new movement after all the players in the circle have started to imitate your previous movement. Each player goes onto the next movement when you are opposite to them. Meanwhile the other players continue with the previous movement.

The sequence of movements: The leader and first player (then in turn the second, third player, etc.) join the palms of their hands and make slow circular circular motions with them. Then they click their fingers, then clap their hands, then slap their thighs and then stamp their feet. When the sequence ends, the actions are all repeated in the reverse order. The effect is to imitate the sounds of a downpour of rain from start to finish.

5

CROSSWORD

1. One of the main seasons.
2. The state of the atmosphere at a given time in a given place.
3. Seasons come and go in one...
4. Severe weather conditions with strong wind.
5. Frozen rain that falls in the form of small ice balls or lumps.
6. A long-term weather pattern at a certain period of the year.
7. One of the main features of weather.
8. The main character of children's winter holidays, the old man whose arrival is always welcome.
9. One of the climate types.
10. Horizontal movement of the air, caused by a difference in atmospheric pressure.
11. The time of year that school children in Northern Europe like the most.
12. A famous Italian composer who wrote a series of works called The Four Seasons.
13. The coldest continent.
14. The main factor that determines climate.

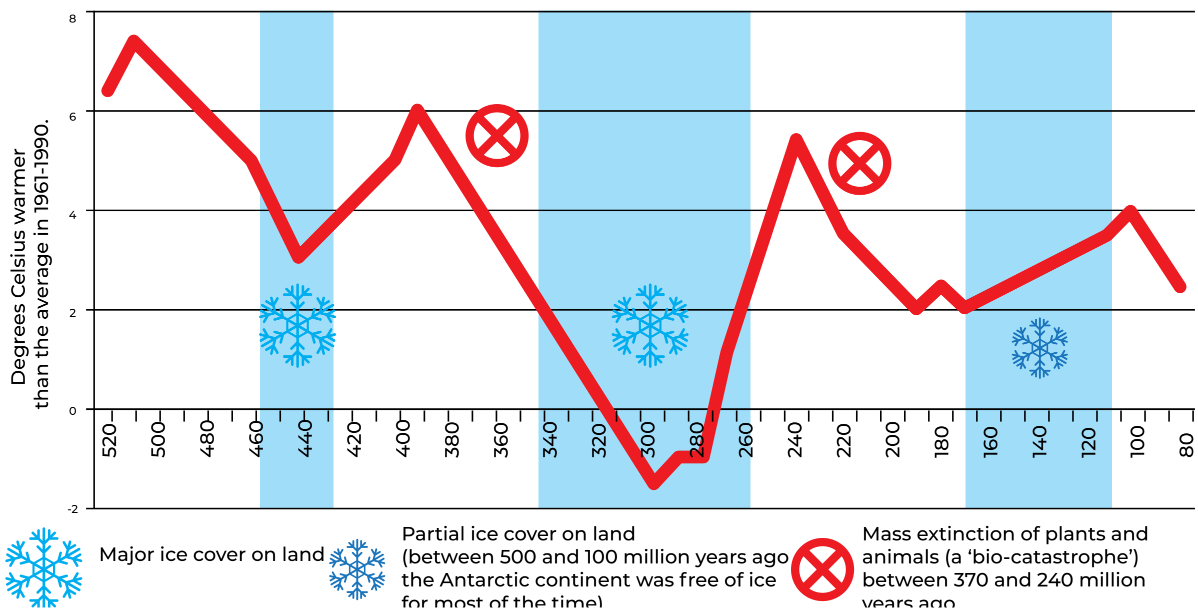


1.3 How and why the climate changed in the past

It is not hard to show that the Earth's climate has always been changing. Of course, the heroes of cartoons and computer games about dinosaurs and the ice age are made up, but dinosaurs really did exist, as we know from finding dinosaur bones and eggs. When these animals were alive, the climate on our planet on earth was much warmer than it is now. But there were cold periods, when the climate was much colder than now, and when glaciers reached as far south as Berlin or Chicago and were as high as a multi-storey building!

Over the hundreds of millions of years in the Earth's history, the temperature has varied greatly – by about 10°C (Fig. 1.3.1). That's a lot! If temperatures today were 10°C warmer, then the climate in Stockholm would be quite different: the average temperature during the year in the Swedish capital would be what it is now at the Mediterranean coast, for example in Barcelona or Marseille. That would be nice, you think. But then southern Europe would be as hot as in Dubai. And on the Arabian Peninsula, it would probably too hot for people to live.

Figure 1.3.1 **The temperature on Earth over the past 500 million years**



How do scientists know what the climate was like in the past?

Scientists assess what the temperature on Earth was in the past by studying rocks, sediments at the bottom of lakes, seas, and oceans. Ice leaves traces on rocks, while sediments from what used to be ancient seas contain the remains of plants, which could only survive at certain temperatures.

Scientists have an even better source of data to assess temperatures in the last million years: they use the ice of Antarctica. The ice contains air bubbles that give evidence of the gas composition in the atmosphere and the temperature on Earth in the past (Fig. 1.3.2). The longest data series (about 800,000 years) has been obtained at the Russian Antarctic station, Vostok.

Tree rings are a good source of information on climate change in past centuries. The rings from warm years are wider, but those from cold years are narrower. The shells of marine and freshwater molluscs are another good indicator of climate in the past.

The science that deals with the study of past climate is called **paleoclimatology**.

Figure 1.3.2 **Scientists extract a column of Antarctic ice, from which they determine the air temperature and carbon dioxide content in the atmosphere over hundreds of thousands of years**

1.3.1 | Causes of climate change: millions of years

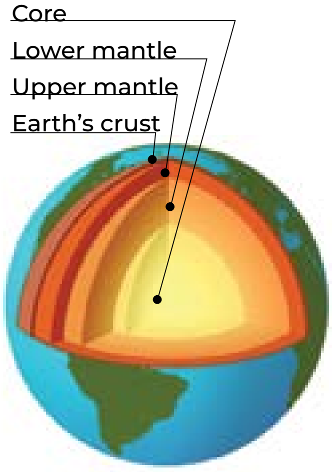
Seeking to explain the major changes of the Earth's climate that have occurred in the past half a billion years, scientists have looked at various geological, astronomical, biological, geomagnetic, and cosmic factors. They have even considered the possibility of visitors from other planets, who might have used some sort of climate weapons. But scientists found no trace of action by aliens. What they found was that the temperature on our planet in the last few hundred million years was determined by the location of its continents.

Moving continents

The Earth's crust is only the thin top layer of our planet (Fig. 1.3.3). Beneath it begins the mantle, which is the main part of the planet and which becomes a very hot and sticky liquid deeper down. The crust and top layers of the mantle consist of relatively hard ('lithospheric') plates, which can crack, move apart or come together, shifting just a few centimetres each year, but covering thousands of kilometers over millions of years! This is called 'continental drift'. The single, ancient continent of Pangaea gradually divided into separate continents, which moved apart and collided with one another (Fig. 1.3.4). If you look at the western side of Africa and the eastern side of South America, you can see that they fit together like pieces of a jigsaw puzzle, and the reason for this is that they were once part of one single continent that split apart.

Figure 1.3.3

Layers of the Earth



Continents that are close to the equator do not accumulate ice, but if they are close to the poles, then they are soon buried under the glaciers (ice masses) that we now see in Antarctica and Greenland. The white surface of ice and snow reflects solar radiation back into space, ensuring that the ice and snow remain cold, while the dark surfaces of earth or water almost completely absorb solar radiation and therefore heat up.

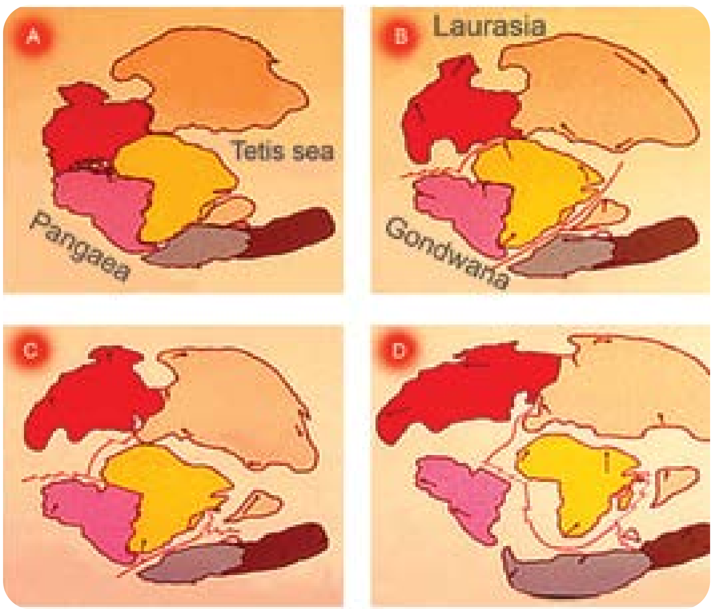


Figure 1.3.4

Continental drift over the past 500 million years.

A – the formation of Pangaea
B – the division of Pangaea, formation of Laurasia and Gondwana
C – the splitting of Gondwana, formation of Hindustan, Australia and Antarctica
D – the formation of South America, beginning of the division of Laurasia

When this occurs over a large area, it becomes the main factor influencing the climate of the entire planet. For most of the time in the last half a billion years the continents had less ice cover than they have now, so the earth's climate was warmer.

The white surface of ice and snow reflects solar radiation back into space, ensuring that the ice and snow remain cold, while the dark surfaces of earth or water almost completely absorb solar radiation and therefore heat up.

When there was a major change of climate, particularly when there was a cooling, so-called 'bio-catastrophes' occurred: whole species of living organisms died out and only those survived which were best suited to the new conditions.

One of these cold spells about 60 million years ago led to the disappearance of the last dinosaurs. This must have been a gradual process lasting more than a thousand years. The exact cause of the extinction of the dinosaurs is unknown, and there may have been several and not just one cause.

Why did the dinosaurs become extinct?

Dinosaurs finally died out on Earth around 60 million years ago. Scientists are still unsure exactly why.

One theory is that the dinosaurs were unable to compete with more 'sophisticated' living organisms. For example, with warm-blooded mammals, that were no larger than a squirrel, but which could eat the dinosaurs' eggs or attack them by night, when the cold-blooded dinosaurs were unable to move.

According to another theory, a huge meteorite struck Earth around the present Caribbean Sea, causing gigantic amounts of dust to spread through the atmosphere, blotting out the rays of the sun for a considerable period. Birds, mammals, and many other organisms adapted to the new temperatures, but dinosaurs did not.

There is one other version. It is known that for some reptiles (crocodiles, turtles) the ground temperature determines whether males or females will hatch from eggs laid in the sand along riverbanks and coasts. Biologists suggest that this dependence might also have applied to dinosaurs, which were also reptiles, only very large ones. If the temperature was such that only females (or males) hatched from dinosaur eggs, the species would have quickly disappeared without any need for disasters or falling meteorites.

The change from an invariable, moist climate to one with seasonal changes (even small changes) could produce short periods of cold nights when the huge reptile bodies of the dinosaurs could not retain sufficient warmth. Many of the animals would weaken and finally die.

But the most important climate event happened 50 million years ago, when the continents moved away from the poles. Snow and ice cover shrank, and temperatures rose to a level about 12°C higher than nowadays. Then, 'suddenly', India, which had previously been a small, separate lithospheric plate, crashed into Eurasia. The Himalaya mountains emerged at the place of the collision. The other plates moved around so that Antarctica took its place at the South Pole and was covered with a layer of ice (30–40 million years ago). The temperature on Earth began to fall sharply as the white ice of Antarctica began to reflect solar radiation back into space.

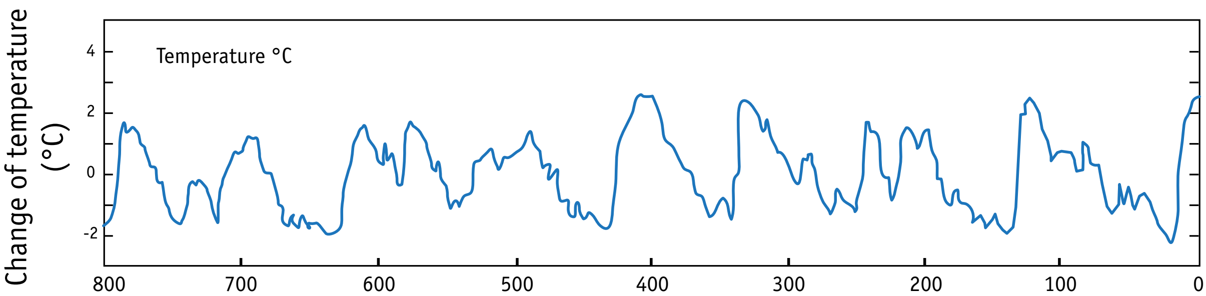
About 10 million years ago Greenland reached its present location and was covered by a layer of ice that lowered the temperature still further, to levels close to those we have today.

It was much warmer on Earth 100 million years ago than it is today. Antarctica became covered with ice 30–40 million years ago and Greenland 10 million years ago, causing temperatures to drop to their current levels.

1.3.2 Causes of climate change: tens and hundreds of thousands of years

We know that the temperature on Earth changes every million years. It has been found that, about every 100,000 years, we experience a relatively short warm period, while for the rest of the time the climate is much colder (so-called 'glacial periods' or 'ice ages'). At present we are living in a warm period.

Figure 1.3.5 **Change in temperature on Earth over the last 800,000 years relative to the average temperature**

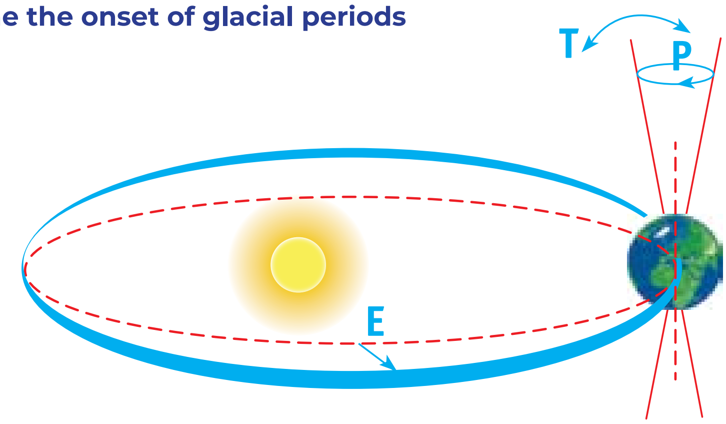


Why does this happen? Scientists think that the alternation of ice ages and warm periods has astronomical causes (Fig. 1.3.6).

Every 41,000 years the tilt of the Earth's axis alters in a range between 22° and 24.5° (it is currently at 23.5°). This variation makes the duration of the polar night in polar regions longer in some periods and shorter in others. Although this makes no difference to the total amount of heat reaching the Earth from the Sun, it affects the severity and duration of the winter season.

Figure 1.3.6 **Changes in the Earth's orbit and its rotation around its own axis, which determine the onset of glacial periods**

T — tilt of the Earth's axis
E — changes in the Earth's orbit (deviation of the orbit from a circle)
P — change in direction of the Earth's axis of rotation



The Earth's axis completes a circular path every 19,000–23,000 years. When you spin a top, its tip points straight upwards to begin with, but then starts to make circles, and then the top stops spinning and falls. The Earth is like a spinning top. There is no chance that it will stop rotating in the next few million years, but there has been a slowing down, and the axis of the earth is not fixed on the same spot in the heavens. The circles described by the axis of the Earth's rotation have no impact on the amount of heat reaching it from the Sun (no more than the tilt of the axis), but they do influence the severity and duration of the cold season in polar latitudes.

The Earth's orbit around the Sun changes about every 400,000 and 100,000 years. When it is close to circular, seasonal changes in the flow of heat from the Sun are less than when the orbit has an elliptic shape.

When winters in polar regions are longer and more severe, and snowfall is greater, less snow melts in the summer, and the accumulation forms glaciers. These white glaciers, unlike the dark surface of the ground or water, reflect nearly all the solar radiation that reaches them. As a result, the cold intensifies and the glaciers continue to grow, moving from the poles into temperate latitudes. A glacial period then begins (Fig. 1.3.7).

After a few tens of thousands of years, the conditions change in a way that causes the winters in polar and temperate regions to become shorter and warmer. The glaciers start to retreat, and the climate returns to what it was before. This is what happened 13,000 years ago, when the last glacial period ended.

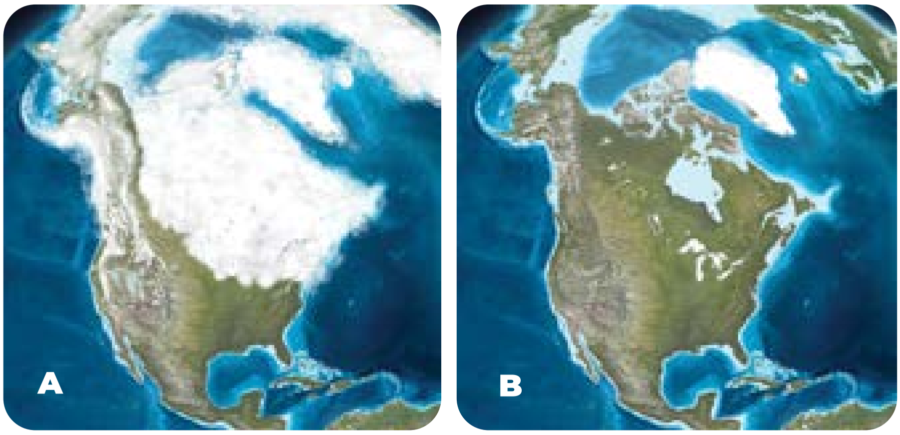


Figure 1.3.7

North America during:
A - the glacial period 125,000 years ago
B - at present

About 5,000-7,000 years ago, the climate was warmer and wetter than it is now, and that created conditions favourable for the development of human civilization, but it would be a mistake to think that warming by a couple of degrees will be good for modern civilization. Human beings today have different needs and different conditions of life: an abundance of grass for domestic animals and plenty of game to hunt in the forests are no longer enough for our societies to function properly.

The level of the Earth's oceans has changed with the coming and going of glacial periods. During cold periods the sea level was 50–100m below its level today. Those were the times when ancient people moved from Eurasia to America, mainly on land and for part of the way across a narrow strait covered by ice. In warmer periods during the last few hundreds of thousands of years, the ocean was at its present level or 5–10m higher.

How many tens of thousands of years remain until the next glacial period on Earth? The complexity of periods of change of the Earth's orbit and rotation around its axis make it impossible for scientists to predict whether it will happen in 15,000, 20,000 or 30,000 years.

Two things, though, are clear. First, that it will happen. Probably our distant descendants will be able to adapt because the climate in central and tropical latitudes will not be much colder than it is now. Second, the next glacial period will not come soon, not in even in hundred years, but the glacial movement will take hundreds and thousands of years. The prospect of a glacial period is therefore of no significance to the climate in the last millennium or the next few centuries to come.

The climate history of Earth for the past million years is characterized by the coming and going of glacial periods. Roughly every 100,000 years, the climate warms up. The warm period lasts for 20,000–40,000 years and then there is another cooling. A new glacial period is inevitable, but it will not happen for the next 15,000 or 30,000 years. The prospects of a new ice age are of no significance to the climate change happening now and that will happen in the next few centuries.

1.3.3 Causes of climate change: centuries

Different parts of Earth have been warmer and colder at various times during the last thousand years. There were several decades when air temperature varied by a palpable 3°–4°C. Of course, there were no thermometers a thousand years ago (people have only been able to measure the temperature for the last 300 years) but surviving records of fertile (warm) and less fertile (cold) periods are evidence of significant climate fluctuations. Scientists have also drawn conclusions about temperature in the past from deposits at the bottom of seas and rivers and by using other signs. The annual growth rings of trees are a particularly good source of information.

Scientists explain periodic temperature fluctuations over decades by changes in solar activity, volcanic eruptions and processes occurring in the world's oceans.

Variations in solar activity

The intensity of solar radiation varies periodically and has 11-year cycles. But observations that began as early as the 17th century also show cycles of change in solar activity lasting 40–45, 60–70, and 100-200 years.

Variations in solar radiation are usually slight, but when several periods of low solar activity come one after the other, the temperature on Earth falls substantially. This occurred, for example, from 1640 to 1715, a period referred to as the 'Little Ice Age'.

That was when people in the Netherlands used to skate along the frozen canals of Amsterdam in the wintertime. Soon afterward the cold snap came to an end and the use of skates became much less common (Fig. 1.3.8).

Figure 1.3.8

Dutch people skating on a frozen canal. Engravings from the series *Fashionable characters* by Romeyn de Hooghe (Netherlands, 1682–1702)

Volcanic eruptions

What natural phenomenon amazes us most by its power and energy? The answer, surely, is the eruption of a volcano. Do you think that volcanoes heat up the Earth's atmosphere or cool it down? At first glance, it seems that they must heat up the atmosphere. It is true that the hot lava and burning-hot gases raise the air temperature, but only near the volcano. What has the biggest impact on climate is not hot lava or gas, but volcanic ash. The eruption sends it high into the stratosphere, to altitudes of 10–15 km, where it stays for a long time. The ash blocks out some of the sun's rays, because of which the whole planet gets colder.

Any powerful volcanic eruption, in which a column of ash reaches the stratosphere, causes short- term cooling a year later. For example, after the Napoleonic Wars in Europe, people wondered why the climate turned cold for several years. The reason was the eruption of the Mount Tambora volcano in what is now Indonesia (Fig. 1.3.9). The same thing happened in 1983 after the eruption of El Chichon in Mexico, and in 1992 after the eruption of Mount Pinatubo in the Philippines.

After two or three years the ash settles, and volcanoes cease to have an impact on the Earth's climate until the next major eruption throws ash into the stratosphere.

Such huge eruptions are rare, and most of those we hear about do not affect the Earth's climate. For example, the eruption of the volcano with the hard-to-pronounce name, Eyyafyad-layëkyudl, in Iceland in 2010 spewed a lot of ash, but only into the lower atmosphere. Aircraft all over Europe were grounded, but the ash settled quickly and did not spread around the globe.

Figure 1.3.9

Mount Tambora volcano on the island of Sumbawa in Indonesia. The massive eruption of 1815 caused its top part to collapse, forming a crater six km wide and one km deep

Ocean currents

It has been shown that the discovery a thousand years ago by Norwegian Vikings of Greenland coincided with a warm period. Hence the choice of name by the discoverers. Of course, even then Greenland was not completely green: glaciers covered the greater part of the island, as they do now, but the southern edge was ice-free and relatively warm. The reason for this was changes in ocean currents: when they are stronger the local climate becomes a little warmer; when they are weaker it gets colder. This behaviour by ocean currents has caused warmer and colder periods in various parts of the world.

The Earth's climate has changed several times in the past. But never has the average temperature of the planet changed as fast as it is changing now: by nearly 1.2°C in 130 years. This unprecedented speed is not usual for natural processes. The fastest natural changes have always taken hundreds or thousands of years, which is a very slow rate of change by the measure of human life. Catastrophes where climate changes drastically in the space of one or two years might be the subject of a disaster movie, but they are far from reality and from what any scientist would forecast.

QUESTIONS

1. What has been the main factor of climate change over billions of years?

2. What ice-cream flavour melts slower in the sun: white vanilla or dark chocolate? Why? How does this illustrate processes that occur on Earth?

3. What major shift of lithospheric plates occurred 50 million years ago? What impact did it have on Earth as we now know it?

4. What do scientists use to find out the temperature and chemical composition of the atmosphere over the last 800,000 years?

5. Why do glacial periods occur?

6. When did the last glacial period end? Will there be another? Could it begin next year?

7. How did ancient people cross from Eurasia to America? They had no boats, and the width of the Bering Strait is now 86km (you cannot see from one side to the other).

8. Do volcanoes heat up or cool down the Earth's atmosphere?

TASKS

1

Lay a sheet of tracing paper on a map of the world, trace the outlines of Africa and South America and cut them out. Join up the cut-out continents.

Does it look as if they were once a single piece of land?
What was that land called? What happened to it?
How did that affect the Earth's climate? Why?

2

Experiment

Materials: Two small sheets of paper (white and black); two pieces of plasticine 4 cm long and 0.5 cm thick.

The experiment: Glue the pieces of paper together, so that the left half is white, and the right half is black. Stick the pieces of plasticine perpendicular to the sheet on its rear side, one piece on the white part and the other on the black. Place the sheet on its edge and hold it close to a lamp (preferably a strong lamp). The lamp will illuminate the paper.

Which piece of plasticine fell first as the lamp heated the sheet of paper? Why? Give an example of a similar process that occurs on Earth.

3

You already know that the climate on Earth at the time of the dinosaurs was warmer than it is now. For the world to be as warm again as when the dinosaurs lived, Antarctica would have to move far enough away from the South Pole for all its ice to melt.

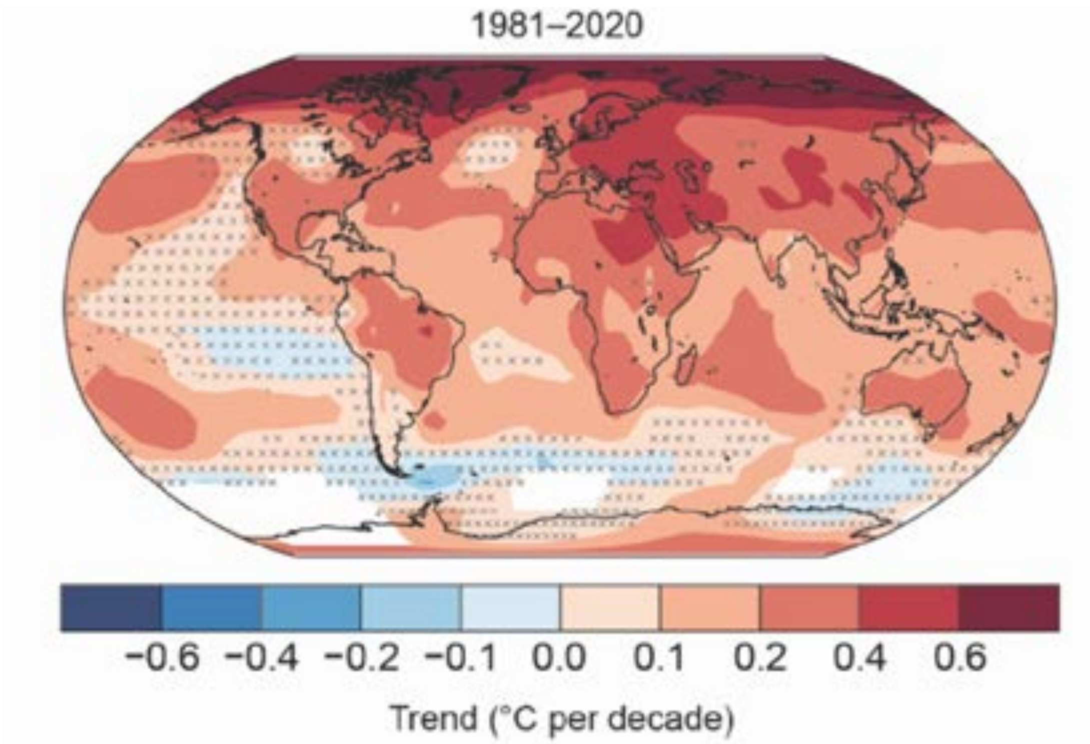
Take a physical map of the world and given its scale, calculate how far in kilometres Antarctica would have to move before its centre is at 40° southern latitude.

Suppose that Antarctica moves at a speed of 2 cm per year. How many years would it take for a warming of the earth caused only by the motion of Antarctica that would be sufficient for dinosaurs to live on earth again?

1.4 Climate change today

During the last century, the temperature on Earth began to rise in a way that could not be explained by natural phenomena. In 130 years, the planet became nearly 1.2°C warmer! According to the IPCC AR6, over the last 50 years, global temperature has increased at a rate unprecedented in at least the last 2,000 years. Global surface temperatures have not been warmer in the past 125,000 years. Observed and projected warming are stronger over land than oceans, and strongest in the Arctic.

Figure 1.4.1 Map of comparative trends in decadal changes in temperature in different regions of the world (1981-2020 and 1850-1900)

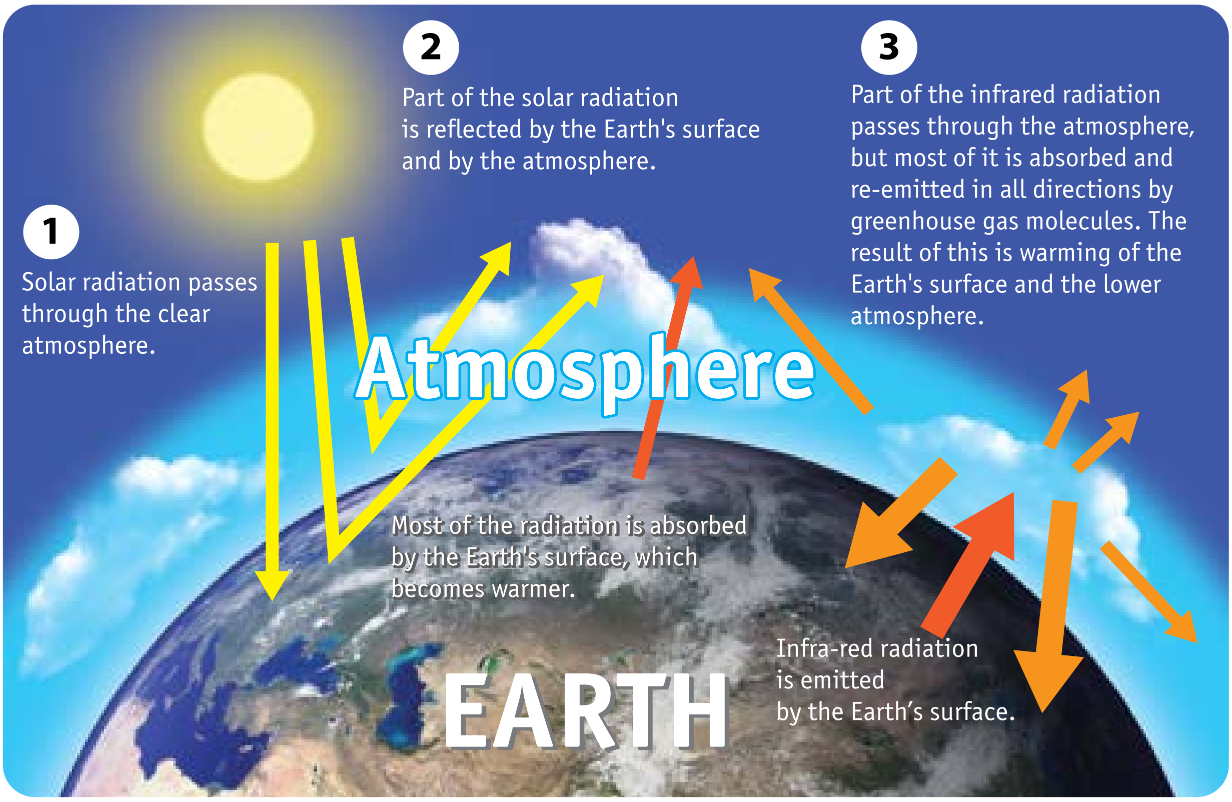


Scientists explain the current warming of the planet by an increase of what is called the 'greenhouse effect'.

The greenhouse effect

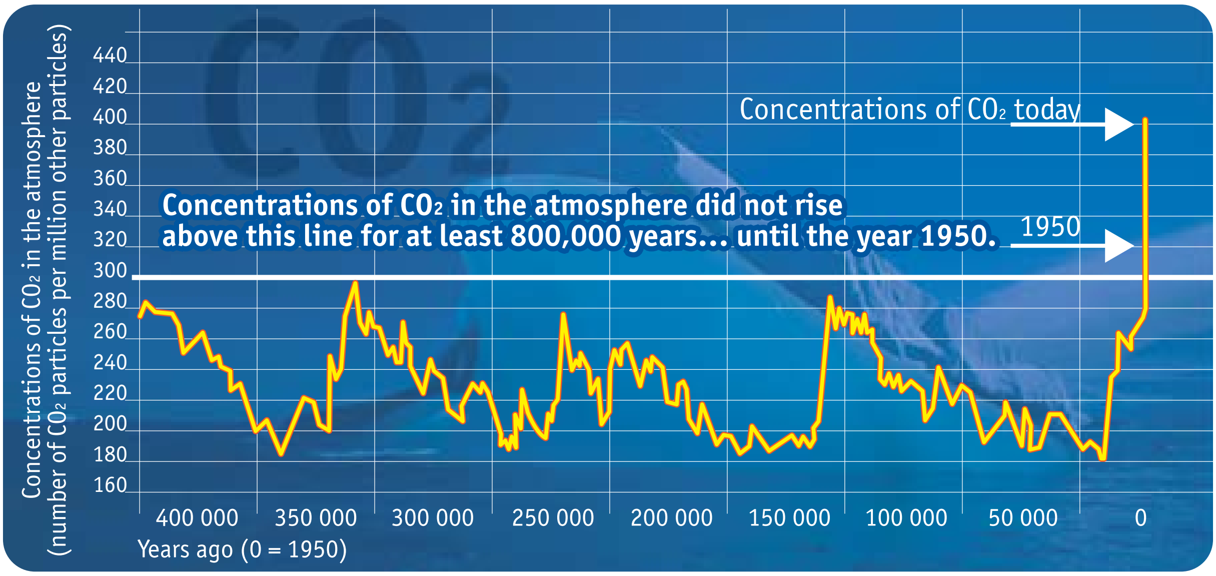
The greenhouse effect is the process by which gases, dust and water vapour in the atmosphere absorb the Earth's heat and hinder its reflection from the surface of the Earth. When scientists first described this effect 200 years ago, they noted how the Earth's atmosphere acts like a greenhouse for growing vegetables. So, the gases that absorb the Earth's thermal radiation were called 'greenhouse gases'. The main greenhouse gases in the atmosphere are carbon dioxide, methane, and nitrous oxide (for convenience, we will refer to them by their chemical formulas, CO_2, CH_4 and N_2O) and some others, as well as water vapour. They obstruct infrared radiation from the Earth's surface. As a result, the lower atmosphere warms up. Without the greenhouse effect, the average air temperature on the Earth's surface would not be +14°C, as now, but -19°C. The heat of the Earth would dispel into space without warming the atmosphere. This would make it hard for life to exist on our planet.

Figure 1.4.2 **The Earth's energy balance and the greenhouse effect**



Scientists have long predicted that by producing and burning coal, oil and gas, human beings would emit large amounts of CO_2 and CH_4, increasing the greenhouse effect. In the mid-20th century, the prediction was confirmed: the concentration of these gases all over the world began to increase rapidly (Fig. 1.4.3).

Figure 1.4.3 **Concentrations of CO_2 in the atmosphere over the past 400,000 years**



Greenhouse gases are the main cause of climate change today. As a result of human activities, primarily the burning of fossil fuels, and the development of transport and deforestation, atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have reached record levels – higher than at any time in the last 800,000 years. The natural concentration of carbon dioxide in the atmosphere varied throughout history between 180 and 300 parts per million (ppm) other particles. The latest analysis of observations from the WMO shows that the globally averaged surface concentrations for CO_2, CH_4 and N_2O reached new highs in 2022, with CO_2 at 418 ppm, CH_4 at 1923 ppb and N_2O at 336 ppb. These values constitute, respectively, increases of 150%, 264% and 124% relative to pre-industrial levels. The suggestion that human activity strengthens the greenhouse effect was first put forward by the Swedish scientist, Svante Arrhenius, as early as 1896.

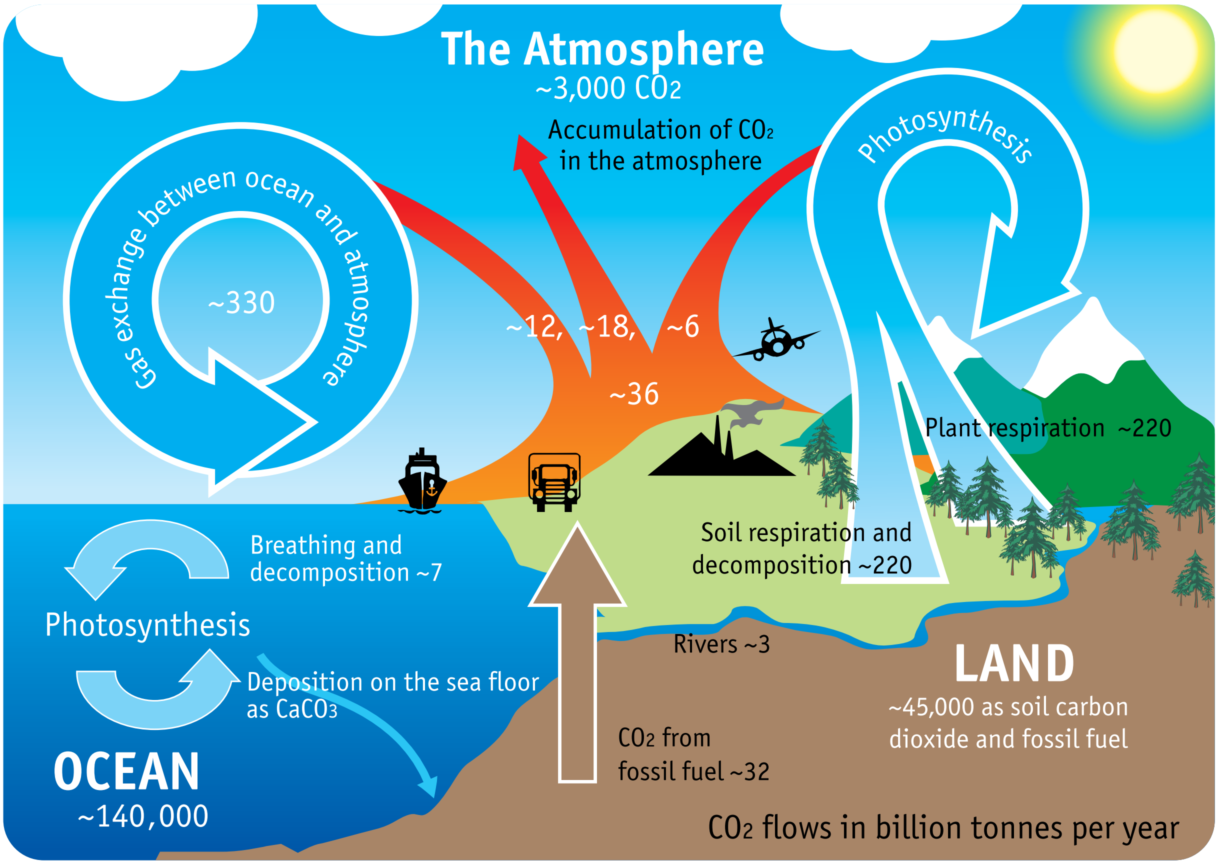
Is the increase in concentrations of CO_2 due only to human activity or is it a natural process?

Natural processes like respiration in living organisms, decomposition, ocean-atmosphere exchange, volcanic activity, and wildfires release CO_2 into the atmosphere, playing key roles in the Earth's carbon cycle (Fig. 1.4.4). However, isotope analysis reveals that the recent rise in atmospheric CO_2 primarily stems from human activities, such as burning fossil fuels, which is distinctively different in molecular composition from CO_2 released by these natural processes.

ISOTOPE ANALYSIS

Atoms of the same substance may contain different amounts of certain particles, called neutrons. The number of neutrons in an atom indicates whether atmospheric CO_2 comes from the respiration of living organisms or from the combustion of coal, oil, and natural gas.

Figure 1.4.4 The CO_2 cycle in nature



The ocean, forests, and soils of our planet 'help' human beings by absorbing half of all their CO_2, but the other half accumulates in the atmosphere (Fig. 1.4.4) and increases the greenhouse effect. This causes the atmosphere (Fig. 1.4.5) and then the ocean to warm up (Fig. 1.4.6). The increase in the global mean average temperature between 1850 and 2023 (Fig. 1.4.5) illustrates the WMO finding, based on data from different meteorological centres, that the past nine years between 2015 and 2023 were the warmest years on record. A similar trend is observed in oceans. People have cut down a large share of the world's forests, so their ability to absorb CO_2 from the atmosphere is now less than it was in the past.

Figure 1.4.5 **Increase in the global mean temperature on Earth between 1850 and 2023 as shown by different meteorological centres**

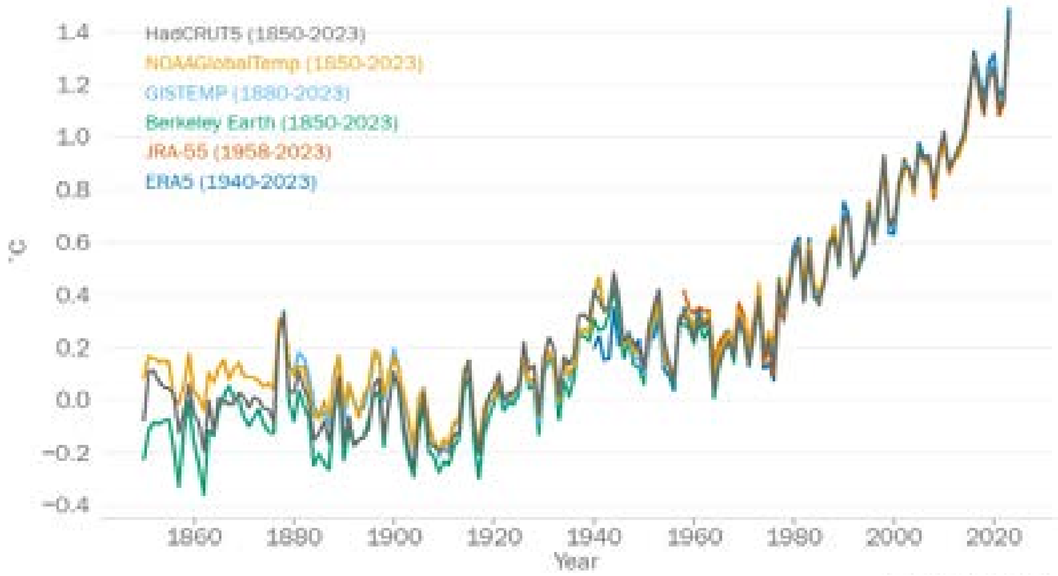
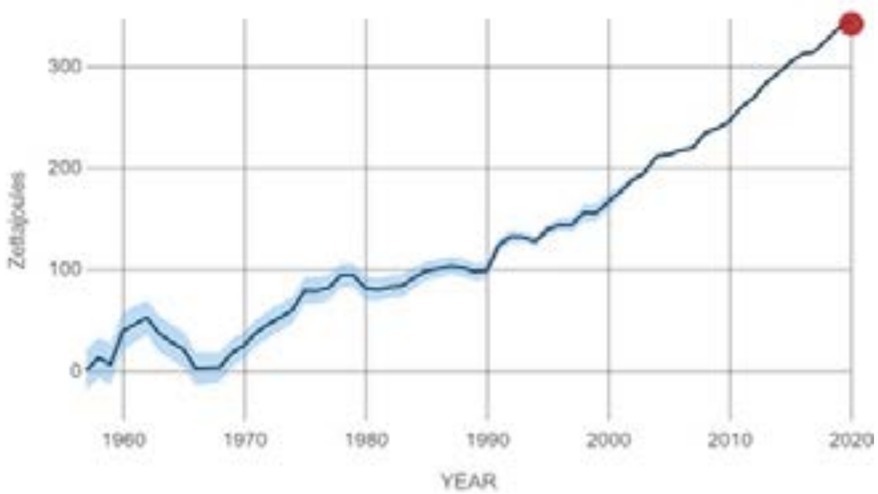


Figure 1.4.6 **Increase in ocean heat content between 1955 and 2020**



Note: Ocean heat content is the heat absorbed and stored by oceans.

The **ocean** plays the most important role of all in shaping the Earth's climate. It contains more than 90% of the energy of the planet's climate system. If only the atmospheric temperature, but not that of the ocean, was rising, there would be much less cause for alarm. This would mean that the main link in the climate system remained unaffected. Unfortunately, the temperature of the oceans is also rising year by year. The annual estimates for warming of the ocean for its first 2,000 metres between 1955, the year when modern recordkeeping began, and 2022 (Fig 1.4.6) present the average over five years – for example, the 2020 value is the average for 2018-2022. So, climatologists believe that instances of cold winters or even a cooling of the air all over the planet cannot signal a halt to global warming, because the amount of heat in the Earth's climate system continues to rise year by year, with most of the increase occurring in the ocean.

Aerosols are yet another factor with sizeable impact on our climate. Aerosols are small particles that come in many forms. They can be natural, like wildfire smoke, volcanic gases, or salty sea spray. Human activities can also generate aerosols, such as particles of air pollution or soot.

Figure 1.4.7 Aerosols emitted by natural and human activities

The role of aerosols in climate science is complex. In general, light-coloured particles in the atmosphere will reflect incoming sunlight and cause cooling. Light-coloured aerosols are those formed from sulphur dioxide (SO_2) gas emitted from volcano eruption, which combines with water in the atmosphere to form tiny particles that can circle the globe and stay in the air for a few years. Burning fossil fuels releases sulphate particles and SO_2 which, like volcanic aerosols, can reflect sunlight and make the atmosphere cooler. Dark-coloured particles absorb sunlight and make the atmosphere warmer. An example of dark-coloured particles is soot, made up of particles of carbon from burning fossil fuels, wood or other plant matter. Because different types of particles have different effects, aerosols are a hot topic in climate research.

Without aerosol pollution, Earth would be around 0.4°C warmer than it already is according to the 2021 IPCC AR6 report. This is compared to the warming coming from the greenhouse gas emissions estimated at around 1.5°C. So, human activity both warms and cools the planet, but its impact on global warming (by strengthening the greenhouse effect) is about three times greater than the cooling effect of aerosols. Therefore, there is every reason to speak of 'climate change' caused by human beings.

As early as the 1970s, the climatologist Mikhail Budyko, who made accurate forecasts of climate change, predicted that human beings would face problems by 2000 in the form of new and 'strange' changes in climate. He was right.

Since the time people began to burn coal, the air temperature on the Earth's surface has risen by nearly 1.2°C, with 0.85°C of that growth occurring in the last 50 years (Fig. 1.4.5). At first glance, the change seems modest and does not seem to pose a threat. But we must remember that this is the average change for the whole planet and for all seasons of the year. The change in certain places has been much greater. Scientists found that the Earth's poles are warming faster than the global average, a phenomenon known as **polar amplification**. This phenomenon is already being seen in the Arctic, which has warmed nearly four times faster than the global average over the past four decades. Recent studies show that the Antarctic is warming twice as fast as the global average.

In some northern parts of Europe, North America and Asia, winters have become colder and not warmer. Looking at weeks and months, we find that the temperature might be 10°C warmer for two to three weeks and then 9°C colder than the average for that time of year in that region in the second half of the twentieth century, with an overall warming of 1–2°C. What is most striking is not the overall change, but the fact that the weather has become much more changeable, with storm winds and heavy rainfall or snowfall.

Didn't the weather behave strangely in the past as well? It certainly did. Alexander Pushkin, the famous Russian poet, wrote in his masterpiece, *Eugene Onegin* (1833):

"That year, the autumn lingered,
In yards and fields, loath to go.
Nature waited, icy-fingered
Winter stalled its fall of snow
Till January the third, at night..."

Pushkin uses Russia's 'old style' Julian calendar, so his 3 January is our 20 December. But that is still very late for the first snow in the central part of European Russia, where it usually starts snowing at the end of October.

Figure 1.4.8 **Tatiana sitting on the bed. *Winter***
Illustration from *Eugene Onegin* by D. Belyukin (Russia, 1999)

In the 19th century too, there were warm days in the wintertime and cold spells in summer, storms and floods, heavy snowfalls and droughts, and even frozen rain that covered everything with a thick crust of ice.

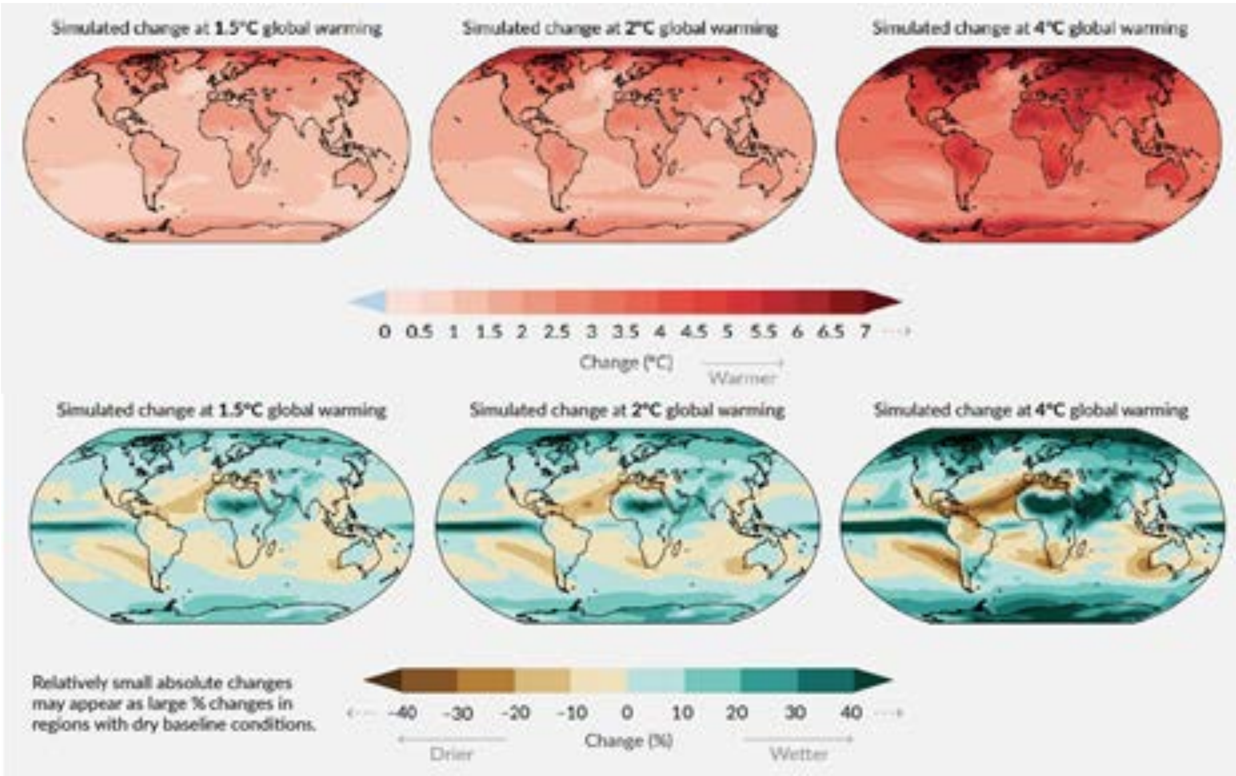
The key point is that such dangerous natural phenomena are now happening more often, and they will become even more frequent in the future. We will continue to experience periods of very cold weather, although, over time, they are likely to become less common. There will be some positive effects from global warming, but at present we see more negative effects.

Using computer models that take account of all the effects (both natural and human-induced), climatologists can explain what is happening now and make a forecast for the entire 21st century. Depending on the level of greenhouse gas emissions, the temperature on Earth could rise dramatically during the current century. In a favourable scenario, the changes compared to the beginning of the 20th century will be 1.5–2°C. But in the worst case the climate could become more than 5°C warmer. Northern Europe is expected to warm more rapidly. Also, the Arctic has warmed nearly four times faster than the global average over the past four decades and it is expected that this warming trend will continue to be more pronounced over the 21st century. This will have a major impact on the levels of precipitation, the sea level, and the frequency and severity of extreme weather events. How the 21st century ends will depend largely on human activity and the actions that we take now. Of course, the influence of the sun, volcanoes, ocean currents and other natural processes is also very significant. But the climate changes they cause are of a short duration and their role over long periods is small.

Scientists stress that every fraction of a degree of global warming results in exponential changes in regional mean temperature, precipitation, and soil moisture. The scientists used a database with hundreds of scenarios to assess how global warming will impact indicators of the climate, such as global temperatures, precipitation, and soil moisture. Because of improvements in global models, they were able to come up with more accurate regional assessments.

Modelling studies now tell us about changes in the annual mean temperature and precipitation resulting from global average temperature increases of 1.5°, 2° and 4°C (Fig. 1.4.9). They suggest that across warming levels, land areas warm more than ocean areas, and the Arctic and Antarctic warm more than the tropics. These results also suggest that precipitation is projected to increase over high latitudes, the equatorial Pacific, and parts of the monsoon region, but decrease over parts of the sub-tropics and in limited areas of the tropics. Many changes in the climate system are projected to become larger in direct relation to increasing global warming, including ocean acidification, melting of ice in the Arctic and Antarctic, and the rise in sea levels.

Figure 1.4.9 Modelled changes in the annual mean temperature (above, °C) and annual precipitation (below, %) relative to 1850-1900 for global average temperature increases of 1.5°, 2° and 4°C



So, most scientists agree that humanity has most probably played the biggest role in the climate change taking place on Earth for the last 70 years (since the mid-20th century) and which will continue in the coming century. They strongly emphasize the urgent need to reduce greenhouse gas emissions in the current decade if we are to have a fair chance of keeping the rise in temperature well below 2°C and 1.5°C.

The biggest human impact on the climate system is from greenhouse gas emissions caused by the combustion of fossil fuels: coal, natural gas and petroleum products. Reducing the use of fossil fuels by power plants, transport, industry and in everyday life will reduce human impact on the climate. But the combustion of fossil fuels is not the only factor. Human beings influence the climate by cutting down forests, which absorb CO_2 from the atmosphere, by allowing major leakage of methane gas from pipelines, and by applying new synthetic and potent greenhouse gases in industry. This is what makes it so difficult to solve the problem of climate change: what is needed is a transformation of our societies and the entire world economy, to make it 'green' and climate safe, so that it can work to the benefit of both people and the planet. Scientists stress on the urgent need for such transformation to have a fair chance of stabilizing the temperature increase at safe levels.

QUESTIONS

1. Was there a greenhouse effect in the past? How was it caused?

2. Why has the temperature on Earth risen so much in the last 100 years?

3. Has the growth of CO_2 concentrations in the atmosphere been due to natural causes or to human activity?
How has this been proved?

4. How do we know that human beings both heat and cool the planet?
Which of the two effects is greater?

5. By how many degrees have temperatures risen over the past 130 years?
Has the increase in northern Europe been greater or less than in the world as a whole?

TASK

Find a thick, cleanly sawn log or a large tree stump.

Look at the annual growth rings: you will see that some are narrower than others.

The oldest growth rings are at the centre of the log or stump and the youngest are at the edge.

Wide rings mark warm years and narrow rings mark cold years.
Count how many of the last 20 years were warm and how many were cold.

2

How climate change affects the natural world and human beings

Can we adapt to the inevitable consequences of climate change?

2 How climate change affects the natural world and human beings

Can we adapt to the inevitable consequences of climate change?

Everything in nature is interconnected. Even a small change in one part of the natural world leads to changes in many others. So, as the temperature on the planet rises, we are seeing many other related changes. The level of the world ocean is rising, glaciers and permafrost are melting, the frequency and power of extreme weather events (heatwaves, hurricanes, storms, floods, and droughts) are increasing year by year. New and dangerous infectious diseases and various pests are appearing in places where they were so far unknown. These and other effects of climate change are dangerous to plants and animals, which cannot adapt quickly to such drastic changes. They also cause enormous economic damage and present a threat to human health and even human life.

The recent findings of the IPCC AR6 show that climate change could lead to even more dangerous consequences for people and for the natural world in the future. The scientists concluded that for every 0.1°C that the planet gets hotter, the impacts get worse, and risks get higher (Fig. 2.1). This is why United Nations Secretary-General António Guterres called this report 'a code red for humanity'. But on the flip side, every 0.1°C that's prevented can be crucial in limiting the extent of future damage.

Increased risks with rising temperatures assessed by the IPCC (Fig 2.2) show that even limiting global temperature rise to 1.5°C is not safe for all. At this level of warming, for example, 950 million people across the world's drylands will experience water stress, heat stress and desertification, while the share of the global population exposed to flooding will rise by 24%.

Figure 2.1 The negative impacts of climate change on the environment and human beings by the end of the 21st century, unless we do all we can to reduce greenhouse gas emissions

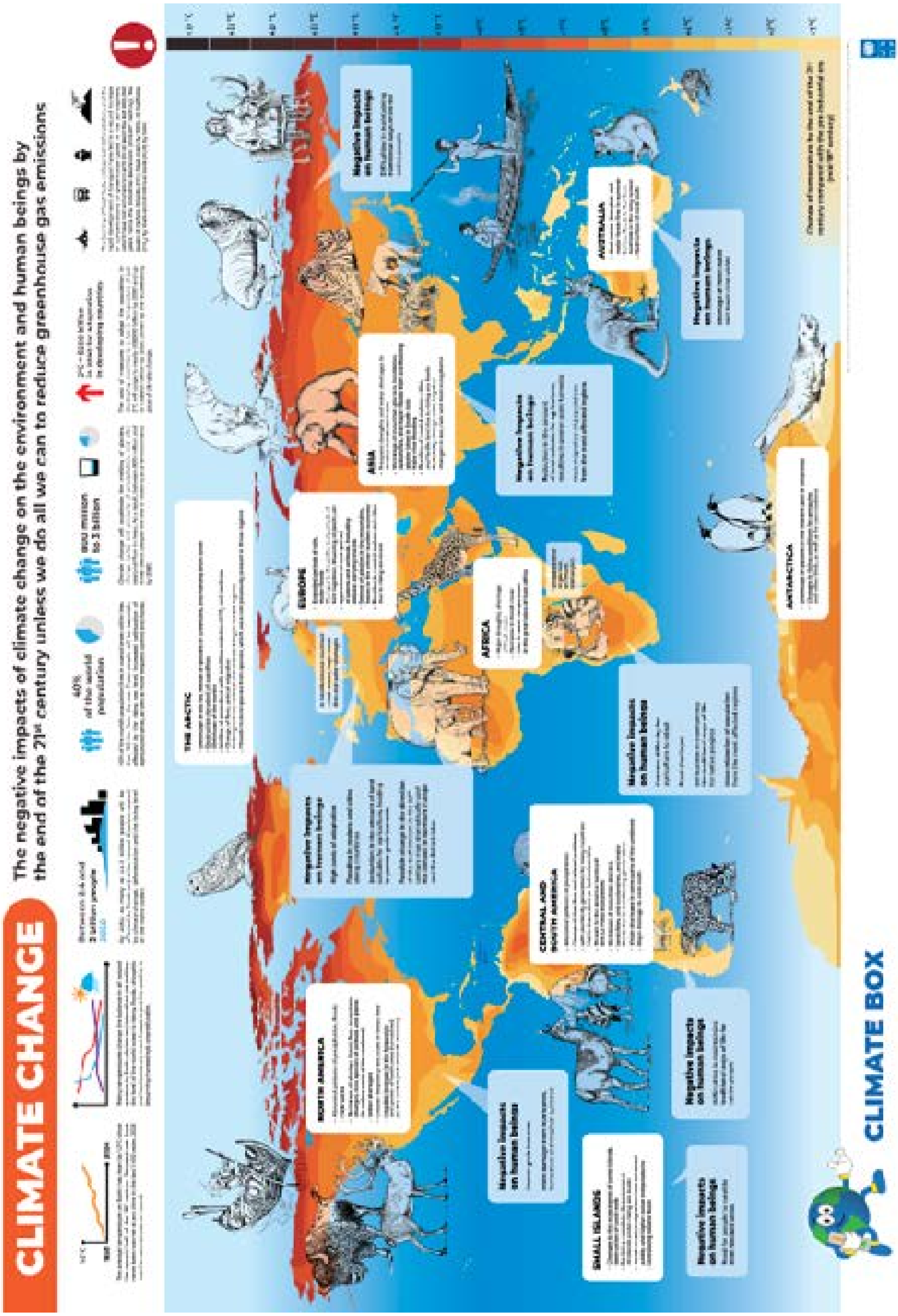
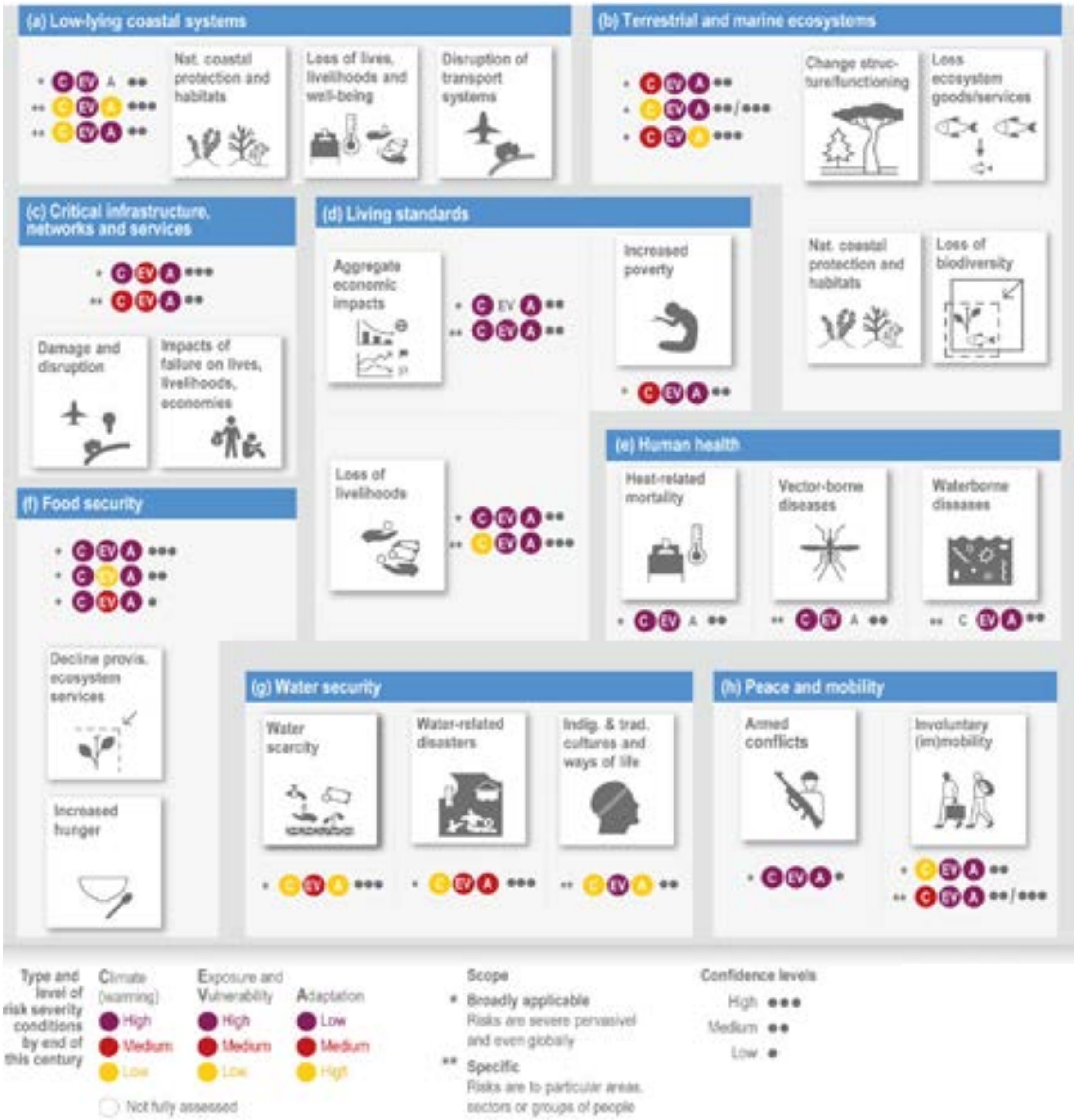


Figure 2.2 Comparing risks at different temperature levels on human and natural systems

	1.5°C	2°C	3°C	1.5°C vs 2°C	1.5°C vs 3°C
BIODIVERSITY LOSS Maximum percentage of species at high risk of extinction across forests and land	14%	18%	29%	1.3x WORSE	2.1x WORSE
DROUGHT Dryland population exposed to water stress, heat stress and desertification	0.95B PEOPLE	1.15B PEOPLE	1.29B PEOPLE	200M MORE PEOPLE	340M MORE PEOPLE
FOOD SECURITY Costs for adaptation and residual damage to major crops	$63 BILLION US	$80 BILLION US	$128 BILLION US	$17B MORE	$65B MORE
FIRES Increases in burnt area across Mediterranean Europe	40-54%	62-87%	96-187%	1.6x WORSE	3x WORSE
EXTREME HEAT Increase in number of days per year with a maximum temperature above 35°C (95°F)	45-58	52-68	66-87	1.2x WORSE	1.5x WORSE
EXTREME HEAT Increase in annual number of heatwaves in Southern Africa	2-4 TIMES	4-8 TIMES	8-12 TIMES	2x WORSE	3.3x WORSE
SEA LEVEL RISE Global mean sea level rise by 2100	0.28-0.55m	0.33-0.61m	0.44-0.76m	1.1x WORSE	1.4x WORSE
FLOODS Increase in global population exposed to flooding	24%	30%	NO DATA AVAILABLE	1.3x WORSE	NO DATA AVAILABLE
CORAL REEFS Further decline in coral reefs	70-90%	99%	NO DATA AVAILABLE	1.2x WORSE	NO DATA AVAILABLE

Today's climate change will indeed reduce agricultural productivity, limit the availability of freshwater, increase the severity of droughts, heat waves and tropical cyclones, and reshape coastal environments on a speed and scale that could provoke destabilizing societal responses. The WMO established that four key climate change indicators – greenhouse gas concentrations, sea level rise, ocean heat and ocean acidification – set new records in 2022. This is yet another clear sign that human activities are causing planetary-scale changes on land, in the ocean, and in the atmosphere, with dramatic and long-lasting ramifications. Unless we do all we can to reduce greenhouse gas emissions, the negative impacts of climate change on the environment and human beings could well be irreversible by the end of the 21st century (Fig. 2.3).

Figure 2.3 **Key risks to natural and human systems stemming from climate change by the end of the century**



Experiences suggest that exploring the resilience of past populations to climatic changes and anomalies could provide key insights into valuable solutions on how to cope with climate change today and in the future. To reduce the damage caused by climate change, humanity must take appropriate measures, especially by building resilience to the human-caused warming that is already baked into the current climate crisis. The evidence from impacts so far and projected risks show that worldwide climate-resilient development action is more urgent than now than ever before.

Feasible and effective adaptation measures are presented for each of the themes discussed in this chapter. They include measures which can reduce risk, such as considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure. They also include measures which can help to safeguard biodiversity and ecosystems that are critical for climate-resilient development, given the threats climate change poses to them and their roles in adaptation and mitigation (Fig. 2.4).

While we all feel the impacts from climate change already, they most hit the poorer, historically marginalized communities. Scientists noted in the IPCC AR6 report that today, between 3.3 billion and 3.6 billion people live in countries highly vulnerable to climate impacts, mostly in the Arctic, Central and South America, Small Island Developing States, South Asia and much of sub-Saharan Africa. Climate change impacts exacerbate existing conflicts, inequalities, conflict, and development challenges (e.g., poverty and limited access to basic services like clean water) across many countries in these regions, and limit communities' capacity to adapt. For instance, from 2010 to 2020, mortality from storms, floods and droughts was 15 times higher in countries with high vulnerability to climate change than in those with very low vulnerability.

This section explores the impacts of climate change on various regions, societies, and economic activities, and presents examples of climate adaptation measures that help mitigate and prepare for some unavoidable negative climate impacts.

Climate change-related hazards, risks, impacts, resilience and adaptation

Today, the Intergovernmental Panel on Climate Change (IPCC) uses the term **resilience** to mean the ability of coupled human and natural systems 'to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure.'

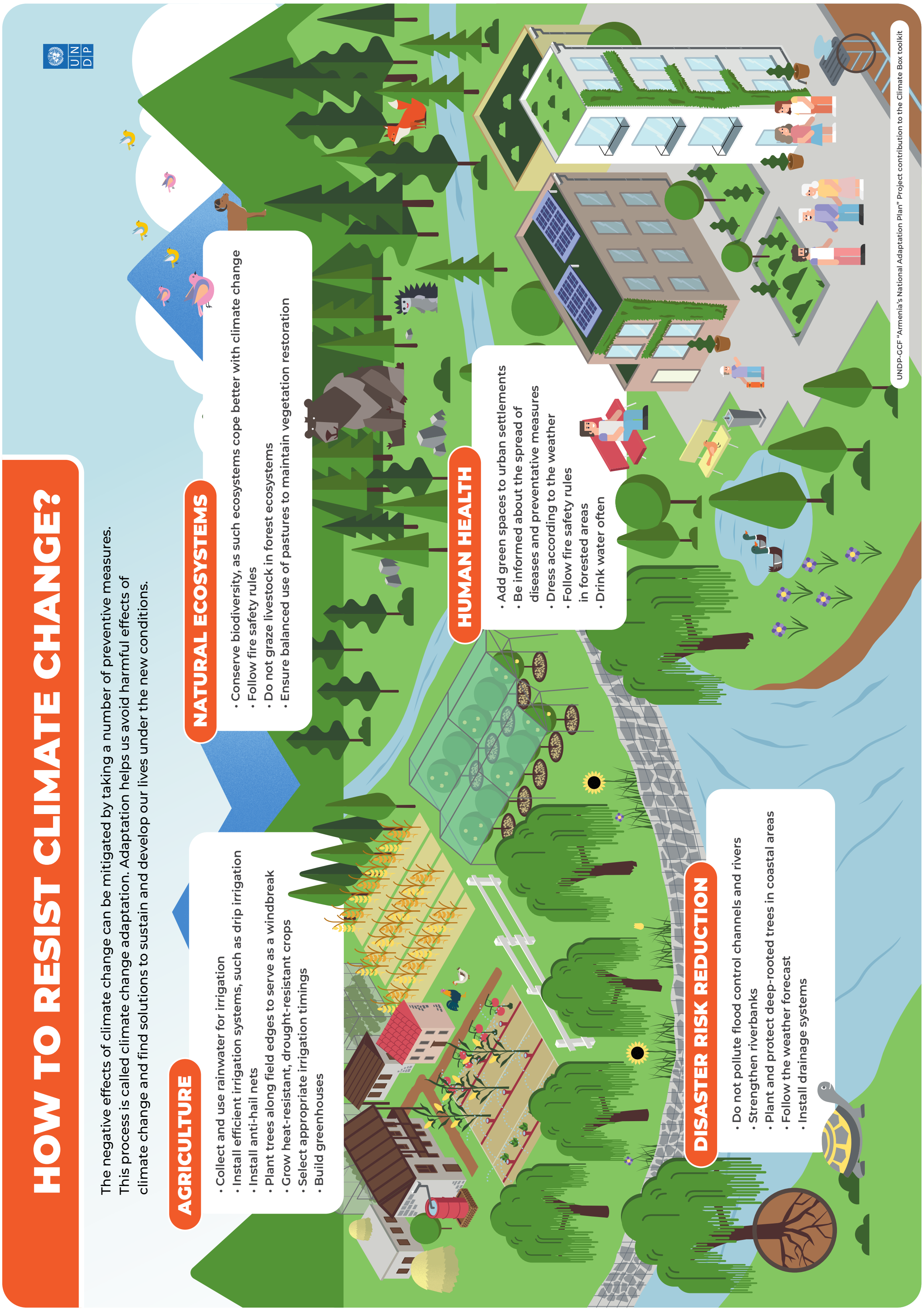
It therefore encompasses **adaptation**, which the IPCC defines as the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. For example, adaptation measures might include the construction of buildings that are more resistant to extreme weather events, building dams to combat floods, developing new, drought-resistant crop varieties, etc.

The IPCC also widely uses the concept of **risks** in relation to the potential for adverse consequences from climate change for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change.

The consequences of realized risks from climate change on natural and human systems define the **impacts**. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure.

Hazards are defined as negative impacts from natural or human-induced physical events or trends that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

Figure 2.4 How to adapt to climate change and build resilience



2.1 How climate change affects **the weather**

Scientists have noted that during the past 50 years the weather around the world has become much more extreme. We hear from time to time of yet another natural disaster: a devastating hurricane in the Philippines, an unprecedented drought in Australia, severe floods in Europe, excessive forest fires due to prolonged heat waves and droughts in Canada, Greece and Hawaii, and snowfall in Cairo and Alexandria, Egypt, for the first time in a century. Every day the temperature hits new records: in Europe we experience exceptionally hot summers, and winter temperatures that plunge suddenly from above zero to -20°C.

Scientists refer to such freak weather conditions as weather anomalies. For example, unusually cold periods in the summer or a prolonged thaw during the winter are the most common weather anomalies in areas with temperate climates in the northern hemisphere. When weather anomalies pose a threat to the health, lives, and economic activity of people, they are **extreme weather phenomena**.

Weather anomalies are any deviation from the ‘usual’ weather in a particular season, month, or day, where ‘usual’ is to be understood as the average state of the weather in that region during a specific past period, most usually 1961–1990.

Extreme weather (meteorological) phenomena are natural processes and events associated with weather conditions that arise in the atmosphere, or on inland or ocean waters, the effects of which can lead to the destruction of people, animals, and plants, and can cause serious damage to the economy.

Extreme weather events include prolonged heat or extreme cold, very strong wind, hurricanes, tropical storms (typhoons), dust storms, heavy rain, heavy snow, whirlwinds or tornadoes, floods, droughts, avalanches, landslides, and many others.

Note: earthquakes, volcanic eruptions and tsunamis are not dependent on climate and weather, so they are not WEATHER phenomena!

Figure 2.1.1 **December rain instead of snow in Moscow is no longer a rarity**

Severe sand and dust storms in the Middle East in 2022

Severe sand and dust storms are defined as storms caused by intense winds over areas of arid soil that pick up large amounts of ground material in the atmosphere. Approximately two tonnes of sand and dust enter the atmosphere each year, according to the United Nations Coalition to Combat Desertification. Sand and dust storms occur most frequently over deserts and regions with dry soil. In the Middle East and other arid regions, they can come in two forms. **Haboobs** (Arabic for 'violent wind') come from storm fronts and often appear as walls of sand and dust marching across the landscape. But like thunderstorms, haboobs don't last long. Then there are the long-lived, wide-reaching dust storms that can last for days. In Iraq, such storms are often associated with the persistent north-westerly winds, called **shamal** (Arabic for North). The construction of more dams, mismanagement of water, extreme dryness, desertification, and other factors all contribute to this nightmarish phenomenon.

In April and June 2022, Iraq and other countries in the Persian Gulf were looking up at an apocalyptic orange sky with a flurry of sand and dust storms. There were reports of port, airport, road and school closures, and flight cancellations. The storm sent thousands of people to hospitals with breathing problems. Dust storms can be especially dangerous for people with asthma; besides, they can transport disease microbes. Dust storms also cause loss of soil, especially its nutrient-rich lightest particles, thereby reducing agricultural productivity.

In recent years, sand and dust storms have become more common in the Middle East and other arid parts of the world, such as North Africa, Northern China, Mongolia and Kazakhstan, Australia, as well as central United States. In Mauritania, where the Sahara Desert covers 90% of the territory, there were just two dust storms a year in the early 1960s, but there are about 80 a year today, according to experts at Oxford University.

Scientists say that more frequent dust storms result from poor farming practices, including overgrazing and ripping up the biological crust, as well as climate change and associated increases in global and local temperatures and droughts. It is now established that sand and dust storms are a global phenomenon that affect our economies, health, and environment, and not just in the drylands. This phenomenon impacts everyone – men, women, boys, and girls – but not all in the same way. The differences stem from gender-based roles in the productive, economic, family and social spheres. Furthermore, sand and dust storms can be life-threatening for individuals with adverse health conditions. They are directly related to land degradation and can be addressed through sustainable land management and by achieving land degradation neutrality.

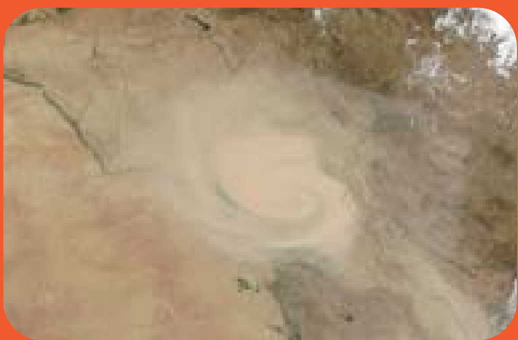


Figure 2.1.2

Satellite image of a dust storm in Iraq on 7 and 9 April 2022

So, what is happening to the weather and what does climate change have to do with it?

Observations suggest that the number of odd weather patterns and extreme weather events is increasing steadily all around the world. Scientists believe that this may be linked with global climate change. As the average temperature on the planet rises, the evaporation of water from oceans, lakes and rivers increases. This in turn increases the amount of moisture in the atmosphere, which leads to heavy rain in some areas. Also, higher temperatures in the surface waters of oceans are causing highly dangerous tropical storms (typhoons) to occur much more often than they did in the middle of the last century.

As we would expect, climate change also leads to more frequent heat waves.

HEAT WAVE
is a period of at least five days, during which the average daily temperature is at least 5°C higher than what is normal for these days of the year.

A recent study published in *Nature* magazine says that heat extremes that previously occurred only once every 1,000 days are now experienced every 200–250 days. However, the effects of warming will vary around the world. Weather events at the equator will become more extreme, meaning poorer tropical countries with already frail infrastructure will experience more than 50 times as many extremely hot days and 2.5 times as many rainy ones. But some already dry regions including parts of the Mediterranean, North Africa, Chile, the Middle East, and Australia will have higher risks of droughts and freshwater shortages.

Another study in the same issue of the magazine concludes that we are now entering an era with heat extremes that simply would not have occurred without climate change. Using an event-attribution analysis that links actual events with climate change, it shows that the prolonged heat-wave conditions in both Siberia and Australia in 2020 would have been virtually impossible without climate change. The Siberian heat wave resulted in massive forest fires (releasing an estimated 56 million tonnes of CO_2 into the atmosphere) and a collapse of infrastructure from the melting of permafrost, leading to the declaration of a state of emergency. A state of emergency was also declared for the Australian bushfires, associated with exceptional summer heat from late 2019 to February 2020, also known as the Black Summer.

Scientists who analysed the observed record highs in the southern hemisphere's winter and spring in 2023 concluded that those temperatures were made 100 times more likely by climate change.

But it is important to remember that unusual weather is not equivalent to climate change. For example, a very cold winter does not necessarily mean that the climate has become cooler. Data must be collected over a long period (about ten years or more) before we can attribute changes to climate change.

Weather anomalies can cause huge damage to the world economy and lead to the loss of many human lives.

Examples of extreme weather phenomena in recent years

On 13 September 2023, torrential rains from Storm Daniel swept across several areas in eastern Libya. The port city of Derna was the hardest hit, with entire neighbourhoods swept away after two aging structures collapsed, creating a catastrophic situation. The International Organization for Migration office in Libya stated that at least 30,000 people were displaced, and the death toll quickly rose to at least 11,300.

A key reason for the high loss of lives was the lack of dam monitoring or evacuation orders despite Storm Daniel's known path. The lack of state capacity to co-ordinate disaster relief efforts worsened the human impact.

The disaster in Libya comes after a string of deadly floods around the world in September 2023, from China to Brazil and Greece.

Tropical cyclones hitting underdeveloped and underprepared countries like Myanmar, Bangladesh, India, the Philippines, and Honduras have also seen very high death tolls in the past. Nations without the resources and political stability to adequately prepare for natural disasters bear damages with huge consequences for people and the economy.

Figure 2.1.3 **The city of Derna, Libya on Wednesday, 13 September 2023. Floods from torrential rains killed thousands of people and washed entire neighbourhoods into the sea**

Extreme weather events in Africa in 2023

While Libya's floods in 2023 made global headlines because of the scale of the death toll, many other deadly extreme events in Africa failed to make international news. An analysis of all disaster data, humanitarian reports and local news stories by the research think tank, Carbon Brief, helped to create a more complete picture of the scale of extreme weather impacts in Africa in 2023 to date.

It shows that at least 15,700 people have been killed in extreme weather disasters in Africa in 2023 and 34 million have been affected by extremes:

- More than 3,000 people were killed in flash floods in the Democratic Republic of the Congo and Rwanda in May. Scientists were unable to assess the role of climate change in the disaster because of a lack of functioning weather stations recording data in the region.
- At least 860 people were killed in floods and mudslides in February during Tropical Cyclone Freddy, the longest lasting cyclone on record affecting Madagascar, Mozambique, Mauritius, Malawi, Réunion and Zimbabwe.
- More than 29 million people continue to face unrelenting drought conditions across Ethiopia, Somalia, Kenya, Djibouti, Mauritania, and Niger.
- Countries in southern Africa have sweltered in a months-long winter heatwave, leaving many facing summer-like conditions for a continuous year.

Examining all recent extreme events and based on recent data, the National Aeronautics and Space Administration of the United States (NASA) confirmed that as Earth's climate changes, it is bringing about extreme weather across the planet. Record-breaking heat waves on land and in the ocean, drenching rains, severe floods, years-long droughts, extreme wildfires, and widespread flooding during hurricanes are all becoming more frequent and more intense. NASA's satellite missions, including the Earth System Observatory, provide vital data for monitoring and responding to extreme weather events, with explanations for each of them (Fig. 2.1.4).

Figure 2.1.4 **The rotating graphic summarizes how climate change influences extreme weather across the planet, resulting in heat extremes, wildfires, droughts, tropical cyclones, heavy precipitation, floods, high-tide flooding, and marine heatwaves**

Heat extremes: Since 1950, the frequency and intensity of heat extremes have increased primarily due to human emission of greenhouse gases. This includes high temperatures and dangerous heat waves. These events will become even more severe and common as the planet warms.

Wildfires: Hot, dry conditions raise the risk of wildfires. Acting as fuel, dry vegetation allows fires to keep burning once they start. As temperatures continue to raise globally, wildfires could become more frequent and intense in some regions, threatening lives and property.

Droughts: As the planet warms, some dry areas are getting drier. Warmer temperatures lead to greater evaporation of water from the surface, turning it into water vapour in the air. Since warmer air can hold more water vapour, this creates a cycle that leads to greater warming and even more evaporation. With less surface moisture, droughts of increasing frequency and severity occur.

Tropical cyclones: With a warmer ocean and more moisture in the air, tropical cyclones can produce more intense and sustained rainfall. Hurricanes, typhoons, and tropical cyclones are also raising coastal flood risk because rising seas lead to higher storm surges. Plus, the storms that form have a greater chance of rapidly intensifying.

Heavy precipitation: As the Earth's temperature rises, the warmer atmosphere can hold more water vapor – providing more water for intense rainfall, snowfall, and other precipitation from storms. Heavy precipitation is already occurring more often and will become more frequent and intense with increasing global temperatures.

Floods: Increases in water vapour in the atmosphere mean some wet areas will get wetter. Extreme precipitation can exceed the capacity of natural and human-made drainage systems, leading to damaging floods. Rising sea levels will also worsen flooding near the coast.

High-tide flooding: As global temperatures increase, ocean warming, and the melting of land ice are causing sea levels to rise. This means high tides will become higher, leading to a greater risk of flooding even when it's sunny. This is already occurring in some coastal cities like Miami and Bangkok.

Marine heat waves: Global warming can lead to extreme heat waves within the ocean. Corals and other marine life are not necessarily adapted to these higher temperatures and may die during multiple-day heat waves. Just like on land, marine heat waves are predicted to get more frequent and intense as the Earth warms.

Combined impacts: Many of these extreme weather events happen in combination with others. For some locations, heat waves and droughts are occurring together more often, a trend likely to continue as the planet warms. The same goes for flooding events, as heavy rainfall from storms and rising seas will increase potential damage along coastlines.

Can we predict extreme weather in advance?

Unfortunately, in most cases it is impossible to predict extreme weather phenomena. The maximum weather forecast range is up to 14 days, as the atmosphere changes completely every two weeks and air flows cannot be tracked for a longer period. For example, the most that can be said in advance is that 'the winter will be 1°C cooler than usual on average'.

Short-term forecasts are more accurate. Weather forecasts for tomorrow, made by European meteorological services, are correct in 96% of cases, predictions for the day after tomorrow are right in 93% of cases, and 90% of three-day forecasts come true. At present long-term warning of severe weather events can be made only in general terms. For example, it can be predicted that the extremely high temperatures, which are now seen in northern Eurasia every 20 years, will occur three times more frequently (once every seven years) by the mid-21st century, and probably every three to five years by the end of the century, making them almost a common phenomenon.

Should we put faith in weather lore?

Weather lore is folklore related to the prediction of the weather. Despite its popularity, it is of no help when it comes to weather forecasting. Even in the days of our grandfathers and grandmothers, traditional ways of predicting the weather often failed to work, and nowadays weather lore has completely lost its linkage to specific places where it might have been applicable. For example, the English have a saying, "Ash leaf before the oak, then we will have a summer soak; oak leaf before the ash, the summer comes without a splash." This used to be true in certain parts of Britain. But people began to move around the country and abroad, taking the saying with them. The result has been confusion, and weather lore has lost any validity it might have had.

What are we to do? How can we deal with extreme weather events? Can we adapt to them?

The United Nations has recommended early warning systems as key elements of climate change adaptation and climate risk management, particularly for extreme weather events and sea level rise. Such systems can help communities living in coastal areas, along flood zones and reliant on agriculture, to deal with flooding and cyclones and thus reduce their vulnerability to extreme events. United Nations Secretary-General António Guterres has called for every person on the planet to be protected by early warning systems by 2027. He launched the Early Warnings for All Initiative (EW4All) in November 2022 at the Climate Change Conference (COP27) in Sharm El-Sheikh, Egypt. The United Nations also launched a partnership, Climate Risk and Early Warning Systems, to help high-risk countries with neglected warning systems in developing them. Similarly, WHO recommends early warning systems to prevent increases in heatwave-related morbidity and disease outbreaks.

Hurricane Irma in Antigua and Barbuda in 2017

There are several good practices in reducing the damage and devastating impacts of storms and hurricanes. In Barbuda, Hurricane Irma wreaked havoc in 2017, resulting in huge losses to property and the evacuation of all 2,000 inhabitants of the Caribbean Island to neighbouring Antigua. With financial assistance of of US$10 million from the global Adaptation Fund, Antigua and Barbuda have been implementing a climate change adaptation project since 2017. The project is designed to help the most vulnerable communities in the coastal McKinnon watershed to build resilience against flooding, hurricanes, and higher temperatures by adopting an integrated approach. Measures include restoring natural drainage canals and climate-proofing vulnerable homes and storm shelters to reduce flooding and disaster risks:

- Restoring natural drainage canals: by cleaning, widening and deepening drainage canals, retention ponds and culverts to natural sizes, this measure aims to build capacity to handle extreme rainfall and storms.
- Climate-proofing vulnerable homes: by providing access to an innovative, low-interest revolving loan programme, this measure helps vulnerable households to climate-proof their homes.
- Storm shelters to reduce flooding and disaster risks: by supporting community groups in depressed areas with grants, this measure sought to develop climate-resilient buildings to serve as storm shelters. The project also enhanced collaboration with other funds such as the Global Environment Facility's Special Climate Change Fund by undertaking a hydrological study with their support and providing potential to scale it up.

Source: www.adaptation-fund.org.

In addition, you don't need to be a scientist or a climatologist or even to work for the emergency services to answer the question of how to deal with extreme weather events. The answer is simple: you must start with yourself. You need to be observant, and you need to care. To be observant is a straightforward matter: keep up with the latest science news; don't ignore calls to consider climate change when you work on long-term projects (for example, the construction of a new railway in a permafrost area should consider the increased melting of permafrost). To be caring is a more complex task: we need to be more careful in our behaviour and change our habits – we need to learn how to save energy and how to behave in extreme weather situations. For example, it is useful to know how to provide first aid to somebody who has fainted from the heat.

How to keep safe in a hurricane, storm, whirlwind or tornado

When you hear a storm warning:

- close doors, windows, attic hatches and vents
- remove items that could be carried by the wind from windowsills, balconies and loggias
- turn off gas, water and electricity, extinguish fires in stoves and fireplaces
- prepare stocks of food and drinking water
- make sure you have all essential things and documents
- take shelter in a basement or a strongly built structure

If a hurricane, storm or tornado occurs without warning:

a) if you are at home:
- move away from the windows
- stay in your home and hide in a safe place (the basement or ground floor is best)

b) if you are outdoors:
- take shelter in an underpass, shop or the porch of a building
- find natural shelter (a ravine, pit, ditch, etc.), go as far down as possible and lie flat on the ground
- stay away from billboards, bus stops, trees, bridge supports, power lines;
- do not in any circumstances touch electrical wires that have been torn loose by the wind

Do not leave your shelter immediately after the extreme weather has passed, as more strong winds could blow unexpectedly.

QUESTIONS

1. Is it harder to predict the weather for urban and rural areas? Why?

2. Imagine that your family wants to celebrate New Year out of doors. But what you do will depend on the weather: you might need to stay indoors if the weather is too bad. What is the earliest date when you will be able to predict the weather on December, at least roughly?

3. Why does extreme weather represent a danger to people?

4. Is an earthquake an extreme weather event?

5. Did the extreme weather events that we see nowadays (strong winds, floods, heat waves, etc.) also occur in the past?

6. What kind of adaptation measures are recommended to address the climate impacts of extreme weather?

TASK

Find out from your geography teacher what the main features of climate are in your location.

What was last summer like: was it warmer or colder than usual?

2.2 How climate change affects **plants and animals**

What is biodiversity?

BIODIVERSITY
is all the various species of plants and animals, fungi and micro- organisms, as well as the many combinations of environments (landscapes) and the huge number of variants between the genes of similar organisms. In other words, biodiversity is the multiplicity of forms and manifestations of life on Earth.

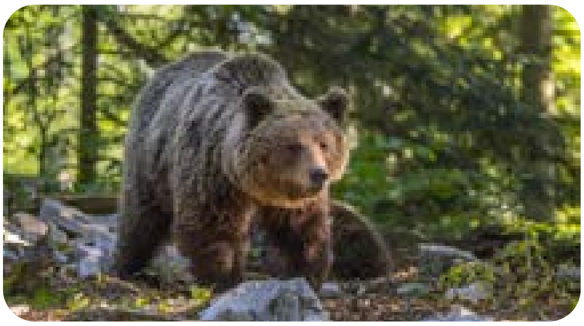
Scientists distinguish **three main types of biodiversity**:

- genetic (between organisms of the same species);
- species (between all of the living beings on the planet);
- landscape or ecosystem (between all the combinations of environments where organisms live).

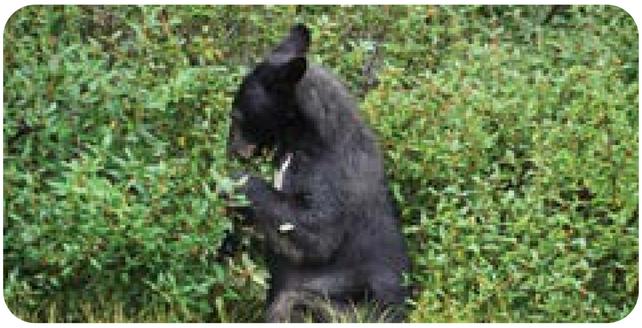
What is **genetic diversity**? Take an example: all the geese in a flock of wild geese may seem the same. In fact, they are all slightly different from one another. Remember how, in the remarkable story about Nils' journey with the geese, each bird behaved differently. Of course, that is just a story, but it is basically true. One goose is quicker than the others to notice a fox creeping up on the sleeping flock across the ice; another remembers where to find a glade with lush grass beside a lake; and a third is better than the others at finding its way by the stars. So, the whole flock benefits from the special skills of the individuals in it. And this doesn't apply only to wild geese. Every kind of animal or plant needs to solve different problems to survive, and they do it better if they each have different special abilities than if they are all the same, like robots built on the same conveyor belt.

Genetic diversity brings new species into existence. Biologists believe that differences in behaviour and appearance – between two bears, for example – can increase over generations. And after many years the great-great-great-grandchildren of these bears settle in different regions, begin to hunt for food in different ways and prepare for hibernation differently (or even give up hibernation). That is how two different species came into existence – in this case, the Brown Bear and the Asian Black Bear.

Brown Bear



Asian Black Bear



The **difference between animals of different species and larger taxonomic groups**, such as phylum or class, is clear: you don't have to be a scientist to tell a dandelion from a plantain, a dragonfly from an ant, or a crow from a fox. But why are these and millions of other species of living beings so different?

African savanna and its inhabitants

Each species of organism on the planet has its own special role. In the African savanna, the top part of the grass is eaten by zebras, the parts further down by antelopes and wildebeest, while gazelles gnaw grass near the ground, and warthogs dig out the roots and tubers. So, plant food is completely used, and the different animals are not in competition. This means that most animals living in a particular region are well-fed and healthy, and the whole ecosystem will remain stable for a long time – all thanks to species diversity.

Ecosystem diversity is easy for any attentive traveller to see if one can distinguish an alder forest from a birch wood or a coral reef from mangroves. The countless variety of ecosystems in nature is like colourful scenery, against which the endless cycle of life unfolds – except that the scenery itself plays a very important part in the cycle. Species diversity creates living conditions for huge numbers of organisms, providing them with sources of food and water, shelter, and migration routes. For example, some plants living in moist ravines can survive a severe forest fire. If excessive numbers of a certain type of insect threaten potato crops, they will be stopped by a zone where the soil freezes to a considerable depth in winter. The greater the diversity of natural conditions, the higher the chances that various species will survive, and that the ecosystem will be preserved.

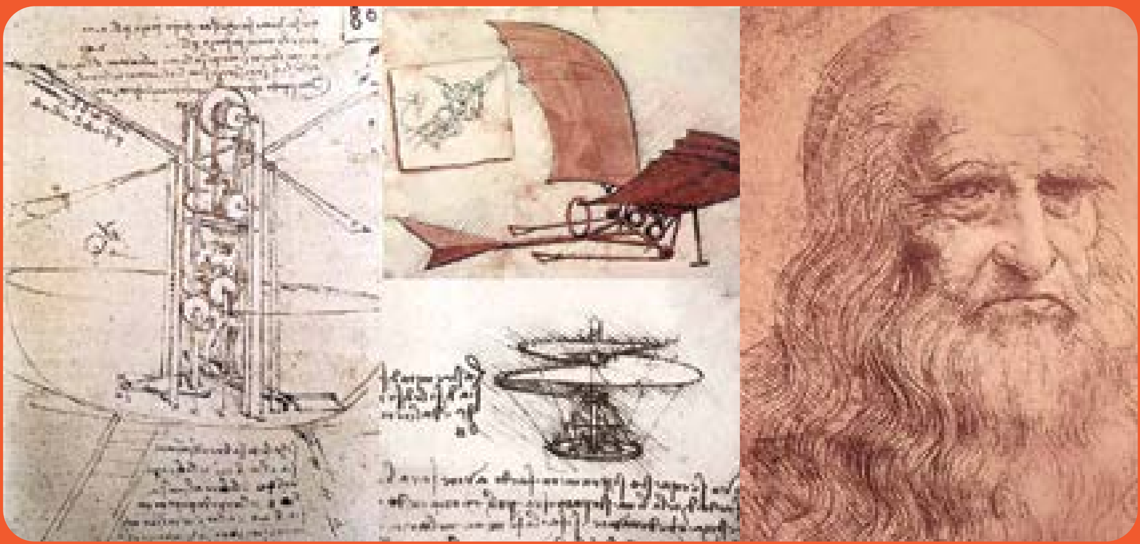
Species are unevenly distributed across the surface of our planet. The diversity of species in nature is at its greatest around the equator and decreases towards the poles. The richest species diversity is found in the ecosystem of tropical rain forests, which cover about 7% of the planet's surface but contain more than 90% of all species that are currently known.

Why is biodiversity so important?

Remember that until very recently (in historical terms) everything that people ate, and used to build their homes, as medicine, to make clothes, and for transport, was taken from nature. Yes, but not anymore, you might say. But you would be wrong. For example, modern scientists still spend much time searching in rainforests for natural raw ingredients for new medicines. Wild plant species are needed to create new crop varieties. And engineers have 'borrowed' many of their most original technical inventions from the kingdom of animals, plants, fungi, and microorganisms.

But that is not the most important role of biodiversity. What is most important is that biodiversity creates a habitat for all living beings, including human beings. What exactly does that mean? For many millions of years everything that grows, runs, swims, crawls, and flies on our planet, has adapted to the composition of the Earth's atmosphere. Changes to this 'cocktail' of gas might only be very slight. But even a slight reduction of the oxygen content in the air we breathe would make us and many other animals feel unwell. If oxygen levels fell even further, we would feel much worse. And what maintains the levels of oxygen in the atmosphere? Green plants!

The **science of bionics** offers solutions to engineering problems by using knowledge of the structure and functioning of living organisms. For example, the design of a new lining for the hulls of ships was based on studies of the structure of dolphin skin, and it has increased the speed at which ships can travel by 15-20%. The great artist and scientist, Leonardo da Vinci, was one of the founders of bionics: he tried to build an 'ornithopter', a flying machine with wings that flapped like those of a bird.



All plants and animals, micro-organisms and fungi form a highly intricate and finely adjusted system. Imagine that you and your friends spent two whole years on a spaceship flying to Mars and back. Think of all the different parts, devices, and other equipment that the spaceship would contain. Can you think of our planet being like that spaceship? Each of its ‘parts’ was created by millions of years of evolution, with the action of each part tuned to work in harmony with thousands of others. What would happen if an error by one of the crew or a meteorite damaged several devices on the spaceship? You could replace them with other similar devices, at least for a while. But what if you then suffered some other space accident?

Biological diversity in our planet is quite similar. Every organism has an important job. One processes energy from the sun, another uses that processed energy to chase prey or escape from predators, a third breaks down dead wood or the remnants of dead animals, and so on. Every one of them, from the vast baobab tree to the smallest lichen, from the mightiest whale to the lightest jellyfish, are all-important components of life on planet Earth. And there are organisms that we have yet to discover.

There may not be many of them, but they are also necessary. You might say: “There have been times in the history of life on the planet when whole groups of organisms became extinct. So, the loss of one species is no disaster, or even of a dozen or a hundred...” But stop! You are wrong! We don’t know how many losses our ‘spaceship’ can tolerate. Perhaps we have already overstepped the mark. In the short history of mankind, nature has irretrievably lost not a hundred or a thousand species, but many more.

Another important point is that biological diversity can be viewed as a measuring device that shows the sustainability and state of health of the natural world. If there are plenty of different species of living organisms, all playing their proper role, then the tropical rainforest, ocean reef or forest wetlands can continue to exist far into the future.

Ever since the beginning of history, one of the harshest punishments has been to lock a person for a long period of time in a small cell with grey walls where they cannot see the sky or communicate with fellow human beings.

If the world contains fewer plants with beautiful and fragrant flowers (or even inconspicuous and odourless flowers), fewer weasels and twirling swifts (or clumsy armadillos and slow-moving tortoises), then our shared planetary home will become more and more like a dull, grey prison cell.

What are the threats to biodiversity?

Human activity poses the biggest threat to the undisturbed existence of wild nature in all its biodiversity. We cut down forests, plough up the steppe, burn savannas, drain swamps, hunt for game, catch fish, and pollute our rivers. Of course, we do not intend to destroy the natural world. We want to feed our growing population, obtain wood to make things, produce energy, breed livestock, make room for our cities, roads, military sites, and landfills, and much more. Biodiversity is highly vulnerable to changes in natural conditions – from changes in temperature, forest fires, and melting of permafrost to drying out of wetlands and fluctuations in the level of the ocean. You already know why these changes are happening.

One unusually hot summer is not a disaster. Over thousands of years of evolution, plant and animal life has adapted to short-term fluctuations in the climate and gradual changes in nature. But what does pose a threat to biodiversity is rapid and irreversible changes in the environment, particularly changes in the climate. Let's try to figure out why.

Mass extinctions and climate change

Throughout the entire period of life on earth that is known to science (three billion years, no less), there were several dozen periods of abrupt climate change that led to a marked reduction in biodiversity. Five of these stand out and are commonly referred to as the 'great extinctions.'

One of the most dramatic occurred about 250 million years ago. At that time the Earth was not yet populated by the plants and animals familiar to us now, but the diversity of life was already substantial. And then, quite suddenly in geological terms, in the space of a few million years, nearly all species of animals and plants disappeared (there were far fewer plant than animal species at the time, since life in the oceans and seas, consisting mainly of animals, was much richer than on land).

The disappearance of certain species and the appearance of new ones is a constant process in the geological history of the Earth's biosphere: no species can exist forever. Extinction has been compensated by the emergence of new species, and the total number of species has grown. The extinction of species is a natural evolutionary process that occurs without human intervention.

What mysterious causes led to the almost complete extinction of some species and the emergence of others? Scientists have strong reasons to suppose that the main causes were major changes on the planet surface, namely the drift of continents over the Earth's crust (we learned about this in previous sections). Continental drift transformed the layout of the natural world as it then existed, including the position of mountain ranges and the system of ocean currents, and, of course, radically changed the Earth's climate. After ancient eras when the world was cooling down, there came a time of climate warming. The climate became drier and seasonal fluctuations in temperature increased. The levels of oxygen in the surface atmosphere also changed. All this led, as we have seen, to the large-scale replacement of certain species by new species of living beings.

The extinction of species was repeated, but never again on the scale of this first event. About 60 million years ago there was another abrupt alteration of conditions on the planet, which led to the extinction of the last dinosaurs. This was also accompanied by climate change, which sped up the process of replacement of some animals and plants by other new species. Other groups of living beings, such as ammonites (sea molluscs similar in shape to rams' horns) and belemnites (whose fossils resemble arrowheads), followed the dinosaurs out of existence. Almost half of all sea creatures disappeared at that time, and how many disappeared on land is not precisely known, because the remains of land organisms are much less well preserved.

Ammonites

Belemnites

The cooling of the climate was accompanied by the formation of ice caps at the earth's poles. The huge tracts of ice that now exist in Greenland and Antarctica can be seen in photographs of Earth from space. How much water is needed to form such ice caps? A great deal. And where does it come from? Only from the ocean. When ice caps form, sea levels drop and living conditions for all organisms that live along coasts, in water and on land, change drastically.

So, among its other effects, climate change affects biodiversity and, in the initial stages, makes it worse. Afterwards life on the earth gradually recovers, but it never reappears in its previous form. Millions of years are required for recovery, and species that have become extinct will never return. Do we want to face extinction as a species?

Which animals react most quickly to climate change?

Of course, everything that we have discussed up to now happened in the long distant past, a past so distant that we cannot even imagine it. But how is climate change in our time impacting wildlife in all its diversity?

The impact of human activity and abrupt climate change has led to rates of species extinction across the planet that are many times greater than the rates that occur in nature.

Small animals with short life cycles are particularly dependent on environmental conditions and therefore respond faster to climate change. Of course, large organisms also react but, in their case, the effect take much longer to see. For our purposes as researchers, we want to know about events taking place today or will take place soon that we will live to see.

A modest but sustained rise of average temperatures by 1.5°–2°C in the mountains of Slovakia has led to unexpected consequences. Beautiful, warmth-loving butterflies of the swallowtail family – the Podalirius and Machaon – have spread beyond the forest-steppe zone, in which they lived, and begun to appear in cooler and damper meadowland. They have also begun to reproduce three times a year instead of twice, as before.

Other butterflies, of the Araschnia genus, previously had a different colour depending on the season: brown in spring, black in summer and brown again in autumn. But they have now assumed black colouring at all times of the year.

Also in the Slovak mountains, biologists have established two opposite tendencies in the life cycles of the spruce bark beetle and the winter moth caterpillar. The beetles have expanded their habitat area as temperatures have increased, while the voracious caterpillar now feeds less on its favourite trees. In both cases, there is a direct correlation between temperature changes and insect behaviour.

Machaon butterfly

Spruce bark beetle

The yellow-striped pygmy eleuth is a small frog that inhabits tropical forests, where fluctuations in temperature and humidity during the day and through the year are small but do occur. Scientists became interested in the peculiarities of the relationship between the frog and a parasitic mould that grows on its body. It was found that the parasite is much less vulnerable to a change in environmental conditions than its host. So, climate change makes the parasite more dangerous to the frog, jeopardizing the entire population of the host species.

Yellow-striped pygmy eleuth

In the cold waters of the Southern Ocean, even the slightest increase in temperature leads to an increase in acidity and reduction of oxygen content. This has led to mass migration by bivalvular molluscs of the species Laternula elliptica away from the danger zone. However, older molluscs (aged more than three years) lack the muscle strength to migrate and are perishing in large numbers. You may ask: can't these creatures settle in new regions and restore population numbers? But it is not so easy: the species is only able to reproduce after the third year of life, when it loses mobility.

Laternula elliptica

Coral reef

Corals have also been among the first to be affected by climate change. Corals are highly sensitive organisms. Water that is too warm or too cold, lack of light and excess impurities all act to slow down or stop the growth of corals. Coral polyps cannot move about and are very poorly adapted to environmental changes. They must live and die where they are born. The micro-algae that absorb the energy of sunlight for coral polyps are very dependent on water temperature. At many places on Australia's Great Barrier Reef, scientists are seeing the death of algae and bleaching of the coral, which occurs when the reef dies. This is because repeated marine heat waves over the last several years have turned much of the Great Barrier Reef a ghostly white colour. Smoke from severe forest and peat fires in Indonesia often leads to atmospheric emissions of iron compounds, which cause the rapid flowering of algae that produce substances that are toxic for corals.

Yet, there are some recent successful innovations in saving corals. The Australian Institute of Marine Science is propagating large numbers of healthy corals in an aquaculture facility to gain a deeper understanding of coral reproductive biology and ecology. The institute is collecting coral fragments from the reef, which are spawned and fertilized, and the larvae then reared in nurseries and settled onto specially designed surfaces. Settled corals, or fragments made from the adults, are placed on devices on the reef. Divers then revisit the sites to identify and understand the environmental conditions in which corals survive and grow best. This knowledge will help design and upscale coral aquaculture systems to enhance end-to-end survival of corals on degraded reefs, from spawning to settlement and adulthood.

Salps

Warming in polar regions is reducing the area of seasonal sea ice, the underside of which is a breeding ground for microscopic ocean plants, called phytoplankton. Phytoplankton are at the beginning of a food chain, which includes krill, fish, penguins and other seabirds, seals, and several sub- species of whales. If there is not enough ice, the phytoplankton cannot grow and breed in sufficient amounts. Krill cannot live in water that lacks sustenance, and their place is taken by translucent, jelly-like salps, which are ancient creatures. This causes an interruption of the food chain as hardly any animals eat salps, except for a few species of fish and sea turtles. So, whales cannot build up sufficient reserves of fat in the winter months, and other creatures also forsake waters that lack the food they need. Once again, we see the complex inter-relationships that exist in nature and are reflected in biodiversity.

The shrinking northern polar ice cap is the most visible sign of climate warming. Polar bears need ice for their migration and to hunt for seals, and the ice is also vitally necessary for the seals themselves, as without it they have nowhere to rear their young. If ice fields start to shrink more than is usual each summer, the seal population also shrinks and hungry polar bears eat the whole carcasses of the seals they catch, instead of devouring only the seal's layer of fat. Previously the remains of a polar bear's meal provided a feast for other inhabitants of the Arctic – the Arctic fox and numerous birds. But now there is nothing left over for them!

Polar bears

As the climate becomes warmer, the forest in the northern fringe of Eurasia is slowly but surely advancing into the tundra at a rate of tens of kilometres each century. This changes the habitat and food sources of numerous types of birds. Warm winters in the Arctic are also disastrous for both wild and domesticated reindeer, as thaws and rainfall in the winter cover the snow with a crust of ice, making it harder for the reindeer to find lichens, which are their staple diet during the winter months.

Reindeer

The lemming, the most numerous inhabitants of the tundra, is also suffering from the warmer climate. The holes they live in are now flooded with water too early in the year, reducing the lemming population and forcing birds of prey and foxes to go hungry.

Lemmings

In the Southern Hemisphere, on the Antarctic coast, which has the appearance of an ice desert with rocky outcrops and very sparse vegetation, researchers are suddenly finding abundant thickets of Antarctic hair grass, a small plant that previously grew only in small clumps between stones, sheltering from the icy winds of the southern continent.

In the Daurian steppe of eastern Russia, between Lake Baikal and the Greater Khingan Mountains of Mongolia, scientists have noted that the climate is growing more arid because of global warming. Lakes and small rivers are disappearing, forest belts are drying out and the vegetation on the steppe is burnt by the sun earlier in the year. The animal inhabitants of the steppe are doing what they can to adapt to the change. Larvae and fish spawn bury themselves deep in silt at the bottom of water courses. Birds migrate to other places, changing their flight paths and nesting sites. There is insufficient food for all the local water birds, such as the cormorant, grey heron, and herring gull. The swan goose no longer nests in the region. Wolves, foxes, badgers and even cranes are moving away in search of more water. Birds of prey, which need plenty of water to digest their diet of meat, are also migrating to more suitable regions. The Tolai hare finds itself short of grass in the summertime, not only to feed on but also to hide from predators. The Tabargan marmot and Daurian ground squirrel, both indigenous to the area, are well-adapted to drought, but are finding life in the new conditions difficult, as they cannot move quickly enough to escape grass fires, an increasingly frequent occurrence in the summertime. Burnt grass also means a lack of winter forage for hoofed beasts, forcing large herds of antelope and gazelle to migrate from Mongolia to Russia.

Tolai hare

The few remaining watering places in the Daurian steppe are now overcrowded with animals in search of water, which increases the risk of disease. As summers become drier, winters have experienced more snowfall, because of which the manul (a species of wild cat) cannot find food. The Daurian hedgehog is almost alone in benefiting from the change of climate: it needs more than five months of warmth for a successful life cycle, so it is expanding its presence in the new conditions.

Manul

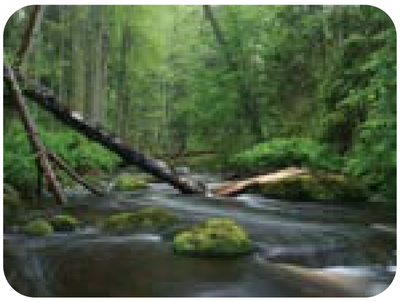
National parks: learning to preserve nature

What is a national park? It is a protected area that can be visited by tourists, where human activity is limited by definite rules. National parks are usually created in places where there are many different landscapes (both typical and unique), rare or endangered animals and plants, and unique geological or water phenomena. Adults and children visit them to learn about global environmental issues. National parks can be used to create nurseries to breed rare species of plants and animals.

Does climate change affect national parks? Unfortunately, global climate change leads to fires, droughts, increases in temperature and many other phenomena that cannot be kept at bay simply by declaring an area to be a national park.

In the Everglades Park in Florida (USA), the conditions for freshwater flora and fauna vary depending on the influx of salty seawater from the nearby Florida Bay, a process being influenced by climate change. Scientists and staff of protected areas understand that such processes threaten the very existence of national parks, and the US Environmental Protection Agency together with the National Park Service have set up Climate Friendly Parks. The programme acquaints park staff and visitors with the causes and consequences of climate change and explains what they can do to help solve global problems associated with climate change.

Lahemaa National Park (Estonia)



Jasper National Park (Canada)

Kruger National Park (South Africa)

The world-famous **Yellowstone Park** was established in 1872. It is the oldest national park in the USA.

The **Great Barrier Reef** is vital to the existence of many living organisms and is being seriously affected by climate change. It is protected as part of the Marine National Park in Australia. One of the seven natural wonders of the world, it is also listed as a World Heritage Site by UNESCO. It is the only living structure on the planet that is visible from space.

The longest pedestrian route through a protected area is also in the USA, in the **Great Smokey Mountains** National Park.

The **Namib-Naukluft National Park** in Namibia (Western Africa) is famous for its remarkable orange dunes that are the tallest in the world, in places rising more than 300 metres above the desert floor. The park has some of the most unusual wildlife and nature reserves in the world and covers an area of over 49,000 km^2 – more than the territory of Switzerland.

Yugyd Va National Park (Russia)

Wildlife reserves: nature without humanity

Wildlife (biosphere) reserves are places where scientists can monitor and record changes in the natural world. In a wildlife reserve it is forbidden even to pick berries or mushrooms or catch fish. Such places are ideal for restoring populations of endangered species, which can then be released into suitable areas outside the reserve.

Biosphere reserves are often created in places where nature is not subject to any substantial human influence. They are used to safeguard typical local ecosystems as well as rare species and communities of animals and plants. For example, the ecosystem to be protected in taiga regions would be that of the taiga, while in a tropical region it would be the tropical rainforest. The conservation of the natural environment in such areas has global importance.

Biosphere reserves exist on all the world's continents. You have probably seen films about such areas in Africa. It is thanks to such biosphere reserves that the diverse natural world of the African continent is being kept alive for us today.

Biosphere reserve Belavezskaja Pushcha / Bialowieza Forest (Belarus, Poland)

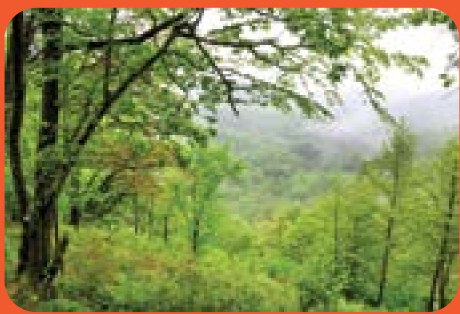
Everglades National Park (USA)

WILDLIFE (BIOSPHERE) RESERVE
is a protected territory where no human activity is permitted, apart from scientific activity.

All biosphere reserves participate in the Man and the Biosphere Programme, run by UNESCO, which supports long-term studies of the environment. Studies are now being carried out in many reserves of the impact of climate change on plant and animal life. Scientists working at the Caucasian State Biosphere Reserve in southern Russia have found that the forest cover on the slopes of mountains is gradually moving higher as the climate becomes warmer.

The **Zion National Park** in Utah in the USA is a fine example of how to achieve environmental safety. About 20 buses, using low-emission gas fuel, carry visitors around the park, replacing about 5,000 cars that visitors would otherwise bring with them. The result has been a significant reduction in greenhouse gas emissions. A 'Green Centre' built at the park to welcome tourists obtains nearly a third of its energy needs from the sun, with 80% of its lighting needs provided by natural light. In the summer the air conditioning system uses special energy-efficient evaporators. In the winter a passive heating system, which uses a wall of heat-absorbing materials (stone, brick) facing the sun, maximizes heat retention.

The **Taganay National Park** in Russia has installed the first eco-friendly energy supply system to be used at a protected natural area in the country. One of the shelters in the park now obtains its electricity from wind energy (wind turbines) and the sun (solar panels). The system automatically determines which of the two sources of energy, solar or wind, should be used at any moment. Previously this and other shelters and facilities at the park were dependent on gasoline- powered generators, an energy source that is both expensive and harmful for the environment. A new lighting system, powered by solar and wind energy, has been installed in Adler at the **Yuzhniye Kultury** section of the Caucasian State Natural Biosphere Reserve in southern Russia.



Wildlife sanctuaries and areas of outstanding natural importance

The point of wildlife sanctuaries is to protect not the whole of the local natural environment, but only individual parts of it: for example, only plants or only animals, or perhaps some geological features (rocks or caves). So, their restrictions on human activity only refer to activity that threatens the protected parts of the environment.

Areas of outstanding natural importance are unique or typical natural areas and landmarks, which have special scientific, cultural, educational, or health-related value. They may be lakes, trees, geological sites, or ancient parks. They are protected by prohibitions on certain kinds of human activity that could damage their integrity.

How do protected areas help to address the problems of climate change

What is the contribution of a national park (and any other protected area) in addressing climate change? The most significant contribution is the reduction of emissions of carbon dioxide into the atmosphere. For example, some parks encourage tourists to use public buses powered by alternative fuel instead of polluting private cars. Park employees themselves also use forms of transport that have minimal impact on the environment. Parks may use energy from the wind, sun, or hot springs in the premises where they receive visitors. Maximum use is made of natural lighting and LEDs, and solar panels provide power for offices. Tourists are offered souvenirs made from recycled materials, the park cafeteria serves dishes made from local products (avoiding 'food miles' and the accompanying transport pollution), made in an environmentally safe manner, and park premises are equipped with water-saving toilets. Visitors receive information on how to behave in a way that is most environmentally efficient and least environmentally damaging.

Ecotourism: harmony between man and nature

Do you enjoy walking and other outdoor activities? If yes, then you and your friends will enjoy travelling and discovering new places. Maybe you will even become ecotourists.

What is the difference between tourists and ecotourists? What sets them apart is their attitude towards the environment. Ecotourism is a recent concept that arose when people began to understand how important the natural world is to us. There are different ways of relaxing outdoors. You can drive into the forest or to the edge of a lake by car, switch on music at full volume, light a fire in the nicest place you can find, have a picnic, and leave a pile of garbage behind you. But there are other tourists who are willing to climb to the top of a mountain just to see a wild animal, find a rare plant, listen to the birds singing, or enjoy the sunset and the silence. Their goal is to see and hear the natural world, which modern people so rarely witness. They don't leave garbage – on the contrary, they often clear up other people's garbage, and make sure to obey all the rules in place to protect the environment. Happily, the numbers of ecotourists are growing year by year!

Ecotourism gives people the opportunity to see the environment in its untouched, natural state, understand how diverse it is, how vulnerable to human activity, and to ponder the question: 'What can I do for my planet?' Ecotourists study the laws of nature and do things that help to maintain and preserve it, they try to reduce their environmental impact to a minimum. What is more, ecotourism firms give a part of their revenue to support the protection and study of the environment.

Many outstanding natural environments are in remote places, in rural areas where people are relatively poor. They are also in areas such as the jungles of South America or mountain regions along the border between northern Thailand, Myanmar, and Laos, which are inhabited by indigenous peoples. Therefore, ecotourists often learn not only about the natural world, but also about human culture. And ecotourism provides work and an additional source of income for people who live in these regions.

So, ecotourism helps people to see the beauty and uniqueness of nature, understand how everything in the world around them is connected, learn how many species of animals and plants live on our planet, and realize the extent to which the state of the environment depends on the actions of each person, teenagers, and children as well as adults.

An eco-hotel in Costa Rica

What are the global Red List and Red Data Book and what are they for?

The Red List is a list of rare and endangered species of animals, plants, and fungi. The colour red reminds us of the risk to these species and the urgent need to protect and preserve them.

Lists of living organisms all over the planet, which need protection, are included in the International Red Book, the main copy of which is kept in the Swiss town of Morges. The book is published by the International Union for the Conservation of Nature (IUCN) and first appeared in 1963. This unusual book is designed like a desk calendar and is constantly changing: as time passes, the situation of species already in the book changes and the names of new species of plants, animals and fungi are added.

For each species it features, the Red Book provides information on the distribution, population numbers, habitat features, other details and measures required for its conservation. Its pages are in different colours. Pages describing extinct species are marked in black. These include, for example, the sea cow, the passenger pigeon, and the dodo. Pages marked in red deal with endangered and very rare species (the far-eastern leopard, the Amur tiger, the snow leopard and the European bison). Animals whose numbers are rapidly decreasing are listed on pages marked yellow (the polar bear, pink seagull, goitered gazelle). Animals and plants rarely found in the wild are recorded on white pages. Species that have not been sufficiently studied because they live in remote places are recorded in grey. The most encouraging are the green pages, which record species that people have succeeded in saving from extinction (e.g., the Eurasian beaver and the Eurasian elk).

Each country and region in the world also create their own lists of rare and protected species.

Before a particular species is included in the Red Book, scientists carry out intensive studies of the flora, fauna, and fungi in relevant areas, find out the causes which threaten the species, describe their habitats, and decide how they should be preserved. The Red Book not only contains rare and endemic species (species found only in a specific territory), but a whole range of flowering, edible and medicinal plants.

Animals and plants may need to be protected for two groups of reasons: direct and indirect. There are direct reasons for protection when people destroy animals and plants through hunting, gathering medicinal plants, fishing, or collecting aquatic organisms. Indirect reasons relate to change of habitat, including that which is caused by global climate change. Such indirect reasons may include difficult acclimatization to climate change, the introduction of new species of plants (when 'newcomers' displace native species, for any of various reasons) and the destruction of plants that are a source of food for animals.

What are the adaptation solutions based on ecosystems?

Available adaptation solutions can build resilience to climate risks and, in many cases, simultaneously deliver broader sustainable development benefits.

One of these solutions is ecosystem-based adaptation that can help communities adapt to impacts already devastating their lives and livelihoods, while also safeguarding biodiversity, improving health outcomes, bolstering food security, delivering economic benefits, and enhancing carbon sequestration. Many ecosystem-based adaptation measures — including the protection, restoration, and sustainable management of ecosystems, as well as more sustainable agricultural practices like integrating trees into farmlands and increasing crop diversity — can be implemented at relatively low costs today. The key to their success is to engage local communities and ensure that strategies are designed to account for how a rise in global temperature will impact ecosystems.

Figure 2.2.1 Ecosystem-based adaptation that can protect lives and livelihoods

QUESTIONS

1 Which of the Earth's ecosystems is the richest in terms of species diversity?

2 What is meant by 'direct' and 'indirect' causes of the extinction of living organisms? Give examples.

3 How would you and your friends begin a story in class about the importance of biodiversity? What arguments are the most persuasive for schoolchildren and which for adults?

4 Why are the Red Book and the Red List red? What plants, animals and fungi do you know that have been listed in the Red Book? Why are they disappearing? Can we help to preserve them?
What different colours are used on the pages of the Red Book?
Why does the Red Book become longer each time it is updated?

5 How does global warming affect reindeer?

6 Who can fairly be called an 'ecotourist'?

7 What kind of adaptation measures, mentioned in this chapter and others, can you recommend that address climate impacts on biodiversity and ecosystems?

8 What solutions form part of ecosystems-based adaptation?

TASK

Working together with the rest of your class, create your own Red List. Draw an animal, plant, or fungus in need of protection on a page of a certain colour and explain your choice.

2.3 | How climate change affects **forests**

What is a forest?

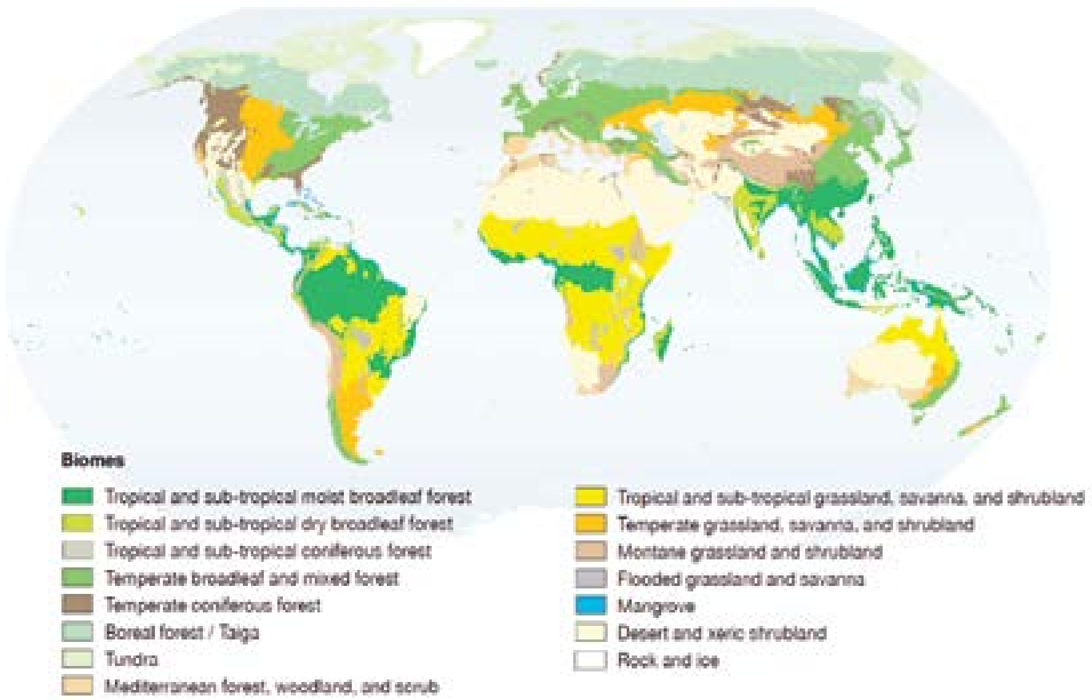
Although 'forest' is a commonly used word, it is not easy to clearly define what it is, as it largely depends on the national context. There are more than 800 different definitions for a forest around the world! But the most recognized approach to identify a forest, used also by the Food and Agriculture Organization, defines forest using indicators such as: 1) trees of minimum height of 5 m, 2) at least 10% for crown cover (proportion of the ground shaded by the crowns of trees) and 3) a minimum forest area size of 0.5 hectares. By this definition, there are just under four billion hectares of forests on Earth, covering about 30% of the total land area. About half of the world's forest areas are in three countries: Russia, Canada, and Brazil.

Types of forests

Forests are usually classified in terms of the predominant tree species – broadleaf, coniferous (needle-leaved), or mixed – and their leaf longevity (whether they are evergreen or deciduous). The main biomes of the world are presented in Fig. 2.3.1 and include the following forest types:

- **Boreal forests** (taiga) are generally evergreen and coniferous.
- **Temperate forests** include broadleaf deciduous forests, evergreen coniferous forests and a mix of both types. Warm temperate zones support broadleaf evergreen forests.
- **Mediterranean forests** are generally composed of evergreen broadleaf and sclerophyll trees. Sclerophyll means 'hard-leaved' in Greek, as such trees usually have small, dark leaves covered with a waxy outer layer to retain moisture in the dry summer months. Coniferous forests also occur in this zone.
- **Tropical and sub-tropical** forests include moist broadleaf forests, dry broadleaf forests, and coniferous forests.

Figure 2.3.1 The main biomes of the world



Why are forests dependent on the climate?

The life of the forest and its geographic distribution depend on climatic conditions, especially air temperature and the amount of precipitation. Only in some places on our planet is the climate suitable for forests to grow. For example, the location of the northern-most forest line depends on the average annual air temperature. Where it becomes too cold, boreal forest is replaced by tundra. However, air temperature, especially on the plains, changes only gradually. So, the border of the forest and tundra becomes a transition zone, where areas of both tundra and forest are found. This transition zone is called forest-tundra (Fig. 2.3.2).

The southern line of temperate forests, where forests give way to grassland (steppe) and semi-desert, is determined by rainfall. In hot conditions, plants and trees are constantly losing moisture from their leaves to keep cool. If rainfall in the summer is scant, there is not much moisture in the soil, and trees have difficulty drawing it upwards as high as their crown. Because the air is warm and precipitation is limited, low herbaceous plants are at an advantage and the landscape becomes steppe.

Relief, soil quality, water bodies and human activity are also important in determining forest cover. The share of forest diminishes in regions where much of the land has been put to work in the economy.

Figure 2.3.2 Forest-tundra

Forests of temperate and sub-arctic climate zones

Boreal forests (taiga) are dominated by coniferous tree species: pine, spruce, larch, fir and cedar. It is interesting that such forests in Europe and Western Siberia consist mainly of pine and spruce, while in Central and Eastern Siberia they are mainly larch trees. This is due to the permafrost in the vast Siberian territories, which make these areas particularly well suited to larch.

Differences in temperature conditions (average summer temperatures, times of formation and melt of the snow cover) justify subdivision of the taiga zone into northern, middle, and southern taiga. Mature trees in the forests of the northern taiga do not grow high, reaching 10–20 m, while in the southern taiga they may be as high as 50 m (Fig. 2.3.3). The middle taiga is intermediate between the northern and southern, not only geographically, but also in terms of the average height of trees, which grow to 20-25 m.

The area to the south of the taiga is occupied by a zone of temperate deciduous forests (Fig. 2.3.4). It is dominated by various species of oak, hornbeam, and elm. Such trees are commonly known as deciduous hardwoods (because their wood is relatively hard). To the south of the deciduous forests in Eastern Europe and Central Asia, the grassland (also called 'steppe') begins, and the transition zone is called forest-steppe. However, there is no deciduous forest zone in western Siberia and the central regions of North America (Fig. 2.3.1), where taiga gives way immediately to grassland. This is due to the regions' continental climate: rainfall is low, so the ground is very dry and deciduous forests, which need a lot of moisture, cannot grow.

Figure 2.3.3 Southern taiga

Figure 2.3.4 Deciduous forest

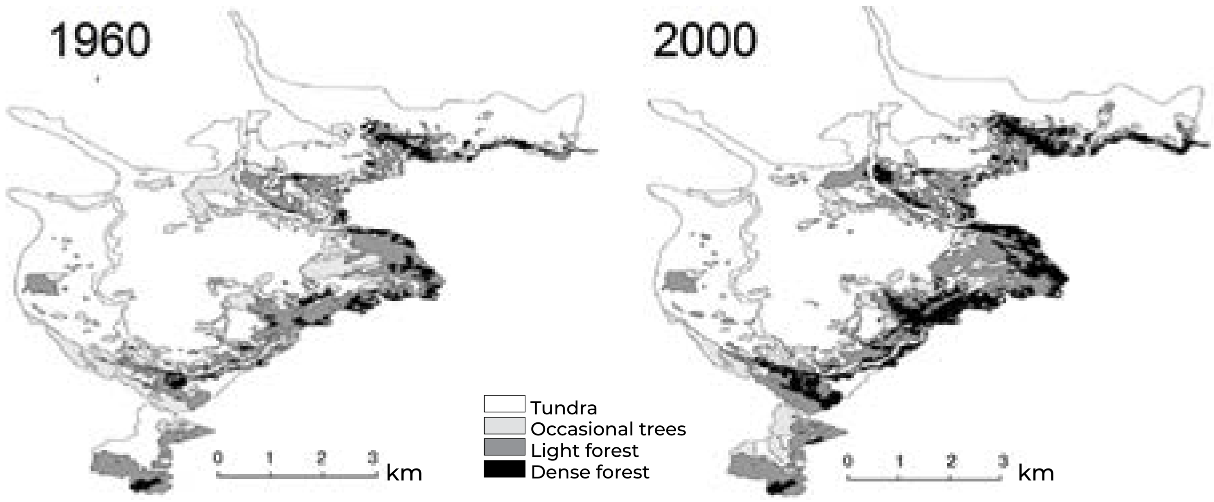
Does climate change taking place today have an impact on forests?

Are forests affected by the current warming of the climate? Yes, they are!

Climate change will have many widely varying effects on trees and the composition of tree species within forest ecosystems. As the climate continues to change, trees must either adapt to new conditions or migrate to more suitable locations.

Changes associated with global warming are particularly apparent on the northern boundary of boreal forests. In polar regions, trees and shrubs rise are moving higher up the mountain slopes, gradually usurping the place of mountain tundra (Fig. 2.3.5). The upper boundary of larch trees on mountain slopes of the Polar Urals (Russia) has moved upwards by 35–40 m in the last 80 to 90 years and by 50–80 m in some regions. Shrubs are now growing more than 50m higher up on slopes in the Khibiny Mountains on the Kola Peninsula (Russia), and an intensive growth of shrubs, particularly willows, has been observed in Scandinavian tundra zones.

Figure 2.3.5 Change of vegetation cover in the Polar Urals (Russia)



Heat is driving trees up mountains in South America

Trees and shrubs in mountainous regions of South America are fleeing unbearable heat on the plains by moving up the slopes of the mountains where the air is cooler, making it possible for them to survive. In the Andes, trees are moving up mountains by an average of 2.5–3.5 m each year. This is a considerable feat for plants, which cannot move except by reproducing. But climate change is happening so quickly in the Andes that trees need to climb more than six metres each year to remain in a comfortable temperature.

Of the 38 plant species being monitored by scientists, the Scheffleris species is migrating the fastest of all: it rises about 30 m higher each year. The fig tree is unlikely to survive in these regions by 2100 if global temperatures rise by 4°C as it is moving higher at a rate of only 1.5 m per year. Climate models suggest that more than 50% of tropical plant species could become extinct.

The southern boundary of the temperate forests is also changing. Oak forests are gradually disappearing in the forest-steppe and steppe zones due mainly to summer droughts. In the region around Lake Baikal, by contrast, pine forests are advancing into steppe ecosystems, due to increased precipitation. So, the southern forest line is shifting because of changes in moisture levels rather than an increase of temperature.

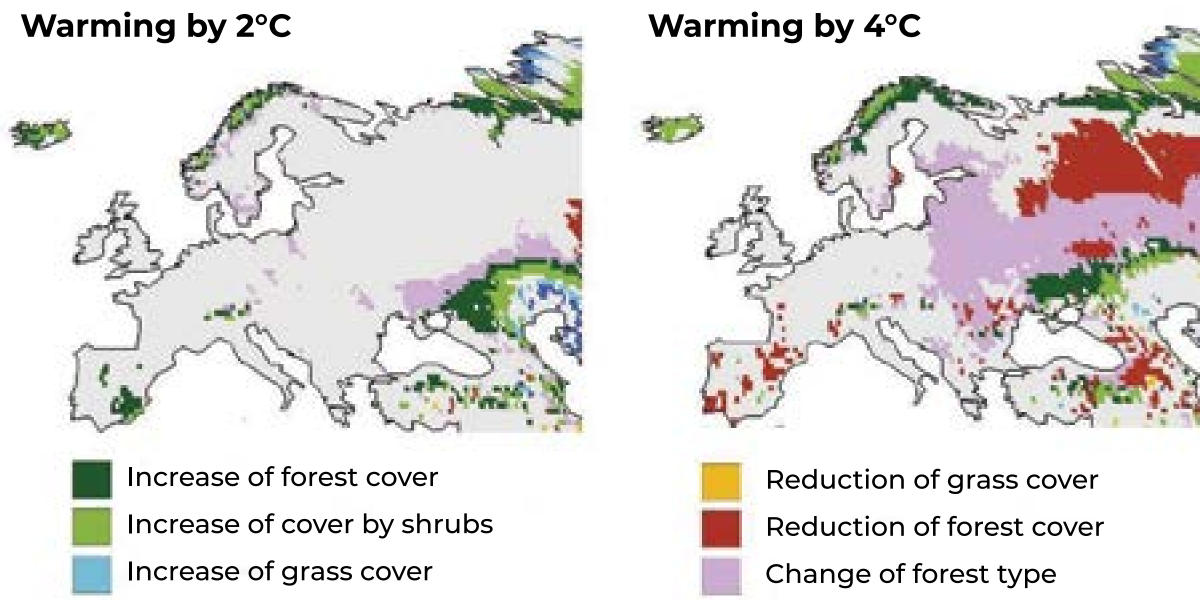
The areas of Russian forests that are occupied by tree species have changed in recent decades and scientists believe that this is largely due to climate warming. For example, oak forests have diminished in southern regions, but are gaining ground further north, on the border between deciduous forests and the northern taiga.

Spruce forest (Fig. 2.3.6) is in retreat in nearly all parts of Russia. The root system of spruce trees is close to the surface, which makes the tree highly sensitive to increase in the frequency and duration of droughts. At the same time, many regions of Russia are seeing an increase in birch forests. This phenomenon is well known to forestry specialists: it is because, after a fire or the felling of coniferous trees, birch and other small deciduous species initially appear in their place, and some time is needed before new coniferous trees appear and begin to displace birch, aspen and alder. However, in recent decades, this last stage has not been occurring: conifers seem unable to regain ground lost to birch forest.

Figure 2.3.6 Spruce forest

Most forecasts predict that forests in northern parts of Eurasia and North America will be more affected by global warming than forests elsewhere in the world, as their northern and southern boundaries are displaced. A rise in temperature of 2°C will cause an increase in the total area of forest cover in Europe of taiga to advance into the tundra zone. However, an increase in temperature of 4°C will cause the southern forest boundary to retreat northward and this effect will be greater than the northward advance into the tundra zone (Fig. 2.3.7).

Figure 2.3.7 **Forecast changes in forest cover in Europe by 2100, assuming global warming of 2°C and 4°C.**



Deforestation caused by climate change will affect almost all Eastern Europe and Western Siberia. This is a worrying forecast, showing how serious a phenomenon the disappearance of forests may be in a worst-case scenario for global warming.

Destruction of forests by fires, pests, and extreme weather

Another major threat to forests associated with climate change comes from large-scale fires and plagues of pests caused by hot weather in summer. Heat and other extreme weather events are often directly responsible for the destruction of forests.

Forest fires are usually started accidentally by people. But they can take hold only in certain conditions, namely, when the weather remains hot and dry for days or weeks. The forest floor of dead leaves, pine needles, small branches, mosses, lichens, and grasses growing under the forest canopy then becomes dry and catches light easily, and the fire can spread over large areas. This is called a ground fire.

When fire spreads in coniferous forests it often reaches the crowns of trees. Pine needles and small branches of fir and pine trees contain large amounts of resinous substances, so living trees can easily catch fire. A crown fire is the most dangerous and destructive and can lead to the complete loss of an area of forest (Fig. 2.3.8).

Fires cause great damage to the forest: many trees perish, their growth is stunted, the variety of trees in the forest becomes poorer, and the spread of harmful insects and pests is made easier. As the climate changes, the risk of forest fires increases because higher temperatures dry out woody materials more quickly. The warm season of the year, during which fires can occur, also becomes longer.

Figure 2.3.8

Forest fire

The unusually hot summers of 2010 and 2012 in the central part of European Russia weakened conifers that are accustomed to very different conditions. Such weakened trees are easy prey for many species of insects that live under the bark. In years when temperature and humidity levels are normal the population numbers of such insects are controlled by other species (insect and bird predators). But if the population of bark beetles becomes too large, large tracts of forest may perish! The dried-up trees first lose their needles, and then their bark. Various fungi that attack wood go to work on the roots, which are eventually unable to support the trees. Strong winds can then blow the trees down, one after another (Fig. 2.3.9). First, birds and then squirrels desert the forest where they can no longer make their harvest of cones. Martens then move elsewhere in search of better hunting. The green forest floor, made up of lilies of the valley and wood sorrel, which flourished thanks to the protection from direct sunlight afforded by the trees, is replaced by thickets of reed grass, raspberry bushes, and nettles. In short, the entire range of species is changed.

All is not lost: the displaced species can return. As happens after a serious fire, a forest of spruce will fully restore itself after one or two hundred years. But only provided that such forest has remained intact elsewhere with all its inhabitants, and abnormal fluctuations of temperature do not recur.

More recently, in September 2021, fires have destroyed more than 18.16 million hectares of Russian forest, setting an absolute record since the country began monitoring forest fires using satellites in 2001. The previous record was set in 2012, when fires covered 18.11 million hectares of forest.

Other extreme weather events – hurricane-force winds and tornadoes – can destroy forests as effectively as drought, by blowing down trees (Fig. 2.3.10). Heavy rains can also do much damage by washing away the soil or killing trees through prolonged waterlogging. Heavy falls of wet snow and the large-scale formation of ice also harm trees, and heavy showers of hail damage bark on the branches, weakening and causing them to dry out.

Figure 2.3.9 Fallen spruce after the drought of 2010

Hurricane winds in Kostroma, Russia

In June 2010, Kostroma and neighbouring regions in Russia experienced hurricane-force winds of up to 70-90 km/h. Houses and buildings were damaged, power lines were torn down, and falling trees caused accidents in towns and villages. There was extensive damage to forest plantations in the Kostroma region (Fig. 2.3.10). Researchers from Kostroma State University estimate that 21,000 hectares of forest were destroyed. Such events are occurring with an increased frequency, most recently in August 2023.

Figure 2.3.10 **The aftermath of hurricane-force winds in Kostroma region**

The history of glaciation, along with current scientific evidence and forecasts, show that forests and other natural ecosystems can adapt to the most varied climatic conditions. But this adaptation is mainly related to migration - that is, to changes in the boundaries of natural areas and vegetation types. During periods of glaciation, forests survived in a relatively small area, and large expanses of Eurasia were covered by tundra and tundra-steppe. When the climate grew warmer, forest regained its status as the dominant vegetation type. But warming of the climate today is happening too quickly, threatening not gradual, but catastrophic change of vegetation types, through the large-scale drying-out of forests with high risk of forest fires.

This makes it highly important not to let global warming reach extremes, and to work toward a gradual stabilization of the climate change on the planet.

How do forests affect climate?

We know now how climate and climate change affect forests. But this relationship also holds in the other direction: forests have an impact on climate!

For example, green forest changes the reflection of sunlight by the Earth's surface, so it affects the amount of heat absorbed by Earth. The difference in temperature between forested areas and areas without forest are especially noticeable in the winter. The sun's rays are reflected from the treeless, snow-covered plains, but the dark spaces of boreal forests reflect less and absorb more of the sun's light.

Forests help to retain moisture in the soil and affects evaporation, making the regional climate milder and wetter.

Snow cover remains longer in the forest, lessening sharp changes of temperature that occur in the springtime and reducing the risk of spring flooding by rivers.

But what makes forests particularly important for climate is the carbon cycle. Carbon dioxide released into the atmosphere by the burning of fossil fuels is the main cause of the global warming occurring today. Forests play the vital role of absorbing carbon dioxide from the atmosphere and retaining carbon in the form of various organic substances.

You may know that green plants absorb carbon dioxide and produce oxygen. This process is called photosynthesis, and it is powered by the energy of sunlight. Forests represent a dense concentration of green plants (trees, shrubs and grass) and are therefore thought to be vital for enriching our planet's atmosphere with oxygen. You often hear the term 'green lungs of the planet' used on TV and in newspapers to describe forests. Absorption of carbon dioxide and emission of oxygen are the two sides of the single process of photosynthesis, so you would think that forests must remove carbon dioxide from the atmosphere. But it is not that simple. To understand the process of exchange of carbon dioxide between the forest and the atmosphere, we need to understand how the forest stores carbon, the element that joins with oxygen to form carbon dioxide. All organic substances contain carbon. For example, nearly half of the weight of dry wood is carbon.

What is a carbon pool?

Any part of the ecosystem that contains significant amounts of organic matter is a store of carbon. Scientists call such stores '**carbon pools**'. Carbon pools can do both, take or release carbon. There are four main carbon pools in the forest ecosystem: 1) phytomass or biomass (the weight of living plants); 2) dead wood; 3) litterfall (dead leaves and branches on the forest floor), 4) organic matter in the soil. In many countries there is a much smaller fifth pool, called harvested wood products.

The **phytomass pool** consists of living plants: the trunks, branches, roots, leaves and needles of trees and shrubs, the leaves and roots of grass and moss (Fig. 2.3.11). As a rule, tree trunks account for most of the phytomass, but moss is also a major part of it in northern boreal and marshy pine forests.

The **dead wood pool** consists of dead trees and roots. The death of trees in the forest is called 'dieback' and it occurs naturally as the growing trees compete for sunlight. The smaller trees are left in shadow by the larger trees and gradually wither because they do not receive enough light for photosynthesis. This is why young forest is much thicker than old forest. But attrition can also occur in various other situations: it can be caused by forest fires, droughts, forest pests, and man-made pollution. In forests that are affected in one or several of these ways, the carbon pool in dead wood may exceed the pool in living wood.

Litterfall is made up of relatively small fragments of organic matter lying on the soil surface (Fig. 2.3.13). It consists mainly of dry leaves and pine needles, small dry twigs, flower petals, cones and other fragments that have fallen from living plants. In deciduous forests replenishment of the litterfall pool is most intensive during the autumn leaf fall, while in boreal forest it occurs more evenly through the seasons.

Figure 2.3.11

The wood in tree trunks is the biggest part of the phytomass carbon pool

Figure 2.3.12

Dead trees are part of the dead wood carbon pool

Figure 2.3.13

The litterfall carbon pool is swollen when leaves fall in the autumn

Soil pool in the forest contains significant amounts of carbon. The soil is a mixture of minerals and of organic matter, mainly '**humus**', which is a dark-coloured substance created by the gradual break-down of plant residues (litterfall, dead wood and dead roots). Carbon accounts for 58% of the make-up of humus, which is a higher share than in phytomass. The darker the soil, the more carbon it contains (Fig. 2.3.14).

The carbon stored in wood products is often referred to as the **harvested wood products carbon pool**. Some wood products, such as high-quality wood furniture and wood framed buildings, can hold onto carbon longer than if the tree had been left in the forest. Wood products are important for helping bank existing forest carbon while harvesting helps give space for replacement trees to grow.

In boreal forests, phytomass contains 21% of the carbon stock, dead wood 4%, litterfall 3%, and 72% is in the soil. So, in these forests, carbon is concentrated in the soil.

These shares are quite different in tropical forests, where living and dead organic matter accounts for 50% of carbon.

Why is the difference so large? In boreal forests most dead plants are broken down by fungi and bacteria, and this process occurs slowly. It takes many decades for the trunks of large dead trees to disappear. Because of this, the forest accumulates large pools of dead organic matter – dead wood, litterfall and humus in the soil. In tropical forests, a large part of the litterfall and dead wood is consumed by animals, especially termites. This speeds up the rate of decomposition and reduces the contribution of dead organic matter to the total amount of carbon in the ecosystem.

Figure 2.3.14

If soil is dark, it contains a lot of carbon

Carbon budget

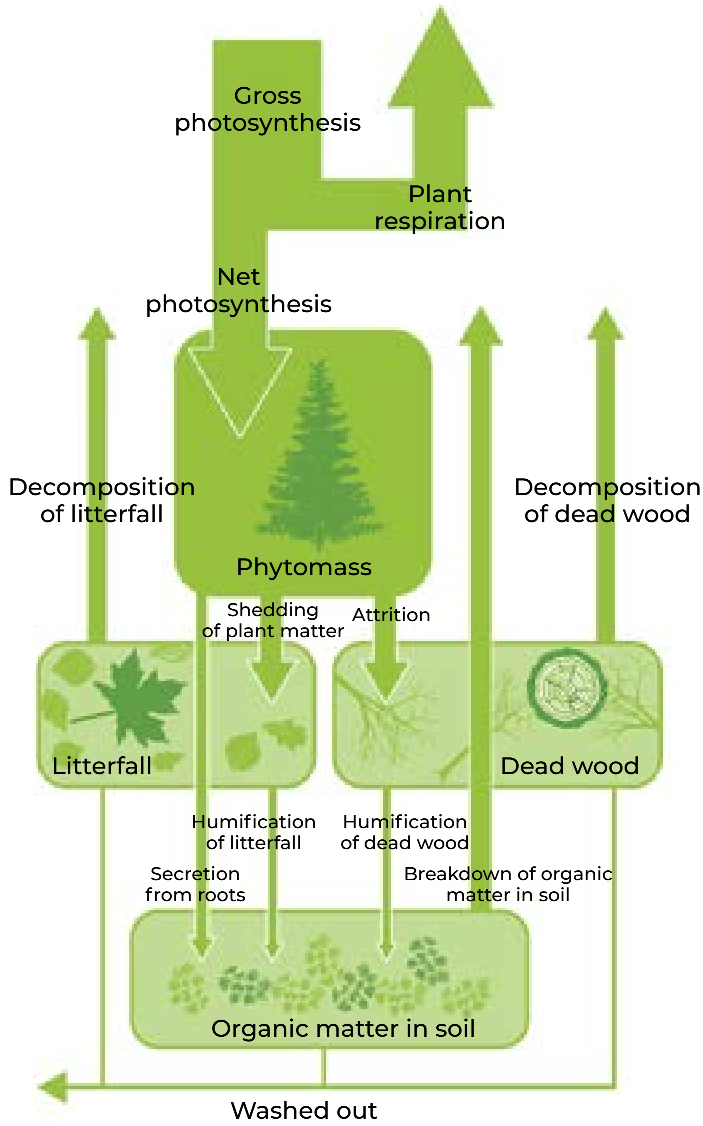
Now that we know all about carbon pools in the forest ecosystem, let's see how these pools relate to one another and the atmosphere (Fig. 2.3.15). Scientists call this system of connections a **'carbon budget'** because it is like the financial budget of a country, a company, or a family, where what comes in (income) must be matched with what goes out (spending).

The only 'income item' in the forest ecosystem is photosynthesis. The sum of photosynthesis creates organic sub- stance. The first consumers of this sub- stance are plants themselves: nearly half of it is used by plants when they breathe, releasing carbon back into the atmosphere. The remainder of the substance is called 'net photosynthesis': it replenishes the phytomass pool.

Various living organisms that inhabit a forest consume the living substance of plants: caterpillars and insects feeding on leaves; birds and rodents collecting fruits and seeds, and hoofed animals that eat grass and young branches.

Figure 2.3.15

The carbon budget of a forest ecosystem



In taiga and temperate forests, a large part of the plant life dies naturally (when a plant withers and dies or when it drops its leaves and twigs) and is then consumed by fungi and bacteria (Fig. 2.3.16). This replenishes the dead wood and litterfall carbon pools.

When fungi and bacteria breathe, the carbon **humification** of litterfall secretion from roots of organic matter binds with oxygen and returns to the atmosphere as carbon dioxide. This happens as dead wood and litterfall decomposes. A modest part of these pools is transformed into humus and replenishes the soil carbon pool (this process is called humification). Carbon also enters the soil from living plants in the form of organic substances that are secreted by the roots.

Organic matter in the soil is also broken down by fungi and bacteria with the release of carbon dioxide into the atmosphere. A part of the carbon is washed out of the ecosystem by groundwater and surface water: you must have seen autumn leaves being carried away by forest streams.

Forests that contain many mature and old trees absorb the same amount of carbon dioxide from the atmosphere as they release back into it. Carbon pools in such a forest remain constant over time. They are like swimming pools: full to the brim and incapable of taking more, except that they are filled with carbon and not water. But that is not to say that mature forests don't play a role in regulating the gas composition of the atmosphere. The point is only that they no longer actively absorb and have instead become the keepers of 'stored' carbon, i.e., carbon that can no longer contribute to the greenhouse effect.

The carbon budget of young, growing forests is different from that of mature forests. Young forests accumulate carbon, removing it from the atmosphere. This carbon builds up in pools. So, it is only young forests that deserve to be called the 'green lungs' of the planet.

Figure 2.3.16 **Tinder fungus breaks down dead wood and returns carbon to the atmosphere**

Differences in the impact of forests on the atmosphere

We have seen how young and old forests work differently: young, growing forests absorb carbon dioxide from the atmosphere and can thus partially compensate for emissions of this gas by the combustion of coal, gas, and oil. Mature forests store enormous amounts of carbon in bound form, preventing the formation of carbon dioxide, which would contribute to the greenhouse effect. So, if we want to use forests to prevent climate change, we need to: 1) plant new young forests, where there was no forest before; 2) take good care of existing forests.

In developed countries with advanced economies (the United States, the countries of the European Union, Canada, Russia, and others) there are many young forests that absorb carbon dioxide from the atmosphere and are less at risk of being destroyed for human industry. Many of these countries are also encouraging landowners to plant forests.

Because boreal and temperate forests grow and absorb carbon over many decades and sometimes hundreds of years, carbon is now being accumulated thanks to renewal of the forest in many of the places where forest cover was severely reduced during the industrialization of the last century. The restoration of pine forest along the Canadian Pacific coast is a striking example of this.

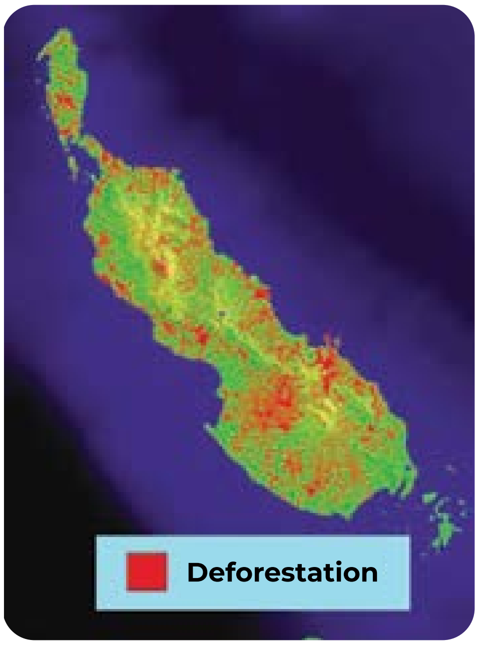
At the beginning of the century this territory was covered with huge conifer forests of Douglas Fir and Red Cedar, some of them as high as 80–90 metres. By the middle of the 20th century, these forests had been cut down, and the giant stumps of felled trees more than two metres in diameter can still be seen (Fig. 2.3.17). Since then, strict environmental laws established in Canada have renewed forests in former logging areas.

Figure 2.3.17

This giant tree stump in the forest of western Canada (British Columbia) is evidence of intensive tree harvesting in the first half of the 20th century

Figure 2.3.18

Loss of forest cover on the island of Bougainville (Papua New Guinea), 1972-2002



The situation is quite different in developing countries, especially in South America, South-East Asia and Oceania. With growing populations and economies, these countries always need more land for agriculture, factories, cities, towns, and roads. This land comes mainly from the destruction of tropical forests, and new forests that would absorb carbon dioxide are not being planted. A photograph taken in the tropical region of Argentina (Fig. 2.3.19) shows the beginning of the destruction of forest. Forest land previously belonging to the army was transferred to local government control in the early 2000s. Local government gave permission for agricultural development of the land, and the felling of trees began.

Deforestation is occurring very rapidly in some tropical regions. Deforestation in Papua New Guinea is extensive and occurs at a rate of 1.4% of the tropical rainforest being lost annually. Illegal logging is the main cause of deforestation, contributing to 70-80% of all timber exports. Between 1972 and 2002) the country lost more than five million hectares of forests, trailing only Brazil and Indonesia among tropical countries (Fig. 2.3.18). As a result, greenhouse gas emissions from deforestation in Papua New Guinea more than doubled over this 30-year period. Thanks to rainforest conservation efforts, the pace of deforestation has recently slowed to an average 0.5% annually.

About 10% of all the carbon dioxide now being emitted into the atmosphere by human action comes from the destruction of tropical forest. The United Nations programme, Reduced Emissions from Deforestation and Forest Degradation (REDD+), is a step towards a global system to reduce greenhouse gas emissions caused by deforestation in developing countries. Bilateral international projects to preserve tropical forests are being set up, for example agreements between Brazil and Norway, and Australia and Indonesia. Some developing countries, such as China, India, and Costa Rica, have their own programmes to increase the area of their forests. Overall, though, the rapid release of carbon stocks by the destruction of tropical forests remains a major concern.

Figure 2.3.19 **A former forest area in Argentina**

The disappearance of tropical forests

Tropical rainforests are among the most important ecosystems on the planet. Their ecosystem is the richest in species diversity. Tropical forests are a source of timber, food and raw materials for medicines. They also play a pivotal role in regulating the Earth's climate. The disappearance of tropical forests leads to the loss of fertile topsoil, loss of biodiversity and disruption of the ecological balance over large areas of the planet.

Despite all efforts, however, tropical forests are continuing to disappear rapidly, particularly in South America and Africa. About 3.6 million hectares of forest cover in South America and 3.4 million hectares in Africa have been lost between 2005 and 2010. Today tropical rainforests cover only 5% of the Earth's surface, compared with 12% 100 years ago. An area of forest larger than all of England (130,000 km^2) is being cut down or burnt each year.

In an encouraging development, deforestation has declined and net forest cover increased since 2010. Government initiatives and international moratoria were successful in reducing deforestation in the Amazon between 2004 and 2015, while forest regrowth occurred in Europe, Eurasia, and North America. But keeping deforestation rates low is challenging, given increased deforestation rates in the last four years in the Amazon and elsewhere.

One of the main causes of deforestation is the conversion of forests into agricultural land to feed a growing world population. Rainforests are often replaced by plantations to produce palm oil, soy, cocoa, rubber, and coffee as well as for cattle farming. Uncontrolled mining operations are another threat to tropical rainforests in South America. These are all leading causes of tropical forest loss, destroying some of the most biodiverse places on Earth, home to species including jaguars, sloths, orang-utans, toucans, and lemurs.
Such major destruction of forests can be irreversible. If the felling of trees is limited to a small area, then the forest will return after a few years, but if a large area of forest is cut down, it may never reappear: heavy rain will wash away essential nutrients in the soil and the sun will burn the top layer of soil, so that only weeds can grow.

What can be done to save the forests? First, developing countries with large areas of tropical forest (primarily Peru, Ecuador and Indonesia), as well as Brazil, must be encouraged to pursue other economic activities, which do not involve deforestation. Otherwise, the destruction of trees will continue for mining and food production.

Economic incentives and regulations can help to reduce deforestation and prevent forest loss. Brazil had considerable success at reducing deforestation in the Amazon in the late 2000s and early 2010s. Environmental laws, a new Forest Code, improved surveillance of slash-and-burn illegal logging and a soya moratorium in the Amazon were credited with the fall. However, there have since been large spikes in deforestation in the world's largest rainforest due to lack of law enforcement. Similarly, Indonesia's recent success in slowing deforestation with a moratorium on palm oil expansion is fragile for the same reasons: the economic incentives to clear forest have not changed.

How to manage the carbon balance of forests and help forests adapt to climate change

The carbon balance of forests depends on many factors, the most important of which are human activity, disasters (forest fires, plagues of pests, etc.) and climate change. The carbon balance of forests can be managed: if the felling of forests for timber and other purposes is reduced, forests will absorb more carbon from the atmosphere.

One project in the far east of Russia aims to halt large- scale logging in the cedar and deciduous forests of the Bikin River Basin, where only local inhabitants will be allowed to cut timber (Fig. 2.3.20). The project encourages residents to develop traditional forms of forest management, including the collection of pine nuts, berries, mushrooms, ferns and herbs.

It is also vital to reduce the damage caused by forest fires, most of which are started by people failing to put out picnic fires, throwing cigarette butts on dry litterfall or lichens, and setting fire to dry grass (Fig. 2.3.21), actions defined as 'being careless with fire'. We have all been warned to protect the forest from fire, but the warning acquires a new urgency in the face of climate change. If you can teach your friends not to burn grass or set fire to summer fluff, and to carefully extinguish the campfire after a family outing in the forest, you will be doing your part to prevent climate change.

Figure 2.3.20

Cedar-deciduous forest in the Bikin River Basin

Figure 2.3.21

Dry grass burning, set alight by people

In general, scientists distinguish between adaptation for natural and for managed forests. Adaptation for natural forests includes conservation, protection, and restoration measures. In managed forests, adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires. Forest management is a popular strategy to cope with drought, reduce fire risk, and maintain biodiverse landscapes and rural jobs. Restoring natural forests and drained peatlands and improving the sustainability of managed forests enhances the resilience of carbon stocks and sinks.

The IPCC AR6 notes that successful adaptation strategies for forests in Europe and Russia include altering the composition of tree species to enhance forest resilience. Diversifying tree species and increasing conservation areas reduce vulnerability to pests and pathogens, strengthen resistance to natural disturbances, and may increase carbon sequestration, biodiversity, and water quality. Active management approaches can limit the impact of fires on forest productivity. These include reforestation, fuel reduction management, prescribed burning, changing from conifers to deciduous, less flammable species, recreating mixed forests and agroforestry.

QUESTIONS

1 What is taiga or boreal forest?

2 What species of tree is dominant in Eastern Siberian taiga and why?

3 How has the border of the forest-tundra shifted in recent decades and why?

4 If temperatures rise by 4°C before the end of this century, how will they affect forests?

5 How do human activities affect forests?

6 What are the major carbon pools in the forest ecosystem?

7 Can plants breathe?

8 Which organisms break down dead plant residues?

9 Can mature and old forests remove excess carbon dioxide from the atmosphere?

10 Why are tropical forests losing their carbon stocks?

11 What kind of climate adaptation measures, mentioned in this and other chapters, are recommended to address climate impacts on European and Russian forests?

TASKS

1

Experiment

Objective: To find out which trees and shrubs are most sensitive to warming.
Materials: branches of trees (before leaves appear), vases with water.

The procedure: The experiment is carried out a few weeks before snow starts to melt in your region. Cut a few branches from various trees and shrubs (birch, elm, willow, poplar, maple). Put them in vases with water and observe them regularly. Take note of how the buds grow, when they open, and how the leaves grow. Also measure how buds develop on the trees themselves. After leaves have appeared on trees, make a chart to plot the growth in the size of the buds and the leaves indoors and outdoors. Find out which three species are more sensitive to a warmer environment (which of them react faster to warmth).

2

Experiment

Objective: To find out which tree species contain more carbon in their wood.
Materials: Pieces of various types of wood (oak, spruce, birch, aspen and others), a ruler, scales.

The procedure: Measure each piece of wood to calculate its volume (multiply the length by the width by the height) and weigh it. Divide the weight of each piece by its volume to find out the weight in grams of a piece of wood with sides of one centimetre. Divide the result by two to get the weight of the carbon in the piece of wood. Discuss the result and decide which tree species has the greater carbon pool. You can then judge which species is best to plant to reduce the greenhouse effect.

3

Experiment
Objective: To compare the amount of oxygen and carbon dioxide emitted by plants in the light and in the dark.

Materials: Two large glass containers with air-tight lids and containing water (about a third of the volume of each container), cuttings of plants with large leaves, a splint, matches.

The procedure: Place a plant cutting in each container and seal it. Put one container in a warm, bright place, and cover the other with a cloth that keeps out the light. After one or two days use a lighted splint to see in which of the containers the flame burns brighter: do this immediately after removing the cover, until the gas in the container has been diffused. Notice the bright flash of flame on the splint you put into the 'light' container immediately after removing the cover and notice how the flame dimmed when you put the splint into the 'dark' container. Now you know that a plant produces more oxygen than carbon dioxide when it is in the light, but more carbon dioxide than oxygen when it is in the dark.

2.4 How climate change affects **water resources**

Water in the natural world

Water has a special place among the vast number of chemical compounds that are found on our planet. It flows from the taps, we boil it in kettles, and it fills rivers, lakes, seas, and oceans.

Water can exist in various states: solid, liquid and gas. When the air temperature is below 0°C, water freezes to a solid state and becomes ice. Water comes out of taps in a liquid state, and the jet of steam from a boiling kettle is water in its gaseous state. Incidentally, the water in the clouds that we see in the sky is very often in three states at once, and that is what determines the different forms that clouds can take.

Figure 2.4.1 Noctilucent clouds in Sweden

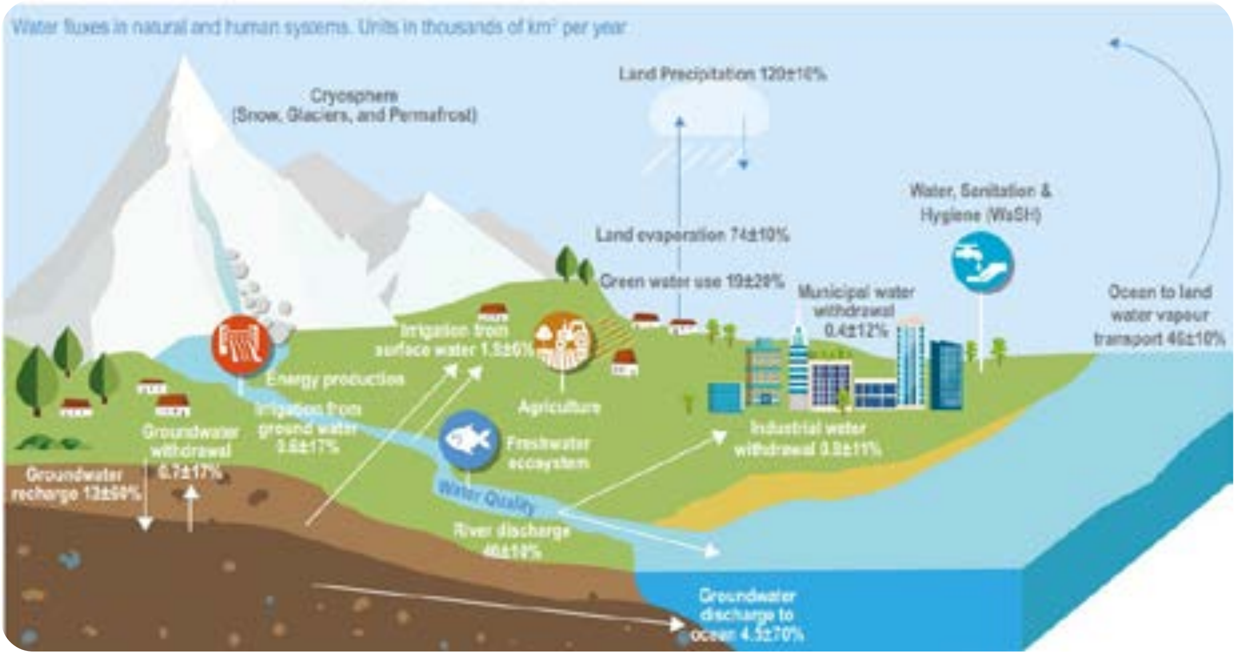
Noctilucent clouds are a particularly beautiful type of atmospheric formation. They are at an altitude of 76–85 km above the earth and are formed of nothing but ice crystals, which determines their fantastical appearance. Noctilucent clouds can only be seen at night in polar latitudes, when they are illuminated by the sun, which has already fallen below the line of the horizon.

The science that studies water is called **hydrology**. It is believed that the first hydrological studies were carried out 5,000 years ago by the ancient Egyptians on the River Nile: they measured the height of seasonal floods by making marks on the walls of buildings, rocks, or steps down to the river.

If there was no water on our planet, there would be no life: many types of plants and animals are composed in large part of water. For example, a human body is 60% water on average. This share depends on age: the body of a newborn infant is 86% water, but that of an elderly person only 50%. It is very important for people to drink enough water. A person can live without food for about a can only survive for three to ten days without water.

Water on Earth takes many forms that are in constant movement and altogether form the water cycle. The water cycle (Fig. 2.4.2) is the process by which water circulates between the Earth's oceans, atmosphere, and land, involving precipitation as rain and snow, drainage in streams and rivers, and return to the atmosphere by evaporation and transpiration. The water cycle is affected by both climatic and non-climatic factors.

Figure 2.4.2 **The water cycle, including direct human interventions**

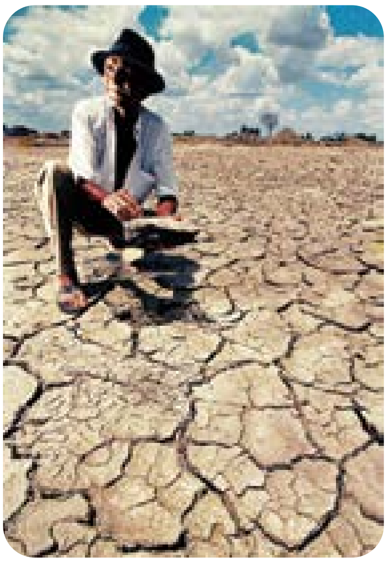


All parts of the water cycle on Earth that are used or could be used by human beings are called 'water resources'. They include all water in rivers, lakes, canals, reservoirs, seas and oceans, groundwater, soil moisture, frozen water (ice) in mountain glaciers and polar ice caps, and even water vapour in the atmosphere.

More than 97% of all water on the planet is in oceans and seas. The water in the ocean is salty and not suitable for drinking. Less than 1% of the total volume of water on the planet is fresh water in rivers, lakes, streams, and other surface water bodies. That doesn't seem like much, but there is another vast reserve of fresh water: the glaciers and ice caps of Antarctica and Greenland. They account for 2% of all the water on Earth – nearly eight times more than all the water in rivers and lakes combined.

Preserving the planet's reserves of fresh water is one of the major environmental challenges facing us today: without these reserves mankind cannot survive.

Climate change and the increasing demand for food and sanitation from the world's growing population have created water shortages in many countries. Since the beginning of the 20th century, the world's population has grown from 1.6 billion to more than eight billion. The rapid growth of population, changes in lifestyle and agricultural expansion have all increased water use in most countries. About 70% of all freshwater is used to water fields for growing crops. UN experts estimate that by 2050, nearly 90% of the world's freshwater resources will be needed for food production.



UN experts also point out how unevenly drinking water is distributed across the continents: Asia is home to 60% of the world's population but has only one-third of the world's water resources. According to the World Health Organization, in 2020, around one in four people lacked safely managed drinking water in their homes and nearly half the world's population lacked safely managed sanitation, most of them in Africa.

Goal 6 of the UN Sustainable Development Goals adopted in September 2015 is on clean water and sanitation, with one of its targets aimed at achieving "universal and equitable access to safe and affordable drinking water for all' by 2030.

How does climate change affect water resources?

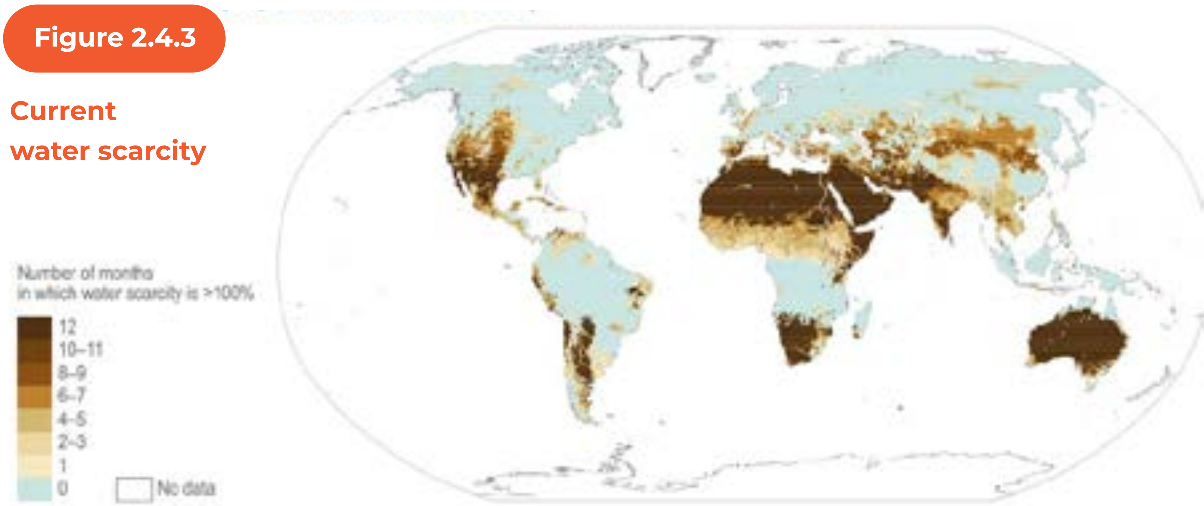
All the sources of fresh water on Earth (rivers, lakes, swamps, snow, glaciers, groundwater) are intimately related to climate. To a certain extent they are all a product of climate, although, of course, they all depend on different components of the natural world.

We already know that warming of the climate in many parts of the world will probably increase the frequency of heavy rains, causing disastrous flooding. In other areas, precipitation is expected to decrease, so that extreme droughts will become more frequent. Unfortunately, very wet regions will become even wetter, while dry regions, especially in the central parts of continents, will suffer increasingly from the effects of drought.

Scientists note that climate change will significantly affect water resources leading to water shortages in arid regions of the world, most notably the Mediterranean countries, the western United States, Southern Africa, and northeast Brazil. They define the mismatch between the demand for fresh water and its availability as water scarcity. It is estimated that around half of the world's population, or four billion people, live under conditions of severe water scarcity for at least one month per year (Fig. 2.4.3). Nearly half of them live in India and China. Although regions with high water scarcity are already naturally dry, human influence on climate is reducing the availability of water in these and in many other regions. At 2°C warming, globally, 800 million to three billion people are projected to experience chronic water scarcity due to drought, and up to approximately four billion at 4°C warming, considering the effects of climate change alone, with present-day population.

Figure 2.4.3

Current water scarcity

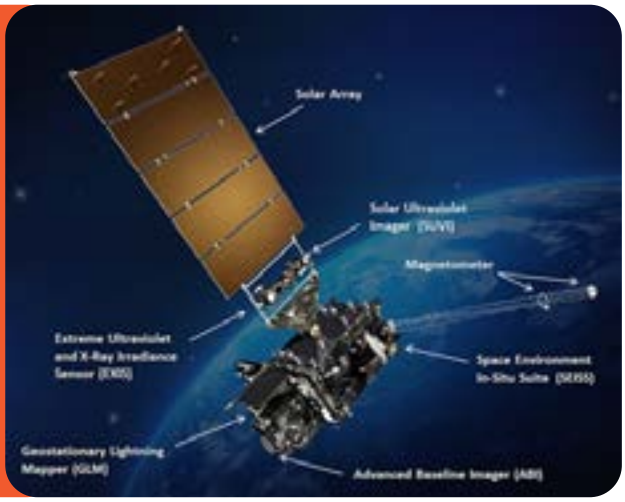


Note: water scarcity is defined as mismatch between the demand for fresh water and its availability. This is why when we speak of regions with water scarcity we usually indicate time period when water scarcity is greater than 100%.

Climate change will also significantly affect glaciers and snow cover. Weather satellites (Fig. 2.4.4) show that the area covered by snow in the northern hemisphere has significantly decreased over the past 45 years. The reduction of snow cover in mountainous areas has been most noticeable in western North America and in the Swiss Alps, mainly at low altitudes.

Figure 2.4.4 United States weather satellite of the meteorological-satellite service

Weather satellites are sent into orbit around our planet to obtain meteorological data, which can be used for weather forecasting and climate observation. Other satellites can transmit TV signals, operate vehicle navigation systems, and much more.

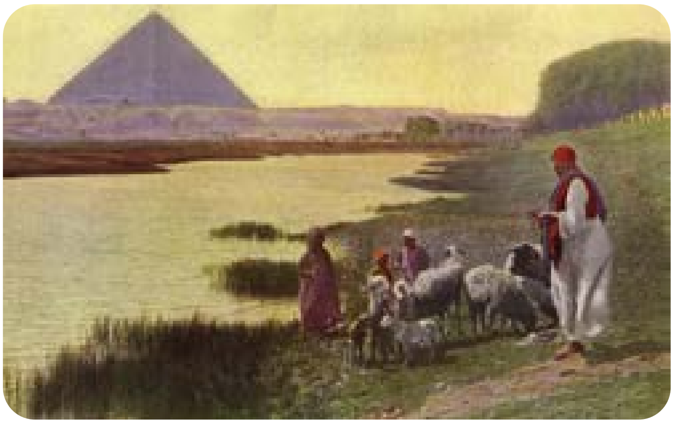


Changes in the amount and the cycle of precipitation, the melting of mountain glaciers and the general rise in temperatures on the planet all lead to changes in the volume of water carried by rivers. Typically, river flow changes from season to season, but there are certain long-term patterns now being affected by climate change. These changes could result in major floods that inundate riverside settlements or, conversely, dry up a riverbed. In temperate latitudes today, rivers freeze later and lose their ice earlier. These changes need to be considered in economic planning, since rivers are vital to the economy of many countries. They are arteries for the transportation of goods and passengers, a source of hydroelectric power, and reservoirs of fresh water for drinking and for irrigation.

DRAINAGE BASIN
is an area of land from which all surface water and ground- water flows into one water body, including its various tributaries.

Figure 2.4.5 The Amazon River in South America has the largest drainage basin in the world, covering seven million km²

Figure 2.4.6 The Nile is the world's longest river



The countries that have the largest supply of fresh water in the world are Brazil (the world's greatest river, the Amazon, flows through its territory), followed by Russia and Canada. However, the distribution of freshwater around the world is extremely uneven. Even in water-sufficient countries like Brazil or Russia there are areas that already experience water stress (Fig. 2.4.9). This natural 'injustice' will grow more marked over time due to climate change: regions that already suffer from water shortages will become even more arid (Fig. 2.4.3 and 2.4.8).

Figure 2.4.7 Lake Baikal in Siberia is the largest reservoir of fresh water on Earth

Figure 2.4.8 Projected decline in water supply in United States counties: (a) without climate change effects and (b) with projected climate change effects

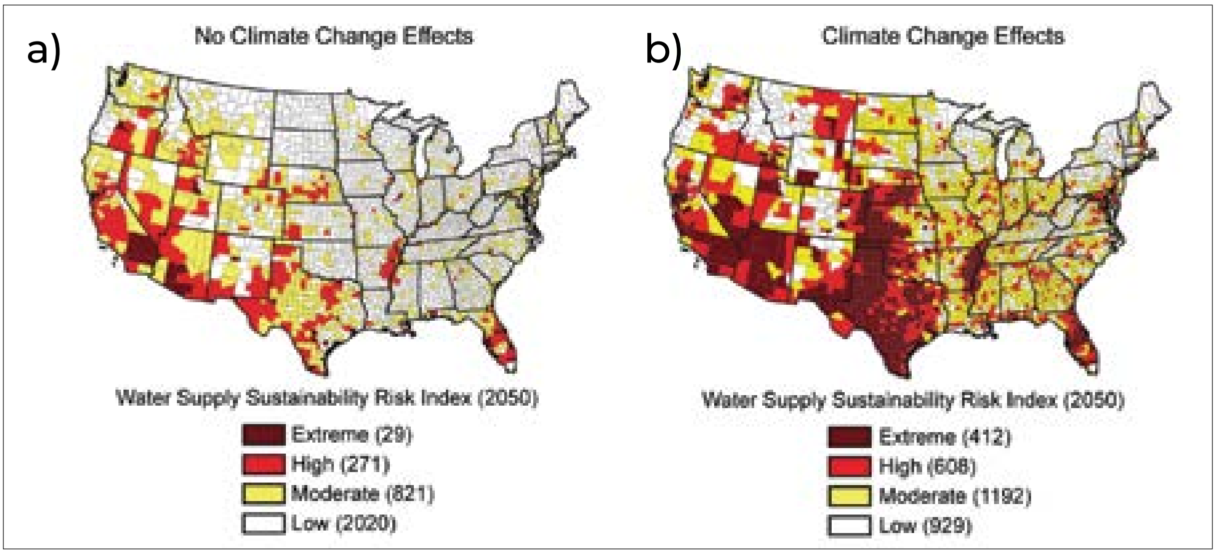


Figure 2.4.9 Water shortages are already a problem in Southern Russia

How can the risks be reduced and adaptation enabled?

Until recently, it did not occur to people responsible for water management that climate change would force them to review the whole system for managing water resources. Unless proper measures are taken in good time, the damage caused by sudden and severe droughts, floods or reduction of freshwater resources could be enormous. Scientists note that adaptation to water-related risks and impacts make up much of all documented adaptation worldwide and propose a range of measures.

The first thing needed is improved weather forecasting to help predict the probable occurrence of severe weather events in advance.

Second, technology and engineering solutions can reduce risks to people and infrastructure, from the construction of dams and reservoirs along rivers to help regulate their flow, to the creation of structures along riverbanks to protect communities from severe flooding.

Third, we must improve water management systems and change consumer behaviour to reduce water consumption. This can be done, for example, by harvesting rainwater or by using the same water twice for different needs. Special installations to convert salt water into fresh water by desalination are also promising (Fig. 2.4.10). Most of all, we must remember to use water efficiently.

Figure 2.4.10 A seawater desalination plant in the United Arab Emirates

Fourth, we can apply nature-based solutions more widely to adapt to water scarcity resulting from climate change. Such solutions rely on natural processes to enhance water availability and water quality, and reduce risks associated with water-related disasters while contributing to biodiversity. Examples include the use of natural or semi-natural systems such as wetlands and healthy freshwater ecosystems to supply clean water, regulate flooding, enhance water quality, and control erosion. Cities like New York and Copenhagen have integrated large-scale investment plans comprising nature-based solutions in urban planning to deal with high-impact extreme precipitation events. This is a growing trend: one in three cities use nature-based solutions to address water-related climate hazards, according to the Carbon Disclosure Project database.

Harnessing indigenous and local knowledge: how the ancient Indians of Latin America adapted to a changing climate

The indigenous peoples of Central and South America lived mainly on crops they grew around their settlements. In highland regions, where many ancient Indian civilizations were focused, food production was limited due to the uneven distribution of water resources. There was no shortage of water during the rainy season, but how did these ancient peoples manage during the dry season?

The main source of water in the dry season was rivers flowing from mountain glaciers, but they only supplied settlements along the river valleys. The ancient Indian tribes invented a range of technologies and contrivances to ensure year-round supply of water in the mountains.

The Indians learnt to catch, filter and store rainwater, to build surface and underground irrigation channels, and invented devices for measuring the amount of water they had in storage. They even connected the river basins of the Pacific and Atlantic oceans. They also developed a system of weather forecasting, which could predict when the rainy season and the dry season were likely to begin, so that they could better organize the sowing and harvesting of crops.

The indigenous peoples of America used their engineering skills to straighten riverbeds and build bridges, both hanging bridges and bridges with supports. They had piped water for everyday use and for religious ceremonies. The priests of the Chavin culture channelled water through pipes inside their temples to obtain a sound like the roar of a jaguar, an ani- mal which they worshipped as a god.

Using an ingenious technique, they used water to cut blocks of stone used in construction. Water was channelled into specially made channels in the stone and left to freeze at night in sub-zero temperatures, gradually creating cracks that divided the stone into the regular shapes required for building.

The Indians of Central and South America, who lived on a vast territory from modern Mexico in the north to Chile and Argentina in the south, were thus pioneers in the use of various technologies that can be used today, melded with the latest scientific knowledge, in adapting to adverse and unpredictable climate conditions.

Figure 2.4.11

Water collection system in Nazca regions (southern coast of Peru) for underground aqueducts and distribution of groundwater

QUESTIONS

1. What do we call the science that studies water?

2. Which country has the largest supply of fresh water in the world?

3. Which regions of the world will be particularly affected by water shortages and why?

4. What is the name of the river basin where your hometown is located and what sea does it flow into?

5. List at least three adaptation measures that help to reduce risk from climate change on water resources.

TASK

Find the Amazon River on a physical map of the world. Measure its length and the area of its drainage basin and compare it with the major river in your country.

2.5 | How climate change affects **agriculture**

One might think that climate change would help agriculture in northern countries. But a warmer climate is not necessarily better. If it gets warmer in regions where it was previously too cold to grow wheat, it will also get warmer in regions where there was already an ideal climate for agriculture, and more heat means less moisture and low productivity. So, it will become much more difficult (if not impossible) to grow crops in areas where they have been cultivated for centuries and where specific traditions of agriculture have taken shape.

So, the conditions for agriculture will get better in some places but worse in others, and it is difficult at this stage to predict the outcome of such a 'global shake-up' for various countries.

It is important to remember that climate is not the only natural factor with impact on agriculture.

For example, one of the main cereal crops in North America, Europe and Siberia is winter wheat. Climate warming means that the zone with ideal climatic conditions for its cultivation will move to the north. But the soil in these new regions is not as good as in the regions where winter wheat is grown today. Improving the soil quality in more northerly regions will require much work and be very expensive.

Winter wheat is sown not in the spring, like other wheat, but in late summer and early autumn, so that the seeds have time to germinate and take root before the winter snows come. The wheat resumes its growth in the warmth of spring and ripens somewhat earlier than crops that were only sown in the spring.

Climate change affects fruit and vegetable production. Stone fruits, particularly cherries, require cold hours to bear fruit. Too few cold nights, and the trees are less likely to achieve successful pollination and will produce fewer fruits. Unusually timed cold weather can be just as disastrous. In 2023, the 'Peach State' of Georgia in the USA lost more than 90%of its annual peach crop after abnormally warm weather in the winter, followed by a late-season freeze.

Countries with temperate and more severe climates, such as Canada and Russia, could face another challenge in the form of increased competition between forestry and agriculture. Climate change will make it possible to turn over land now occupied by forests to agriculture, which could speed up the felling of forests. Even in areas with borderline conditions for agriculture (in the extreme north of the agricultural zone), productivity from one hectare of land under crops is still greater than from one hectare of forest land. So, much thinking is needed before new territories are turned over to agriculture.

Agriculture everywhere in the world will have to adapt to the new climatic conditions. Experts at the Food and Agriculture Organization (FAO) believe that crop yields in many parts of the world will decline after 2030 due to climate change. Forecasts indicate that the most serious consequences are likely to occur in tropical regions, where rainfall is likely to decrease further.

The increasing occurrence of droughts, floods and rainfall fluctuations in sub-Saharan Africa will make feeding the local population one of the major challenges of the coming decades. World Bank experts calculate that a reduction of rainfall and an increase in average global temperatures by 1.5–2°C will lead to a 40-80% loss of land suitable for maize, millet, and sorghum crops in sub-Saharan Africa by the 2030-2040s.

In Mexico, drought is reducing the extent of land suitable for growing maize, the country's main agricultural crop.

Cereals are a highly important group of plants, producing grain, which is a staple food of people, as well as a raw material for many industries and feed for farm animals. Cereal crops include wheat, rye, rice, oats, barley, maize, sorghum, millet, buckwheat, and many others.

The principal cereal crop in South-East Asia is rice, which is mostly grown in the deltas of large rivers. As water levels rise in the ocean because of climate change, low-lying sections of rivers are becoming salty, which may lead to loss of crops. Parts of the Mekong Delta in Viet Nam, which is one of the world's centres of rice cultivation, are particularly affected by the rise in sea levels. Even a 30 cm rise in the level of the ocean can reduce rice crops by 11%.

In summary, agriculture is threatened by climate change impacts such as the rise in temperatures, changing rainfall patterns, the rise in sea levels (affecting coastal lowlands) and frequent droughts and floods, especially in areas prone to natural disasters. These changes are greatly affecting agriculture, and food security is an increasingly serious problem.

The concept of **food security** requires that all people always should have access to safe, nutritious, familiar, and tasty food to promote an active and healthy lifestyle.

FAO has estimated that 2.3 billion people, or 28% of the global population, faced food insecurity as of 2021, exacerbated by the effects of the COVID-19 pandemic. India, Pakistan, and the Horn of Africa were particularly affected due to losses from extreme weather events. Extreme heat in India and Pakistan led to a decline in crop yields which, combined with a ban on wheat exports and restrictions on rice exports by India, posed a threat to international food markets and countries already affected by food shortages. Monsoon rains led to unprecedented flooding in Pakistan, with an increase in water-borne diseases, which spread across the most vulnerable and food-insecure regions. In Ethiopia, Kenya, and Somalia, an estimated 22.5-23.4 million people faced food crisis or food insecurity due to drought and other factors. Major cuts in food assistance affected 75% of the total refugee population.

Agriculture is the main source of income for one-third of all working people in the world. In some countries in Asia and Africa, more than half the population is engaged in agriculture. Climate change reduces the volume of food production, which in turn lowers incomes from agriculture. And if heat and drought mean that food, in short supply, is prepared in dirty dishes by dirty hands and cannot be properly stored, it becomes a hazard to human health.

So, even northern countries cannot expect climate change to bring benefits for agriculture, free of any disadvantages; and those who live in temperate or colder climates can hardly expect to be growing oranges in their backyards in the future. Climate-smart adaptation strategies that will sustain agriculture and the people who work in it have become an urgent priority.

What are the best means of adaptation in agriculture? Most adaptation approaches in agriculture rely on efficient use of water resources and focus primarily on increasing the efficiency of irrigation systems. This includes using drop irrigation, expanding irrigated areas, collecting, and using rainwater for irrigation, adjusting irrigation timings, and shifting from rain-fed to irrigated agriculture.

Other adaptation options related to water resources include the restoration of catchments of rivers and integrated water management schemes. Options specific to agriculture include promoting sustainable agriculture and agroforestry, diversifying plants and livestock, changing crop patterns and crop systems by planting heat-resistant and drought-resistant plants, and changes in agricultural practices, such as planting trees along field edges to serve as wind breaks, installing anti-hail nets and building more greenhouses.

Scientists are warning us that crop irrigation, adjusting planting times, and changing crop patterns and systems may increasingly reach adaptation limits as we move above 1.5°C and 2°C in global warming. This particularly applies to Africa, where adaptation becomes much less effective with an increase of 1.5°C.

Figure 2.5.1 **Smart irrigation systems as a step ahead for water conservation and adaptation to climate change**

QUESTIONS

1 What is the difference between spring and winter wheat? Which is better to plant in your region and why?

2 What cereal crops grow in your region? Are they threatened by climate change?

3 Why do rising sea levels represent a threat for rice production in South-East Asia?

4 What is food security? Explain it using an example.

5 What percentage of people around the world are engaged in agriculture?

6 What kind of adaptation measures - mentioned in this chapter and others - are recommended to address climate impacts on agriculture? How do these measures relate to water resources?

TASK

With the help of your geography teacher, make a list of major crops that are cultivated in your region.

Find information on the yield of these crops in your area in recent years. Is it increasing or decreasing? Have there been crop failures during this time and what caused them?

Think how climate change might affect the yield of these and other crops in your region. Could new climate conditions make it possible to grow other crops?

2.6 How climate change affects **coastal regions**

About 40% of the world's population lives within 100 kilometres of the coast. Many of the world's largest cities, ports and tourist zones are located on or near seacoasts, which account for more than 70% of total world production.

Coastal areas are closely linked with regions far inland. Impacts on coastal zones seriously affect the economy and living conditions, even in places that are far away from them. Coastal zones are highly vulnerable to the effects of climate change. The main threats to them are from rising sea levels, more intense storms that cause flooding and shore erosion, and more frequent extreme weather events.

The rising level of the world ocean

The level of the world ocean has been rising steadily for over 100 years, mainly because of global climate change. It rose by 15-25 cm, an average of 1-2 mm per year, between 1901 and 2018. That may not seem like much, but it presents a real danger for countries where the land is not much above sea level (or even below it).

The IPCC says that the rise in the level of the world ocean since the middle of the 19th century has been faster than the average in the previous 2,000 years. Since 1901, sea levels have been rising at an increasing rate. The average rate of sea level rise was 15-25 cm, or 1-2 mm per year between 1901 and 2018, increasing to 4.62 mm per year for the decade 2013-2022.

Human-induced climate change is mainly behind the rise in sea levels, and is caused principally by:

1. Thermal expansion of water: as temperatures increase, water expands and takes up more space.

2. The melting of glaciers in Greenland and Antarctica, which swells water flows into the world ocean.

In forecasting climate change, scientists use sophisticated mathematical models, which take account of the variety of factors that lead to climate change. Of course, these models cannot predict precisely by how many centimetres sea levels will rise in the next 30, 50 or 100 years. Though they apply scenarios that say that compared with 1995-2014, the level of the world ocean will rise between 15 and 29 cm by 2050 and between 28 cm and 1.01 m by 2100. Over the next 2000 years, the level of the world ocean will rise by about two to three metres if warming is limited to 1.5°C and two to six metres if limited to 2°C.

The expected rise in sea level by the end of this century represents a serious threat to coastal zones, the people living there, coastal infrastructure and coastal ecosystems, particularly small coral islands and the low-lying Pacific coast of South-East Asia. The rise will be uneven and is expected to be much greater in the tropics, where the 22nd century could see rises of one to three metres, followed by an increase of five to 10 metres from current levels in the following century.

High population growth and urbanization in low-lying coastal zones will be the major driver of risks resulting from sea level rise in the coming decades. By 2030, 108–116 million people will be exposed to sea level rise in Africa (compared to 54 million in 2000), increasing to 190–245 million by 2060 (medium confidence). By 2050, more than a billion people located in low-lying cities and settlements will be at risk from coast-specific climate hazards.

The Netherlands prepare for a climate shock

The Netherlands are very low-lying. A large part of the land in this small but highly industrialized country was originally obtained by draining coastal regions.

The Dutch have been developing technologies for the removal of water from their swampy plains for many centuries. Innovative Dutch engineers have long foreseen the threat posed by rising sea levels and have improved the design of hydraulic structures, which can hold back the advance of the sea.

Figure 2.6.1

Windmills were used to pump water from lakes

Figure 2.6.2

Afsluitdijk in The Netherlands is the biggest dam in Europe

Will coastal regions be swallowed up by the sea?

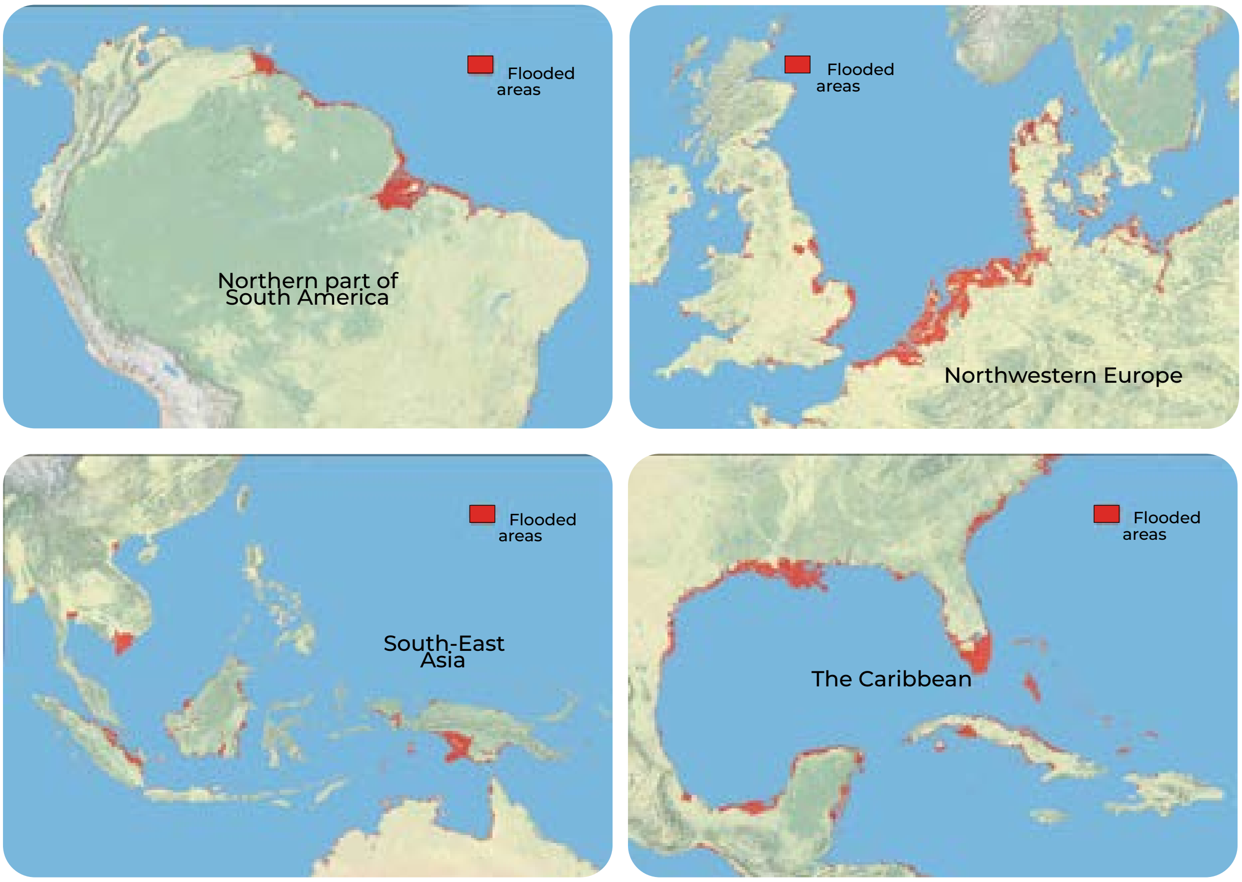
Coastal plains will be flooded because of rising sea levels, coastlines will be gradually swallowed by the sea, and fresh water supplies to coastal areas may break down. These changes can be catastrophic for densely populated coastal countries like Bangladesh, Nigeria, and Indonesia. Several major cities the world over are at risk from rising sea levels, including Shanghai, Bangkok, Mumbai, Jakarta, Buenos Aires, Rio de Janeiro, Miami, and New Orleans.

A rise in sea levels by 1 m will flood up to 15% of arable land in Egypt and 14% of arable land in Bangladesh, forcing millions of people to resettle. Salt sea water may infiltrate coastal groundwater, which is the main source of fresh water in many parts of the world.

In China, forecasts suggest that even a sea-level rise of 0.5m will lead to the flooding of about 40,000 km^2 of fertile plains. Low-lying plains and the lower reaches of major rivers such as Yellow River and Yangtze River will be particularly vulnerable. The average population density along such rivers is sometimes as high as 800 people per km^2.

In many of the Small Island Developing States (SIDS), the land mass rises only a few dozen centimetres above sea level. They could be submerged by the rising ocean, and their inhabitants forced to seek refuge in other countries.

Figure 2.6.3 Forecasts of coastal flooding on different continents, assuming a rise of sea levels by 5 m



Storm warning

Storms have recently become more frequent in coastal areas and at sea. Extreme storm winds, whether near the coast or in the open sea, cause **'storm surges'** – a sudden rise in water levels in water bodies that are semi-open to the sea (bays, the lower reaches of rivers). Storm surges attack coastal regions and are often accompanied by extreme precipitation and flooding, threatening the passage of ships, work on oil and gas platforms and seaside tourism, as well as causing coastal erosion.

Figure 2.6.4 Storms have become more frequent in coastal areas

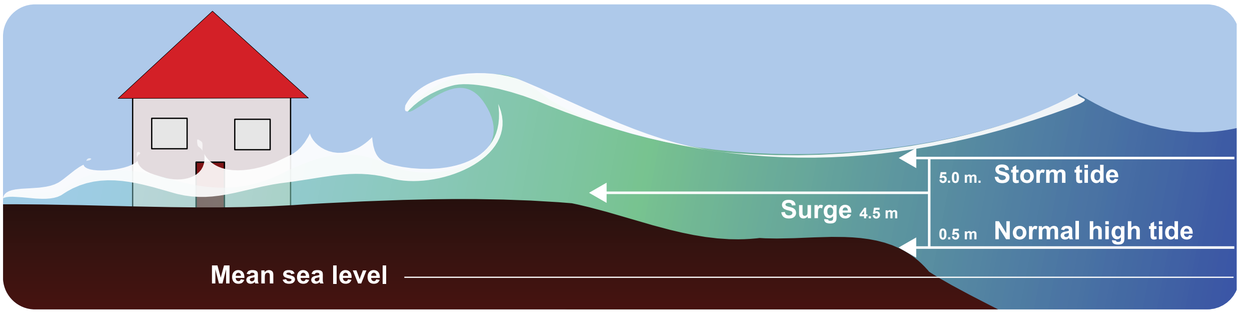
Tragedy in the Philippines

In November 2013, the Philippines suffered a disaster comparable in scale to the tragedy in Japan two years earlier, when the latter country was hit by a giant tsunami wave caused by an undersea earthquake in the Pacific Ocean. The Philippines is an upland archipelago, which often bears the brunt of typhoons coming from the Pacific Ocean; as such, the Philippines effectively protects the Asian continent behind it. Such was the scenario in 2013.

First the Philippines was struck by a super typhoon Haiyan (known in the Philippines as Yolanda), which claimed 6,300 lives; and then it was hit by a second storm, Zoraida. Authorities said the disaster affected almost seven million people in the country (the freak weather destroyed 21,200 homes and damaged 20,000).

The catastrophic impact was from the storm surge reaching up to five metres – as high as two storeys – in some areas; and there was no dam to protect the coastline.

Figure 2.6.5 Storm surge effect



Erosion and destruction of coastline

Erosion and destruction of coastline by the sea is another consequence of rising sea levels (Fig. 2.6.6–2.6.9). Erosion is a particularly serious problem along the Arctic coastline, which was previously protected by ice, but is now losing ground rapidly as the ice cover has lessened and storm weather has become more frequent. The coast in the Arctic is retreating by as much as 10–25 metres or more each year in some places.

Figure 2.6.6 Destruction of coastline on the shores of the New Siberian Islands in the Arctic

Of course, the erosion of seacoasts by waves and floods is not something new. If you look at a map of island archipelagos from over 100 years ago, you will see that many islands in it no longer exist (Fig. 2.6.8). This process is now advancing more quickly. Light beacons that were originally built at a safe distance from the cliff-edge are falling into the sea (Fig. 2.6.9), large human settlements are being engulfed and their inhabitants must be resettled, and roads need to be diverted.

Figure 2.6.7 Example of eroded seacoast

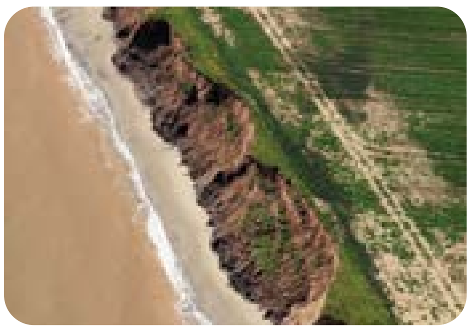


Figure 2.6.8

Coastal erosion in the Arctic. On this section of a map from 1890 showing the Laptev Sea and the New Siberian Islands the red circles highlight islands that no longer exist (they were swallowed up by sea storms)

Figure 2.6.9

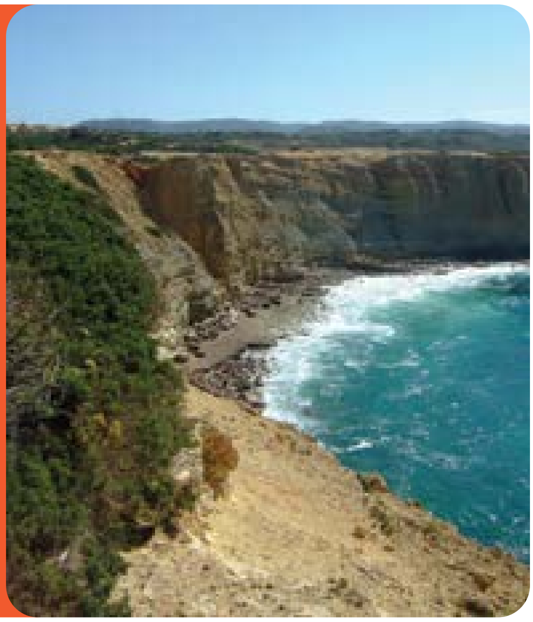
The Vankin coastal beacon (East Siberian Sea, Bolshoi-Lyakhovsky Island), which no longer exists

In Alaska, the entire village of Kivaluna, where 400 people lived on a narrow strip of land beside the Arctic Ocean, had to be abandoned and its inhabitants relocated away from the coastline. The cost of the operation was more than $200 million, although the village had no more than 70 dwellings.

Portugal's disappearing beaches

Environmentalists are concerned by the impact of erosion on the coastline of Portugal, which could soon deprive this European country of many of its beaches.

In some places along the coast the sea is swallowing several metres of land each year, and the situation is critical in the northern region of Espinho, where the shoreline has receded by up to 70 metres in the last few decades. This process is irreversible.



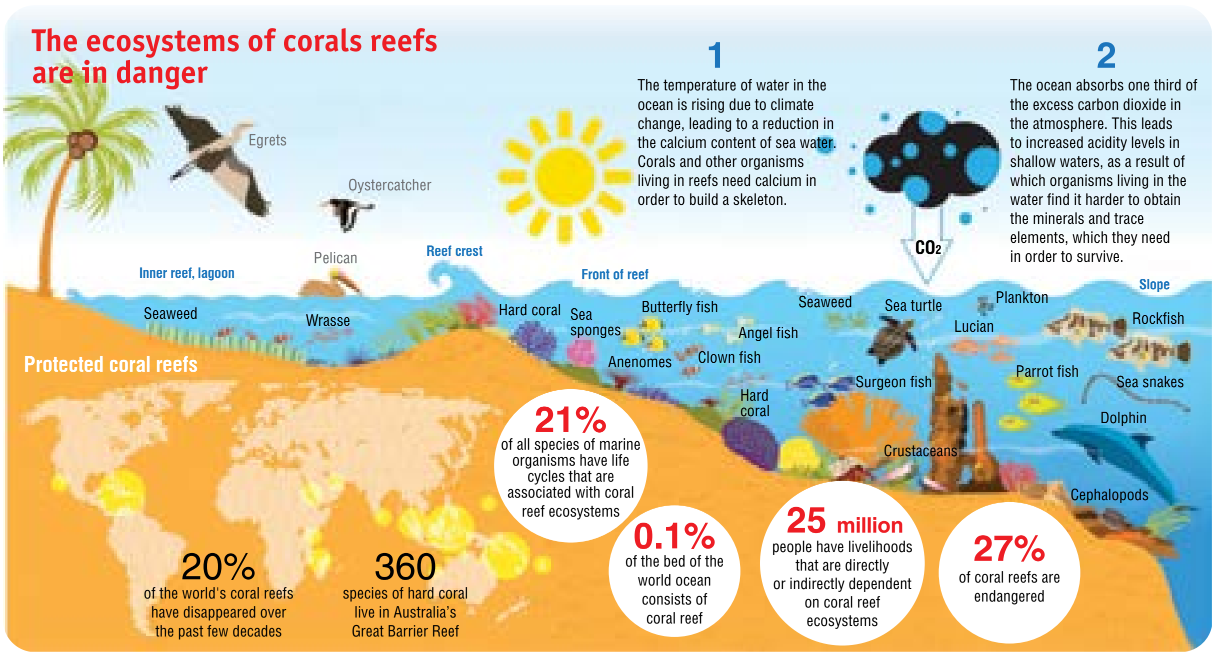
Risk to coastal ecosystems

The rise in sea levels not only affects people and the economy but also sea and land ecosystems along the coast.

The ecosystems of coastal lowlands are particularly vulnerable since they are typically only a few centimetres above the sea. Such lowlands are the habitat of many species of animals and plants and play a key role in the accumulation of nutrients. These ecosystems include salt marshes, which are flooded with sea water at high tide. Mangrove forests, commonly found in coastal lowlands with a humid tropical climate, are also threatened by rising sea levels.

Global warming poses a significant threat to coral reefs since the rise in water temperatures above a certain limit will lead to bleaching of the coral. Bleaching means that corals lose the symbiotic algae normally found in their tissues and become white because of stress. If bleaching is severe or prolonged, they can die. Such coral bleaching is already being observed in many places.

Figure 2.6.10 Coral reef ecosystems at risk



A long-term increase in the temperature of sea water may lead to major degradation of the whole coral reef ecosystem. Coral atolls, which serve as a habitat for a great number of living organ- isms, may be destroyed. Forecasts by the IPCC suggest that 18% of the world's coral reefs will be lost in the next three decades because of a variety of factors.

Climate change and fisheries

Scientists and fishermen are concerned by the increase in temperature and acidity of ocean water. As the concentration of CO_2 increases in the atmosphere, its absorption by the ocean is also increasing, which raises levels of acidity (pH). Changes in pH and water temperature have been enough to cause coral bleaching. By the middle of the present century, acidity may increase by 0.06–0.34 pH, which is 100 times faster than the rate of change in the last 20 million years. Many marine organisms will find it hard to adapt to the new conditions, with serious impacts on fish diversity and productivity.

Figure 2.6.11 Forecast changes in acidity of the ocean's surface water by the end of the 21st century under the most favourable (left) and the least favourable (right) climate change scenarios change

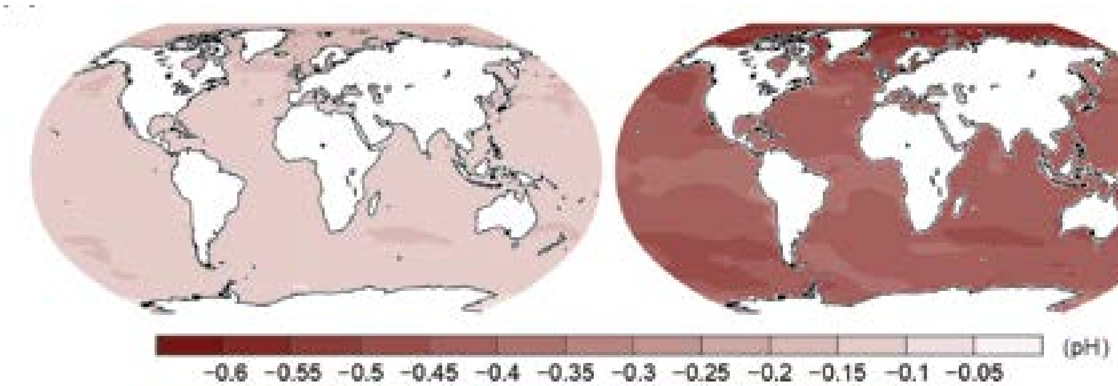
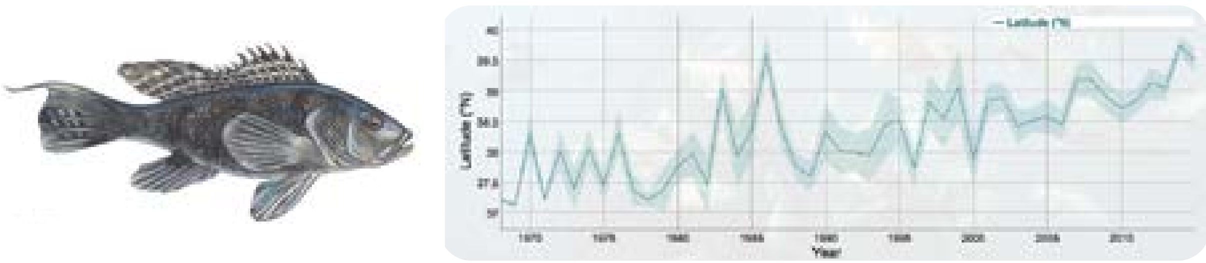


Figure 2.6.12 Black sea bass is moving North as the oceans warm



The National Oceanic and Atmospheric Administration (USA) and Rutgers University have developed the **OCEANADAPT webtool** to track changes in the movements of fish and invertebrates caused by changing climate and ocean conditions. The tool provides easy access to information about the changes in depth and latitude for nearly 650 marine species over the last 40–50 years. It is a useful resource for managers, fisherfolk, fishing communities, and scientists in developing timely adaptation strategies.

Changes in the properties of sea water are already leading to massive displacement of marine and freshwater fish species and the direction of their movements is not chaotic, but purposeful. Warm-water fish are moving to higher, cooler latitudes. This is not because of higher water temperature but a reduction in the amounts of phytoplankton, the staple diet of ocean fish, as the water temperature rises.

The numbers of cod off the coast of Greenland, and Japanese and Adriatic sardines increase during periods of climate warming and fall sharply during cold periods.

Many fish species are currently being fished at the limits of capacity to preserve their populations. Additional pressure from the need to adapt to climate change may push some species beyond their ability to reproduce in sufficient numbers to survive.

The loss of coastal habitats, including coral reefs and mangroves, is another major factor threatening fish populations.

The World Food Programme notes that fish represent more than 15% of the average protein intake for over 2.9 billion people. In small island states and some developing countries (Bangladesh, Cambodia, Equatorial Guinea, French Guiana, Gambia, Ghana, Indonesia, and Sierra Leone) fish provide more than 50% of animal protein intake. The populations of these countries are dependent on fisheries, so that any reduction in local catches represents a serious problem.

The rise in sea level is one of the changes to the global system resulting from climate change to which it is the most difficult to adapt. Strategies aimed at promoting adaptation are raising awareness of expected increases in the sea levels, improving early warning systems, and strengthening coastal defence and integrated coastal zone management.

QUESTIONS

1. Which country, Switzerland, or the Netherlands, will suffer the most if sea levels rise by more than half a metre?

2. Why are seacoasts being eroded rapidly?

3. What happened to lost islands?

4. Give examples of the impact of climate change on coastal ecosystems.

5. Why are some fish species moving to northerly latitudes?

6. What can be done to adapt to climate change in the coastal zones?

TASKS

1 Locate Tuvalu and the Republic of the Maldives on a physical map of the world. Find their height above sea level and explain why a rise in the level of the world ocean is so dangerous for them. Find other island nations and coastal countries which are also in danger of being fully or partially submerged by the sea in the next 50-100 years. Suggest ways of addressing the problem.

2 Show on a contour map how the appearance of the continent of South America would change if sea levels rose by 100m. Use coloured pencils to colour areas of land that would disappear under the sea. Think of geographical names for these areas. What will happen to the animals and plants there? Will they perish? Write down your suggestions in an exercise book.

3 Using the OCEANADAPT webtoo (http://oceanadapt.rutgers. edu/), find out how different fish species in the USA have changed their habitats in the past 40–50 years. Which species had to move the most? Why are these movements happening?

2.7 How climate change affects **mountain regions**

What are mountains?

"What are men to rocks and mountains?" exclaimed Elizabeth Bennett, the heroine of Jane Austen's *Pride and Prejudice*, excited about her forthcoming nature tour of pleasure in the summer. And it is true that mountains are one of the greatest creations of nature. What can compare with the breathtaking feeling when you stand on the top of a mountain, with only the blue sky above, and below you the world that looks so tiny, glimpsed under white clouds? At such moments you feel the beauty and power of nature, and at the same time its fragility.

Scientists define mountains as an elevated form of relief that rises above the surrounding plain. Unless they are volcanoes, mountains rarely stand alone, but usually form mountain ranges and ridges. Mountain ranges, in turn, come together to make mountainous countries or mountain systems.

Mountains may be high (above 3,000 m), of medium height (1,000–3,000 m) and low (up to 1,000 m). Low mountains usually have rounded summits and gentle slopes, but high mountains have steep slopes and angular peaks.

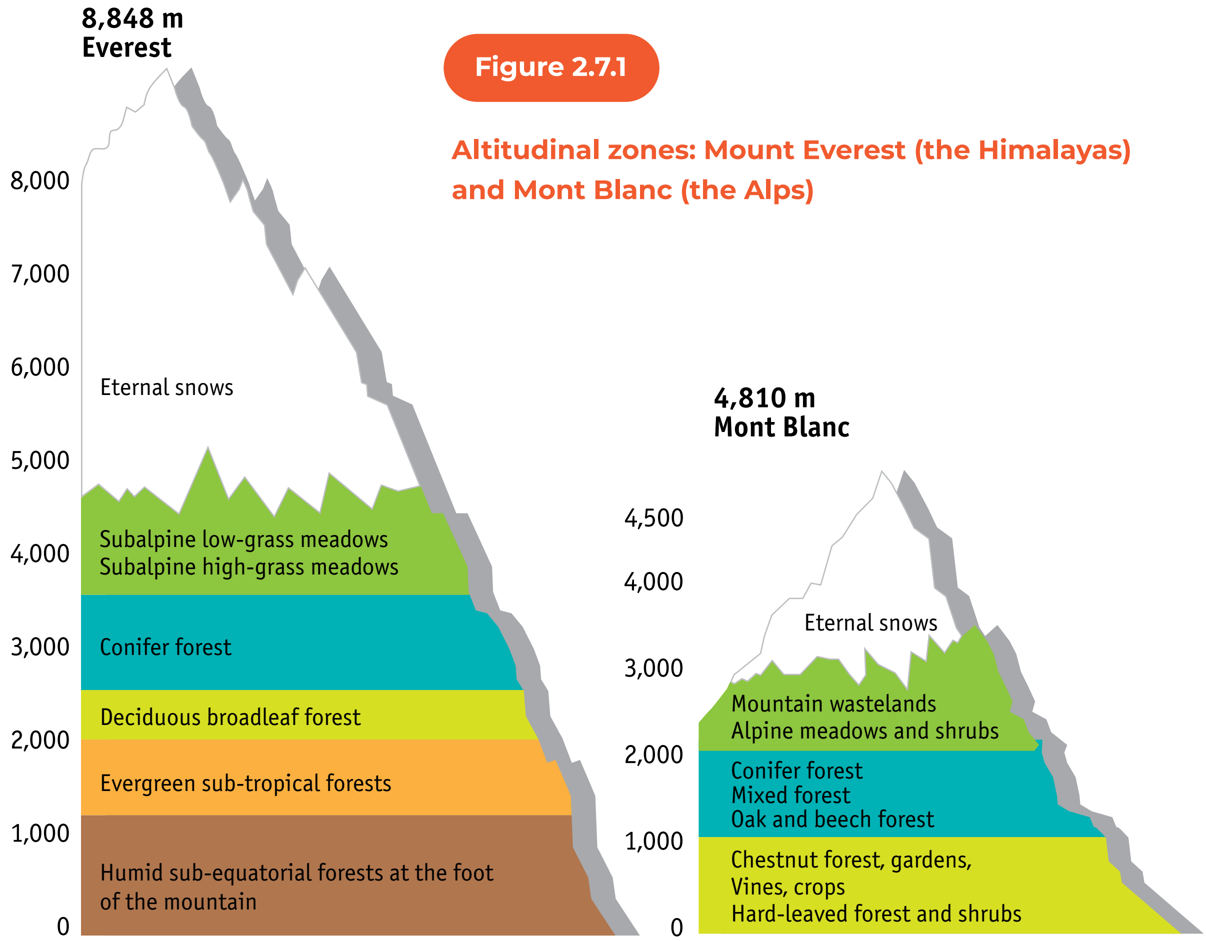
Mountains and climate

Mountains play a critical role in shaping the climate. They create a barrier to air masses, which cannot easily pass the high peaks. For this reason, different slopes of the same mountains often have different climate conditions, with more precipitation on one side than on the other. Average temperatures and landscapes may also differ significantly.

Mountains are also distinctive in that they bring together several different climates in a small area: the climate and landscapes change at different levels from the bottom to the top of the mountain. (Fig. 2.7.1). They are therefore called 'altitudinal zones' ('altitude' means 'height').

Figure 2.7.1

Altitudinal zones: Mount Everest (the Himalayas) and Mont Blanc (the Alps)



The world's highest mountains

The highest mountain range on the earth is the Himalayas, which in Sanskrit means dwelling of the snows. Ten of the world's 12 mountains that are over 8,000 metres high are located here, including the highest land point: Mount Everest, also known in local languages as Chomolungma or Sagarmatha. Mount Everest is 8,848 metres high.

The longest mountain range on land is the Andes. This gigantic South American mountain range extends along the entire Pacific coast of the continent.

Mount Aconcagua (6,960 m) in the Andes is the highest point in the western and southern hemispheres.

The largest mountain system in Europe is the Alps, which are shared between eight countries: Austria, Germany, Italy, Liechtenstein, Monaco, Slovenia, France, and Switzerland. Mont Blanc (4,807 m) in the Alps, on the border between France and Italy, is the highest point in Western Europe. The highest mountain on the European continent is the two-headed Elbrus Volcano (5,642 m) in the Greater Caucasus, which is also the highest peak of Russia.

North America has a system of mountain ranges, the highest of which are the Alaska Ridge and the Rocky Mountains. Mount McKinley (6,193 m) in Alaska is the highest peak in North America. Former US President Barack Obama announced on 31 August 2015 that Mount McKinley will be renamed Denali, as Alaskan natives call it. Africa's highest mountain is Mount Kilimanjaro (5,895 m). The highest mountain in Australia is Mount Kosciuszko (2,228 m).

Figure 2.7.2

N. Roerich. *Himalayas.* Everest. 1938

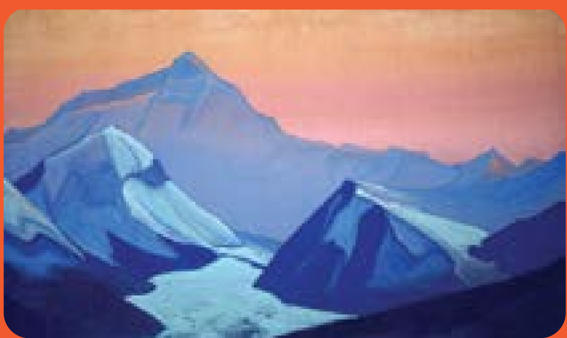


Figure 2.7.3

The two-headed Elbrus volcano (5,642m), the highest peak in Europe

You've probably wondered why mountain peaks are often covered with snow, even in tropical latitudes. The first mountain climbers quickly found that the higher they went, the lower the temperature became and the harder it was to breathe. Air is heated by the sun and by the earth's surface. Once it has become warm, it rises and expands, losing its heat. So, with increasing altitude, the air pressure, and its temperature gradually decrease.

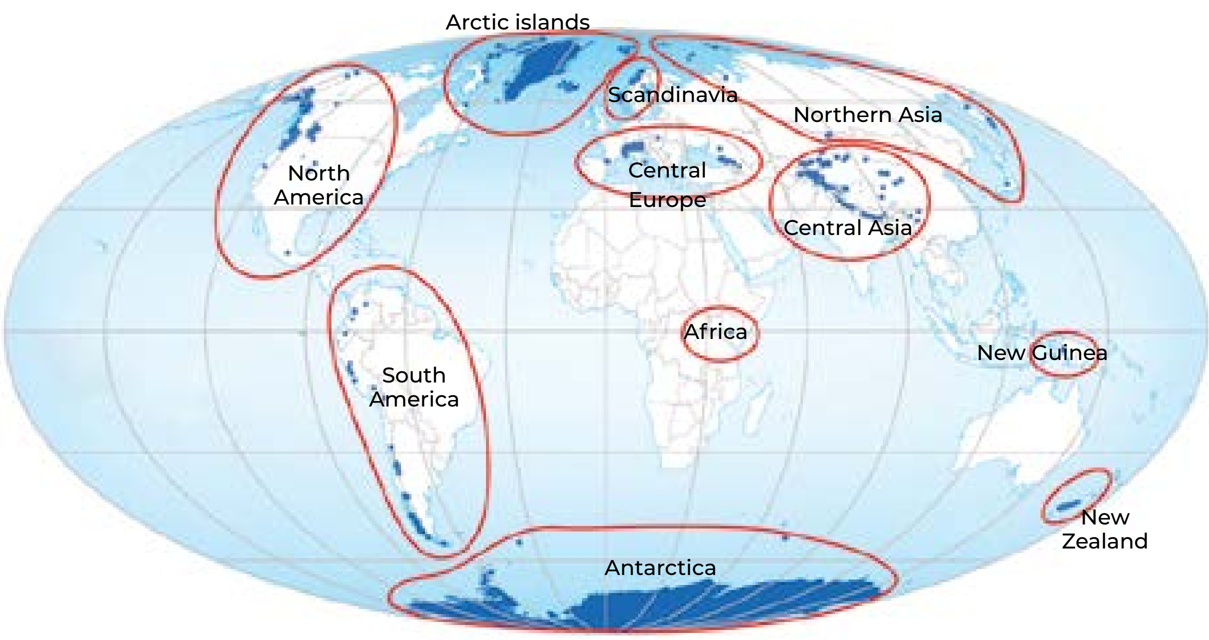
With elevation, temperature falls on average by 6°C per kilometre from the earth's surface. So, if the temperature at the foot of a 4,000-metre mountain is +24°C, the temperature at the top will be around 0°C. That is why, even though the average air temperature in the tropics never drops below zero, there can still be snow at high altitude on mountains.

Mountains affect the climate, but they are also highly dependent on it. Mountain regions are among the first to respond to changes in climate conditions. The main 'indicator' of climate change in the mountains are glaciers, which shrink or grow depending on whether the climate is becoming warmer or colder.

Melting beauty

Glaciers are formed in mountain ranges when the build-up of snow in the upper parts of the mountains turns to ice. The formation of a glacier requires a cold and wet climate, in which more snow falls during the year than has time to melt. As soon as temperatures rise and precipitation declines, the glacier ceases to grow and starts to melt.

Figure 2.7.4 Glacial regions of the Earth



Mountain glaciers around the world began to melt (to 'retreat') about 15,000 years ago, when the last period of glaciation gave way to a new period of warmer climate. This melting process was accompanied by short periods when glaciers advanced once again. We know from history that in the 5^{th}–7^{th} centuries A.D., many mountain passes now occupied by glaciers were used as caravan routes. When the climate grew colder, glaciers began to grow, and by the 17^{th}–18^{th} centuries these passes were no longer open.

One example is the famous St. Gotthard Pass in the Alps. As the poet Frederick Schiller described it in 1799, "To the solemn abyss leads the terrible path / The life and death winding dizzy between," crossing the snow-covered pass was wildly dangerous and possible only during a couple of summer months.

Figure 2.7.5 **W. Rothe. *Crossing St. Gotthard Pass*, 1790**

However, over the past 70 years, glaciers around the world have been retreating particularly fast (Fig. 2.7.6). Scientists are sounding the alarm: the rapid melting of mountain glaciers we are seeing today does not coincide with a natural cycle. A reduction in the volume of mountain ice may lead to catastrophic consequences for the environment and the economy of mountain regions, as well as their surrounding plains, which are home to as many as one in six of the world's population.

Figure 2.7.6

Change in the mass of mountain glaciers around the world, 1950–2022, measured in units of meter water equivalent (m. w. e.)

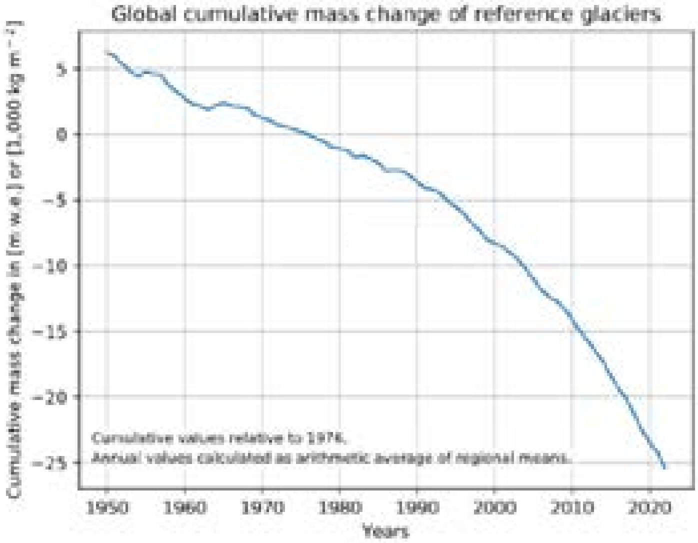


Figure 2.7.7

This is how scientists study glaciers

Mountain glaciers are retreating

Glaciers in the Himalayas are retreating by an average of 10–15 metres per year. The Gangotri Glacier, which is the source of the River Ganges, is melting particularly fast, retreating by 30 metres each year. Gangotri is one of the main sources of water for the 500 million people who live along the River Ganges.

Glaciers in Peru are also retreating rapidly. According to the most conservative estimates, their area has fallen by a third over the past 30 years.

The African volcano, Kilimanjaro, has suffered perhaps the worst of all: its famous ice cap, immortalized in Ernest Hemingway's novel, *The Snows of Kilimanjaro*, has almost entirely disappeared.

Figure 2.7.8

The Gangotri Glacier

Figure 2.7.9 **The cap of ice and snow of Mount Kilimanjaro has almost disappeared**

Glaciers in the Alps are melting faster than ever. According to research conducted in 2023 by the scientific group Glacier Monitoring Switzerland (GLAMOS), Switzerland's glaciers lost as much ice in two years as in the three decades before 1990: in just two hot summers in 2022 and 2023, the Alpine glaciers have lost the same volume of snow as that between 1960 and 1990. Scientists concluded that climate breakdown caused by the burning of fossil fuels is the cause of unusually hot summers and winters with very low snow volume, which have accelerated the melting of the glaciers. The European Environment Agency expects that 75% of Alpine glaciers will have melted by 2050.

In the mid-19th century, the Glacier National Park in the Rocky Mountains, on the border between USA and Canada, was home to as many as 150 glaciers. By the start of the 21st century, only 25 remained, and scientists predict that they will disappear in the coming decades, so visitors who want to see what the park was originally famous for should hurry up!

Figure 2.7.10 Glacier National Park in August 2013

The volume of glaciers in New Zealand decreased by 11% from 1975 to 2005. The most rapidly melting glaciers in that island country are the Tasman, Classen, Mueller and Maud glaciers.

Figure 2.7.11

The Greater Azau Glacier in the Caucasus. The photograph displayed by the woman is from 1956. Behind her you can see what remained of the glacier in 2007

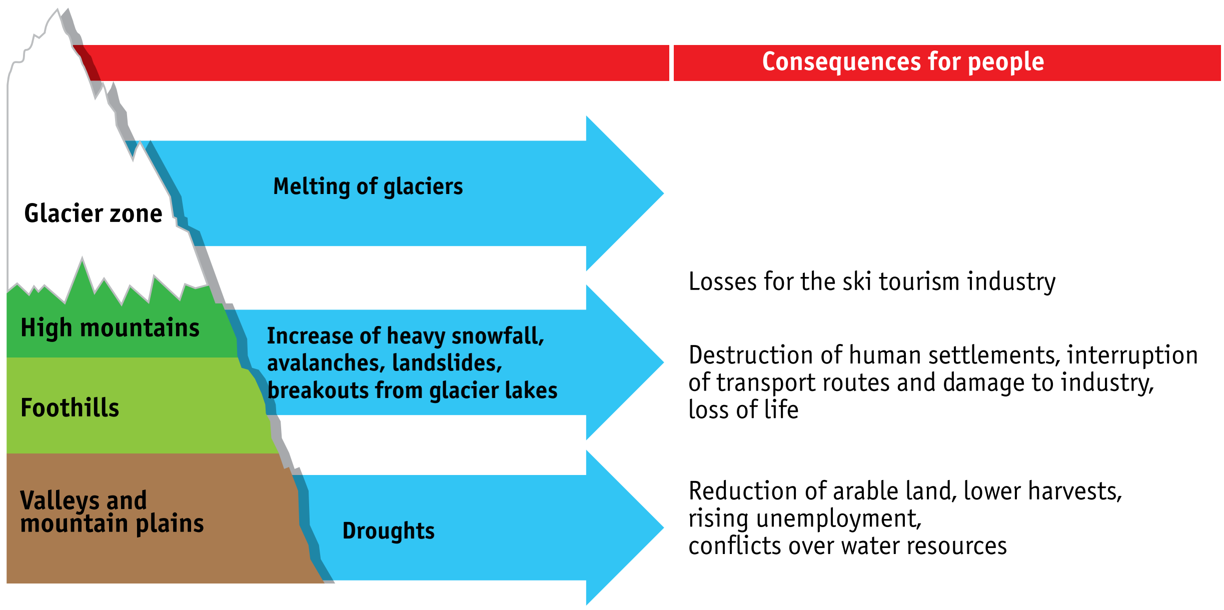
The Azau glacier in the Caucasus has undergone significant changes. At the end of the 19th century the melting process caused it to divide into two parts, called the Lesser and Greater Azau. Today the Greater Azau is no longer great. From 1957 to 1976, the glacier retreated by 360 metres, and then by a further 260 metres from 1980 to 1992. The Lesser Azau retreats by about 16 metres each year.

The number of glaciers in the Altai Mountains in Eastern Russia decreased by 7.5% from 1952 to 1998, and those which remain have retreated by 100–120 metres from their position in the mid-19th century. The Sofia glacier, being observed by experts from Altai State University, has retreated by 1.5–2 km in the last 150 years. This glacier is also 'rising' at a rate of 20–30 metres each year.

How climate change affects people who live in the mountains

Living in the mountains is not easy. The high altitude, difficult terrain and frequently changing weather make it much harder to grow food and manage cattle here than on the plains.

Figure 2.7.12 The impact of climate change on human life in the mountains



Since ancient times, people have settled in narrow mountain valleys, separated from one another by high mountain ranges with steep slopes, which often made contact between the neighbouring valleys (and populations) difficult. Even now, people living in mountainous regions often have their own unique customs, culture, and ways of making a living. The way of life of mountain people and their principal livelihoods – agriculture and tourism – are directly dependent on the climate. Even small changes in climate can affect their wellbeing.

Tourism going downhill

The example of the Alps shows how climate change is affecting tourist industry in mountain areas. Ski tourism provides up to 20% of the income of Alpine countries (Fig. 2.7.13). For the 13 million people living in the Alps in Austria, Germany, Switzerland and France, the lack of snow is an economic catastrophe: two thirds of all tourists who come here do so for skiing and snowboarding.

Forecasts give serious cause for concern: by 2030 there will be almost no snowfall in the Alps below 1,000m altitude, which will put many popular ski resorts out of business. Half of all the ski resorts in Austria are at altitudes up to 1,300 metres and will be forced to close due to lack of snow. The pessimistic predictions are already starting to come true: in the winter of 2006–2007, as many as 60 of the total 660 alpine ski resorts remained closed, and many others could only operate by using artificial snow, which greatly increased their already high costs. The result has been a fall in demand for holidays in the Alps.

How can mountain regions cope without snow? The sport and leisure industry is adapting as best it can, working to develop other types of tourism and recreation, which are less dependent on snow. Areas that were used for skiing are being converted into leisure parks and all-year-round health resorts. A time may come when people will go to the Alps, not for winter sports, but to enjoy walks along mountain lakes, savour the local food and breathe the fresh mountain air.

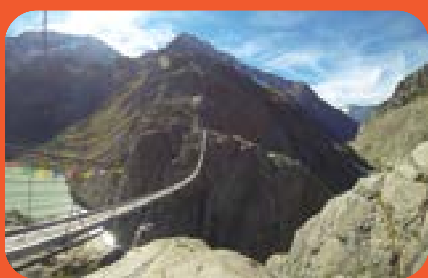
Figure 2.7.13

Tourist industry makes a large share of the income of mountain regions

Trift Lake in the Swiss canton of Bern is an interesting instance of how global warming is affecting the Alps. In the 1990s, a nearby glacier began to shrink rapidly, the melt water formed a small lake and more of the valley became free of ice. Previously, people could walk from one mountain peak to another across the glacier. The local authorities decided to build a suspension bridge for walkers before the glacier completely melted, and the bridge quickly became a major attraction, drawing visitors from all over the world.

Figure 2.7.14

Bridge over Trift Lake, Switzerland



The Pastoruri Glacier in Peru is retreating

Until recently, tourists and professional climbers used to flock to the Pastoruri Glacier, which towers over the Andes in Peru. But the glacier has shrunk by more than a quarter in the last 35 years and scientists predict that it may disappear altogether in the next few decades. A breathtaking landscape of snow and ice has given way to black cliffs. Local authorities have prohibited climbing because the melting glacier has made the rocks unstable.

The number of tourists who come to admire the Pastoruri Glacier has fallen three times since the beginning of the 1990s, with major impacts on tourism in Peru and the income of residents. But Peruvian entrepreneurs have not despaired: they now show off the remains of the glacier as a striking example of the results of climate change, and the region has been successful in attracting increasing numbers of environmentalists and curious tourists.

But, of course, restoring the glacier itself is a much harder task than restoring the fortunes of local business.

Figure 2.7.15 **Retreat of the Pastoruri Glacier in the Peruvian Andes**

Natural disasters in the mountains

The decline of the tourist business is not the deadliest threat to mountain people from global warming. They also must fear natural disasters – avalanches, landslides, and floods – which have become ever more frequent in the mountains as the climate changes, posing a threat to human life and causing huge damage to the local economy.

When a glacier retreats it produces melt water, which accumulates in a mountain valley to form a glacial lake. As the quantity of water increases, the lake may overflow, causing a flood. Scientists believe that 20 glacial lakes in Nepal and 24 in Bhutan pose a serious threat to people living further down the valley. If these lakes breach their banks, and the water gushes into the valley, many people are in danger of losing their lives and/or their homes. Several such floods have already occurred in recent years in the valleys of the Thimphu, Paro and Punakha-Vangdu rivers in Bhutan.

The danger to the local population can be reduced by digging protective channels and dams before such flooding occurs.

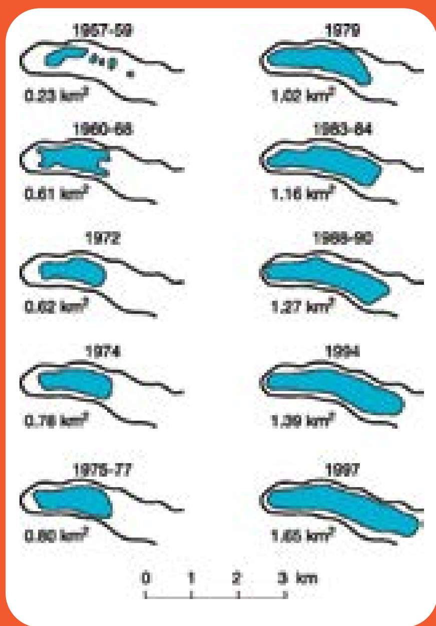
The **Tsho Rolpa Lake** in Nepal, which was formed by water from melting glaciers, has expanded seven-fold over the past 50 years. Studies show that more than 20 glacial lakes in Nepal and 24 in Bhutan may soon overflow, which could lead to catastrophic consequences for the people and economies of these countries unless appropriate precautions are taken.

Figure 2.7.16

Glacial lakes in the Himalayas

Figure 2.7.17

Lake Tsho Rolpa has grown by seven times in the past 50 years



An **avalanche** is a huge mass of snow that falls or slides off mountain slopes. Avalanches can have disastrous consequences. In February 1999, an avalanche weighing 170,000 tonnes destroyed the village of Galtur in Austria and claimed the lives of 30 people. In March 2012, a series of avalanches in Afghanistan destroyed homes, killing more than 100 people. More recently, in January 2023, an avalanche struck a road in Nyingchi, China, and killed 28 people and injured 53 others.

A landslide is a tremendously powerful mass of mud and rocks, which suddenly slides down mountain river valleys. Landslides are usually caused by heavy rains or rapid snow melt. They can also be caused by the breakout of water from glacial lakes. Landslides, like avalanches, can cause massive destruction.

Reduction of freshwater stocks

The future reduction of freshwater stocks, both in mountain regions and in adjacent plains, presents a serious threat. Glaciers are one of the main sources of fresh water since they are the source of many rivers. Melting ice will lead to water shortages in the regions around mountains, making conditions much worse for agriculture, mining, and electric power generation. A shortage of fresh water in areas near mountains is already leading to serious political conflicts in some parts of the world. Scientists note that climate change impacts on the mountains, such as hydrological changes resulting from the retreat of glaciers or some ecosystem changes, cannot be reduced through adaptation measures.

Mountains have always been associated with danger, and climate change may add to the risks. Rise of temperatures, changes in the amount of precipitation, the melting of mountain glaciers, and the more frequent occurrence of unpredictable natural disasters could lead to catastrophic consequences for the environment, the people and the economy of mountain regions and surrounding areas.

QUESTIONS

1. How high has a mountain climber climbed if he is at a level where the temperature is -9°C, when the temperature at the foot of the mountain is +18°C?

2. Will snow remain at the top of a mountain 5200 m high, if the air temperature at its foot is +30°C on the hottest day of summer?

3. Why are mountain glaciers often called indicators of climate change? What happens to them when the air temperature changes?

4. Why is there often a great deal of ethnic diversity in mountain regions?

5. What are the main livelihoods of people living in mountain regions? How are they affected by climate change?

6. What can be done to preserve the main livelihoods of people living in the mountain regions and adapt to consequences of climate change?

TASKS

1 Mark the highest peaks on each continent on a contour map of the world. Which mountain systems are they a part of? In which countries are they located?

2 The beauty and the inaccessibility of mountains have always inspired the greatest poets, writers, artists, and composers. Name some famous works of literature or art that show various mountain ranges or peaks. Choose any work that you particularly like and explain what the author would have to change if they had lived in an era of global climate change. How could they do it?

3

Game
The players divide into two teams.

Team № 1 live in High Village, which is in the Rapid River Mountain valley. In recent years the melting of glaciers in the high mountains has caused the Rapid River to flood its banks on several occasions, causing problems for residents. So, they want to build a dam on the river to protect themselves from floods and at the same time produce electricity and create new jobs. The mountain people are not rich, they have no money for the construction of the dam and live mainly on what they can grow and the animals they keep. In recent years, due to rising temperatures the people of High Village have begun to grow flowers and exotic fruits.

Team № 2 live in the village of Cowgrazing, which is on the plain near the mountains, downstream on the Rapid River. The village is prosperous, its people are farmers and use water from the river for irrigation and for drinking. The people of Cowgrazing like exotic food, entertainment, and travel. The local budget has plenty of money to finance new construction projects.

Members of the teams need to discuss the following questions (the teacher or one of the students can play the role of Minister for Regional Development, who will manage the negotiations):

1) What will be the consequences for the village of Cowgrazing if the people of High Village build a dam without consulting them?

2) On what terms can the village of Cowgrazing agree to the dam and provide money for its construction?

3) Can the people of High Village find ways to protect themselves from the consequences of climate change without building a dam?

4) What new projects and types of business can the people of High Village and Cowgrazing work on together?

2.8 How climate change affects **the Arctic regions**

The Arctic is the Earth's northern polar region, which includes the Arctic Ocean and its seas, the northern parts of the Pacific and Atlantic Oceans, the Canadian Arctic Archipelago, Greenland, Svalbard Island, Franz-Josef Land, Novaya Zemlya, Severnaya Zemlya, the New Siberian Islands and Wrangel Island, as well as the northern coasts of Eurasia and North America.

There are no hard and fast boundaries to the Arctic region. The most common definition of its southern boundary is the Arctic Circle at northern latitude of 66 degrees and 33 minutes. This makes the total area of the Arctic 21 million km^2 (Fig. 2.8.1).

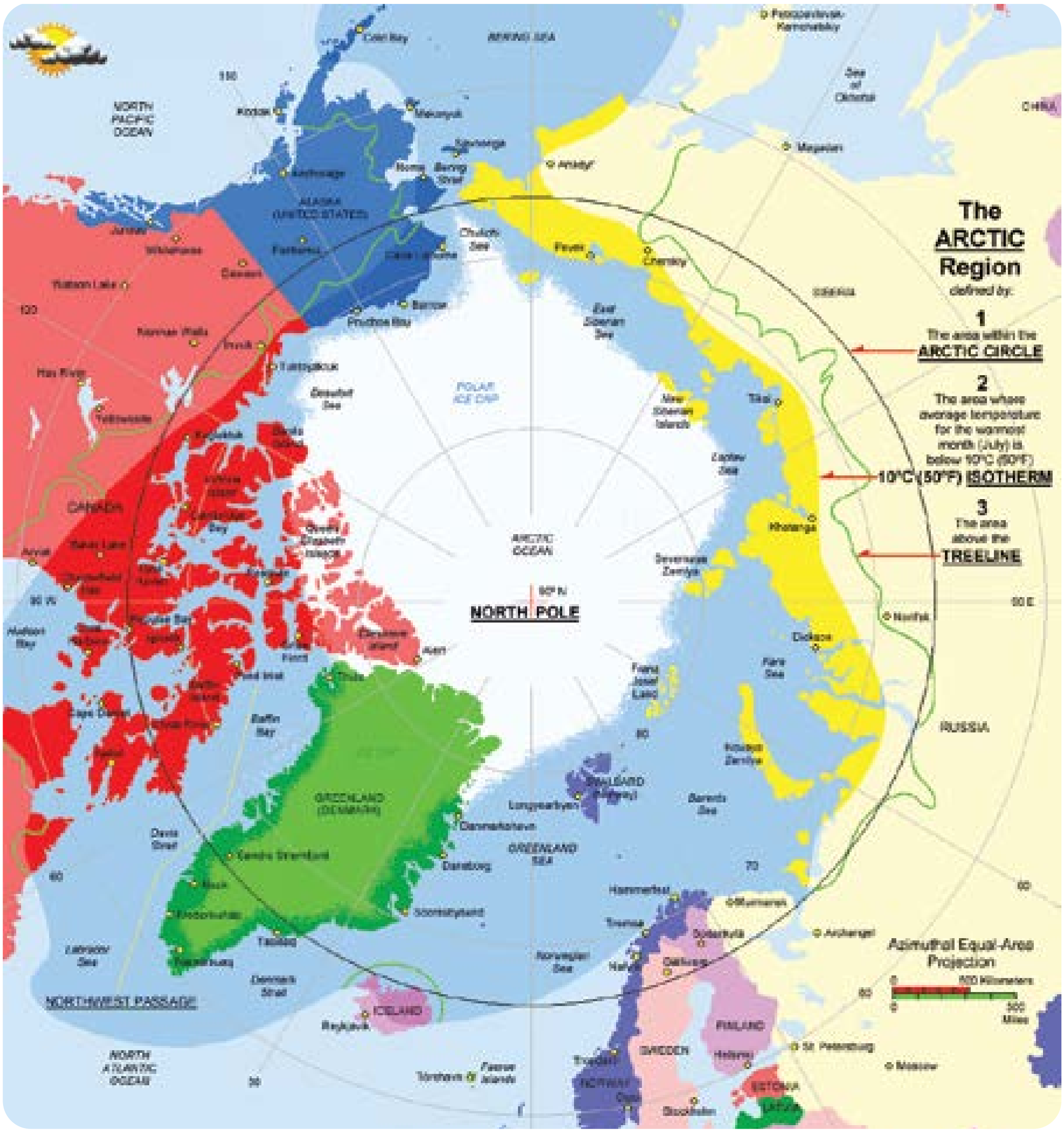
A second definition of the Arctic region is the July isotherm – an imaginary line where temperatures in the warmest month of the year are not greater than 10°C. The tree line roughly correlates to the July isotherm and constitutes the third definition of the Arctic. The tree line marks the transition from the forests zone to the shrubs and grasses of the tundra. Russia, the United States (Alaska), Canada, Norway, Sweden, Finland, Iceland, and Denmark (Greenland) all have Arctic territories.

The Arctic is getting warmer faster than the rest of the world

Climate change in the Arctic is much more pronounced than on average in the world. Temperatures along the Arctic coast have risen already by 2-3°C in recent decades.

But the most noticeable effect of climate change on the Arctic has been an increase in fluctuations of climate and weather. In temperate climates, sudden changes of temperature are usually not greater than 10°C: it may be quite warm today, but tomorrow the temperature falls by 10°C, and then it rises again by 10°C a week later. But in the Arctic the temperature can change suddenly by as much as 20°C, and summer temperatures in one Arctic region can be 5°C warmer than they were in the mid-20th century, while in a neighbouring region they are 5°C cooler.

Figure 2.8.1 The Arctic and definition of its boundaries



It might seem that warmth in the Arctic is a good thing, but that is not always true! Which is better: a temperature of -35°C with clear, windless weather, or -20°C with a blizzard? Of course, it's better to be colder, but without the blizzard, particularly since the Arctic is used to such temperatures. The issue is not temperature: whatever happens, temperatures in the Arctic will never be high enough for people and animals there to get overheated.

There is a concept in meteorology called the **wind chill index**, which reflects how cold people feel from the combined effect of low temperature and wind. For example, at air temperature of -10°C and wind speed of 30 km/h the wind chill index will be -20°C, which is to say that a person will feel and react to these conditions as if the air temperature was -20°C.

Various climate parameters affect the lives of people and ecosystems in the Arctic: the power of the wind (blizzards and storms), reduction of the extent of sea and river ice, severe coastal erosion, and the melting of permafrost. Changes to these parameters are not just a consequence of rising temperatures – the parameters themselves are active forces helping to drive temperatures upwards. Scientists call such inverse effects 'feedbacks'. There are at least two of them:

1. Higher air temperatures cause ice fields to melt and break up, leaving large expanses of open water between ice floes. The dark surface of the water, unlike ice, does not reflect but absorbs solar radiation, so the water grows warmer, more ice melts and the process is accelerated.

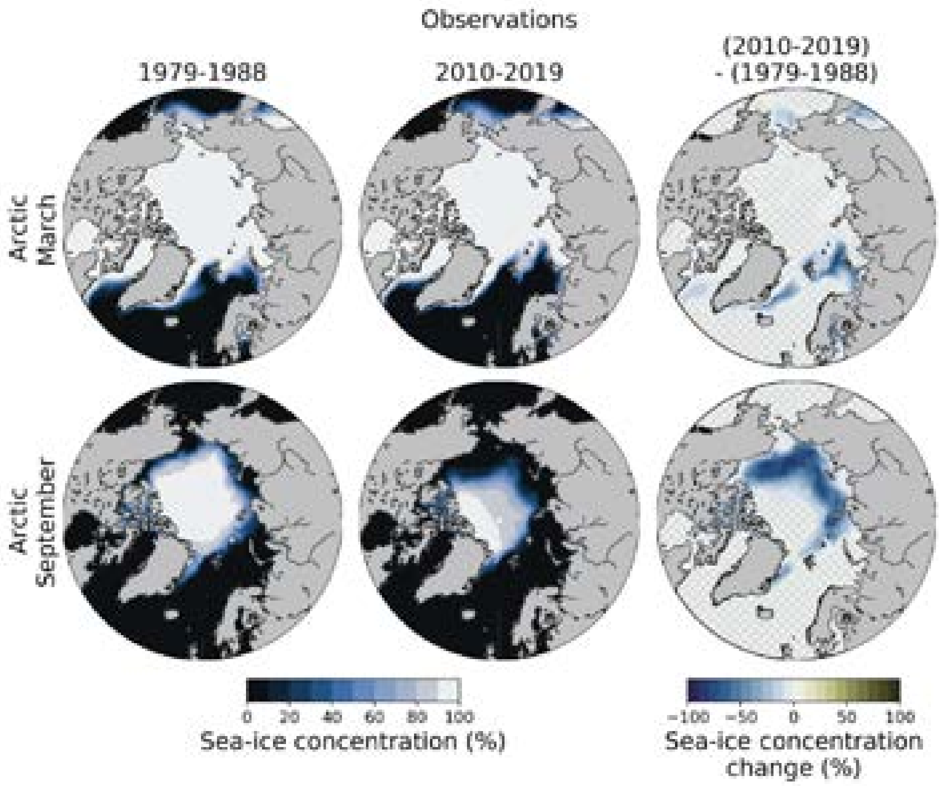
2. More open water means more evaporation of moisture and more clouds. Remember, nights are relatively warm when the sky is cloudy, because clouds trap heat, and it is much colder on a clear night. Similarly in the Arctic, when there is a lot of open water and clouds, the temperature is higher, especially at night, which also makes ice melt faster.

The Arctic economy has two polar types of activities. On the one hand, there are the traditional activities of the indigenous population, such as hunting, fishing, reindeer herding. On the other is large-scale production of oil and natural gas, iron, zinc, gold, diamonds, fish, and timber for an international market. The largest economies in the Arctic belong to Russia and Alaska (USA) mainly because of their mining and petroleum sectors. Regions that are still heavily dominated by more traditional small-scale activities, especially in Greenland and Northern Canada, have a much lower economic output.

The disappearing ice of the Arctic

Scientists have been monitoring ice in the Arctic since 1979 by means of satellites. Satellite data show that the amount of ice in the Arctic has declined dramatically (Fig. 2.8.2). Maps of Arctic sea-ice show satellite-retrieved mean sea ice concentration during the decades 1979–1988 and 2010–2019, as well as the absolute change in sea ice concentration between these two decades. Over the past 40 years, the sea-ice concentration in the Arctic Ocean and its seas has decreased by more than 20%.

Figure 2.8.2 Maps of Arctic Sea ice concentration for March and September, which are usually the months of maximum and minimum sea ice area, respectively



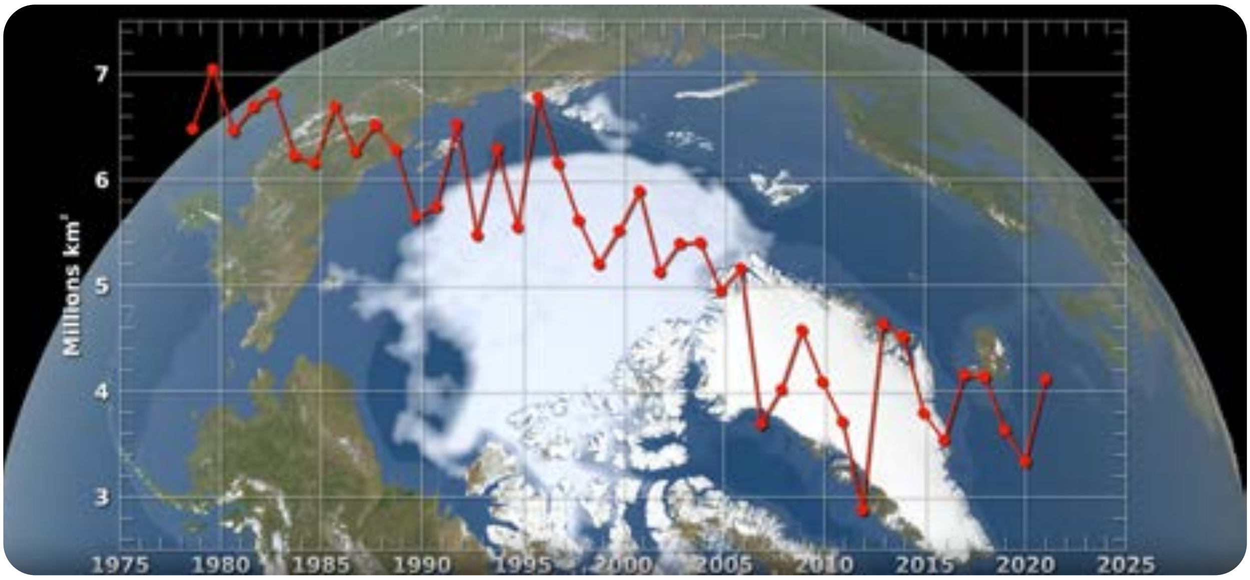
The area of ice is usually measured by its maximum and minimum extent for the year, normally at the end of March and September. The shrinkage in September 2012 set an absolute record: the area of sea ice shrank to 3.41 million km² (Fig. 2.8.2 and 2.8.3).

Of course, ice still covers the whole of the Arctic in winter. Even gigantic warming of 15–20°C would not lift winter temperatures in the polar regions above zero. But it would greatly thin out the ice. This effect is already clearly visible.

Scientists note that a reduction in the extent and thickness of sea ice could offer new opportunities for greater use of the northern sea route for transporting goods between Europe and Asia, and vice versa. Transit via the seas of the Arctic Ocean is much shorter than the traditional route through the Suez Canal and can significantly reduce the cost of shipping.

Ships have the best chance of traversing the northern sea route in September, when the area of ice is at its lowest extent. But even when ice cover is at its lowest (Fig. 2.8.2), there is no guarantee that all the straits will be open. This is particularly true of the Vilkitsky Strait between Taimyr and Severnaya Zemlya, which represents a bottleneck for the entire Northern Sea Route. This strait remained ice-bound even in 2007. On the other hand, there are occasions when the overall ice cover is much greater, but straits are passable. In sum, it is too early at present to speak confidently of ice-free navigation along the Arctic coast of Russia. Climate models suggest that the Arctic will become completely free of ice in the summer only from about 2050.

Figure 2.8.3 Extent of Arctic Sea ice (annual minimum area) between 1978 and 2022



It is important to remember that the melting of ice in the Arctic leads to the formation of icebergs, which pose serious dangers to ships and oil platforms positioned on the continental shelf in the open sea. In the future, shipping and oil companies will need to ensure proactive protection from icebergs avoiding collisions and accidents.

Threats to the animals in the Arctic

The melting of ice in polar regions has major impacts on marine animals, including the 'king' of the Arctic, the polar bear. He does not need ice, but his main prey are seals, which are always found at the ice edge.

Due to global warming the ice edge now retreats northwards very quickly in the Arctic spring – so quickly that polar bears do not have time to react and are cut off from the seals by vast expanses of ice-free water (Fig. 2.8.4). A bear can swim dozens of kilometres but not hundreds of kilometres, and the swimming ability of cubs is very limited. As a result, many bears are stranded on the coast. They grow hungry and may enter villages to seek food at garbage dumps, which can be very dangerous, both for the animals and for people. There are a few ways of addressing this problem.

Figure 2.8.4

This bear, left stranded on the coast, more than 100 km from the edge of the ice pack, is very unhappy about climate change

First, people should have means of deterring bears, such as guns that fire rubber bullets. Second, villages should be kept clear of old food waste, which should be left at least one to two kilometres away from the village, so that the bears go there, away from people. Third, men who are specially trained, armed and equipped (with radios and satellite phones) should keep a watch on bears to prevent bear attacks and poaching.

Although having to do without their favourite meal of seal, bears can find enough food to eat on the seacoast (dead birds, eggs and small animals). They can also hunt walruses, although a polar bear will not tackle an adult walrus: a weak, wounded animal or walrus calves are better prey. Bears will sometimes break into a walrus rookery, causing a panic in which the walruses press together, and calves are crushed by the large males, leaving food for the bears. Such bear tactics are particularly successful if walruses have made their home not on a flat beach, but on a slope or on cliff ledges: as the large animals fall downwards. They may crush younger animals beneath them.

Walruses are increasingly forced to choose such unsuitable places for their colonies, also due to the lack of ice. Walruses not only need ice floes, on which they can rest during migration without losing their strength. They also need shore ice. Where there once were large quantities of thick, coastal ice, part of it lying on the beach as a crust, there is now much less of it, and storms are rapidly eroding suitable sites for walrus colonies. The animals are therefore forced to choose other places, where they are threatened not only by bears, but also by people.

There have been instances when thousands of walruses have appeared in new places (Fig. 2.8.5), including locations near aerodromes. The sound of an approaching aircraft caused a panic stampede, in which dozens of animals were killed. To prevent this from recurring, people at the aerodrome made noise on purpose before the arrival of planes, so that the walruses would take to sea. But such solutions require careful monitoring of the movement of walrus populations, with the deployment of people and equipment.

Figure 2.8.5 **A record number of some 35,000 walruses gathered on shore near Point Lay, Alaska in September 2014. They were looking for a place to rest after a long swim in the absence of sea ice**

The Barents and Kara seas are the habitat of the Atlantic walrus, which is listed in the Red Book. There are only a few rookeries of these animals, some of which are in remote areas of Franz Josef Land, but others are in relatively accessible places, along transport routes and in locations where there are plans to build oil and gas platforms. It will be essential to carefully monitor and identify problems early on, to prevent the disappearance of walruses in this part of the Arctic.

The survival of harp seals in the White Sea presents another challenge. Unlike bears and walruses, seals cannot live on the coast, where they fall easy prey to wolves, dogs, and other predators. For a long time, the harp seal was hunted by the human population of the Arctic coast, and the white fluffy fur of young cubs was specially prized. Hunting is now prohibited. Many seals also perished due to the passage of ships through areas where they lived. Ship captains are now required to avoid places where seals congregate.

Seals in the White Sea were previously hunted for the fur of seal pups. Shipping routes that cut through places where the animals congregated also caused problems. Nowadays the seals face another problem: the depletion of strong ice cover in the White Sea due to global warming, making it harder for them to raise their baby seals.

Seals have another problem caused by climate warming: the fur of seal pups is very warm, but not waterproof, so falling into water or even into puddles formed on the ice as it melts can be fatal for them: they freeze, fall ill and often die. In the future, if quantities of ice are much reduced, it may be necessary to find a protected island where young pups can grow up in safety.

Climate change is also affecting reindeer. Poor ice cover on rivers means that herders find it harder to guide the herds to the right places at the beginning of the winter. Reindeer can swim across a river or walk across sturdy ice. But they cannot cross a river with weak ice. The disappearance of ice on rivers earlier in the year and melting of the tundra create obstacles to reindeer migration and often leads to the death of many animals.

We cannot stop climate change easily and quickly, so it is vital to address such problems by removing other man-made barriers – for example, by making sure that gas pipelines do not impede the migration of reindeer. At present pipelines in the permafrost zones are built above the ground on special supports, and deer can neither crawl under the pipes nor jump over them. Special overhead sections are needed so that the animals can pass under the pipes.

Melting of the permafrost

People have lived in the Arctic permafrost zone for many thousands of years, but they were indigenous peoples (Chukchi, Nenets, Yakuts, Evenks, Aleut, Yupik, and Inuit) who did not build houses, and their existence did not damage the frozen ground in the Arctic permafrost zone. When Russians first came to the Arctic and found that the ground freezes to a depth of several metres and that only the top layer melts in the summer, they were much surprised. Leaders of the colonists wrote that the land was frozen, so that it was impossible to sow wheat. In the Russian city Yakutsk, a well was dug to find out how deep the frozen soil went: in 1686, it was dug to a depth of 30 metres, but did not reach the bottom of the permafrost. Some 150 years later work on the well resumed and it was dug to a depth of 116 metres, but the ground at that depth was still frozen.

Figure 2.8.6 Melting permafrost, Svalbard, Norway

The nature of permafrost was only understood at the end of the 19th century, when it was found that permafrost went as deep as 1,500 m in some places, but the frozen layer, with temperature between -2°C and -7°C, was usually 100 m thick.

In places where there is no permafrost, the sub-soil temperature is always a few degrees above zero, so that water pipes can be safely laid and streams and small rivers be channelled through pipes and tunnels, as may be necessary in towns and cities. The top layer of soil thaws in the summer, but the frozen layers remain in place from a depth of 10 cm in the north to 1m on the southern permafrost boundary.

Figure 2.8.7

A vertical section of permafrost with ice layers

Building on permafrost ground is difficult because frozen ground cannot be dug but must be laboriously broken up or melted. It is possible to drill, saw, and even explode the permafrost, but that is expensive and requires special equipment. The permafrost contains large quantities of ice, sometimes whole layers of it (Fig. 2.8.7).

So, when the top of the permafrost melts in the summer, it forms a very weak 'semi-liquid' layer incapable of supporting buildings, bridge supports or power lines. Such constructions must rest on stilts, which go deep into frozen ground, reaching levels at which the ice never melts.

Further problems arise from the fact that the summer thaw is very uneven. The surface terrain is not flat, and the nature of the ground may alter just a few metres to the left or right. It might happen that more water accumulates in a certain place during the warm season and cannot escape underground due to the permafrost. When the winter comes, the trapped water freezes into ice inclusions (lenses) and layers. Ice occupies more space than water, so the ground swells. Bumps and irregularities are formed, which can destroy buildings and roads (Figs. 2.8.8, 2.8.9).

Figure 2.8.8

A section of railway track damaged by permafrost effects

Figure 2.8.9

A building destroyed by uneven bulging and subsidence above permafrost

As the climate changes and temperatures increase, the permafrost thaws to ever deeper levels in the summer. The depth of previously constructed piles may not be sufficient, and they could begin to 'float', causing buildings to warp and collapse.

The problems do not end there. As climate warming advances, a particularly warm year may cause thawing of the permafrost to a deeper level than usual, and the trapped water escapes. This creates empty spaces underground, the land subsides, and bridge supports, power lines or even a small building can collapse into the ground. This effect is called **thermokarst**. It is highly dangerous, and its widespread nature due to global warming could not have been foreseen when buildings were designed and built in the Arctic in the past (Figs. 2.8.10, 2.8.11).

Leakage of water into the ground due to human action adds to the risk. Further weakening of the permafrost due to global warming could lead to major thermokarst problems associated with leakage from water and drainage pipes, which was less dangerous when the permafrost was well established. Rules that need to be followed include clearing snow from roofs and the areas around a building before it melts, as water should not be allowed to penetrate beneath the building.

What is to be done? We cannot stop climate change quickly, and its damaging impacts are increasing rapidly. Large amounts will have to be spent on direct freezing of soils, and on the design of more expensive buildings, which can cope with the new conditions.

Figure 2.8.10

A collapsed building in the village of Chersky (Russia)

Figure 2.8.11

The collapsed corner of a building in Yakutsk (Russia)

Permafrost can be maintained in the Arctic by relatively simple devices. Sometimes underground ventilation ducts are sufficient: very cold air from the surface freezes the ground to such low temperatures that it does not have time to thaw in the summer. This method is particularly suitable for roads on raised embankments. The soil of the embankment can be kept frozen by laying pipes of about 20 cm in diameter, 50 cm apart from one side of the embankment to the other.

The ground can also be frozen using devices called thermosiphons – vertical tubes, hermetically sealed at both ends, with their lower part in the ground, and their upper part rising two to three metres above the ground (Fig. 2.8.13). The tube is partially filled with a coolant (refrigerant), such as ammonia or liquid carbon dioxide. The thermosiphon freezes the ground in the winter due to the temperature difference between the relatively warm ground (a few degrees below zero) and the air (20–40°C colder). The liquid refrigerant at the bottom of the pipe evaporates due to the higher soil temperature, causing the soil to cool. The refrigerant vapour then rises upwards and condenses in the cold atmosphere above ground, after which it flows back downwards and the process repeats.

The thermosiphon thus transports cold underground, lowering the soil temperature by a few degrees more than would otherwise occur, and this is enough to ensure that the ground will not melt in the summer. The thermosiphon does not operate in the summer, because the air is warmer than the ground and the refrigerant inside the pipe does not circulate. During the summer the metal pipe conducts heat into the ground, but this effect is weaker than that achieved in the winter. This is a way of freezing the ground under roads and pipeline supports, and even under large buildings. But the thermosiphons much be installed no more than about one metre apart (Fig. 2.8.13).

Figure 2.8.12

Future permafrost thaw across the Arctic. Red areas indicate regions thawed by 2050, orange areas thawed by 2100 and yellow areas still frozen by 2100

It would be wrong to think that thermosiphons offer an easy solution to the problem of melting permafrost. They need to be replaced often and, despite their simplicity, they are expensive. It has been estimated that permanent freezing of the ground under gas pipeline supports in Russia would require spending of $10 billion!

Thermosiphons are also only a temporary measure since they can only lower the temperature of the ground by a few degrees and will be powerless against more intensive warming. Roads will have to be mounted on special supports sunk deep into the ground – essentially, building an overpass on piles, which will increase construction costs manifold (Fig. 2.8.14).

Figure 2.8.13

Road with soil-freezing thermosiphons

Figure 2.8.14

Road standing on supports sunk deep into the ground

It is not always possible to ensure that the ground stays frozen, and freezing technologies are helpless in the face of storms and intensive coastal erosion. In more and more cases it is proving impossible to save buildings and infrastructure, and the only solution is to move people elsewhere.

Large amounts of greenhouse gases are released from the tundra soil in the process of permafrost melting, increasing the greenhouse effect and speeding up global warming.

Weather anomalies in the Arctic

You know already that wind as well as temperature must be considered when assessing the weather. Extreme cold without wind is far better than a powerful blizzard, which makes it almost impossible to do anything useful outdoors, even to travel from one place to another. Working in blizzards is dangerous and difficult. Strong winds are becoming increasingly common in the Arctic, requiring the use of ever greater quantities of special equipment, clothing safety gear and supplies to cope with prolonged snowstorms.

Humidity levels in the Arctic have increased, leading to an alternation of thaws and frosts. This means that roads, bridges, and power lines are often covered with a layer of ice, leading to more frequent accidents and breakdowns. Buildings and structures deteriorate more quickly due to the action of water and ice on microcracks. Water can penetrate the tiniest crack and then expands when it turns to ice, also expanding the crack. The ice melts, more water flows in, the new water freezes and the crack expands even more. The more often this cycle is repeated, the faster the building deteriorates.

Low-lying regions, such as the Yamal Peninsula, are increasingly affected by powerful spring floods, when huge territories are inundated with water to a depth of a metre or more. Yamal is now experiencing more snowfall and these large quantities of snow are now melting more quickly in the Arctic spring. Another problem in Yamal is the penetration of sea water into ground water, which leads to rapid erosion of the underground sections of all kinds of buildings.

How does climate change affect the indigenous peoples of the North?

Native peoples in the Arctic are suffering because of climate change since their way of life and traditional livelihoods are directly dependent on climate conditions. Hunting, fishing, gathering of natural harvests and reindeer herding provide people with food, are the main source of income and are crucial to preserving the traditions and culture of these peoples and of the territories where they live.

Figure 2.8.15 The way of life of the indigenous peoples of the Arctic

Reindeer herding is an important part of the livelihood and way of life of the natives of the Far North. More frequent thaws due to climate change mean that the ground is often covered by a layer of ice, which makes it hard for reindeer to find and eat lichens. Melting of the permafrost, changes in snow conditions and earlier melting and later freezing of river ice are disrupting reindeer migration routes between winter and summer pastures. Changes in reindeer migration routes and reduction in populations of marine animals, hunting of which is part of the way of life of people in the Far North, are forcing people to seek new sources of food and income.

What can be done to help the indigenous peoples of the Arctic to adapt to changing climate conditions?

1. Carry out information campaigns among the local population on climate change and its possible consequences so that they can prepare to address the challenges.

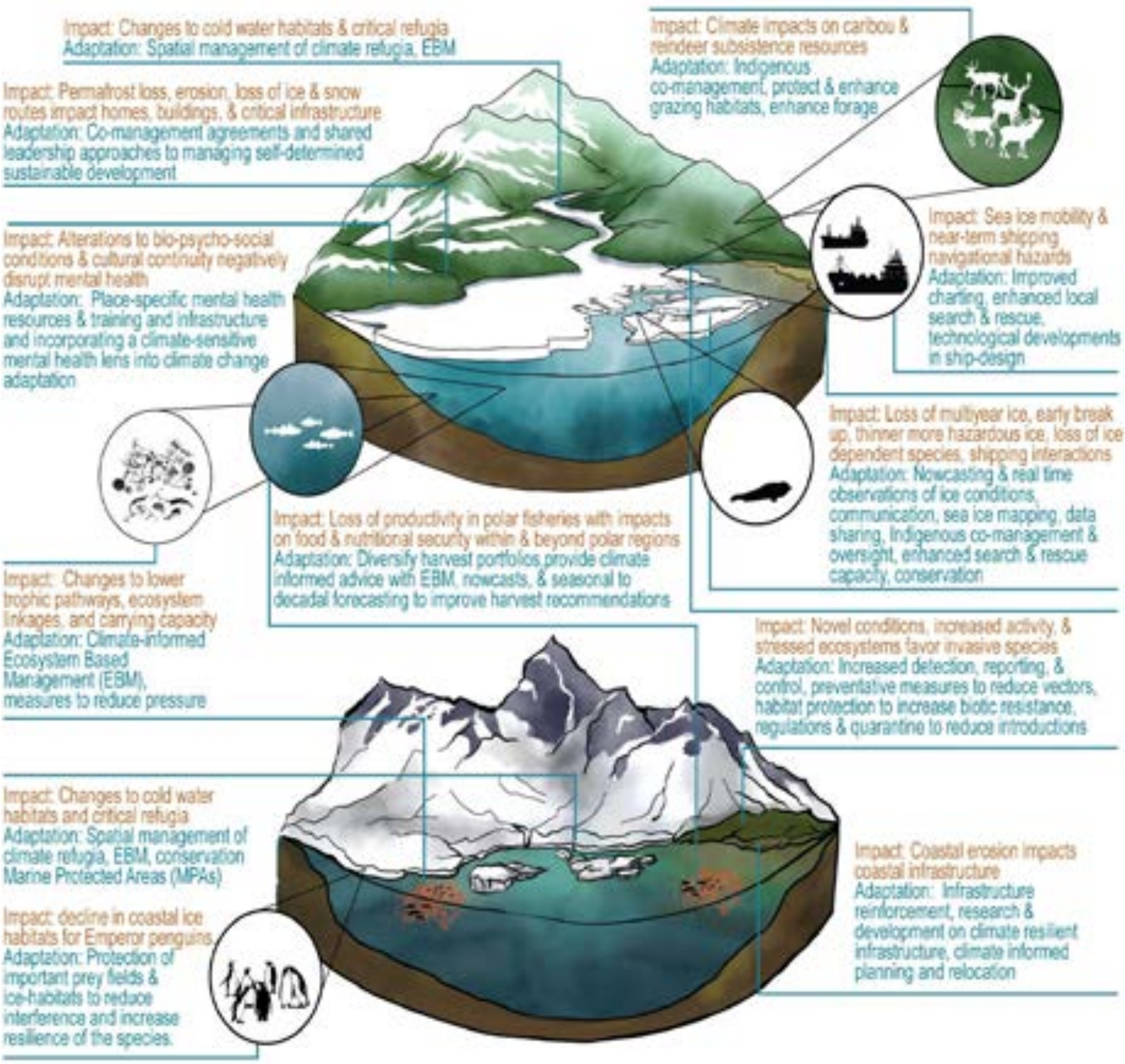
2. Develop eco-tourism in these areas.

3. Raise the availability of health care in the Far North, especially in remote areas and villages, and ensure reliable supplies of heat and electricity.

How do climate change impacts and potential to adapt in the Arctic compare to those in the Antarctic?

We are already familiar with polar amplification, which means that the Earth's poles are warming faster than the global average. We also already know that the Arctic has warmed nearly four times faster than the global average over the past four decades and that the Antarctic is warming twice as fast as the global average. Scientists compared climate change impacts and options for adaptation in the Arctic and Antarctic, which show some similarities and differences, e.g., because of different habitats (Figure 2.8.16).

Figure 2.8.16 **Climate change impacts and potential for adaptation in the Arctic and Antarctic**



What about the positive effects of a warmer climate?

It is true that climate change in the Arctic creates some opportunities. Less money can be spent on heating. Receding ice cover in the Arctic Ocean means that it can be used as a sea route between Europe and Japan and China and back. Infrastructure for marine traffic needs to be built along the Northern Sea route, including beacons, rescue equipment for emergency response, and harbours, where ships can ride out storms or take shelter in case of the sudden appearance of ice.

But the increasingly unstable Arctic climate and overall warming will also bring more frequent blizzards and sudden fluctuations of temperature.

The heating season may be shortened, but more unpredictable weather means that we must learn to adjust heating levels based on the real temperature outside the window and not on the date on the calendar. That will mean installing regulators on radiators, so that residents can adjust the temperature in their homes as required. Russian housing services are not ready for such measures, which call for extra work and equipment.

Climate change will bring more negative than positive impacts in all Arctic regions. Climatologists and economists have concluded: adaptation to melting of the permafrost, coastal erosion, and all the other possible negative consequences of climate change is possible, but it is very expensive. So, it is very important to find ways of minimizing global warming.

QUESTIONS

1 Where is climate warming happening faster: in the world as a whole or in the Arctic?

2 Why does the air temperature increase rapidly when ice fields in the Arctic break up in the spring to reveal open water?

3 Why are polar bears affected by shrinkage of ice packs? Do they need ice?

4 What is the danger currently threatening seals in the White Sea?

5 Why is melting of the permafrost dangerous for buildings? What would you recommend for buildings and other infrastructure to adapt to melting permafrost?

6 How does climate change affect the lives of indigenous peoples in the Arctic? What could be done to help them adapt to the changing conditions?

TASKS

1

Experiment

Purpose of the experiment: To observe how the volume of water changes when it freezes.

Materials: Airtight glass bottle, water.

The procedure: Fill the glass bottle with water, seal it and put it in the freezer. What happens to the bottle when the water freezes? Why does this happen? Draw a parallel with the processes caused by permafrost.

2

Experiment

Purpose of the experiment: To observe the changes in the physical properties of materials when they freeze and thaw.

Materials: A plastic or paper box containing sour cream.

Note. Soil that has frozen and then thawed will not be the same as it was before freezing. Ice layers may appear in it, which will divide into water and soil when thawing occurs. Sour cream behaves in a similar way when it is first frozen and then thawed.

The procedure: Take a paper or plastic package of sour cream. Put it in the freezer. When the cream freezes, it will not be as a single piece: layers of ice will appear. When it thaws, the sour cream divides into a white liquid and a thicker white substance (once stirred, this mixture regains the appearance of sour cream, and it is perfectly eatable).

2.9 How climate change affects **cities and human health**

Half of the world's population lives in cities

Since time immemorial, the human population of every country and geographical region in the world has been divided into city and town people on the one hand, and country people on the other hand. Historically, cities have offered better conditions for crafts and industry – the first factories were in cities – and they have traditionally been safer places to live, being protected by walls. People living outside towns and cities have been focused on agriculture: growing crops and raising cattle.

Since the end of the 19^{th} century there has been a major population influx to towns and cities. This process is called **urbanization**.

Figure 2.9.1 The old town of Berne in 1820

URBANIZATION
is the process by which towns and cities become dominant in a society. It is caused by the growth of industry in cities, development of their cultural and political functions and a deepening of the territorial division of labour.

By 2008, because of urbanization, the share of the world's population living in cities rose above 50% for the first time and continued to grow thereafter (Fig 2.9.2). By mid-2023, approximately 4.6 billion of the more than eight billion people worldwide lived in towns or cities. This represents 57% of the global population. According to the United Nations, the urban population is set to increase by almost 600 million by the year 2030, reaching a total of 5.2 billion (about 60% of the global population).

At present there are 34 cities worldwide with more than 10 million inhabitants. Most of these **megacities** are situated in Asia (21), Latin America (6) and Africa (3). The largest city is the urban agglomeration of Tokyo with a population of over 38 million (Table 2.9.1). This is followed by Delhi (26.5 million) and Shanghai (24.5 million). By United Nations calculations, the number of megacities is expected to increase to 43 by 2030. Delhi will then be the largest city in the world, with a population of almost 39 million.

So, the study of the climate in cities is important for at least half the population of our planet.

Figure 2.9.2 Share of urban population in total population and the largest cities of the world in 2018

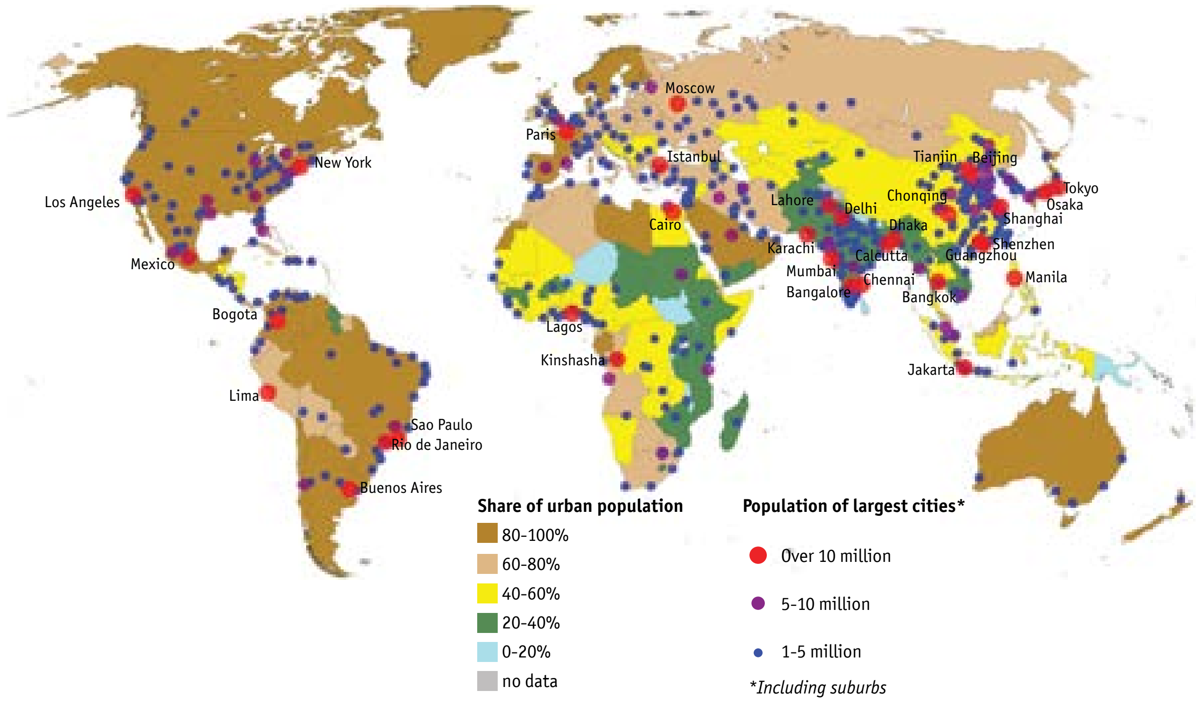


Table 2.9.1 The 15 largest cities in the world

№	City	Country	Population (million people)
1	Tokyo	Japan	38.1
2	Delhi	India	26.5
3	Shanghai	China	24.5
4	Mumbai	India	21.4
5	São Paulo	Brazil	21.3
6	Beijing	China	21.2
7	Mexico City	Mexico	21.2
8	Osaka	Japan	20.3
9	Cairo	Egypt	19.1
10	New York	USA	18.6
11	Dhaka	Bangladesh	18.2
12	Karachi	Pakistan	17.1
13	Buenos Aires	Argentina	15.3
14	Kolkata	India	15.0
15	Istanbul	Türkiye	14.4

Figure 2.9.3 Tokyo with more than 38 million inhabitants is the largest city by population in the world

Why are cities called heat islands?

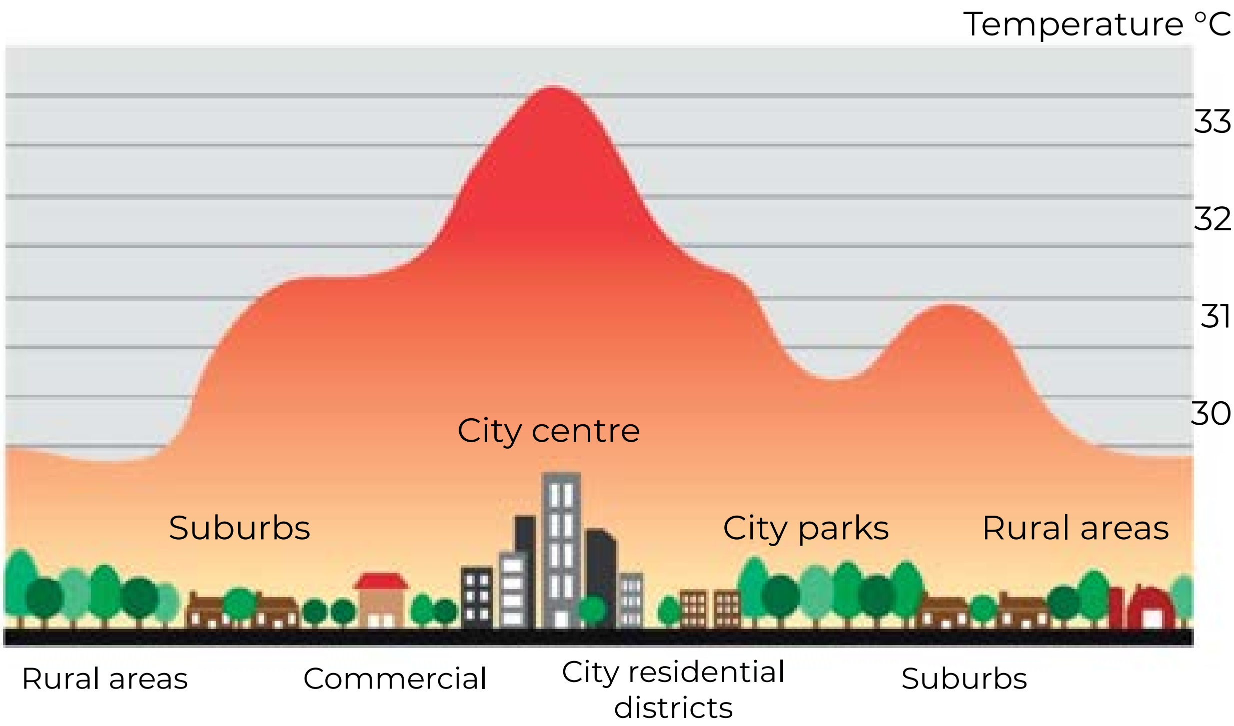
Cities are unique environmental hot spots on our planet, taking the word ‘hot’ quite literally: emissions of various substances from factories and motor vehicles ‘stagnate’ in the surface layer of the atmosphere above the city, creating a greenhouse effect, which raises its air temperature by several degrees compared with the surrounding territory. Scientists therefore call cities heat islands.

HEAT ISLAND
is an area in the centre of a big city, where the air temperature is higher than in outlying areas. The urban heat island effect is most noticeable in the evening and at night, especially in the spring and autumn, when the temperature difference between the centre of the city and outlying areas can be as much as 10–15°C.

The heat island effect in large metropolitan areas is being intensified by the process of climate warming.

We all know about the urban heat-island effect from personal experience: if you step out of a city building in the evening of a hot summer’s day, the temperature on the street is warm enough for a stroll in light clothing, but outside the city you would find it quite chilly outdoors in the evening without a jacket, even during the hottest summer month. This is because in an urban environment, surface air cools more slowly: it is kept warm by the walls and roofs of buildings that have soaked up heat during the day.

Figure 2.9.4 Air temperature distribution over a city (urban heat island)



The first studies of city climate

The first studies of city climate were carried out by Luke Howard (1772– 1864), an amateur meteorologist in London with a lifelong fascination with clouds and the weather.

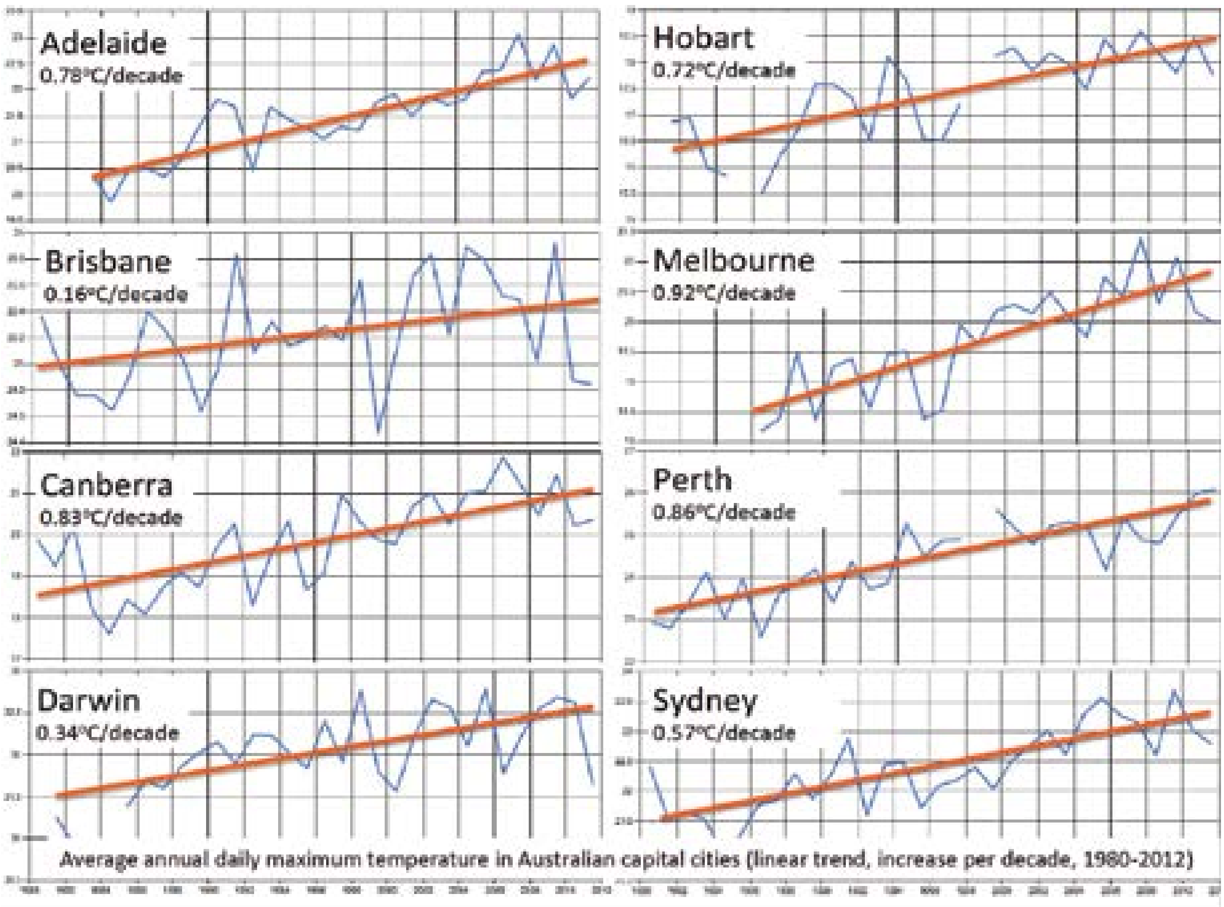
From 1806 to 1831, Howard carried out daily measurements of atmospheric pressure, air temperature and humidity, rainfall, and evaporation in the suburbs of London. For his observations he used newspaper reports on specific weather events. Howard did not study the specific climate in London, but carried out general climate studies, using London as the base for his observations. But what gives him a claim to be the founder of urban climatology was his attempt to compare the data from his own meteorological measurements with those of the Royal Society at a site in central London. The comparison revealed what modern researchers refer to as the 'urban heat-island' effect.

How does climate change affect the health of city dwellers?

Climate change has a substantial impact on human life and health. We already know that our health depends on lifestyle, food security, heredity, occupation, environment, and access to health care, but it is now becoming clear that it also depends on climate change.

Climate change is particularly noticeable in cities, and most of all in large cities. For example, the increase in air temperature in Moscow over the last century has been more than 2°C, while the increase in global average temperatures during the same period has been only 1.2°C. Air temperatures are also rising quickly in other major cities around the world (Fig. 2.9.5).

Figure 2.9.5 **Change in average annual daily maximum temperature in major Australian cities in 1980–2012. Linear trend increase is per decade**



Experts at the World Health Organization expect that global warming will cause extremely hot spells in cities to become more frequent, intense, and long-lasting. It is well-known that fluctuations in pressure, temperature and humidity can make living conditions in cities uncomfortable; there are more and more instances of excessive city heat taking a tragic toll among the elderly, young children, and people in poor health. Intense heat is accompanied by higher concentrations of pollen and other particles that cause allergies and asthma.

People who live and work in the city centre and those whose jobs require spending much time out of doors (road workers, construction workers, delivery men) are particularly at risk on hot days.

If a heat wave lasts for more than a week, it can lead to heart problems and even death among the elderly, and people with poor health.

According to a study published in the journal, Nature Medicine, nearly 62,000 people died of heat-related causes in Europe during the summer of 2022. The study analysed temperature and mortality data between 2015 and 2022 for 35 European countries, representing a total population of 543 million, and used it to create epidemiological models to calculate heat-related deaths. Researchers found that Italy was the hardest-hit country, with around 18,000 deaths, followed by Spain with over 11,000, and Germany with around 8,000. The extreme heat disproportionately harmed the elderly and women. Of the nearly 62,000 deaths analysed, the heat-related mortality rate was 63% higher among women than men. Age was also an important factor, with the death toll rising significantly among people aged 65 and over.

Timely forecasting of a coming heat wave is of great importance, since it gives medical personnel a chance to prepare for it. The World Meteorological Organization (WMO) recommends that such a warning forecast be given at least two days before the period of intense heat begins.

The USA, Canada, France, and some other countries have already taken steps to address the challenges posed by the heat island effect in the context of global warming. For example, the US city of Philadelphia has advocated a system of 'good offices' during heat waves: the media regularly report on the changing weather conditions and offer advice on how to avoid heat-related illnesses. The number of a telephone hot line is published in the newspapers and displayed prominently on a large screen in the city centre. Emergency medical services and fire departments take on extra staff. Special air-conditioned premises are provided for elderly people, who are brought there by a special, free-of-charge transport service to take a break from the heat.

Temperatures that people from a hotter climate consider normal can be termed a heat wave in cooler areas if they are outside the normal climate pattern. In the USA, for example, the definition of a heat wave depends on the region. In the northeast, it is typically defined as three consecutive days of temperatures reaching or exceeding 90°F (+32.2°C). In California, where the climate is hotter, a heat wave has a higher threshold of 100°F (+37.8°C) for three or more consecutive days. The National Weather Service issues heat advisories and excessive heat warnings when unusual periods of hot weather are expected.

Precautions to take in hot weather

- Wear clothes made of natural fabrics: they help to prevent overheating by allowing the skin to breathe.
- Keep a bottle of water with you, preferably water that is not too cold. A person should drink at least three litres of water a day in hot weather.
- Keep out of direct sunlight so far as possible. The sun is at its strongest from midday until about 1600 hours, so try to stay indoors during this time.
- Always wear a hat or headpiece.
- Do not buy perishable products: bacteria multiply very quickly in high temperatures, so there is a risk of severe food poisoning.
- Eat plenty of fruits, vegetables, various salads, and cold soups.
- Avoid oily and salty foods.
- Do not overdo sport and physical training.
- Stay relaxed: any nervous stress increases the risk of heat stroke, sun stroke and cardiovascular disorders.
- Do not sit directly under air conditioning: the temperature difference between the hot streets and an air-conditioned room is very large, and such temperature swings can induce colds and pneumonia.

Climate change has negative impacts on human health (Fig. 2.9.6). Dangerous infectious diseases, such as encephalitis and malaria, spread to areas where they were not previously present, and the period of the year when there is danger of infection becomes longer.

Climate change intensifies infection risk

Tick-borne encephalitis is a viral infection. The virus enters the human body through a bite from an infected tick. Encephalitic ticks, the main virus carriers, live in taiga and forest areas of Siberia, the Urals, and the Russian Far East. But there have recently been an increasing number of cases of infection in the central part of European Russia, the North-West and the Volga region. Cases of tick-borne encephalitis are being recorded for the first time in parts of European Russia, and scientists attribute this to global warming.

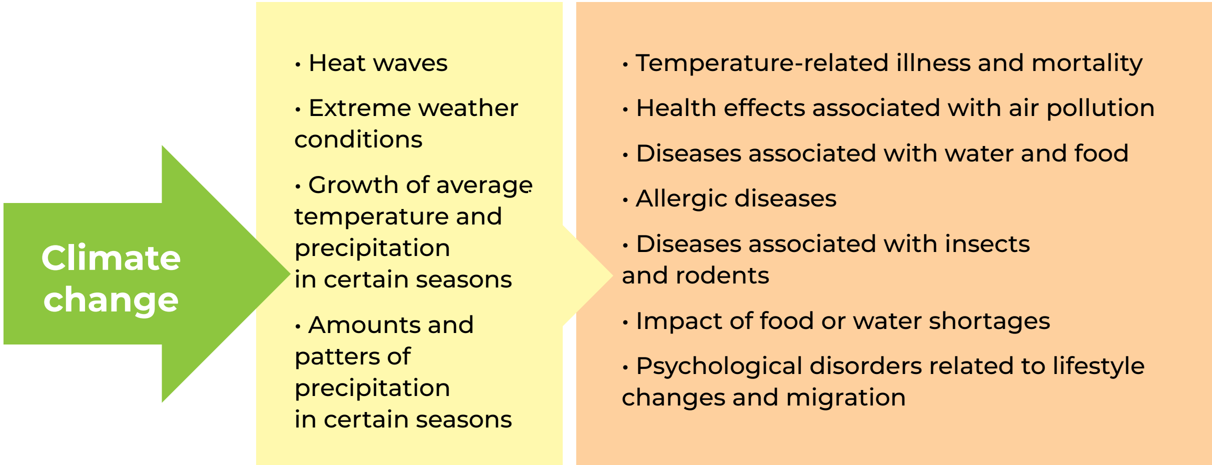
Warmer weather in the winter and spring favour the spread of ticks: they are more likely to survive the winter and can multiply rapidly in the spring. Typically, only a small fraction of all ticks is infected with encephalitis. But an increase in the total number of ticks leads to an increase in the number of infected individuals.

Malaria (from the Italian '*mala aria*', meaning 'bad air'), also known as swamp fever, is an infectious disease transmitted to humans by bites of malarial mosquitoes, causing a high fever. Malaria transmission depends on the presence of malarial mosquitoes in a given area and ambient temperatures, at which the viral agent that causes the disease can develop in mosquitoes.

Malaria usually occurs in tropical countries, but the disease is much less common in tropical highlands, where colder temperatures slow down the mosquito and the development of the parasite within it.

As the climate warms, the boundary of the area where malaria occurs moves into milder climate zones further and uphill from the equator, and the 'malaria season' (the time of year when outbreaks are most likely to occur) grows longer. Some studies have shown that malaria has spread into higher altitude areas in Kenya, Colombia, and Ethiopia, where it was previously too cold for the disease to thrive. This puts millions of people at risk of the disease, necessitating extra measures to prevent outbreaks of malaria.

Figure 2.9.6 **Impacts of climate change on human health**



A recent study on the health impacts of climate change published in the Lancet Medical Journal provides a set of indicators that help to understand the impacts of climate change on human health, such as heat mortality, food insecurity and air pollution exposure.

On extreme heat, for example, the study finds that in the Small Island Developing States, 103 days of health-threatening temperatures every year are attributable to climate change over 2018-2022. Across Europe, North America and Oceania, this number is less than 30.

The study estimates that under a 2°C warming scenario, for example, 525 million additional people will experience food insecurity by 2041-2060, compared with the 1995-2014 average.

A combination of climate change, urbanization and human movement are driving up the incidence of diseases such as dengue fever. The study finds that 'cases of dengue have doubled every decade since 1990, and almost half of the world population is now at risk of this life-threatening disease.'

Floods also pose a threat to human health, since flooding disrupts water supply and sewerage systems, which increases the risk of intestinal diseases. In some parts of the world, flooding may bring poisonous snakes and crocodiles with it, as happened in Australia in 2011.

Changes in the environment and lifestyles can induce psychological stress and depression. You have probably noticed that sometimes, when the weather is bad, you don't want to go anywhere or do anything. So how will people feel if they experience bad weather more often?

How does climate change affect the urban economy?

Extreme weather events can disrupt transport, electricity, and water supply in cities. Flooding may inundate buildings, roads, railways, seaports, and airports. Higher temperatures lead to faster deterioration of road surfaces, which need more frequent repairs. Sudden temperature drops in the winter cause the formation of ice that damages power lines, leaving homes, schools, hospitals, and businesses without electricity.

Residents in northern countries with colder climates may be able to reduce the cost of heating their homes as air temperature in the cold season rises. But cities in southern countries with hot climate conditions will face higher costs as there will be greater need for air conditioning in the summer.

In-depth studies of climate change impacts on cities over the last decade can help improve our understanding of the possible consequences of global warming and offset some of the costs. For example, the cost of clearing damage caused by flooding can be partly compensated by savings on heating in the winter.

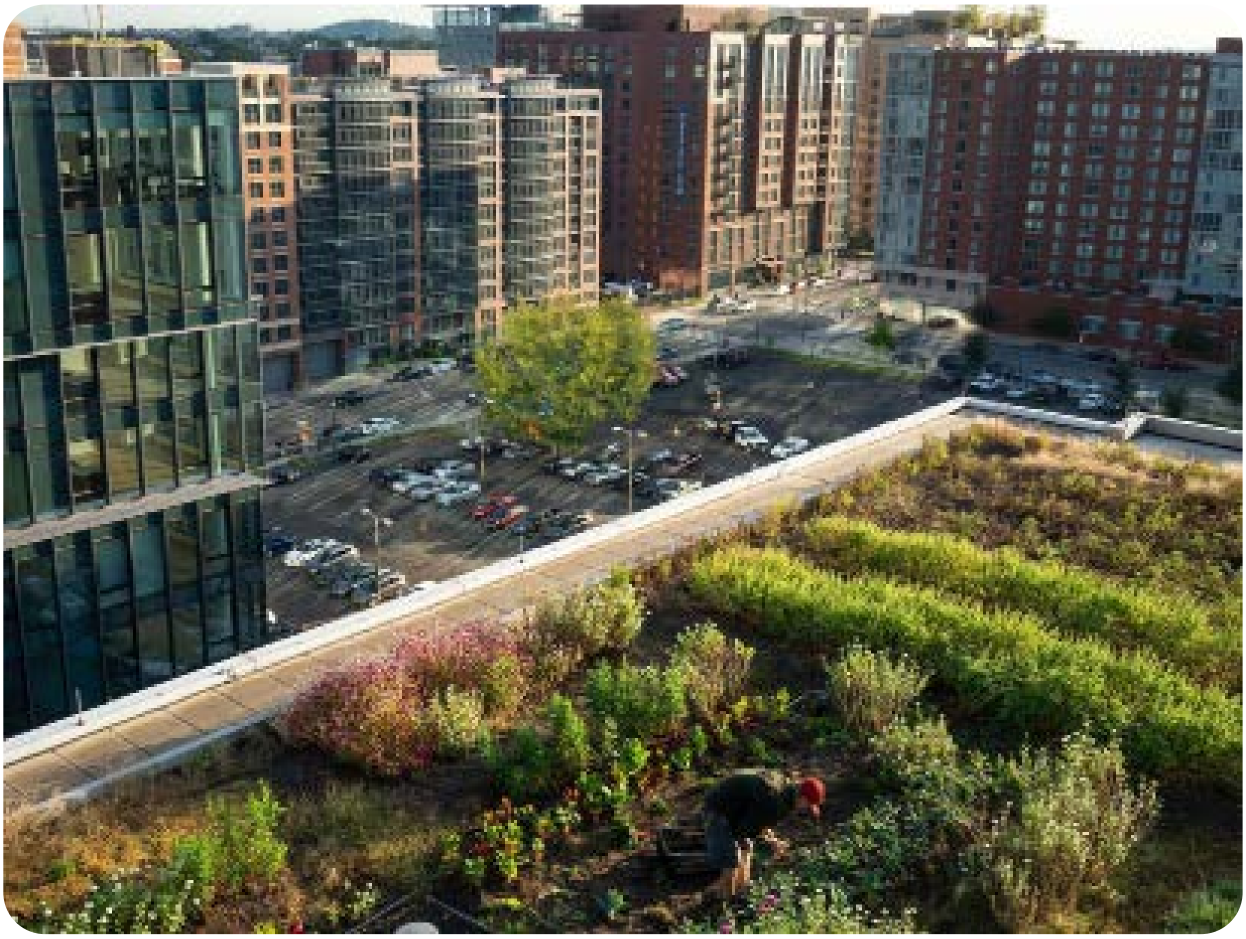
How can we adapt and live in healthier and climate-resilient cities and settlements?

IPCC scientists noted in the AR6 that rapidly growing urban populations and unmet needs for healthy, decent, and sustainable housing and infrastructure pose a persistent challenge. But urbanization also offers many opportunities to build adaptation measures into the planning and development of cities and their infrastructure. This is a critical priority, given that an additional 2.5 billion people are projected to be living in urban areas by 2050, with up to 90% of this increase concentrated in Asia and Africa.

Many cities and urban settlements are already taking actions to adapt to current and near-term climate impacts and risks as part of their social and economic planning and policies. These actions include hard engineering interventions and planning, such as further development of urban public transportation, engineering flood defence, redesigning and fortifying buildings, setting up cyclone shelters, introducing hurricane-resistant building codes, developing standards, regulations, and guidelines for construction, improving stormwater management, drainage and flood protection systems, and, where relevant, strengthening infrastructure to withstand permafrost conditions. There is also growing interest in adaptive urban design and nature-based solutions aimed at green cooling, such as green roofs, walls, and parks. Expanding green and natural spaces simultaneously enhances biodiversity, improves air quality, and moderates the hydrological cycle; it also helps reduce health risks associated with heat stress and respiratory illnesses, and mitigates mental health challenges arising from congested urban living. Green roofs in the USA (Fig. 2.9.7), are an example of how cities are working to mitigate the effects of stormwater runoff, which is a major polluter of waterways, while at the same time keeping buildings cooler.

Health-related measures include redesigning and retrofitting homes, schools, and health care facilities to reduce the impacts of extreme heat, managing increases in infectious diseases such as malaria, and improved access to water and sanitation services. Actions taken in different sectors to address the risks of climate change can generate benefits for human health and well-being. Transitioning away from internal-combustion vehicles and fossil fuel-powered generating stations to renewable energy mitigates greenhouse gas emissions, improves air quality, and lowers the risks of respiratory illnesses. Policies and designs that facilitate active urban transport (walking and bicycling) increase efficiency in that sector, reduce emissions, and improve air quality and the physical and mental health of residents. Energy-efficient buildings and urban design improve indoor air quality and reduce risks of heat stress and respiratory illness. Food systems that emphasize healthy, plant-centred diets reduce emissions in the agricultural sector while helping in the fight against malnutrition.

Figure 2.9.7 Green roofs in the USA help with stormwater runoff and to cool buildings



QUESTIONS

1 Does more of the world's population live in cities or outside cities?

2 Where is it warmer - in the city or in the city suburbs?

3 Why are heat islands bad for human health?

4 Can you list three measures for adaptation to climate change in cities?

5 What are the negative impacts of global warming on human health? What are vector-borne diseases?

6 What precautions should be taken in hot weather?

TASKS

1 If you take your summer holiday in the countryside, try placing a thermometer outdoors in the shade at the level of a person's height above the ground and write down the temperature it shows in the early morning (before the sun starts to raise the air temperature). Compare it with the forecast for night air temperatures in the nearest large city on the same day. Are the figures different? Why?

2 Using textbooks, reference books and the Internet, find out and write down how you can help someone suffering from heat stroke, sunburn, frostbite, and severe allergic reaction to pollen, or someone who has been bitten by a tick. What preventive measures can you take to protect your health during a period of intense heat?

2.10 | How climate change affects **social problems**

Different worlds: developed and developing countries

There are about 200 countries in the world. All countries are different from one another in geographical location, territory, natural environment, climate, population, economy, standard of living, history, and traditions. They have contributed in different levels to climate change and are all affected differently by it. They also differ in their capacity to cope with new climate impacts.

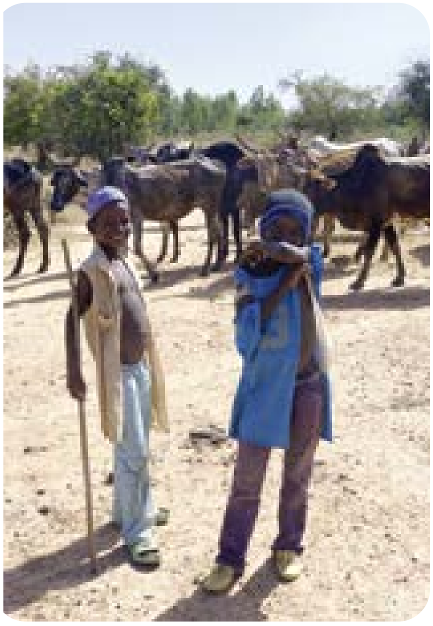
Countries are often divided into two large groups by their level of development: so-called 'developed countries' and 'developing countries'.

Developed countries are relatively rich, with favourable living conditions and strong economies, in which industry, services and the financial sector play a major role. Their residents generally have social security, access to good health care and education, fulfilling work opportunities, and relatively high incomes that enable them to spend money on restaurants, shopping, or travel. The group of developed countries usually includes, but is not limited to, the USA, Canada, Australia, New Zealand, the United Kingdom, European countries, Japan, Singapore, and Israel. Some countries in Eastern Europe with so-called '**transition economies**' represent a sub-group within the group of developed countries. The term 'transition economies' comes from these countries' transition since the 1990s from centrally planned to market economies.

Developing countries as a group are at an earlier stage of their economic and social development compared to developed countries. Many of these countries are still heavily dependent on agriculture, commodities trading and mining. Large sections of the population have a lower standard of living, uneven access to health care, fewer social programmes, and fewer opportunities for education and employment.

The group of developing countries is very diverse. These include **emerging economies** (newly industrialized countries) such as China, India, South Korea, Türkiye, Brazil, Argentina, and Mexico, with rapid growth of industry and services. China and India are among the world's ten largest economies today. Many things we use every day – clothes, shoes, dishes, furniture, appliances, and toys – are made in these countries, particularly in China. China leads the world in the volume of manufactured goods it produces every year, followed by the USA.

And then there are 46 countries considered to be the **least developed** in the world. They include small island states, landlocked mountainous countries, as well as countries with overcrowded territories and unfavourable climate conditions. These countries are very poor, their economies are weak, and their people and way of life are highly vulnerable to climate change impacts and natural disasters. Most least-developed countries are in Africa and Asia, and the poorest of them, according to the World Bank, are Afghanistan, Burundi, Chad, the Democratic Republic of the Congo, Liberia, Malawi, Mozambique, Niger, and Somalia. Poverty in most of these countries is widespread, with most of the population living on less than two dollars a day. Many people are short of food, clean drinking water, hospitals, and schools. Families living in poverty try to have as many children as possible who will help their parents with housework, contribute to family income, and support them in old age. Poor sanitation, lack of food and clean water, and uneven access to health care mean that many children die before they can grow up, so having many children is a way of ensuring that at least some of them will survive. About 880 million people (12% of the world's population) now live in the world's poorest countries, which contribute less than 2% to the global economy.



Social inequality

In 2023, the world's population crossed eight billion. The vast majority of the world's people – 6.64 billion, or 83% of the total – live in developing countries and only 17% or 1.36 billion people (the so-called 'golden billion') live in developed countries.

Not surprisingly, the 17% of people living in rich countries consume the lion's share of the world's production, given their high incomes and lifestyle requirements. Operating industrial enterprises and creating the daily production for people in rich countries requires tremendous amounts of resources and energy. The largest energy consumers include Iceland, Norway, Canada, the USA, and wealthy nations in the Middle East such as Oman, Saudi Arabia, and Qatar. The average person in these countries consumes as much as 100 times more than the average person in some of the poorest countries. For example, the average American needs 3.5 times more resources during their lifetime than the average inhabitant of the Earth, and the average American uses nine times more energy than the average Indian. So, the contribution of people living in developed countries to global greenhouse gas emissions (their 'carbon footprint') is much higher than that of people in developing countries, and they bear greater responsibility for the consequences of climate change.

The gap between the quality of life of the world's rich and poor is huge. Average incomes in the richest 20 countries are 37 times higher than those in the poorest 20. So, for every $100 in income received by the average citizen of Europe or the USA, a resident of Nepal or Ethiopia receives only $2.50. The incomes of the 500 richest people in the world exceed the total income of the 416 million poorest people on the planet.

High birth rates in many developing countries mean that their rate of population growth is 3.5 times higher than that of developed countries. The populations of many poorest countries in Africa and Asia could double in less than 40 years. So, the numbers of the poorest people on the planet continue to increase.

The gap between the world's rich and poor is huge. People in developed countries, who are just 17% of the world population, consume the greater part of the world's production and more than 70% of all energy, while nearly 2.5 billion people worldwide are living on less than two dollars a day. According to the Food and Agriculture Organization, 770 million people lack access to clean drinking water, and 821 million people do not have the food they need to live an active and healthy life.

It would be a mistake to think that poverty is limited to the least developed countries. Rich countries also have backward regions and poor people. In the USA, for example, the Census Bureau put the number of poor people at 38 million in 2021, or about 12% of the total population. In Germany, nearly one in seven people, or 13.5 million, were living on or below the poverty line in 2022. Often the poorest people in developed countries are those who came there to work from developing countries, as well as people living in rural areas and declining industrial cities, where mines and factories are closing because they are unprofitable.

But the situations of a poor American and a poor African are quite different! The poverty line in the USA is an annual income of $22,000 for a family of four people, or about $15 per day per person. That really is very little in view of the high cost of essential goods in that country. But, to a poor person in the developing world, an American pauper, with their own accommodation, complete with toilet and bath, seems like Rockefeller.

Stark inequalities in living conditions – the unequal distribution of incomes and opportunities between the people of our planet – have grown to become one of the most pressing social problems in the world today. As noted in the *Human Development Report* of the United Nations Development Programme in 2013: “Every person has the right to live a fulfilling life according to his or her own values and aspirations. No one should be doomed to a short life or a miserable one because he or she happens to be from the ‘wrong’ class or country, the ‘wrong’ ethnic group or race or the ‘wrong’ sex.” Unfortunately, climate change only intensifies social inequality and complicates the task of overcoming poverty. The recent COVID-19 pandemic exacerbated these problems and, over two years, reversed some of the gains in social and economic development, poverty alleviation and reducing inequalities (*UNDP Human Development Report 2021-2022*).

Climate change makes social problems worse

We have already seen how every region and country in the world is experiencing the impact of climate change, but we have also seen how some of them – coastal, Arctic, mountainous or agricultural regions or countries – are more affected than others. This happens because the lifestyle and economy of the local population depends greatly on natural conditions and climate, so that any change leads to major problems for the economy and for society.

People in poor countries and regions depend mainly on agriculture for their livelihoods, so any drought, flood or hurricane can instantly deprive these people of their only source of income. Countries such as Bangladesh, Haiti, or Chad are not only among the first to feel the effects of climate change, but also lack the resources and capacities to address the potential risks.

Climate change in poor countries has especially major impacts on women, who are mainly responsible for raising children, looking after the sick and elderly, growing crops, and collecting water and fuel, and feeding their families. All these tasks are seriously affected by climate change.

In all regions, even in high-income countries, small children, the elderly, and people with disabilities may be at particular risk because their health is highly dependent on weather conditions.

CLIMATE INJUSTICE
means people who are least responsible for global warming may suffer the most because of it.

Climate migration

Climate change is causing tens of millions of people to migrate to escape the effects of storms, droughts, and floods. According to research by the Columbia Climate School of Columbia University, around 23 million people around the world moved away from their homes in 2017 due to sudden extreme weather events. Another 44 million or so were displaced due to 'humanitarian crises', likely exacerbated by the cascading effects of climate change. Their numbers may reach 200–250 million by 2050.

Areas threatened with mass migration include the Mekong and Ganges River deltas in South-East and South Asia. These are densely populated agricultural areas, where a predicted rise of two metres in water level in these rivers will lead to flooding of large areas of arable land. People who work in these fields will be forced to seek new places to live and work.

Frequent droughts or floods, with particularly serious consequences for agriculture, will force many people in rural areas to move to cities in search of work. Such migration leads to the creation of whole neighbourhoods of poor migrants – slum areas with poor basic services and a high crime rate.

An increasing number of people from the Caribbean islands are leaving their homes due to more frequent tropical storms and tornadoes as these countries have only limited capacities to cope with tougher climate conditions.

Figure 2.10.1

Slums in Rio de Janeiro (Brazil)

Figure 2.10.2

A camp of migrants who were forced to leave their homes due to a severe drought (Somalia, 2011)

Figure 2.10.3

The aftermath of Hurricane Haiyan (The Philippines, 2013)

Australia and New Zealand have received climate migrants from the island states of Oceania. Islands in the Tuvalu and Kiribati Archipelagos, located not far from Australia, are gradually being submerged by rising water levels in the ocean. Environmentalists in Australia are pressing their government to allocate a special quota for these climate refugees. Similarly, the Government of the Maldives has agreed with Sri Lanka (also an island nation) on resettlement of its people if there is imminent danger of this island chain disappearing under the sea.

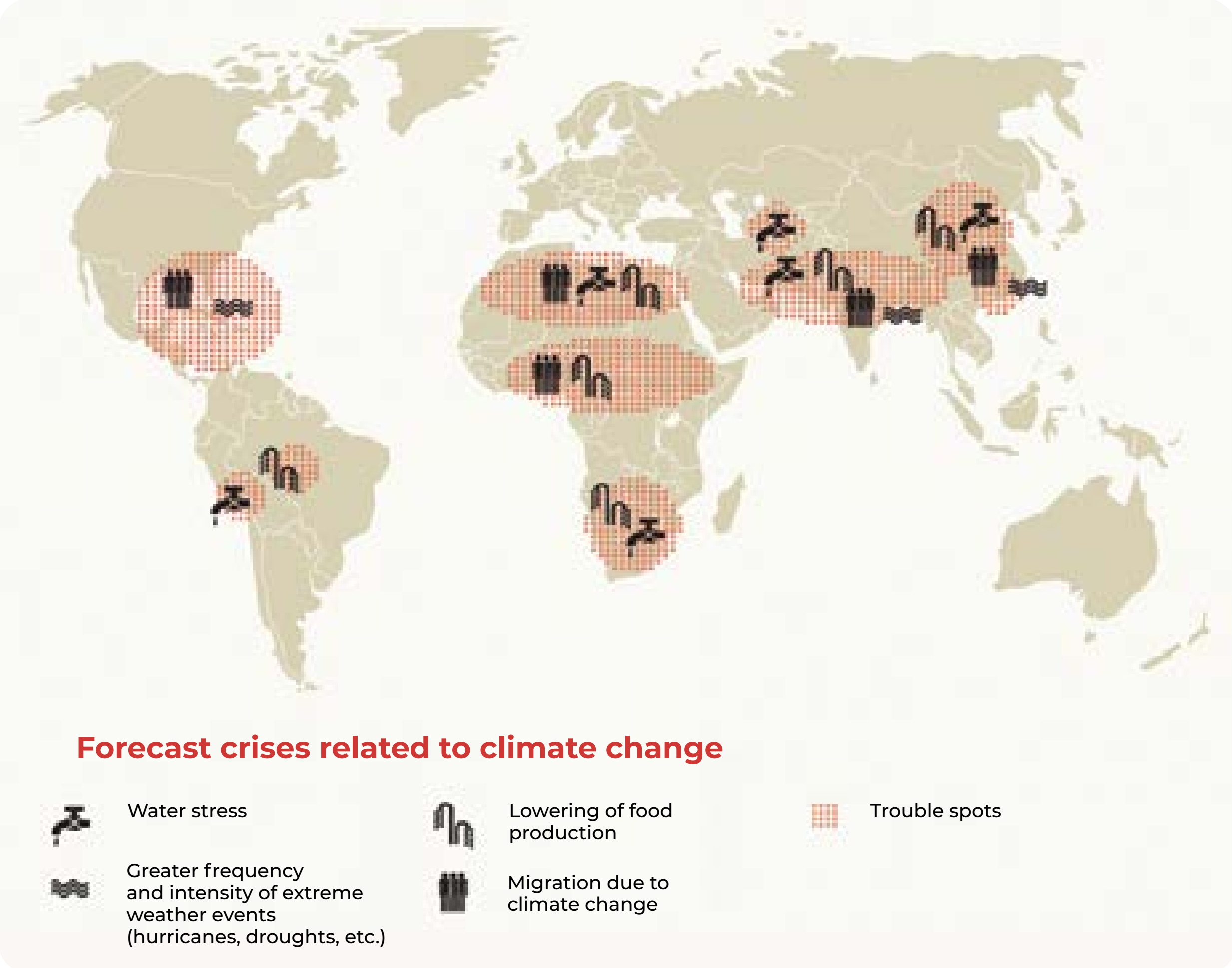
The island nation of Kiribati consists mainly of coral islands, which are only two metres above sea level on average, so that rising sea levels could inundate them within the next 50 years. In 2012, the government of the islands decided to buy land in the Republic of Fiji, where the inhabitants of islands, which may be lost to the sea, can be resettled.

New conflicts

Climate change can cause serious conflicts between people in different regions, particularly over land rights, water scarcity and climate migration, with widespread social consequences (Fig. 2.10.4).

Regions marked in red are particularly at risk of crises related to climate change. These are regions threatened by prolonged droughts, water shortages, rising sea levels, soil salinity and crop failures, lack of access to energy and other factors that could provoke political and social crises, and increase migration flows.

Figure 2.10.4 Areas of potential crises related to climate change



International cooperation for social assistance

Special programmes of assistance for the most vulnerable populations are needed to reduce the social risks arising from climate change. These may include: training and professional reorientation for people in rural areas, giving them alternative livelihoods to agriculture; projects to resettle the inhabitants of threatened regions; the creation of jobs in poor areas; research to develop more drought-resistant crop varieties; and setting up early warning systems for natural disasters. But all these measures require money that poor countries and poor people do not have.

There are various funds and financial instruments to help developing countries overcome social problems associated with the adverse effects of climate change. The main donors are the governments of developed countries, large companies, and international organizations, primarily the United Nations.

QUESTIONS

1 How are developed countries different from developing countries?

2 Do most of the people in the world live in developed or developing countries?

3 Which countries are the most vulnerable to climate change? Why?

4 Why do the consequences of climate change have the greatest impacts on the world's poor?
What social problems does climate change make worse?

5 Animals and plants cannot adapt to rapid changes in climate, but how about people?

TASKS

1

On a map of the world, underline the top 20 countries in terms of economic development and colour them using a green crayon. On the same map underline the 20 countries that are the top emitters of greenhouse gas emissions (data can be found in Wikipedia) and colour them red.

Is there a lot of overlap? How many of the leading countries of the world are now a 'dirty brown', indicating that they cause the most harm to the Earth's climate?

Explain why these countries are the most to blame for ongoing climate change.

2

Imagine that you are working for an international fund that allocates money for projects to combat the consequences of climate change. What projects to help poor countries would you finance first and foremost?

3

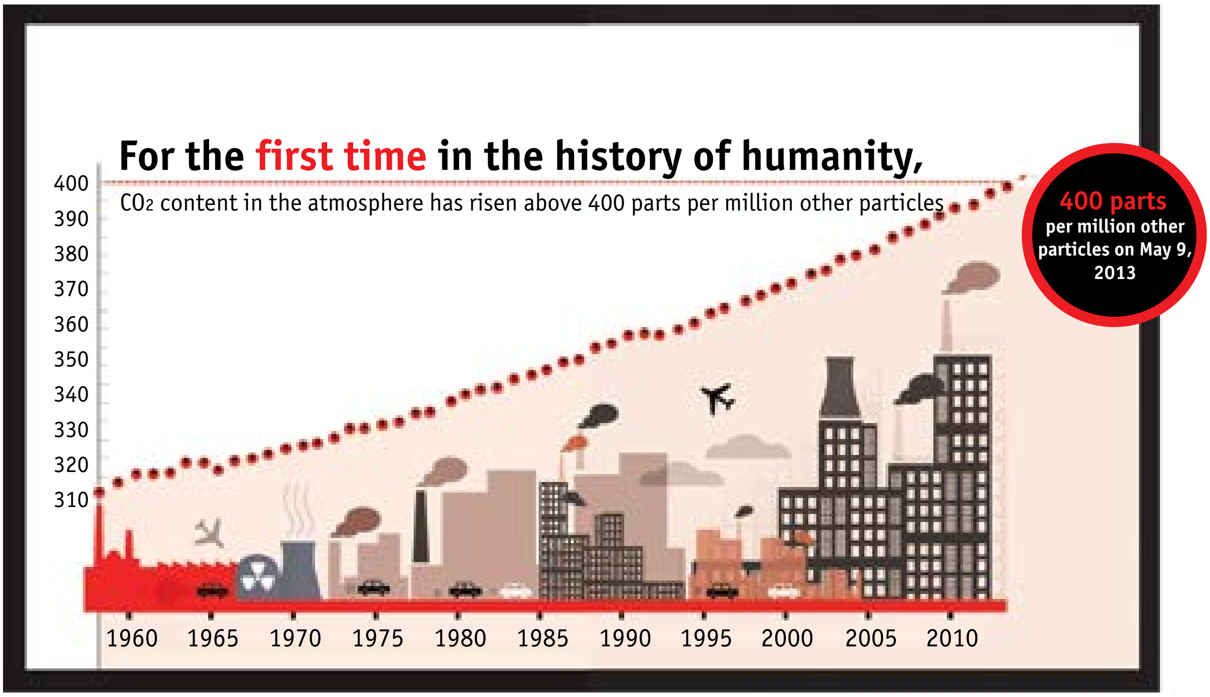
How to prevent dangerous climate change

3 How to prevent dangerous climate change

You already know that the amount of greenhouse gases in the atmosphere has been increasing rapidly in recent years leading to increases of its concentration in the atmosphere (Fig. 3.1.1). The natural content of carbon dioxide in the atmosphere has varied in the last few hundred thousand years (which have included periods of interglacial warming and glacial cooling) between 180 and 300 particles of CO_2 per million other particles.

In 2013, the level of CO_2 in the atmosphere exceeded 400 parts per million for the first time in at least 800,000 years. This concentration continues to grow rapidly, reaching levels of 421 parts per million in 2022. The reason is that globally, net greenhouse gas (GHG) emissions from human activity, defined as a difference between the gross emissions minus removals, for example by forests, have continued to grow. Between 2010 and 2022 the level of GHG emissions was higher than at any previous time in human history. Their concentration in the atmosphere will continue to grow until annual emissions are reduced sufficiently to be balanced by removals.

Figure 3.1.1 Growth of Co_2 concentrations in the atmosphere since 1960



Everyone on the planet contributes to climate change by emitting greenhouse gases into the atmosphere year after year. We are the end users of goods and services, the production of which requires energy, and energy comes mostly from non-renewable fossil fuels (oil, coal, and natural gas). The production of goods and services accounts for 75% of all greenhouse gas emissions associated with human activities.

We already discussed the devastating impacts of climate change on the health of our society and the planet. Scientists confirmed that the recent changes in climate are widespread, rapid, intensifying, and unprecedented in thousands of years. Such changes are expected to continue, as under all emissions scenarios outlined in the IPCC AR6 report, the Earth's surface warming is projected to reach 1.5ºC in the next two decades. Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C or even 2°C will be soon beyond reach.

To decrease the concentration of greenhouse gases in the atmosphere and limit global warming, strong, rapid, and sustained reductions in CO_2, methane, and other greenhouse gases in this decade and reaching net zero emissions by 2050 are critical. Together with reductions of the 'short-lived climate forces' such as aerosols and particulate matter, these would not only reduce the consequences of climate change but also improve air quality, reduce health impacts, and bring other sustainable development benefits. Such reductions need to follow a nature-positive approach, which can help to enrich biodiversity, store carbon, purify water and reduce pandemic risk. In short, reducing greenhouse gas emissions in the atmosphere should also enhance the resilience of our planet and our societies.

Many countries have taken action to reduce emissions. As of 2022, most industrialized countries have steadily reduced greenhouse gas emissions for more than ten years and many developing countries have taken measures to slow down emissions growth. However, scientists have shown us that this is not enough, and we need a system transformation in all countries and in all sectors of economy and society towards net zero emissions by mid-century.

What does this mean in practice and how can we reduce the concentration of greenhouse gases in the atmosphere? There are several ways of doing this.

The first is by switching to **climate-friendly sources of energy**. If we compare the different types of fossil fuel, the most polluting is coal, followed by oil and oil products, and the least polluting is natural gas.

But it is possible to produce energy without using fossil fuels at all. Since ancient times, people have used the heat of the sun, the power of wind and running water, and biomass. These are all renewable energy sources. Modern technologies make it possible to use them more widely. A rapid increase in the use of renewable sources of energy should go hand in hand with the phasing out of fossil fuel energy. Other carbon-free sources of energy, such as nuclear energy, can also help to reduce emissions in many countries, provided that all necessary safety measures are in place.

The second way of lowering greenhouse gas emissions is to **reduce our daily energy consumption**, by developing more energy-efficient machines and household appliances, improving the energy efficiency of buildings, and increasing electrification and energy storage. Current industrial processes, such as iron and steel, and cement, need to be replaced by carbon-free ones, and electrification in transport needs to go faster. We must also change our own habits to save energy and water.

The third way is to get plants to help us or use technologies that **remove CO_2 from the atmosphere**. Plants and trees absorb CO_2, so by reducing deforestation and by planting trees, people can reduce the amount of greenhouse gases in the atmosphere. Using environmentally friendly agricultural practices and restoring and protecting natural ecosystems can help soils absorb more carbon and bring other sustainable development benefits. New technologies that remove CO_2 from the atmosphere, such as carbon capture and storage or CO_2 removal, are at early stages of development and demonstration. They hold the promise that some emissions that cannot be avoided, e.g., some residual emissions from agriculture, will be captured by such emerging technologies soon.

Lastly, climate change is a complex global problem that can be solved only with cooperation among all governments, and an “all-of-society-approach” that especially involves business in efforts to manage the climate risk and disclose such risk as part of their business practices.

3.1 ‘Green’ energy sources

3.1.1 What is energy?

Everything that has ever been created in the world, by nature or by human beings, has been created using energy. To obtain any form of energy, we must get it from somewhere.

Consider a bar of chocolate. It came to the shop from the factory, whose workers produced and packaged it. To do this, they used cocoa beans and sugar, which were brought to the factory from fields where other people grow cocoa beans and sugar cane. All the people who worked on making our chocolate had to eat and buy clothes for themselves. All the machines and devices that were used to make the chocolate bar are made from materials (steel, plastic, etc.) that came from minerals (iron ore, etc.) taken from the earth, and those machines are driven by energy. So, everything that we have was made by using energy. We ourselves grew from a tiny embryo, which took the energy of chemical compounds for its growth.

Can it really be the case that we constantly take from nature and give nothing in return? Of course not! We convert the energy that we receive into other forms and return it to the world. So, the energy itself never disappears, but only changes its state. The science that studies the most general laws of the transformation and transfer of mechanical and thermal energy is called **‘thermodynamics’**, which is a branch of physics. The law of conservation of energy is the first law of thermodynamics.

Other laws of thermodynamics tell us that at the moment energy changes its state, a small part of it is lost and dissipated and cannot be ‘gathered back’.

Let’s see how people today use energy. Why are the consumption of energy and climate change so strongly interrelated?

And can humanity use energy to transform the global economy and society, making life on Earth green, flourishing and happy? Most importantly, how can we all start working towards this transformation today?

3.1.2 Main sources of energy

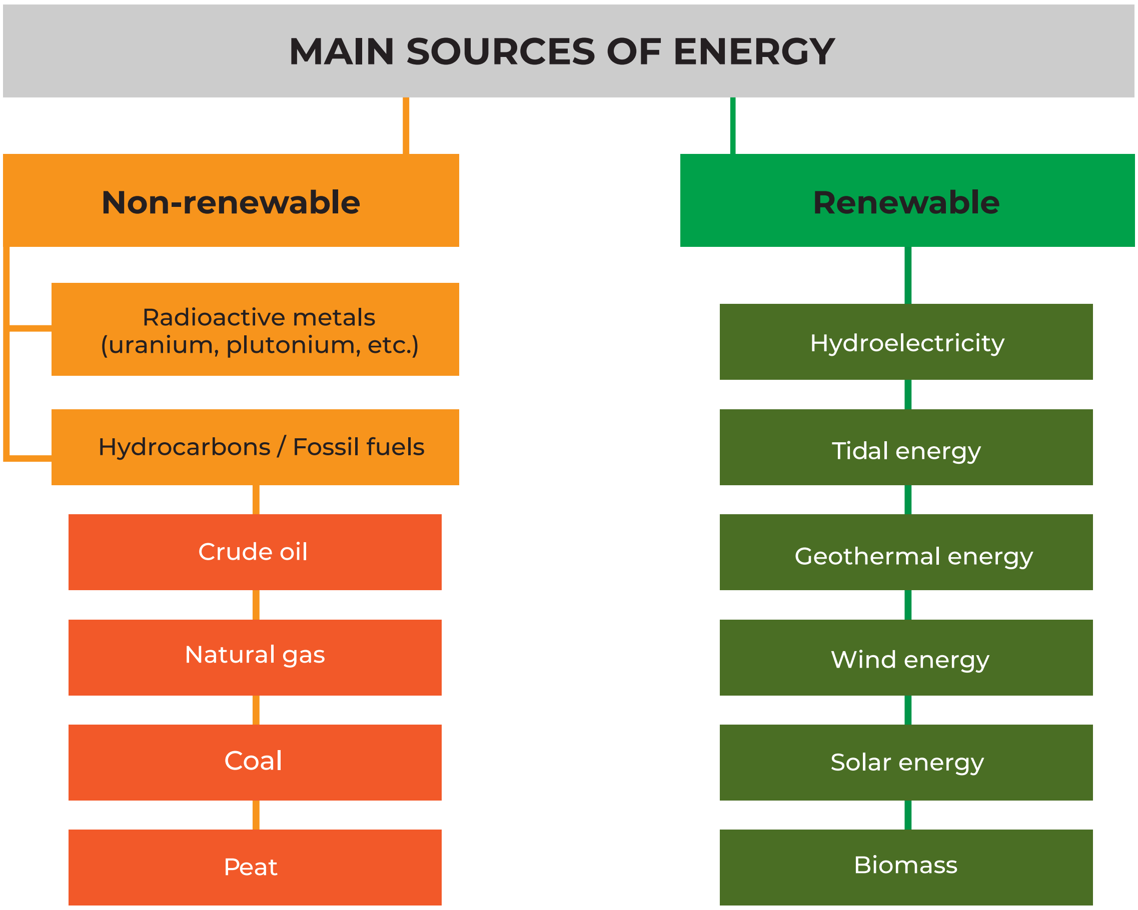
People have always used energy. Scientists began to think about this process in ancient times, when they began to study the simplest form of energy – mechanical energy, which they called a 'living force'. Gradually, other forms of energy were discovered: electrical, electro-magnetic, thermal, and nuclear. Discovering new forms of energy, people investigate where they come from and find ways to make use of them.

We use a huge number of devices and appliances in our daily lives. Television sets, computers and refrigerators all work thanks to electricity channelled into our homes, which is the kind of energy we are most familiar with. This means that electricity is central to many parts of life in modern societies and will become even more so as its role in transport and heating expands through technologies such as electric vehicles and heat pumps. The role of electricity in industry will also increase because of the electrification of some industrial processes, such as iron and steel production.

Where does electricity come from?

People learnt to make electricity by transforming types of energy, which they found in nature. Natural sources of energy on our planet are usually subdivided into two major groups: non-renewable (traditional) and renewable (alternative) (Fig. 3.1.2).

Figure 3.1.2 Main natural sources of energy

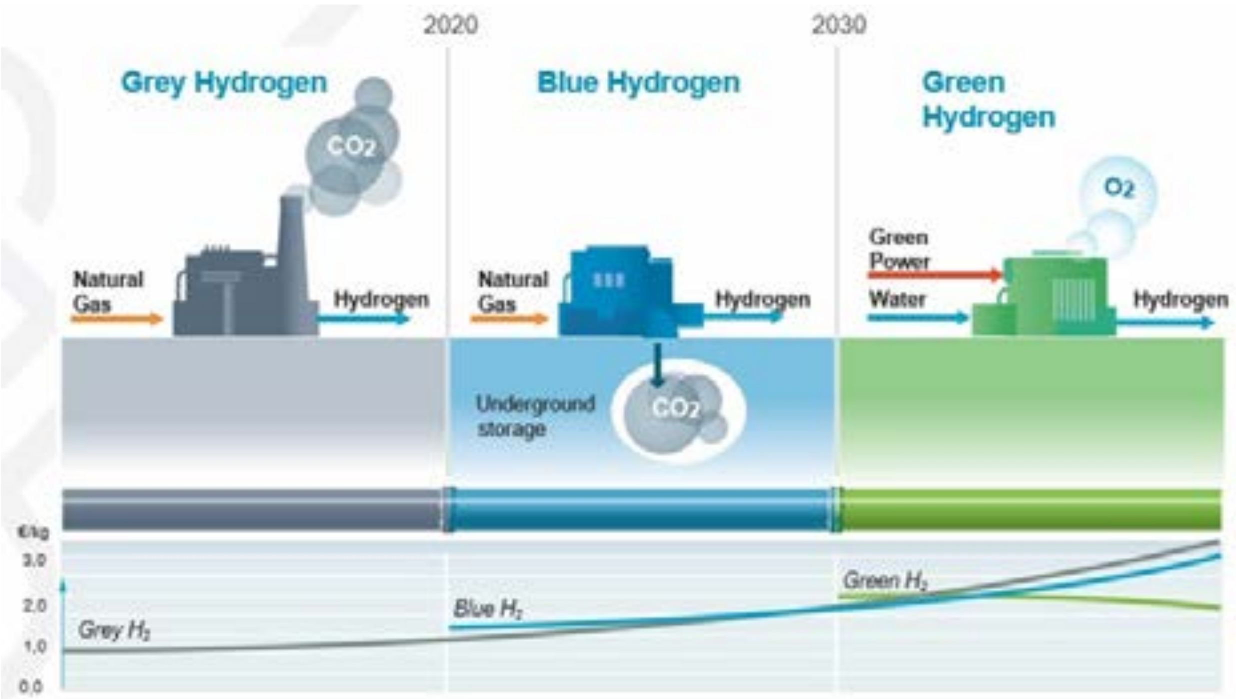


Non-renewable sources of energy are produced or replaced in nature much more slowly than they are consumed by mankind. The main non-renewable sources are coal, oil, natural gas and peat, and they are also called 'hydrocarbons' or 'fossil fuels.' Non-renewable energy sources also include radioactive metals (uranium, plutonium, and others), which are used to generate nuclear power.

Renewable energy sources draw energy from processes that occur continuously in nature. Sunlight, wind, flowing water, rain, tides, and heat rising from the earth can provide huge amounts of energy. What is more, these resources are practically inexhaustible: they will only run out in the unthinkably distant future when our solar system itself completes its life cycle. Biomass (plant fibre, animal waste, and charcoal derived from wood, which was widely used in the past) is also a renewable source of energy, as it is quickly replaced in nature.

A new fuel with a growing rate of use is **hydrogen**. It could be grey, blue, or green, depending on the sources from which hydrogen is produced – natural gas, natural gas with carbon capture and storage, and renewable electricity respectively (Fig. 3.1.3). While hydrogen was used in the past mostly as feedstock product serving heavy industry, it is now at the forefront of decarbonising the transportation and shipping industries.

Figure 3.1.3 Types of hydrogen, how they are produced and starting year of production



3.1.3 Fossil fuels

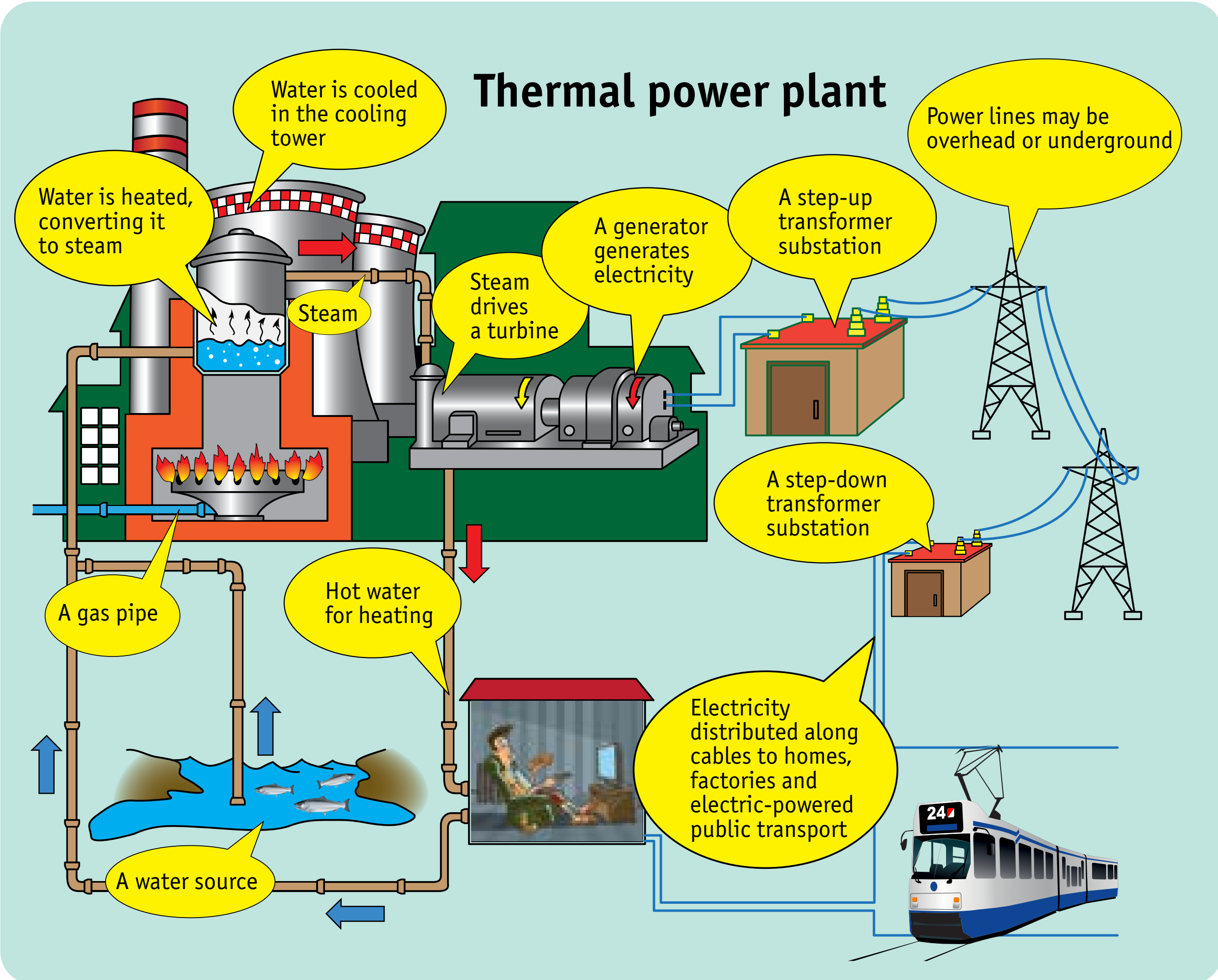
The evolution of living organisms on our planet progresses from the simple to the complex. There was a time when Earth was inhabited by simple organisms and plants, which absorbed the sun's energy and transformed it into live weight - into themselves. And the traces of their existence are still with us today: the energy gathered by these life forms, our predecessors, continues to live in what we call 'fossil fuels', substances formed from the remains of dead organisms. Crude oil, natural gas, coal, and peat are fossil fuels.

Fossils fuels are the legacy of living beings that came before us on Earth, and we should treat them sparingly and with gratitude. We must remember that no legacy is ever infinite. If we spend it unthinkingly, we will have nothing to leave to our children.

The combustion of fossil fuels, also known as hydrocarbons – coal, oil, or natural gas – can be used to produce electricity. This process occurs at thermal power plants. The engine room of a thermal power plant is fitted with a boiler and the combustion of fuel heats the water in this boiler, converting it into steam. The vapour pressure of the steam makes the blade of a turbine rotate and the turbine then drives a generator, which generates electric current. The electricity is carried to homes and other facilities by power lines (Fig. 3.1.4).

Hydrocarbon energy sources (fossil fuels) are crude oil, coal, natural gas (including shale gas produced from coal and shale formations), shale oil and other flammable substances, and minerals produced by underground or open-cast mining. Fossil fuels are formed over millions of years in the Earth's crust from the remains of living organisms. Their combustion extracts and uses their thermal energy.

Figure 3.1.4 How a thermal power plant works



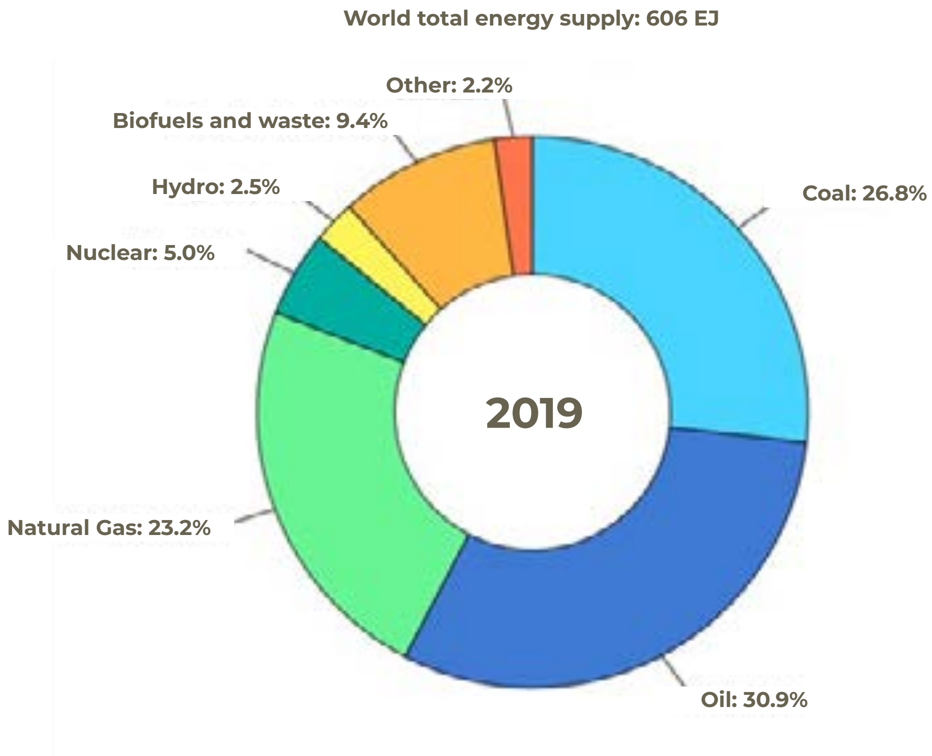
It was found that the production of electricity can be efficiently combined with heating of water, which is then channelled through pipes to the heating and hot-water systems of residential buildings, hospitals, schools and kindergartens, industrial plants, and other facilities. Such plants are called combined heat and power (CHP) plants. Usually, CHP plants are more efficient than plants that only produce electricity, which are called condensation power plants.

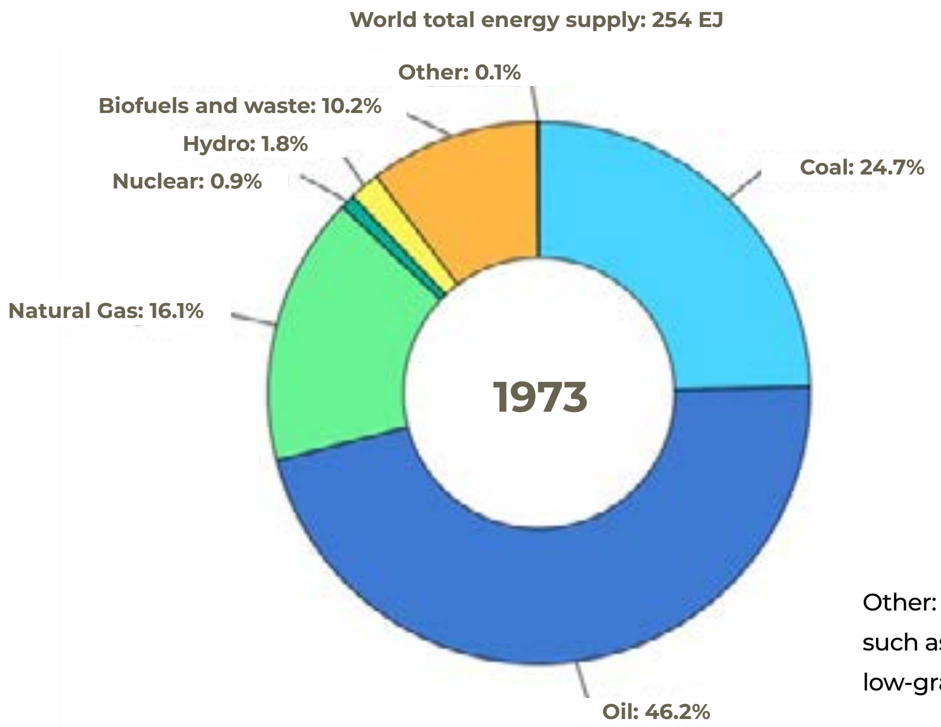
It is not always practical to channel hot water to apartment blocks from a CHP plant. In that case a boiler house is built, which uses fuel to heat water for the heating systems of local buildings.

The use of fossil fuels grew with the industrial revolution that began in the late 1700s in England. For many thousands of years earlier, wood, solar energy, wind, and water were the most common energy sources, although fossil fuels were already used in some places.

In 2019, fossil fuels dominated and accounted for 80.9% of all the primary energy supply of the world and their use was as follows: 30.9% for oil, 26.8% for coal and 23.2% for natural gas (Fig. 3.1.5).

Figure 3.1.5 World primary energy supply in 2019 and 1973

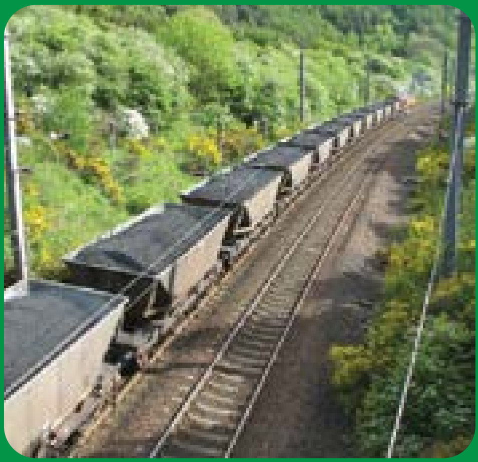




Other: renewable sources such as wind, solar, geothermal, low-grade heat, etc.

There are two major downsides to using fossil fuels. First, they are not inexhaustible, and the world's reserves are being depleted, especially reserves of oil and gas. Second, the combustion of natural gas, oil, and especially of coal, emits large quantities of pollutants and greenhouse gases whose accumulation in the atmosphere increases the greenhouse effect. This leads to a rise in global temperature and other climate changes, and can be harmful to the climate, the environment and human health.

When did people start using fossil fuels?



The world's oldest coal mine was opened in Holland in 1113. But there is evidence of people using coal, lignite, and peat as sources of fuel in the much more distant past.

In the Middle Ages, coal was already being mined in many places in Europe. It became cheaper than wood and was increasingly used in everyday life, even by poor families. But, since houses at the time were not equipped with chimneys, rooms filled with acrid smoke, making it hard to breathe.

The consumption of coal increased dramatically with the start of the industrial revolution.

By the 19th century, 700 million tonnes of coal were being mined each year. Then people turned their attention to oil.

Crude oil was known to mankind since ancient times. But it began to be used as fuel only in the middle of the 19th century, after the American chemist Benjamin Silliman found that kerosene could be obtained from crude oil. The oil boom that followed was also driven by a new way of extracting oil by means of boreholes instead of by simply digging wells. Natural gas came into widespread use as a fuel only in the 20th century.

Assessments by scientists have shown that the combustion of fossil fuels to produce energy substantially increases the greenhouse effect. For the sake of the climate, humanity must reduce its consumption of hydrocarbons and use more climate-friendly sources of energy.

Figure 3.1.6 Emission of greenhouse gases from the use of various hydrocarbon sources of energy

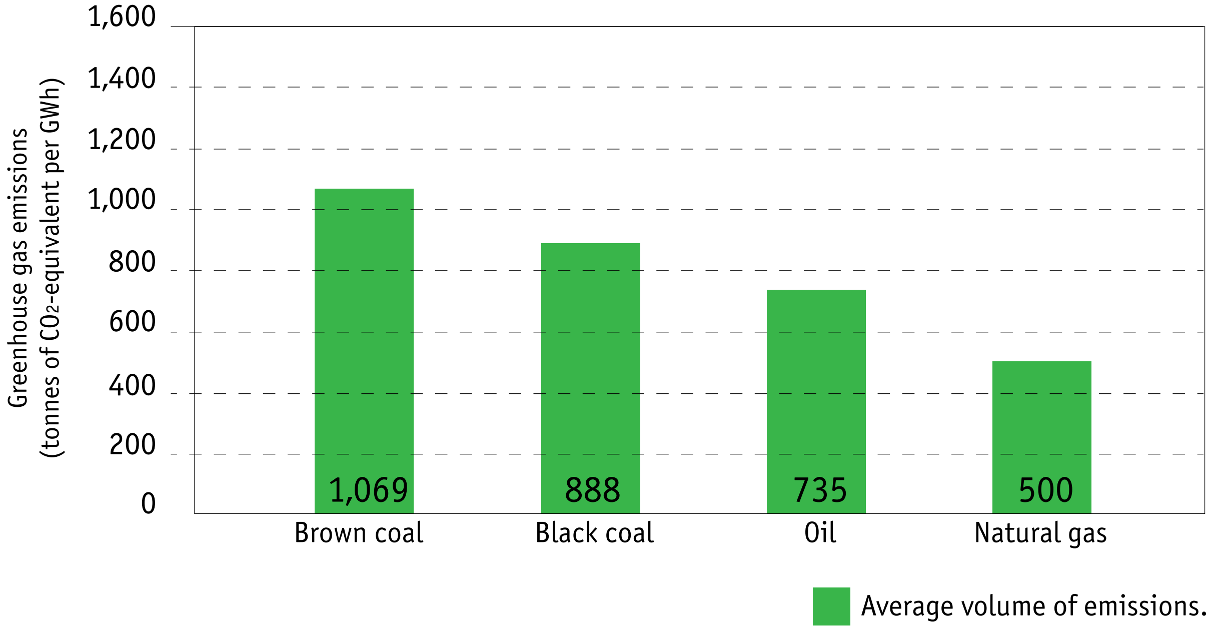


Table 3.1

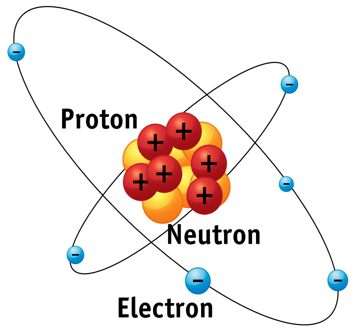
Average pollutant emissions into the atmosphere from power plants using various fossil fuels in the European Union (grammes/gigajoule)

Fossil fuel type	Dust	Carbon monoxide (CO)	Nitrous oxides (NO_x)	Sulphur dioxide (SO_2)
Brown coal	3,254	89	183	1,361
Black coal	1,203	89	292	765
Oil	16	16	195	1,350
Natural gas	0.1	15	93	1

3.1.4 Nuclear energy

Nuclear power plants produce almost zero greenhouse gas emissions. Could they be the answer to the climate change problem? Scientists have gone a long way before they made it possible to use nuclear power to produce electricity for industry and households. First, it was found that all substances consist of many similar particles, called molecules. Then it was discovered that the molecules themselves are constructed from a set of atoms. Different types of atoms were called 'chemical elements.' They were numbered and listed in Mendeleev's Periodic Table.

Under certain conditions the molecules of various substances can break down into their atoms and form the molecules of new substances in a process called a 'chemical reaction'. During a chemical reaction the energy holding the atoms together is released. The new compounds may require more energy or less, so that the chemical reaction may absorb energy from the space around it or may give off energy into space. The combustion of fossil fuel is a chemical reaction that produces heat.



But what would happen if changes occurred within the structure of the atom itself, rather than the molecule? Scientists have found that the atom also consists of particles: it has a nucleus, made of protons and neutrons welded tightly together, around which electrons revolve. The nuclei of some chemical elements can break up. This produces, first, a large amount of heat energy (which can be collected and used), and second, special particles that are called radiation. This phenomenon is called 'radioactive decay' or 'radioactivity'.

Radioactivity is part of the nature of our planet. On average, according to data from the International Atomic Energy Agency, the global annual amount of natural background radiation per individual is about 2.4 millisieverts (mSv) per year. Such low doses of radiation are harmless and even necessary for human beings and the whole natural environment. However, at higher doses radiation can be deadly.

In 1975, experts in the United States made the first attempt to calculate the probability of serious accidents at nuclear power plants. They found that such an accident could happen once every 10,000 years. And yet it was only four years before just such an accident occurred at the Three Mile Island nuclear power plant near the town of Harrisburg. The immediate damage from the accident was estimated at one billion dollars and the indirect damage at $100 billion, although only a few people were affected by radiation leakage. Seven years later, an accident occurred at a nuclear power station near the town of Chernobyl in the former Soviet Union, where nuclear scientists had also insisted that it could only happen once every 10,000 years.

Klaus Taube, the former head of the German company, Interatom, has said that any statistical estimates of the probability of an accident with meltdown of nuclear fuel elements must be considered as pseudo-scientific nonsense.

People have learnt to control nuclear reactions and use the energy they release. This process is the basic mechanism used by nuclear power plants. A nuclear power plant uses the complex process of radioactive nuclear decay as a source of energy. An enormous amount of energy can be derived from a small amount of nuclear fuel without the emission of any GHGs into the atmosphere. In terms of its impact on climate, nuclear power is very safe, although it should be remembered that the extraction of uranium for use in nuclear power plants consumes a lot of energy and emits a lot of greenhouse gases.

The major downside of nuclear power plants is that the new nuclei – called daughter nuclei – formed by the artificially organized, energy-producing decay, may also be radioactive. They are not useful as fuel but cannot be returned to the natural environment since they are dangerous. Scientists have been thinking carefully about different means of safely disposing this 'radioactive waste.' Pilot projects are under way for a new generation of nuclear power technology in which radioactive waste from existing nuclear power stations is used as input fuel with modern technologies based on fast neutron reactors with advanced fuel cycles. There is also ongoing and promising research on small modular nuclear reactors that could provide energy directly to cities. If these methods worked as perfectly as planned, it could indeed be said that nuclear power plants are completely harmless. However, the health and safety issues of nuclear plants remain a major concern. The dangers associated with the use of nuclear energy, which remain even after a nuclear plant is closed, have led to an ongoing debate about whether to develop nuclear power plants further or to prohibit them.

The explosion at the Chernobyl nuclear power plant on 26 April 1986 shocked the world. Many people were killed or seriously injured. About five million hectares of land (comparable in size with a country like Slovakia) became unusable for agriculture. A 30-km exclusion zone was created around the accident site and hundreds of small settlements had to be abandoned and destroyed.

Many years have now passed, and the designers of nuclear power plants now claim that the mistakes of the past will not be repeated with new and better equipment that has been invented.

However, in current conditions, when the climate is undergoing major changes, it is not possible to predict exceptional natural phenomena. During the construction of nuclear power plants in Japan, the frequent occurrence of earthquakes in that country was, of course, considered. Nevertheless, on 11 March 2011, a powerful earthquake and the resulting tsunami led to the failure of all systems for normal and emergency cooling of the reactor core at a Japanese nuclear power plant, and thermal explosions ensued. A large amount of radioactive material was released into the sea and the air, and the effect was felt in many countries. Three years later, the levels of radiation on the coastline where the Fukushima-1 nuclear power plant is located still exceeded normal levels by more than 100 times. As many as 80,000 people had to be moved from the area. Despite assurances from the Japanese authorities that the situation had stabilized, more radioactive substances entered the groundwater beneath the station two years after the accident and their concentrations grew, and there was further leakage from radioactive water tanks.

Nuclear energy is powerful energy, but it is also dangerous. The devastation it can cause if it runs out of control means that it is neither safe, nor cheap. Nevertheless, there is increased attention recently to nuclear energy because of the fast-growing demand for electricity and pressure to reduce carbon dioxide emissions from electricity production.

3.1.5 Renewable energy sources

As we have already seen, renewable energy sources use natural processes and resources that are either virtually inexhaustible or are relatively quickly and naturally restored. They include sunshine, wind, flowing water, tidal energy, and the heat of the earth. All these kinds of energy are often called ‘alternative’ or ‘green’ because, unlike hydrocarbon fuels, they do not damage the environment and climate. Biomass is also green energy, although it is a special case, for various reasons.

About 29% of world electricity production in 2022 came from renewable sources, up from 27% in 2019. Where renewable resources are available, it is now cheaper to build a plant using such resources than a plant using fossil fuels. In sub-Saharan Africa, for example, countries are meeting their diverse energy and climate change goals overwhelmingly from renewable energy, which is now 85% of the entire power generation. The massive expansion in the use of renewable energy makes it likely that CO_2 emissions will peak in 2025 and decline thereafter.

Experts have prepared various scenarios for the development of renewable energy in the future. In the most favourable scenario, the share of renewable energy in primary energy supply must grow from 16% in 2020 to 77% in 2050 to keep the rise in temperature below 1.5°C. Importantly, 80% of the necessary reduction in emissions to achieve this goal could come from tripling the capacity of renewable energy and doubling energy efficiency improvements.

Technology improvements, growing markets and climate policies have together helped to bring down the cost of renewable energy and its worldwide expansion. This was despite rising materials and equipment costs. China was the key driver of the global decline in costs of solar PV and onshore wind because of the size of its market.

Figure 3.1.7 Examples of a bioenergy plant and solar power station

Table 3.2 Comparing costs of different renewable energy technologies

	Total installed costs (2022 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2022 USD/kWh)		
	2010	2022	Percent change	2010	2022	Percent change	2010	2022	Percent change
Bioenergy	2 904	2 162	-26%	72	72	1%	0.082	0.061	-25%
Geothermal	2 904	3 478	20%	87	85	-2%	0.053	0.056	6%
Hydropower	1 407	2 881	105%	44	46	4%	0.042	0.061	47%
Solar PV	5 124	876	-83%	14	17	23%	0.445	0.049	-89%
CSP	10 082	4 274	-58%	30	36	19%	0.380	0.118	-69%
Onshore wind	2 179	1 274	-42%	27	37	35%	0.107	0.033	-69%
Offshore wind	5 217	3 461	-34%	38	42	10%	0.197	0.081	-59%

Note on terms: total installed cost: cost of building of a power plant; capacity factor: overall time when the plant is in operation; levelized cost of electricity: the average cost of electricity generation for a generator over its lifetime; CSP: concentrated solar power; solar PV: solar photovoltaics.

The sun

The sun is the energy source provided by nature herself for the creation of life on Earth. So why not seek ways of using the sun's energy directly? The midday sun heats every square metre of the earth with a solar capacity of about one megawatt.

Any room with windows grows warm when the sun shines. If the sun is shining in from your window, but it is quite chilly inside the house, open your curtains and wipe any dust off the windowpane, and the sun will bring a little more heat into your room. In the old days, in European villages, people used wooden shutters on windows. In the daytime the window was opened to let in light and at night it was closed with shutters to keep the captured warmth inside the house.

With the advance of science, people have learnt better techniques to 'catch the sun'. There are two main ways of using the sun's energy.

Units of measurement of electric power

Watt is a unit of power. One watt is defined as one joule per second (1 J/s), representing the rate of energy transfer or conversion of one joule of energy per second.

- **1 watt (W):** the power of the transmitter in a standard mobile phone.
- **1 kilowatt (kW, 1,000 W):** the power of a small heater, approximately equal to the heating of one square metre of land by the sun at midday.
- **1 megawatt (MW 1,000 kW):** railway locomotives have average power between three and ten megawatts.
- **1 gigawatt (GW, 1,000 MW):** the unit to measure the power of the largest electricity generating plants in the world.
- **1 terawatt (TW, 1,000 GW):** the peak power of a lightning strike.

Solar collectors capture the heat of the sun. Water flows along tubes inside the collector and becomes warm (air or antifreeze is sometimes used instead of water). Such collectors can be used for heating buildings and to provide hot water.

Photovoltaic cells are another popular method to collect and store solar energy. Photovoltaic cells convert sunlight into electrical energy. We are all familiar with calculators that use photovoltaic cells and garden lanterns that collect energy during the day and provide light at night. Large solar energy power stations – so-called 'solar farms' – operate on the same principle.

Solar collectors are installed on the roofs of houses at an angle to the horizon equal to the latitude of the location where they are being used.

Photovoltaic cells can also be used to power various means of transport: boats, cars and even airplanes! In Italy and Japan, photovoltaic cells are installed on the roofs of trains to produce electricity for air conditioning, lighting, and alarm systems.

The main advantages of solar energy are that it is freely available, inexhaustible, and safe. Solar installations do not emit greenhouse gases or pollutants, so this method of obtaining energy does not harm the climate.

Solar energy: hot water plus electricity

Using the sun's heat to generate energy has long been a common practice in countries with hot climates. In warm countries you often see tanks of water on the roofs of houses, which are heated by sunlight to be used for everyday needs.

In Israel, every building has to be equipped with solar panels for water heating. The city of Freiburg in Germany is a showcase for the potential offered by solar power, which is used to meet the energy needs of entire neighbourhoods. Similar experiments are increasingly frequent all around the world.

The disadvantages of solar energy are its strong dependence on the weather and time of day, and high manufacturing costs due to the use of rare elements in solar panels. However, new technologies are fast reducing the cost of solar installations and broadening the areas of their application. Recent data show that the cost of renewable power has fallen by 80% since 2010, leading to the rapid use of solar for electricity generation worldwide. However, there are problems associated with the disposal of used solar cells, since they contain toxic substances. A market for the recycling of solar panels has not yet taken shape, and panels have useful lives of several decades. Another drawback is the large consumption of energy and clean water to produce solar panels. Engineers are working on new, more environmentally friendly solar cells, and producers need to develop systems for the disposal and recycling of used panels.

How big are the largest solar power plants in the world?
What about solar energy after sunset?

The largest solar power plant is the Talatan PV Power Station in China with a solar park that spans 609.6 km^2. Reflecting the sheer scale of the Talatan PV Power Station is its capacity – a gargantuan 9 GW, which contributes to an average annual power output of 9,600 GWh. But the Talatan PV Power Station isn't just one of the world's leading examples of how the future of renewable energy looks – it's a case study of how solar farms can transform the geographic and economic prospects of an area for the benefit of the people.

The second largest solar thermal power plant in the world as of 2022 is the Bhadla Solar Park, in the Jodhpur district of Rajasthan, India. The Bhadla Solar Park is a 2.25 GW solar photovoltaic power plant and the largest solar farm in the world, encompassing nearly 14,000 acres of land. Its construction cost an estimated $1.4 billion. What are some of its benefits? It helps to reduce India's dependence on imported fossil fuels. In rural areas, solar power provides a much healthier and safer source of indoor lighting than kerosene. Additionally, solar power plants like the Bhadla Solar Park drive economic growth and job creation in surrounding areas.

The Solana Generating Station is located 110 km south-east of the city of Phoenix in Arizona, USA. It can generate up to 280 MW of power from the rays of the sun and is one of the most powerful solar power plants in the world using parabolic mirror technology. But what makes the complex special is not its size, but its ability to continue generating electricity for six hours after the sun has gone down by means of special reservoirs that retain heat. This is a valuable feature, since the time after sun- set is the time of peak electricity consumption in the region.

Many experts view solar power as the energy of the future and as one of the main alternatives to traditional hydrocarbon energy sources. Governments in many countries support the development of solar energy, and private companies are investing much money in the construction of solar power plants. China is the global renewable energy leader, hosting nearly half of the world's total operating wind and solar capacity, followed by the US and India. Although not known as a sunny country, Germany is among the leading countries in the world in the development of solar energy. Other frontrunners are Spain, Sweden, Costa Rica, Iceland, Italy, France, Japan, Kenya, Morocco, New Zealand, Norway, Uruguay, and the UK. This list shows that solar power is becoming increasingly important for developed and developing countries and emerging economies. Importantly, solar power helps to provide distant villages in developing countries that are not connected to the grid with modern, yet cheap energy services.

Wind

Wind is another commonly used renewable energy source. The principle behind wind power is that mechanical energy (the energy of movement) can be converted into electrical energy. Miniature windmills and wind-driven toys are fun to play with, but if you build huge wind turbines and place them together in a windy area, the rotation of turbines can generate electricity for public use.

Windmills have been used since ancient times, but they became especially popular in medieval Europe. For a long time, windmills and water mills were the only machines known to mankind. Windmills were mainly used to grind corn into flour, to process timber or for irrigation. In the Netherlands, windmills pumped water from land that had been reclaimed from the sea so that the land could be used for agriculture.

Modern wind turbines use a principle analogous to that of windmills.

Wind turbines are usually located in coastal areas, where there is constant wind, and it has recently become possible to build such installations at sea as well as on land. So-called 'offshore wind farms' are now built 10–12 km or more from the coast. Wind turbine towers are set on pile foundations that are driven into the seabed to a depth of 30 metres. The latest technologies help the construction of wind turbines installed on floating platforms.

Two offshore wind projects off the east coast of England are now among the largest operating projects in the world. They include the 1.32 GW Hornsea 2 and the 1.2 GW Hornsea 1 which comprise the largest operating offshore wind farm in the world. Hornsea 2 is 462 km^2 and can power more than 1.3 million homes. Together, Hornsea 1 and 2 are capable of powering 2.5 million homes. The planned 2.8 GW Hornsea 3 project is expected to be in operation in the next few years. Another example is the Greater Changhua with a total capacity of 900 MW, making it the largest and first far-shore wind farm in Taiwan. This off-shore wind farm significantly supports Taiwan's fast-track build-out of renewable power and provides it with the much-needed green energy to achieve its net-zero goal.

A large wind farm may consist of several hundred turbines extending over a large territory (up to several hundred square kilometres). Wind farms are connected to a country's electricity grid and transmit electricity over long distances. Smaller wind farms or stand-alone wind turbines can be used to supply electricity in remote districts or to power small facilities.

In 2022, wind power provided more than 2100 TWh of electricity, which was over 7% of the world's electricity production, and more than all other non-traditional renewable energy sources combined. It is a rapidly growing source of power as new, more advanced technologies are invented, which allow wind energy to be used more efficiently.

The share of wind and solar is rising constantly (+1.5% in 2022), reaching 12.2% of the energy mix for electricity generation in 2022. Experts at the International Energy Agency predict that wind and solar power will grow even faster in the current decade and together could produce up to 18% of the world's electricity by 2026. Along with traditional hydropower, the share of wind and solar (also called variable renewables) will reach 37% by that year.

Wind energy already has an important role in some European countries. Denmark has been a global leader in solar and wind power production. In 2023, wind power accounted for over 57% of the country's electricity generation, compared to 1994, when coal accounted for 83% of electricity production.

Figure 3.1.7 Wind farms in Kansas, USA (above) and Austria (below)

Water

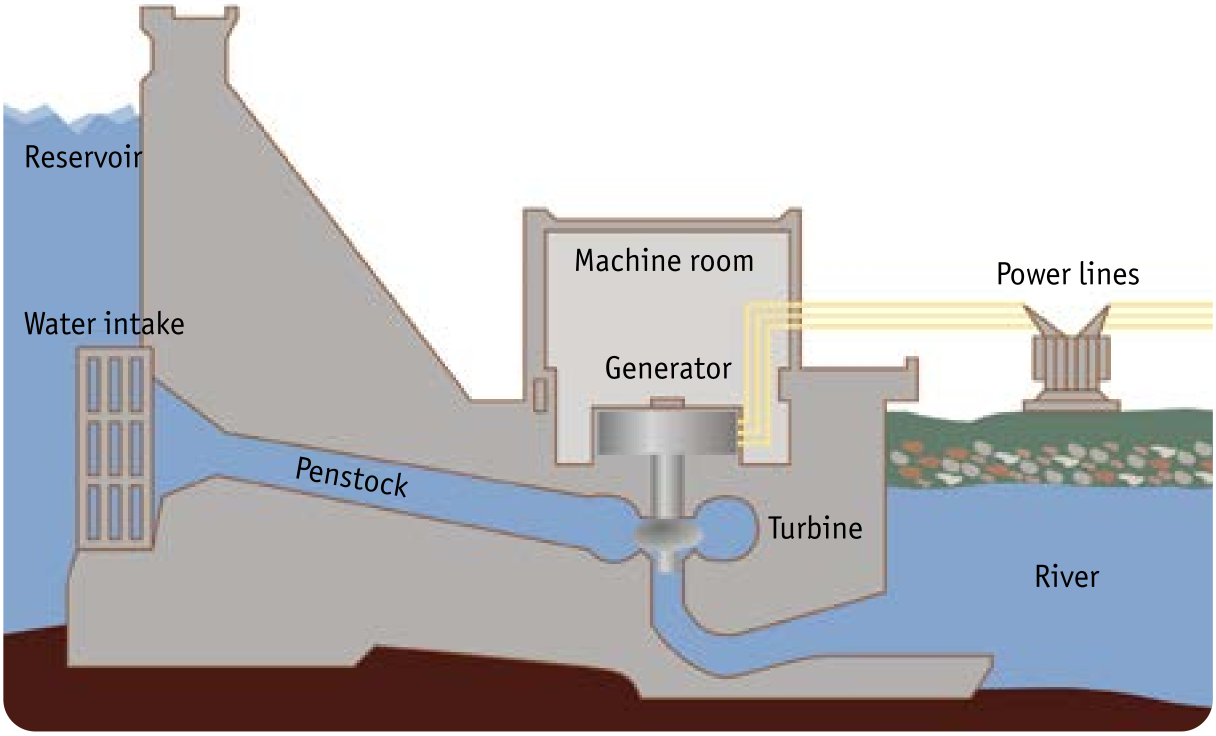
The energy of moving water can be harnessed in many ways.

The most common is **hydropower**: the flow of a river rotates a turbine, which produces electrical energy.

This sounds simple, but hydropower has its drawbacks. To create a powerful and efficient hydroelectric power plant, you must build a high dam so that all the river's power can be channelled to rotate the turbine blades. The construction of such a dam upsets the natural life of the river: it may alter the river's microclimate, destroying or harming the animals and plants that live there. This is why the construction of a hydroelectric power plant must be approached very carefully, paying due attention to environmental balance.

The maintenance of large dams also requires constant attention: if an accident causes the dam wall to burst, the water that is released will gush down the river valley, sweeping away everything in its path, and breaking the banks of the river for miles downstream. For example, the collapse of the Bantsao hydroelectric dam in 1975 in China killed more than 200,000 people unofficially (26,000 according to official sources).

Figure 3.1.8 Schema of a hydroelectric power plant and a dam



Small hydroelectric installations can operate without a dam (Fig. 3.1.9). They are built on small rivers or even on streams, and store energy in a battery. They have limited power but are adequate to meet the needs of a small farm or essential services at a wildlife reserve located by the river.

Hydropower is safer for the climate than traditional thermal power and costs only about half as much to produce. As a result, many countries are trying to maximize the potential of their rivers for energy production. In some countries hydroelectricity provides 90-100% of all electricity (Paraguay, Norway, Tajikistan, Uruguay, Uganda, Zambia, Namibia, Cameroon, and Brazil). China has a strong commitment to hydroelectric power: up to half of all the world's small hydropower plants have been built there as well as the biggest, the Three Gorges plant on the Yangtze River with capacity of 22.5 GW (Fig. 3.1.10). An even bigger plant, called Grand Inga, with capacity of 39 GW is planned on the Congo River in the Democratic Republic of the Congo in Africa. Brazil and Canada are also key producers of hydropower.

Figure 3.1.9

Small hydropower plant on the Kokra River in Slovenia

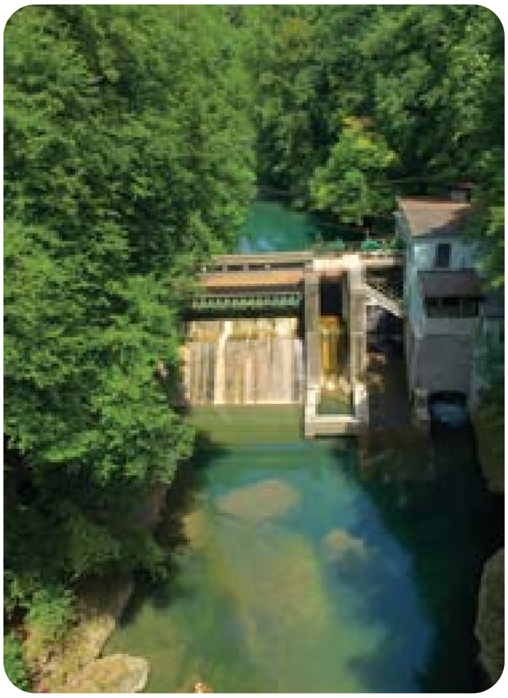


Figure 3.1.10

Three Gorges hydropower plant, China

Figure 3.1.11

Yacyreta Dam on the Parana River, Paraguay, Argentina

Wave power stations use the energy of waves in the ocean, which is essentially the energy of a float bobbing up and down on the sea. Thus, the churning power of the ocean, so dreaded by sailors in the past, can be made to serve us. The power of the waves is dozens of times greater than that of the wind if it can be harnessed.

Tidal power plants use the extraordinary phenomenon of tides. All planets, stars and other celestial bodies are linked by gravity and affect one another. Earth revolves around the Sun and around its own axis, the Moon revolves around Earth, and the positions of the Sun, Earth and Moon change all the time. This affects the ocean.

A dam is built at a point across a bay where tides are strong. Initially it prevents the rising water level from entering the bay, until the tide level is close to its maximum point. Then a valve is opened, and the ocean water rushes through with great force, turning a rotor. When the water level on both sides of the dam has equalized, the valve is closed again. When it is low tide and the ocean is in full retreat, the trapped water presses to leave the bay, and is allowed back out through the valve, turning the rotor once again.

Experiments using wave energy have been attempted since the end of the 18th century: the first patent for a mill driven by wave power was taken out in 1799. But a long time was to pass before this form of power could be used on a large scale. There are also tidal power stations that rely on gravitational forces, unlike wave power stations that rely on wind and waves.

The first large wave power station was opened in 2008 in the Agucadoura region of Portugal, five kilometres from the coast. The station has 2.25 MW capacity.

Another large wave power station with comparable capacity is the Sotenäs wave farm in Kungshamn, Sweden. The plant consists of 36 wave energy converters (WECs), with a total installed capacity of nearly three MW.

The Rance Tidal Power Station in Brittany, France is the oldest tidal installation in the world. Since 1967, it was also the largest tidal power station by installed capacity until the Sihwa Lake Tidal Power Station in the Republic of South Korea surpassed it in 2011. The Rance power station has 24 turbines that reach peak output at 240 MW and average 57 MW, a capacity factor of approximately 24%. At an annual output of approximately 500 GWh, it supplies 0.12% of the power in France. The cost of electricity production is estimated at €0.12/kWh. The difference in level between high and low tide in this part of France averages eight metres and can be as great as 12 metres.

Geothermal energy

Geothermal energy uses heat produced by the earth. It cannot strictly be called 'renewable,' but the stocks of heat in the depths of our planet are immense. Evidence of the heat contained in the earth is visible in areas of volcanic activity, where hot underground water sometimes rises through cracks in the earth's surface and occasionally bursts upwards in the form of jets of water and steam known as geysers.

A borehole can be drilled to hot underwater lakes and their water used for heating or electricity generation, and as a supply of hot water (if the chemical composition of the water is suitable). A key problem with hydrothermal energy is that used water must be returned to the ground, since it often contains chemicals that would be harmful if released into rivers and lakes. Another is that use of water from underground lakes leaves voids, which could lead to surface subsidence.

Another possibility is to pump ordinary water from the surface via a borehole into hot zones under the ground, where it is heated by a 'natural boiler' to boiling point and returns to the surface through an adjacent borehole in the form of steam. This is called petro-thermal energy. Petro thermal projects have been developed in the United States, Australia, Japan, Germany, and France.

The world's largest and most powerful geothermal field is located north of San Francisco in the USA. Called The Geysers, it consists of 22 geothermal power plants with a total installed capacity of 1,517 MW.

In the Philippines and Iceland, both countries with major active volcanoes, geothermal power plants provide about one quarter of all electricity consumption. New Zealand, Indonesia, Japan, and Italy also make extensive use of geothermal energy.

Figure 3.1.12

A pipe at a geothermal power station

Low-grade heat

Refrigerators rely on several principles for their proper functioning. The key principle is this: a liquid cooling agent (the refrigerant) absorbs heat from inside the refrigerator and a compressor then sucks and compresses the cooling agent under pressure, outside the refrigerator, so that (by the laws of physics) the absorbed heat is emitted into the air of the room where the refrigerator is kept.

This is why if we touch the outside rear part of a refrigerator, we find that it is hot. It is also why a refrigerator should stand away from heating appliances and not be directly in the sun – because it is important that the heat it emits is quickly dissipated in the surrounding air and not retained in its external walls.

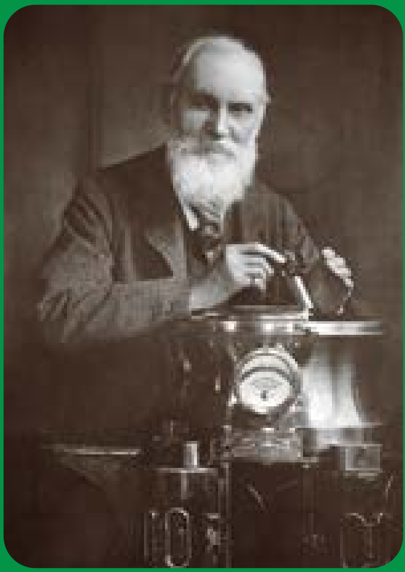
The point of a refrigerator is to retain cold and get rid of heat, but the same operation can also be carried out in reverse, so that heat is retained and cold discarded. A device which does this is called a heat pump.

Heat pumps can absorb heat from weakly heated liquid, air or other substances. They can also 'take up' the heat of the earth at shallow depths. If in the winter you pass the warm air coming from your apartment or the used warm water draining out of the bath through a heat pump, a substantial part of the outgoing heat can be returned to your apartment. However, a heat pump cannot heat water to a very high temperature. The upper limit is usually no more than 50 or 60°C, which makes it a supplementary and not self-sufficient energy source to reduce fuel consumption for heating.

Nevertheless, scientists consider heat pumps a key technology in practically all future scenarios leading to zero emissions in 2050, as they not only use renewable energy but offer efficiency gains that are two to four times more than conventional heating systems. This is why the number of heat pumps installed is growing fast and by 2050 is expected to see a tenfold increase.

Just in Europe, heat pump sales have soared because of technology improvements and cost reduction. The rapid fall in production costs of PV systems also influences the heating market: using self-produced electricity in combination with a heat pump system provides buildings with a low-cost energy source.

The concept of heat pumps was developed in the 19th century by the British scientist, William Thomson (Lord Kelvin), and was further improved by Peter Ritter von Rittinger of Austria. But the most important practical application of heat pumps was only developed in the 20th century. An inventor, R. Weber, who was carrying out experiments with a freezer chamber, touched the hot pipe of the chamber and began to wonder how this heat could be used. He thought of using the hot pipe to heat water, but that produced too much hot water, so he instead made a pipe coil to warm the air in the house. Weber then found a way of pumping heat from the ground. Soon he was able to sell the old coal burner his family had relied on, as it was no longer needed!



The British physicist,
William Thomson (Lord Kelvin).

Biomass

The living plants we see around us today use photosynthesis to accumulate energy from the sun in their bodies. A bonfire or the fire in a fireplace warms us because a tree that people cut down for firewood spent years capturing energy from the sun and gathering carbon dioxide from the air. Trees have worked for us storing up energy when they were alive, and they finally yield that energy to us when they burn in a fire.

It takes nature several hundred million years to create fossil fuels, so (at the rate we are using them) they are not being replaced. But biomass fuel can be easily replaced: if we cut down an old tree for fuel, we can plant a new one in its place, which will grow into a new tree in a few decades. Some plants and agricultural crops used to make fuel grow in one summer or even faster.

But let's think: many of us have been kept warm and had a nice time sitting around a campfire, or looking at the flames dancing in an outdoor stove in the summer, but how many trees have we planted to pay nature back for that wood? It is simple enough to cut down forests and use the wood. But how often do we plant new trees to make up for the ones cut down?

It is not just trees that can be used as fuel. Parts of plants generally considered to be waste – e.g., husks from cotton plants, straw from wheat, stones from fruit – are also good for fuel. Plants absorb about the same amount of carbon dioxide during their lives as they release when they are burnt. If they had died in the natural environment instead of being used for fuel, roughly the same amount of gas would have been given off gradually as was obtained from their combustion. Biomass is a relatively safe source of energy, but it is not always a good option: for example, it makes good sense to use the offcuts from woodworking as fuel, but if we cut down healthy trees for firewood, we are wasting valuable natural resources.

Biofuel is fuel obtained from vegetable or animal raw materials, from the waste products of organisms or from organic industrial waste, i.e., from biomass. Science has now made it possible to make liquid biofuels for internal combustion engines (bioethanol and biodiesel) as well as hard biofuels (firewood, briquettes, pellets, wood chips, straw, husks, and shells) and gas fuel (biogas).



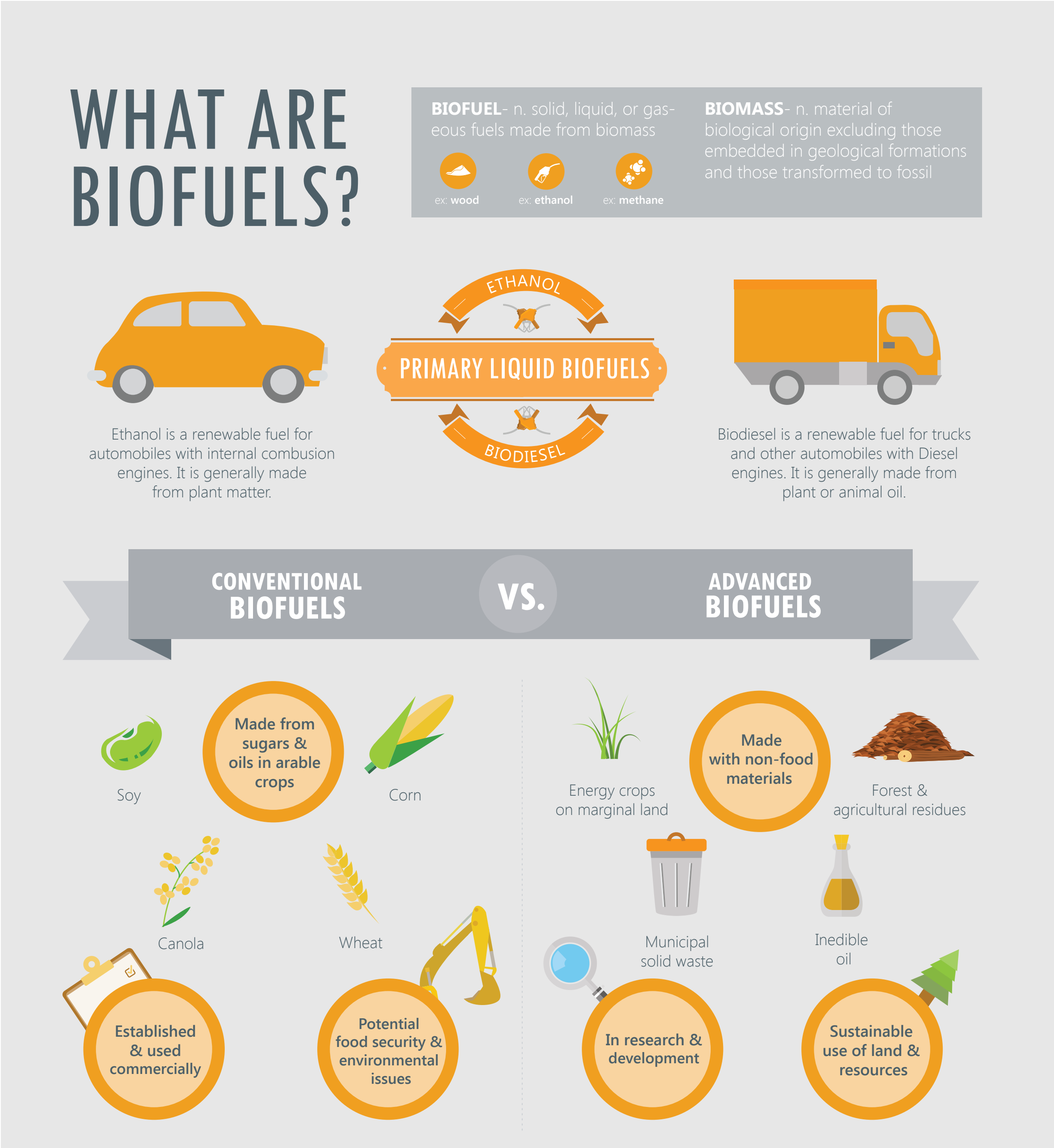
The easiest and most common way of producing energy from biomass is by burning it. But you can only make a bonfire with dry and resinous wood, and you must make sure that the bonfire is laid in a way that will let it burn. So, scientists are working to design more economical technologies, which will let us burn raw biomass that is damp or has mixed ingredients in a more efficient and environmentally friendly way.

Plant fibre can be burnt to obtain energy directly, or transformed into a universal fuel that is easier to transport and use in various existing machines and devices. Plants containing oil can be used to produce various liquid diesels (biodiesel). Plant products that contain sucrose and starch can be used to produce alcohol (ethanol), which is also used as fuel.

There are different types of biofuels. Ethanol and biodiesel are the primary fuels used by cars and trucks. There are also conventional biofuels produced from sugar and oils in arable crops, as well as advanced biofuels produced from products such as forest and agricultural residuals.

Concerns over the sustainability of production of biofuels and competition for land for food production is increasingly shifting attention to advanced biofuels. In addition to saving on CO_2, these fuels are also part of the so-called circular economy.

Figure 3.1.13 Types of biofuels



Brazil is among world leaders in the production and use of ethanol from sugarcane. The ethanol produced in the country meets 18% of its automotive fuel needs.

Figure 3.1.14

Bioethanol plant in Brazil

Figure 3.1.15

At a filling station in Brazil you can fill your car with biofuel.

Amazing sources of energy

Australia now has the world's first electric generating facility that uses nutshells as fuel. Its construction cost AU$3 million, but it should pay for itself quite quickly: the high-performance power plant can process up to 1,680 kg of nutshells per hour to produce 1.5 MW of electricity.

Indian scientists have come up with another alternative energy source, using bananas, other fruits and vegetables, and their inedible parts (peel, seeds). Four batteries powered by these fuels can operate a wall clock, an electronic game, or a pocket calculator. This energy is primarily for people in rural areas who have an abundance of their own fruit and vegetables to recharge the batteries.

In the not-too-distant future, people might be able to generate electricity from the movement of their own bodies. US researchers are developing special shoes with plastic inserts: when a person walks, their feet alternately press and release the inserts, causing them to shrink and expand. This movement can be used to generate up to three watts of electricity, enough to listen to the radio or to music as you walk, saving on batteries.

Fermentation is another way to use biomass.

Farm animals, which eat and digest plants, produce manure that can be used to generate energy. If manure and food waste are collected in a closed container which is then heated to 50–60°C, bacteria will break down the organic matter to produce methane gas, which can be collected and used as fuel.

Every year the world produces and uses or destroys about 170 billion tonnes of primary biomass.

3.1.6 The advantages and disadvantages of various energy sources

Now that we have learned about different sources of energy, we might ask which of them is the best? Which is the most environmentally friendly and which the least harmful for the climate? And which is the cheapest?

The answers to these questions are not as simple as might seem at first glance. We must consider a lot of factors when we compare different fuels.

Criteria for comparing energy sources

- Greenhouse gas emissions in their production and use.
- Emissions (during production and use) of harmful substances that are hazardous to human health and the environment.
- The cost of transporting fuel from the place it is produced to an electricity generating plant.
- The cost of distributing heat and electricity to consumers at a distance from where the heat and electricity is generated.
- The cost of building and operating a power plant and dismantling it at the end of its service life.
- Environmental and human costs (dealing with accidents, treating victims, compensating their families, and planting trees to offset greenhouse gas emissions).
- The climatic and geographical location of electricity generating plants. What source will they use for their water needs and how will the water be cleaned? What are the prevalent winds at the location and are there any critical weather or seismic conditions? Are there convenient transportation routes for the supply of raw materials? What natural habitats and landscapes and human settlements are in the vicinity?
- Purification equipment and recycling. Does the generating plant use up-to-date equipment? Is the system to prevent pollutant emissions up to standard, and has a sufficient area been set aside for the storage and recycling of waste? Perhaps there will be no serious problems with waste in the early years of the plant's functioning, but the question of what to do with them may arise at some point in the future.

It makes no sense to discuss the efficiency of technology and the cost of energy in isolation from issues of climate change, the environment and health. So, before deciding what kind of power stations need to be built and operated, a wide variety of assessments (technical, economic, environmental, etc.) must be carried out.

Let's recall and compare the advantages and disadvantages of the main natural sources of energy once again.

Coal

Coal is a universal fuel: it can be used in any climate, at large and small power plants and even to heat water in boilers.

Coal is the 'dirtiest' fuel for power generating. A coal-fired power plant with 1 MW capacity emits 36.5 billion m^3 of hot gases containing dust and harmful substances each year. It also produces a large amount of ash that mustbe stored. And, most importantly, the amount of CO_2 emissions from coal-fired power plants per unit of energy produced is the biggest in comparison with other hydrocarbon energy sources.

Coalmining is also a dangerous business. The release of natural gases underground can lead to explosions that are fatal for coal miners. The salty and dirty water pumped out of coal mines often finds its way into rivers and lakes (on average 3 tonnes of water has to be pumped out per tonne of coal produced), doing harm to plants and animals, and polluting local water and soil.

Oil

Oil is very easy to use, it can be transported over long distances through pipelines as well as in tanks. Oil is used to produce rubber, plastics, dyes, detergents and other products.

Oil reserves are being depleted and the costs of producing oil are on the increase. Oil is highly flammable, and spillages of oil are disastrous for the environment, since it covers all living things with a thin film that is highly destructive for ecosystems. Such a spill in a river or the sea can spread over great distances. The combustion of oil produces large amounts of CO_2.

Natural gas

Natural gas is the cleanest and most environmentally friendly hydrocarbon fuel. It is easy to transport.

Gas is explosive, even in relatively small quantities. Greenhouse gas emissions from the combustion of natural gas are less than from other hydrocarbon fuels, but are still significant. Also, gas reserves are not infinite, although the development of shale gas technology has added to them.

Nuclear power

Nuclear power generation does not emit greenhouse gases. Stocks of nuclear fuel are quite large, since large amounts of energy can be obtained from a small amount of fuel.

Nuclear energy must be produced at very large plants and can only be transported in the form of electricity (not heat), because the danger of radiation leaks makes it essential to position nuclear plants far from any big city, where consumers of hot water and heat are concentrated. Nuclear power plants produce waste, which remains hazardous for many centuries and must therefore be disposed of in a special way. Although it produces zero greenhouse gas emissions, nuclear generation does produce spent, radioactive water. The main disadvantage of nuclear energy is that even minor accidents can have disastrous consequences.

The sun

Solar energy is renewable. It can be used in many places around the world. It produces no harmful pollutants or greenhouse gases.

Solar energy flows are uneven, and additional batteries are needed to convert the energy flow at night or in cloudy weather. Solar cells remain expensive, although scientists are looking for ways to reduce the cost of their production. There are problems associated with the disposal of spent solar cells, since they contain harmful substances, and solar power plants take up large areas of land.

Wind

Wind power is renewable and produces no emissions of greenhouse gases and harmful pollutants.

Wind plants need constant strong wind. Additional batteries and transformers are required for a wind farm to be able to function during light wind. The rotation of the blades creates vibrations and noise that can frighten animals and create an annoyance to people, who may also object to the sight of giant windmills, which transform the landscape. A system is also needed to scare away birds, which could otherwise fall into the spinning blades.

Water

Hydropower, tidal power and wave power, are renewable, freely available and create no emissions of greenhouse gases and pollutants.

Waterpower can only be produced where there are water bodies. The construction of large hydropower plants requires flooding of the land around the reservoir, which is a very difficult and expensive process. The construction of hydroelectric plants adversely affects river and coastal ecosystems. Accidents at hydropower plants can lead to flooding of towns and villages downstream.

The heat of the earth and low-grade heat energy

☺ The energy that comes from inside the earth is renewable and available everywhere. It emits no greenhouse gases or pollutants.

☹ The process of extracting energy from deep underground sources remains expensive and complicated at present. Long-term use of geothermal reservoirs (pumping of water and steam) leads to ground subsidence. Such heat can only serve as an auxiliary source of energy.

Biomass

☺ Biomass is freely available and easy to use. Its emissions of CO_2 into the atmosphere are no greater than the emissions that would be generated by the natural decomposition of plants. The use of biomass in the areas where it is created (agriculture and logging areas) solves the problem of waste disposal. Biomass fuels are, essentially, a way of extracting energy from garbage. Manure can be used to obtain both gas fuel and fertilizer.

☹ Raw biomass is difficult and expensive to transport. The production of gas fuel from biomass requires maintenance of fermentation temperature, and care to avoid explosions and the escape of bacteria to become a source of disease. Also, the gas has an unpleasant smell!
Some enterprising producers of agricultural products now want to use their fields to produce biomass, instead of traditional food crops as it brings more income. This reduces food production, threatening food security.

If renewable energy is inexhaustible and environmentally friendly, why not change over completely from coal, oil, gas, and nuclear power to green technologies?

The fact is that there are still limitations to the mass development of renewable energy. The operation of power plants using renewable energy sources depends on climate conditions, which is why they are called variable sources of energy (wind strength, the presence of rivers, the number of sunny days). Renewable energy-generating plants usually have their own site-specific design. So, the successful use of renewable sources requires a high investment of effort and money at the time of their design and construction. When the capacity of renewable generation plants reaches a certain level, further expansion requires large investment in the electricity network and gradual transition to the so-called ‘smart grids’. Nevertheless, new technologies are steadily making energy production from renewable sources more efficient and driving down the production cost and expanding the market.

Energy is always in demand, so the energy industry, particularly the production and trade in oil, gas, and coal, is very profitable. The huge amounts of money in this industry result in frequent and serious disagreements between government, business, and environmental civil society organizations. This is a global problem. But in the long term, people are moving towards an understanding of the urgent changes needed for the future of humanity and of the planet. The introduction of new, climate-friendly technologies is delayed by the inertia of human thinking. Our planet and the universe are ready to give us their energy, but in return we must learn to use our natural resources in a way that helps the climate and does not destroy it for the sake of short-term benefits.

QUESTIONS

1 What sources of energy were used in ancient times?

2 What ways do you know of using solar panels?

3 List all the factors that must be taken into account if we are to determine the total cost of generating electricity from one or other source of energy.

4 Electric engines do not produce harmful emissions. So can we consider them to be the most environmentally friendly type of engine?

5 Flat solar cells are installed on the roofs of houses at an angle to the horizon equal to the latitude of the place where they are installed. Why do you think that is?

6 What are the main barriers to the fast growth of renewable energy capacity?

TASKS

1

Experiment
Purpose of the experiment: to build a light using renewable energy.

Materials: a transparent plastic bottle with water in it, a small table, blankets.

The experiment. Make an opening in a blanket where a bottle can be placed. Cover the table with blankets so that no light penetrates the little 'house' you have created under the table. What do you think will happen when you enter the 'little house' and place the bottle in the opening you have made on the cover? What did you notice? How do you explain the phenomenon you observed? Suggest an alternative to the water bottle as a handy tool. What are your ideas for lighting the little house you made?

What do you think will happen when you enter the 'little house' and place the bottle in the opening you have made on the cover?

2

Divide into groups by different ways of producing electricity.

Each group should prepare a report to defend its way of producing energy, including information about problems associated with all the other ways. Then prepare and hold a discussion about the benefits and harm caused by different types of power-generating plants, making it relevant to the area where you live.

3.2 Energy efficiency and energy saving

The first way to mitigate climate change is to use energy sources that least damage the environment and the climate, as discussed in the previous section.

The second way is to reduce our overall energy consumption. In this chapter we will look at two similar, but different concepts: energy efficiency and energy saving.

A device is energy efficient if it uses less energy than other similar devices to do the job it was designed for. For example, two lamps may give an equal amount of light in your room but may consume different amounts of electricity. The lamp that consumes less energy will be more energy efficient. We can save a lot of energy by turning off lights when they are not needed, keeping windows, light, and lamps clean, and installing bulbs that are more energy efficient. Instead of taking a car, we can walk and use bicycles, where possible.

Figure 3.2.1 Comparison of the energy efficiency of different lamp bulbs

Traditional incandescent bulb

Fluorescent bulb (contains mercury; special disposal required)

Light-emitting diode (LED)

ENERGY EFFICIENCY
is the ratio between the amount of energy consumed and the useful result that is obtained from its consumption, such as lighting or energy for cooking. In recognition of the importance of energy efficiency, it is sometimes called 'the first fuel.'

ENERGY SAVING
are all measures taken to reduce the amount of energy consumed.

So, most of the time, there is no need to invent anything to save energy. We simply need to change our habits, so that we stop wasting it.

Electricity for lighting accounts for 15-20% of global power consumption. In the EU, lighting represents around 10% of electricity consumption in residential buildings and is the third consumer after electricity for heating and cold appliances. In office buildings, lighting can use even more energy – 30–40%. But it is possible to reduce the energy used for lighting in both commercial and residential buildings without making rooms darker, while significantly cutting electricity bills by choosing appropriate light bulbs based on light emitting diodes (Fig. 3.2.1).

For example, we all brush our teeth in the morning. Do we need to leave the tap running while we do? No, we only need the tap on when we rinse our mouth. But watch yourself and your family: do they all clean their teeth with the tap off? A lot of energy is used to make water come out of our taps, from operations at the water treatment plant to the pumping system, not to mention the water itself.

When you turn off the TV (and some other electronic devices), you leave it on standby. What a lot of people don't know is that the TV goes on using energy when it is on standby, though not so much as when it is working, and that pushes up the family's electricity bill by a few cents every month. It may not seem worth bothering about, but think how much energy is being wasted, if you count in terms of a whole neighbourhood, a whole city, or a whole country! So, in countries where energy saving is taken seriously, people are advised not to leave appliances on standby, but to switch them off.

Charging a mobile phone emits about 0.3 kg of CO_2 a year. If a mobile phone charger is plugged in all the time (without being used), 2.4 kg of CO_2 are emitted.

CO_2 emissions from the use of mobile phones

- Two minutes' use per day produces 47 kg of CO_2 per year
- One hour's use per day produces 1,250 kg per year
- One minute's use produces about 57 g
- One text message produces 0.014 g
- One Google search produces 0.2 g (total annual emissions from the use of Google are 1.3 million tonnes)

The demand for digital services is growing rapidly. The IEA estimated that since 2010, the number of internet users worldwide has more than doubled, while global internet traffic has expanded 25 times. Rapid improvements in energy efficiency have, however, helped moderate growth in energy demand from data centres and data transmission networks, each of which accounts for 1–1.5% of global electricity use. Overall, the IT industry is responsible for about 2–2.8% of global carbon dioxide emissions, with some scientists putting the figure at around 3.8%, including emissions from the use of personal computers.

You may have heard of 'green hosting', a kind of internet hosting service that uses green technologies to reduce negative impacts on the climate and the environment. Green hosting works by compensating for the carbon dioxide emissions caused by its hosting service. It does this by using renewable energy sources (solar, wind, water, geothermal), planting trees and other plants, and through other actions that save energy. Some experts point to cloud technologies as a promising form of green hosting. Cloud technologies that became widespread enable much more efficient use of computing power, mainly by reducing power consumption.

Human invention makes new progress every day. But only a small part of it is used. Before new technology can replace an old one, people must change their habits.

Cloud technologies

It is not only the real world that is changing, but also the virtual world. Internet users have recently been given a new tool, called ‘cloud computing’, which is already used by Facebook, Twitter, and the ‘engines’ that drive services such as Google Docs, Gmail, and the like.

Most websites and server applications run on specific computers or servers. The cloud is a network of computers, constituting a system that lets people use certain applications or store data. You could call it a global, virtual computer where applications run independently of each individual computer with its specific configuration.

As broadband Internet develops, it becomes less and less important to have an application installed on your computer. Because all ‘clouds’ are configured to work together, the total power of these computers is available to the applications as if the application was running on just one individual computer. An increasing share of today’s software is based on web technologies, and ‘clouds’ are just lifting the advantages of web applications to a new level.

Changing habits means first finding the time to get acquainted with the invention.

Second, you need to spend money and effort to replace the old machine with a new one and teach people how to use it. This effort and money will pay off, but not straightaway, and not everyone wants to go to this trouble for future gain.

Third, people who earn money by selling the old technology do not want to lose their business, particularly if it brought in more money than the new technology. They might even do whatever they can to obstruct the invention, preventing it being widely used, persuading people that it is harmful, or even threatening the inventor.

A summary of all energy-efficient technologies would require a thick volume. Whatever you do in the future, it will be important to have a good knowledge of the equipment you use, and to support efforts to make it better. And you should remember that the way forward is not always by making machines more efficient – a lot also depends on how people’s work is organized.

Energy efficiency and energy saving are very important. For families they mean savings on gas and electricity bills. For electricity companies, they mean reduction of fuel costs and supplying consumers with cheaper electricity. For the country, they mean spending less on resources, and making industry more productive and competitive. For the climate, they mean a reduction of greenhouse gas emissions into the atmosphere.

Reducing electricity consumption in different countries will lead to different amounts of saved emissions as it depends on the mix of fuels used for electricity generation. The ratio of CO_2 emissions per kW hour produced or saved is known as the grid emission factor. Countries with a hydro-based power system, such as Bhutan, have a zero-grid emission factor. UNFCCC provides a harmonized set of grid emission factors for more than 200 countries (see https://unfccc.int/documents/198197).

For example, each person in Russia consumes about two kWh each day on average. An economical citizen manages with one kWh, while a more wasteful energy user might be consuming three kWh per day. Fig. 3.2.2. shows how the average Russian in an apartment uses energy for various purposes over a year. On average, the generation of one kWh of power results in 800g of CO_2 emissions. Emissions from power generation in the European part of Russia are twice lower, because a large part of energy needs in that part of the country are met by power plants using natural gas, hydroelectric and nuclear-powered generation, while coal is hardly ever used. CO_2 emissions from natural gas combustion are much less than from coal combustion, and newer combined heat and power plants emit less CO_2 than older plants.

In Russia's northern and far eastern regions, where coal is much used for power generation and fuel must be carried over large distances, reducing electricity use by one kWh yields a reduction of emissions of about three kilogrammes of CO_2. So, the annual CO_2 savings of three people who change from being 'average' to being 'economical' consumers would be three tonnes.

Figure 3.2.2 **Potential energy savings in residential buildings**

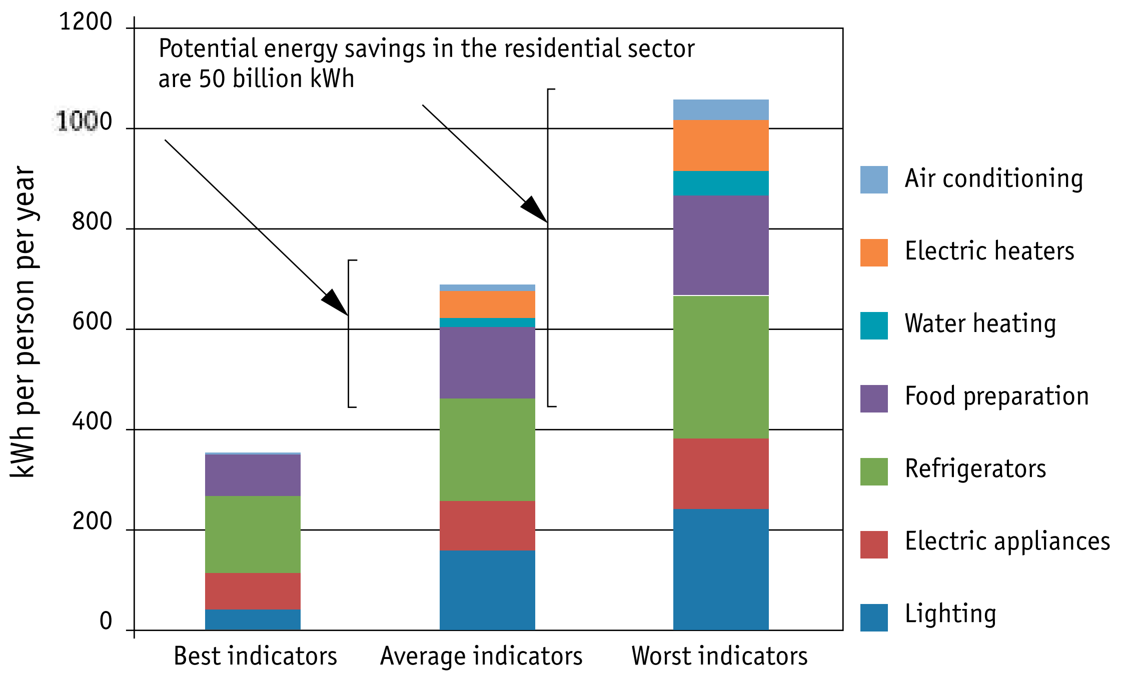


Figure 3.2.3

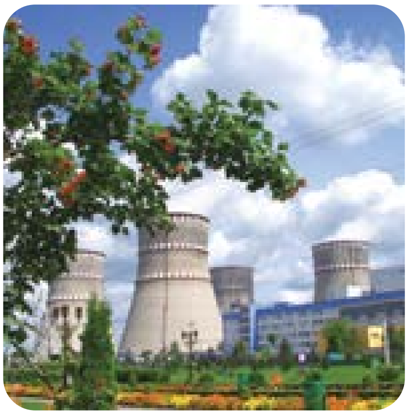
Coal-fired thermal power plant

Figure 3.2.4

Natural gas-fired thermal power plant

Figure 3.2.5

Nuclear power plant



3.2.1 Environmentally friendly transport

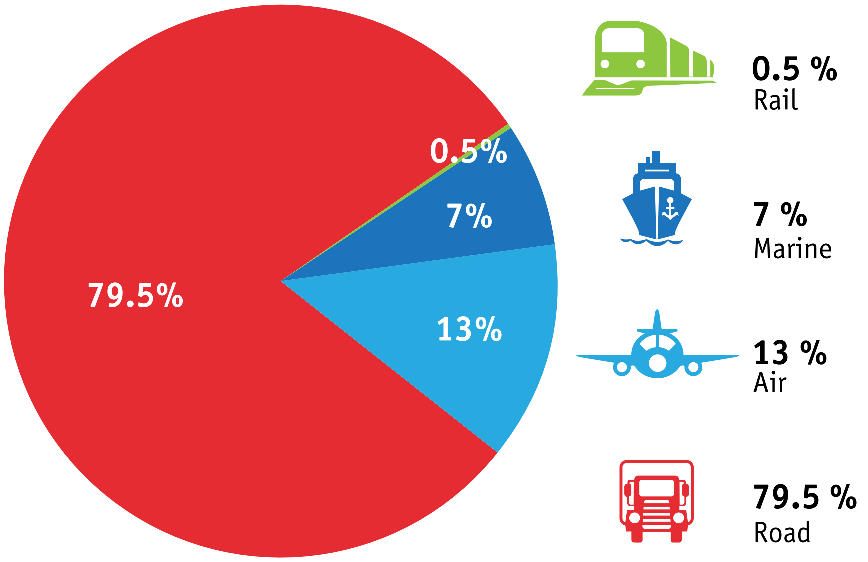
From cars to aircraft, transport uses as much fossil fuels as electricity-generating plants. Of course, the fuel needs of a single car are negligible in comparison with the enormous needs of a power plant. But the number of cars is many times greater than the number of power plants. In total, transport accounts for about 14% of global greenhouse gas emissions.

Most cars still run on petrol. Burning one litre of petrol produces approximately 2.3 kg of CO_2. For example, the average Canadian vehicle, which burns 2,000 litres of petrol every year, releases about 4,600 kg of CO_2 into the atmosphere. The internal combustion engine, which powers motor vehicles, releases exhaust gases into the atmosphere, containing nitrogen, water vapour, and CO_2 (between 1–12% of the emissions volume), as well as toxic and even carcinogenic compounds (soot and benzopyrene).

Overall, CO_2 emissions per tonne of gasoline, from the extraction of crude oil from an oil well to combustion of the refined gasoline in an engine, total 3,769 kg.

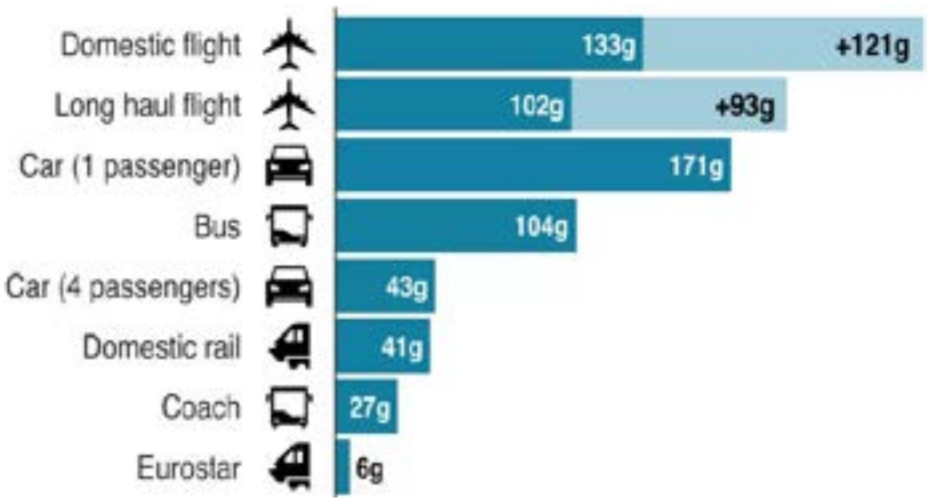
The impact of transport on climate change is huge, as most forms of transport use fossil fuels, the combustion of which releases CO_2 into the atmosphere. However, different types of transport have different impacts. Railways are the most environmentally friendly, while air flights are considered the most carbon intensive. Overall, cars are responsible for more than 80% of greenhouse gas emissions from transport (Fig. 3.2.6).

Figure 3.2.6 Breakdown of GHG emissions by different modes of transport



The UK estimated the emissions per passenger per kilometre travelled in different modes of transport. It shows that taking a flight leads to more than 20 times more emissions than taking the train, Eurostar (Fig. 3.2.7).

Figure 3.2.7 UK estimates of GHG emissions (gCO_2e) from different modes of transport per passenger per km travelled



What can be done to reduce the impact of transport on the climate?

An obvious and highly effective method is to connect with people far away by telephone or video/audio communication instead of travelling to them. The most popular ways are various applications, such as Skype, Zoom, Viber, Telegram, and WhatsApp, which let you communicate with friends anywhere in the world where there is Internet.

The best way to reduce climate impacts from transport is using public transport. If you and your parents can choose how you travel, choose a train. Trains are a more environmentally friendly way to travel long distances than airplanes.

Railway transport technologies have made significant advances in the last decade. Locomotives and rolling stock are built from materials that are less heavy and bulky, and engines have become more efficient.

The number of high-speed trains and networks are growing worldwide, further improving the most energy-efficient mode of transport. The high-speed rail (HSR) network in China is the world's longest and most extensively used – with a total length of 42,000 kilometres by the end of 2022. HSR is also an increasingly popular and efficient means of transport in Europe. Several countries have built extensive high-speed networks, e.g., Germany, France, the Netherlands, Spain, Italy and the UK, and there are now several cross-border high-speed rail links. Railway operators frequently run international services, and tracks are continuously being built and upgraded to international standards on the emerging European high-speed rail network.

Japan's high-speed rail, called **Shinkansen** (Fig. 3.2.8), has recently increased its speed, and cut back its energy consumption by 40%. By reducing the bullet train's weight and redesigning the shape and length of the nose to be more aerodynamic, the trains are now far more efficient and their use results in less emissions from transportation.

Figure 3.2.8

Energy-efficient 'Shinkansen' high-speed train in Japan

Figure 3.2.9

The back of this train ticket in Italy informs passengers of their contribution to combating climate change by choosing train travel

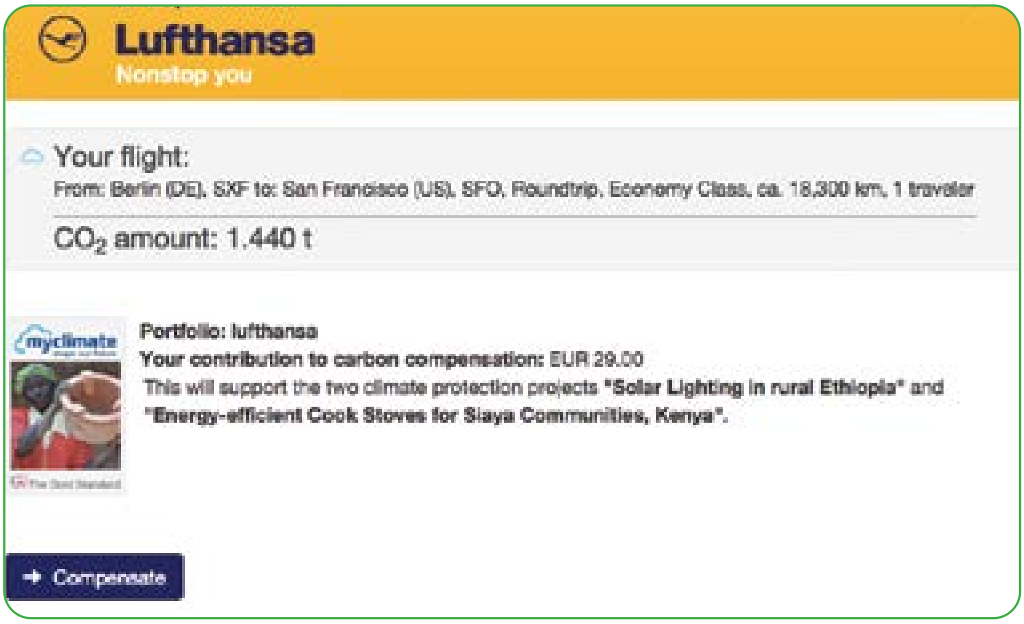
Many railway companies take the trouble to remind their passengers of the fact that rail travel is environmentally friendly (Fig. 3.2.9).

If you fly somewhere by plane, then choose airlines that use up-to-date aircraft: modern aircraft do less damage to the environment than older ones.

Speed is no longer the only, or even the main consideration in designing new models of aircraft. Designers today use a more holistic approach that takes account of the aircraft's fuel efficiency as well as its carbon footprint during manufacture. Developers are looking again at turboprop aircraft, which seemed a thing of the past 20 years ago, as jet aircraft are faster. With improved design, turboprop aircraft could offer good air transport solutions.

Several airlines nowadays offer services to compensate CO_2 emissions by their aircraft; there are Internet services that calculate CO_2 emissions by all flights and invite passengers to compensate them. For example, a long-distance flight from Berlin to San Francisco by Lufthansa produces 1.4 tonnes of CO_2 emissions per passenger. The suggested contribution for carbon compensation with a round trip in economy class is EUR29, which is used to help finance environmental projects related to climate change (Fig. 3.2.10).

Figure 3.2.10 **Calculation of CO_2 emissions and appropriate compensation for a Berlin–San Francisco return flight in economy class with Lufthansa**



The International Civil Aviation Organization is working with its members to find the best ways to reduce emissions from the aviation sector. Along with efficiency improvements, one option is the use of Sustainable Aviation Fuel (SAF) – fuel that does not come from fossil fuels. Airlines already use it, usually blended with regular jet fuel. But many doubt whether SAF can be produced cheaply enough, or in large enough quantities, to meet the needs of the airline industry.

This is why there is growing interest in hydrogen as a fuel for aircraft. Hydrogen can store a lot of energy, e.g., from renewable electricity outside the peak hours of consumption and, when used as fuel, does not produce any CO_2.

Reducing carbon emissions from car trips

If your parents are planning to buy a car, tell them about the energy efficiency of different motor vehicles. Suggest that they buy a car that at least meets Euro-4 standards (the Euro standards for vehicles regulate the content of hydrocarbons, nitrogen oxides, carbon monoxide and particulate matter in vehicle exhaust fumes).

The impact of cars on the environment can also be reduced by following 'eco-driving' rules, which reduce the carbon footprint from vehicle transport. Eco-driving does not just make sense for the environment – it is also cost-effective for car owners. Explain that to adults who drive cars!

The efficiency and environmental performance of vehicle engines is crucial. Until recently nearly all motor vehicles ran on fuel oil, diesel, or petrol, but now an increasing number of vehicles are running on gas. Fuel consumption using gas is much the same as with traditional motor fuels, but pollutant emissions from gas are much less.

You have probably also heard of 'hybrid' cars, electric cars and cars that run on bio- fuel. There are even exotic vehicles that can operate on nothing but water and air movement to make them go ('wind-mobiles'), as well as solar-powered electric cars. A solar car racing championship held regularly in Switzerland is the best place to see all the latest solar-powered vehicle technologies in action. They are no longer a rarity: there are now solar filling stations in the USA, Bulgaria, Switzerland, Germany, and other countries.

Figure 3.2.11

Parking for electric vehicles

Eco-driving rules: how to reduce a vehicle's carbon footprint

- Turn off the engine at stops and in stationary traffic jams.
- Look after your car properly: correct adjustment of the wheels reduces fuel consumption by 5-10%, and regular maintenance saves up to 10% of fuel.
- Check tyre pressure regularly: even in urban environments, tyre pressure 25% below the recommended level requires 10% more fuel to make the car move.
- Use climate control and air conditioning sparingly. Do not use them if the outside temperature makes them unnecessary. Don't open the car windows if the climate control is operating.
- Brake smoothly to use the car's inertia to best effect, reducing fuel use.
- Carry passengers. This is called 'carpooling'. If you give a lift to three or four people going the same way, you reduce emissions by three to four times.
- Stay in the same lane: weaving from lane to lane increases fuel consumption and therefore CO_2 emissions.
- Start out early, avoid travelling at peak travel times, and plan your route in advance.
- Drive at a moderate and steady speed. Use the brake pedal less and use the car's momentum more, brake and accelerate smoothly, watch the road ahead (don't accelerate if there is a red light in sight). Smooth driving saves fuel.
- Do not carry excess loads on the roof. At speeds of 120 km/h an empty luggage carrier on the roof increases fuel consumption by 5–10%, a ski-carrier adds 10–20%, a bicycle 30%, and carrying a case full of luggage uses 35–40% more fuel.

Figure 3.2.12 An electric car

All leading car manufacturers today are designing cars that are more environmentally friendly compared to the previous models. Fuel consumption and environmental impacts have become as important to buyers as quality, safety, and price. Companies are competing with one another to save energy and reduce negative impacts on the environment.

Even though electric vehicles (EVs) have been in use since the beginning of the car industry in late 1900s and early 2000s, it was not until Tesla's arrival in 2003 that the battery-electric revolution began in earnest. This provided a viable alternative in the efforts to decarbonize road transport and propelled EVs from 0.2% of new car sales a decade ago to 13% in 2022. Sales tripled between 2018 and 2022 and are expected to grow by around 30% annually in the next decade, making up half of all car sales by 2035. By 2025, EV sales are expected to reach almost 40% in Europe and China.

Greenhouse gas emissions in a city can be reduced by encouraging people to use public transport instead of cars. But that is possible only if public transport is fast and convenient, serves all parts of the city, links the centre with the suburbs, and is a more reliable and cheaper alternative to private cars. The use of gas, hybrid and electric engines in public transport can greatly reduce greenhouse gas emissions and improve air quality in cities.

Carpool: sharing journeys by car

Carpooling means carrying other people (including strangers) in your car, usually on regular (daily) journeys.

It is a good way of reducing pressure on the transport system in cities.

Carpooling dates from the 1940s when the Government of the USA was trying to save fuel for World War II needs by requiring car owners to carry passengers on any journey. The policy was successful in reducing fuel use, but its impact was limited because most car owners at the time were well-off and unwilling to share their cars with strangers.

In the 1970s, the city of Los Angeles introduced separate lanes on roads for use by car poolers. Nowadays they exist all over North America and in Europe as well (they are marked by road signs and a white rhombus on the road surface). Carpooling reduces the number of cars on the roads, reduces the demand for parking places and cuts down greenhouse gas emissions. The gains for passengers are evident: they spend less on fuel, vehicle repairs and parking.

Figure 3.2.13

Special carpool lanes on roads in the USA

Bicycles: the most environmentally friendly transport

Bicycles are the most environmentally friendly and healthy form of transport. Scientists have calculated that a person who travels to school or work every day by bicycle instead of using a car saves a tonne of greenhouse gas emissions every year.

Bicycles are the preferred means of transport in the Netherlands, Denmark, Norway, Sweden, and Germany. In Copenhagen, one in three people commute to work by bicycle. In Amsterdam, 40% of people use a bicycle every day, and the total length of bicycle lanes in the city is 400 km.

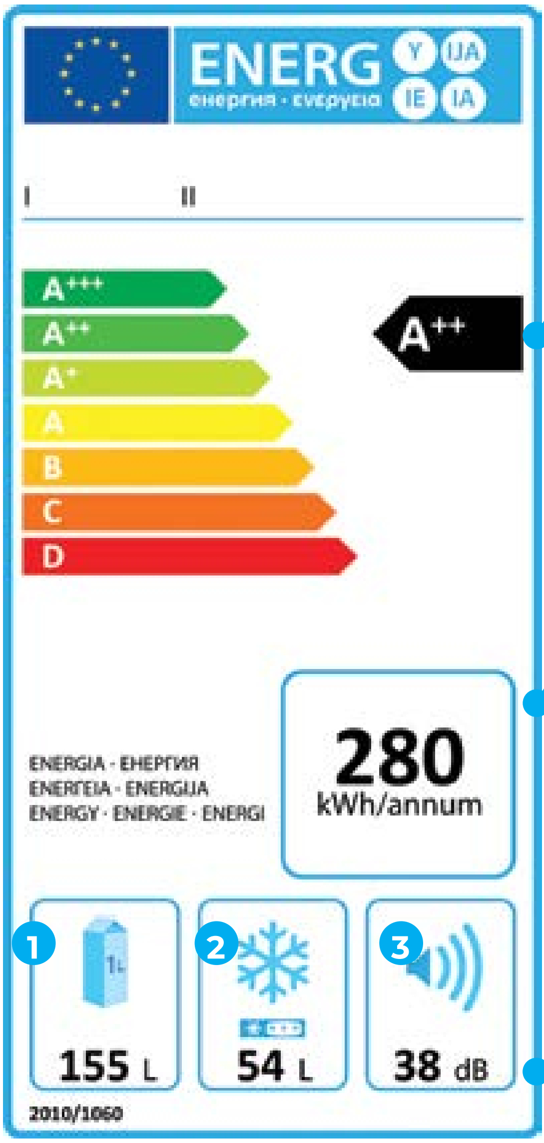
3.2.2 Household appliances and electrical devices

Many countries have a special system for standards and labelling of household appliances by their energy efficiency.

The European energy label is obligatory for certain electrical household appliances and light bulbs sold in the EU since 1995 (Fig. 3.2.14).

The label is intended to let consumers compare the energy efficiency and some other features of similar products made by one or several manufacturers. The most energy-efficient products are those in energy efficiency classes ‘A’ or ‘A +’, ‘A++’ and ‘A+++’.

Figure 3.2.14 New energy efficiency labelling for refrigerators sold in the European Union



Energy efficiency class

Annual energy consumption by the device in kWh, a standardized measurement assuming 24-hour operation during 365 days

1. Total useful space (litres) for storing fresh produce
2. Total useful space (litres) for storing frozen produce
3. Noise level (decibels)

Energy Star is a programme for energy efficiency certification developed by the US Environmental Protection Agency in 1992 for computer monitors with low power consumption. Monitors that meet certain energy efficiency criteria have the right to bear the Energy Star label and as many as 98% of all computers today do so. Use of the label has been extended to 65 other types of goods, from appliances to buildings, which are now assessed using the Energy Star system (more than 1.4 million buildings and over 20,000 factories in the USA today are Energy Star-certified).

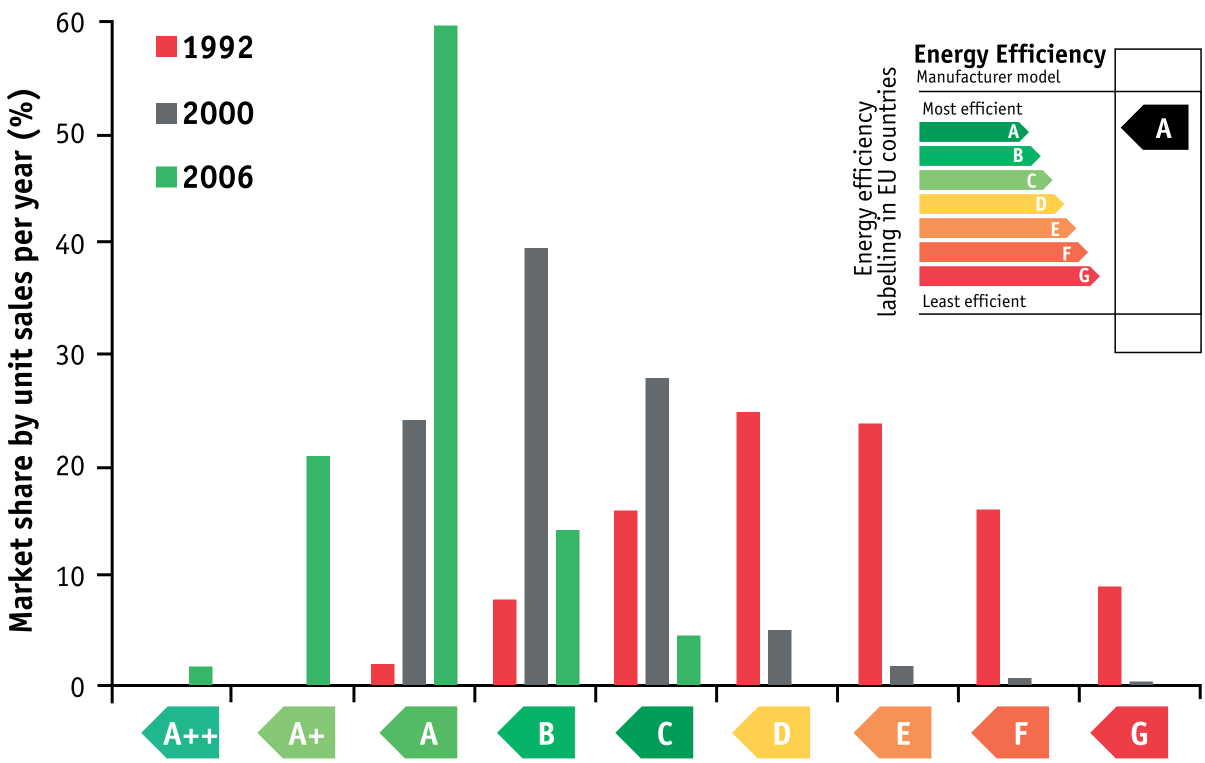
Figure 3.2.15 The US Energy Star label

Energy Star is one of the key programmes that the USA reported in its 2022 Climate Ambition Report (eighth national communication under the UNFCCC), which outlines advances in its climate policies under the Paris Agreement. It stated that since 1992, Energy Star and its partners have helped American families and businesses save five trillion kWh of electricity, save more than $500 billion in energy costs, and achieve four billion tons of CO_2-equivalent greenhouse gas reductions. In 2020 alone, savings resulted in emissions reductions of more than 400 million tons of CO_2-equivalent greenhouse gases, roughly equivalent to more than 5% of total greenhouse gas emissions in the country.

More and more countries are recognizing the benefits of energy efficiency standards and labelling programmes to effectively reduce energy bills, drive product innovation, create jobs and reduce the cost of CO_2 emissions. Such programmes for appliances and equipment now operate in more than 120 countries around the world and are the cornerstone of most national energy efficiency and climate change mitigation programmes. Such programmes have been operating the longest in the USA and the EU where, by IEA estimates, they have delivered annual reductions of around 15% of total current electricity consumption.

An energy efficiency label doesn't just tell the consumer about the energy efficiency of a device, but also about what it can do. After all, the main task of a washing machine is to wash and rinse clothes, and its ability to save energy is secondary, though important. In recent years consumers have been increasingly keen to choose devices and technologies that not only do their job well, but also use less energy and resources and thereby save the consumer money (Fig. 3.2.16).

Figure 3.2.16 **Impact of energy-efficiency labelling and minimum energy-efficiency standards on the EU market for refrigerators and freezers**



The impact of an electrical appliance on human health is at least as important as its energy consumption. We must remember that health hazards from new inventions might only be detected after some time. The discovery of such problems doesn't mean that new technology cannot be used: a design improvement might be enough to set the problem right. But we must approach new technologies carefully: without prejudice, but with caution.

For example, a new device that has recently gained popularity is the induction cooker, which is very easy to use and very economical in its consumption of energy, since it only heats the bottom of the pan and not the whole space around it. However, the impact of eddy-current magnetic fields on human beings has not yet been properly studied.

3.2.3 Green construction: passive and active buildings

People have different lifestyles – not every family has a car or a complete set of home appliances. But everyone needs a roof over their heads. So, the idea of building an energy-efficient home has always been of interest. Peasant huts in Europe and the tents of nomadic peoples were built using special know-how, even if was not always given scientific explanation. A masonry heater, which was traditionally used in houses in Eastern, Northern Europe and North Asia, was a fine example of energy efficiency (Fig. 3.2.17). The thick walls retained heat and the chimney with its different sections extracted heat from the smoke before it left the building.

Figure 3.2.17

The traditional masonry heater, a fine example of energy efficiency

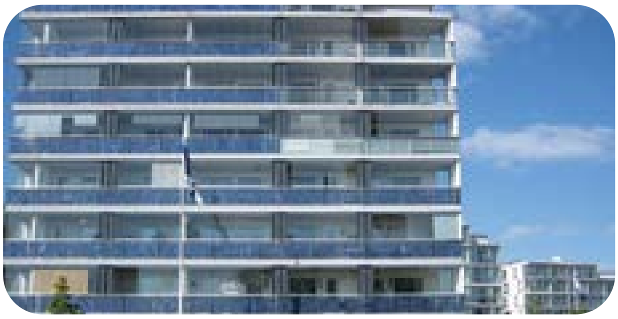
More recently, in 1974, a sharp jump in oil prices made it much more expensive to provide buildings with energy and heat, inspiring architects and engineers to take a new look at building design. Houses started using new environmentally friendly technologies and alternative energy sources. Special demonstration buildings were built to show what could be achieved, and governments in some countries actively encouraged such projects.

The World Green Building Council was formally established in 2002 to facilitate the global transformation of the building industry towards sustainability. The council brings together more than 30,000 property and construction companies from 80 countries. Its members are constantly seeking new ways to reduce the resources needed at all stages of the life of a building: during its construction and use, when it is repaired and when it is finally dismantled. Green construction strives to reduce greenhouse gas emissions and water pollution, minimize waste, and protect nearby natural habitats. Such buildings are somewhat more expensive to build, but the extra investment pays for itself in five to 10 years.

Energy-saving buildings are called 'passive' or 'active', depending on their efficiency. A passive building may not need any heating or may consume just a tenth of the energy that an ordinary building does. But an active building not only requires very little energy, but produces energy – perhaps even surplus energy to feed into the central electricity grid. You may have heard of the expression, 'smart building.' What this means is that the building in question automatically analyses its energy consumption and carries out automatic control of various energy-using systems in the building.

Figure 3.2.18

Several low-energy buildings have been constructed in the Viikki district of Helsinki, the capital of Finland. Panels that store energy from the sun have been built into the facades



Passive buildings

One of the main objectives of a passive building in northern countries with colder climate is to reduce heat loss. Ideally, a passive house is heated solely by the heat given off by its occupants and by the appliances used there. If additional heating is needed, preference is given to renewable energy sources.

Bricks made from recycled materials are often used for the construction of such a house.

It is not only the building's walls that require thermal insulation, but also its floors, ceilings, attic, basement, and even the foundations. It is important to ensure that the design does not permit so-called 'cold bridges': apparently minor details and connecting points in the construction that can drain heat from a generally well-insulated building. These techniques can reduce heat loss from a building by almost 20 times!

Environmental certificates for buildings

Environmental certification standards for buildings have become widespread in recent years. The best-known and most used systems in the world are BREEAM (UK), LEED (USA) and DGNB (Germany).

The BREEAM environmental certification system, developed in 1990, has certified more than 200,000 buildings worldwide. The criteria for certification are the quality of building management, the health and well-being of its residents, energy efficiency, transport, water, materials, waste, use of the land plot where the building stands, and the pollution that it generates.

The LEED environmental certification system was devised in 1998 with the following criteria: sustainable site development, water consumption efficiency, energy efficiency, air protection, materials and resources, internal environment quality, and innovations. Buildings can qualify for four levels of certification: Certified, Silver, Gold, and Platinum, depending on the criteria they meet.

The DGNB system of environmental certification, introduced in 2009, uses an integrated planning concept to assess ecology, economy, sociocultural and functional aspects, as well as a building's location.

The first LEED Platinum building in the Middle East

Originally constructed in 1995, the head office of the Dubai Chamber of Commerce and Industry is a shining example of how an existing high-rise building that consumes a lot of energy and water can be transformed into a healthy, green skyscraper.

Between 1998 and 2013, energy and water consumption per person in the building was reduced by 63% and 92% respectively, saving almost $5.8 million through low and no-cost initiatives. After the renovation, the building earned the Energy Star label and the LEED Platinum certification.

In a passive house, careful design of windows is highly important: double-glazed window units are hermetically sealed, panes of glass are covered with a special film that admits light and warmth from outside but reflects them back when they attempt to pass outwards. The biggest windows face the direction from which sunlight mainly comes.

The system of heating, air conditioning and ventilation uses resources more efficiently than in conventional buildings. For example, in winter, air leaving the building is ducted alongside air that is entering it, in a special heat exchanger, so that the warm air transfers its heat to the cold air. In the summer, hot air from outdoors is ducted underground where is cooled. Similar principles are used to take heat from used water.

Of course, even such carefully designed buildings sometimes need additional heating or cooling, but much less energy is required to provide it. Such advanced design has inherent problems: the air duct must be carefully monitored as accumulations of dust, use of artificial materials, or a conduction fault can affect air quality. It is also important to ensure that furniture in such buildings does not release any harmful substances into the air.

Solar cells and (if appropriate) small wind turbines are installed on the roof. The most economical lighting system (LED) is used, and it may even be possible to light the building by means of sunlight alone.

Added together, these and various other devices produce savings.

There is rising construction of passive energy-saving houses. Estimates suggest that in 2022, there were more than 120,000 passive house buildings around the world, including office buildings, shops, schools, and kindergartens (mostly in Europe). Begun as a concept implemented only in Germany or regions with similar climate conditions, it has now been adopted worldwide, with clearly defined applicability criteria for different climates.

Under cold climate conditions, the design process typically is focused on minimizing heat losses and optimizing solar gains. In milder climates, moderate insulation, including windows with improved performance, is sufficient, though building performance during summer requires more careful consideration. For hotter climates, the insulation requirements increase, and solar loads through windows, walls and roofs must be limited. In hot and humid climates, humidity loads need to be minimized. Examples of passive houses in climates as varied as Canada, the USA, Germany, China, Greece, Spain, Taiwan, Mexico, and the United Arab Emirates illustrate the range of possible solutions.

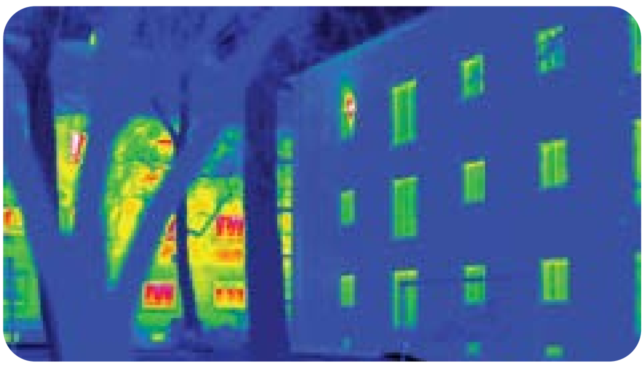


Figure 3.2.19

An infrared picture shows how effective the heat insulation of a passive house (right) can be in comparison with a conventional house (left)

Energy-efficient residence of the British prime minister

10–12 Downing Street is famous in London as the residence of the British prime minister.

The 300-year-old building has been undergoing a phased modernization and refurbishment programme to become more energy efficient. Environmentally friendly initiatives introduced have included the following:

- controlled lighting using motion detection and low energy lamps
- waste heat recovery from IT equipment to heat water
- thermal insulation
- low water-use fittings
- rain water harvesting for garden irrigation
- building management system with utility monitoring
- timber sourced from legal and sustainable sources
- more than 90% of construction waste recycled.

These renovations have earned 10 Downing Street a 'Very Good' BREEAM rating.

Climate-friendly school in the United States

The Sidwell Friends School in Bethesda, Maryland, and Washington, D.C has succeeded in reducing its energy consumption by 60% and water consumption by 90%.

Vegetables grown by students on the building's roof using rainwater are served in school lunches. Water that is good enough to drink is only used for drinking.

The school is in a part of the USA that is often very hot, so the school building has its own system of cooling towers, which lower the temperature of warm air from outside before it reaches the interior. Air conditioning is only needed in the classrooms on exceptionally hot days.

Optical systems have been installed that regulate the flow of sunlight, channelling it to darker rooms in the building. Windows on the sunny side of the building have special shades to protect the interior from overheating.

Active buildings

The active building incorporates some of the same concepts of the passive, such as insulation, or optimal solar exposure of the windows. But it also promotes renewable energy systems, such as solar water heaters and/or geothermal heat pumps. The world's first active energy-saving building was built in Denmark (which has an Internet portal for active buildings: www.activehouse.info). A draft EU directive from 2023 that regulates energy performance of buildings calls for all new buildings to be emissions-neutral as of 2030, with the aim of having emissions-neutral building stock by 2050. That means that such buildings need to have features of both passive and active buildings.

Active house in Denmark

'Home for Life' in Denmark is an example of CO_2-neutral active house. It produces nine kWh/m^2 energy per year – more than it consumes. A solar heat pump and 7 m^2 solar collectors generate energy for heating and hot water, while 50 m^2 solar cells generate electricity. Floor-to-ceiling windows cover 40% of the facade – twice the area of a traditional house – and help to illuminate and heat the rooms from the sunlight. All rooms are equipped with sensors that register heat, CO_2 levels and humidity, and an intelligent control system makes sure that the house adjusts to the family's need for a healthy, comfortable indoor climate. Automatic window opening mechanisms let in fresh air, while sensors turn off lights when you leave the room.

Optical systems have been installed that regulate the flow of sunlight, channelling it to darker rooms in the building. Windows on the sunny side of the building have special shades to protect the interior from overheating.

3.2.4 Green cities

There are many examples of the use of energy-efficient technologies in buildings around the world and, more recently, people have started implementing larger projects at the city level.
One ambitious objective is the creation of environmentally friendly cities. Imagine a whole city designed in harmony with the environment, whose inhabitants only consume resources they really need, and do everything they can to protect the natural world. All the energy in the city is produced using renewable energy sources. Waste is recycled and reused. People in such a city fully understand the importance of caring for the planet and for one another, and therefore live in peace and harmony.

More and more of the world's population wants these dreams to come true, so the design of green cities is being given ever greater thought. Such cities have clean air and clean water. Waste and wastewater are recycled and re-used. Rooftops are used for gardens or solar panels and have tanks to collect rainwater. Active- and passive-house technologies are used in the construction of residential, public, and commercial buildings.

It is impossible to make all cities environmentally friendly straight away, but these dreams are becoming a reality little by little all over the world.

SamsØ, Denmark

The inhabitants of the Danish Island of SamsØ are self-sufficient in energy from renewable sources and even sell some of the energy they generate. This result took 10 years and investments of $80 million, but the money has already been repaid from electricity sales. The islanders built 10 wind turbines on land and 11 at sea, which produce 28 gigawatt-hours of energy each year in total.

Heating on the island comes from renewable biomass: straw, sawdust and other plant waste is burned in boiler plants.

The island has an area of 114 km^2, stretching about 50 km from north to south and with a breadth of more than 20 km at its widest part. There are 4,000 inhabitants, most of them engaged in agriculture. The largest settlement, Tranebjerg, has a population of only 800 people, but proudly calls itself a town.

Masdar City, United Arab Emirates

Masdar City ('masdar' is Arabic for 'source') is a new eco-city in the United Arab Emirates (UAE). It is in the Emirate of Abu Dhabi, 17 km from the capital and close to the international airport.

The Government of Abu Dhabi put forth the idea of building a green city in the desert and launched it in 2006 with a budget of $22 billion. The new city when completed is expected to have a population of 45,000-50,000 and about 60,000 more will commute to work every day. Most companies and industrial plants in Masdar will specialize in the development and production of environmentally friendly technologies and products. Vehicular transport is not permitted in Masdar City: residents will move around on foot, by bicycle, by public transport or using new, computer-controlled taxis. A high wall is being built around the city to protect it from the hot desert wind, and its streets will have abundant shade.

Masdar City is designed to be a hub for clean technology companies. The Masdar Institute of Science and Technology has been operating in the city since September 2010. The city also hosts the headquarters of the International Renewable Energy Agency.

The experience of Masdar City illustrates how living sustainably has its difficulties and challenges. From electric scooters, autonomous green vehicles to future tech, the city not only showcases its solutions to make living sustainably easier, but also smart choices that lead to a better world.

Treasure Island, San Francisco, California, USA

Treasure Island is an artificial island created in California in 1939 as the site of an airport. These plans were changed with the outbreak of World War II, and the island was instead used as a military base, which remained there until 1996. Now Treasure Island is being used as a testing site for a highly sustainable urban community that will draw more than 50% of its energy from renewable sources such as rooftop solar panels and windmills. Citizens will be able to buy fruits and vegetables from an organic farm on the island, all cars will be eco-friendly, and buildings will be energy efficient. Buildings on the island are certified under the LEED energy efficiency standard.

Sherford, England

Sherford in England is a new eco-friendly town

to be designed in traditional English style. The project was launched in 2015 and has the support of King Charles III. All its buildings will be made from environmentally friendly materials, produced in England, no more than 80 km from the construction site. This will reduce the carbon footprint from construction work by avoiding transport of materials over long distances, emitting greenhouse gases from the combustion of vehicle fuels.

Sherford will follow traditional urbanization to make the town carbon-neutral by constructing energy-efficient buildings and laying out the town so that people live close to a main street. This makes it easy to travel on foot and on bicycles easily and quickly, so that residents will have no need for motor transport in some parts of the town. Space on rooftops will also be used for solar panels and for growing plants. About a fourth of the houses will be 'low cost' due to the high discrepancy between house prices and wages in the area.

The City of Vancouver, Canada

The City of Vancouver in Canada is known as one of the most environmentally friendly cities in North America. The city has adopted an ambitious plan to become the greenest city in the world. Developed by city authorities in collaboration with local people, the plan includes such measures as a shift toward 100% renewable energy power by 2050, a zero-waste programme, expanding walking and cycling networks, developing green buildings and public transportation, expanding green areas, as well as increasing farmers markets and community gardens. The city administration has established a two million Canadian dollar Greenest City Fund in collaboration with The Vancouver Foundation to support community-led projects to green the city. When all these measures are fully implemented, the City of Vancouver aims to reduce community based GHG emissions by 80% below 2007 levels by 2050.

QUESTIONS

1. What time of day is the peak of electricity consumption?

2. Do you think that hot countries need to worry about saving energy?

3. How does a city need to be designed if it wants to be a 'green' city?

4. Where do you think your home loses most of its heat in winter and coolness in summer? How could this be avoided?

5. What is the difference between 'passive', 'active' and 'smart' buildings?

TASKS

1

Ask your parents to let you see the electricity bills for your house or apartment for the past year, write down how many kilowatt-hours were used, and build a graph.

Find out how much electricity is used by your main household appliances: refrigerator, washing machine, vacuum cleaner, TV, lights, etc. You can do this by: 1) finding the power of each device in the technical information that came with it; 2) calculating roughly how many hours a day the device operates; 3) multiplying that time by the number of days in a month; 4) multiplying the power of the device by the time it operates.

Draw a second graph on the same piece of paper, summarizing total power consumption by your domestic appliances. Analyse the graph, see which appliances use more power and think why that is. Together with your parents, think what you can do to reduce energy consumption.

2

Draw a large map of an environmentally friendly city where you would want to live. What will it be called? Where in the world will it be?

How will its streets be laid out? Will motor vehicles be allowed to drive around the city? What companies and industries will it have (if any)?

Where will the residential district be located and why will it be located there? Draw what your own home in this city will look like. What sort of a building will it be and what will it be made of? Write an essay about this.

3

Find out about the environmental initiatives in various cities around the world from the ‘Sustainable Cities’ page in Wikipedia and other online resources. Find detailed information about the status of any ecological city and give a report about this city in school.

3.3 Carbon footprint and how I can help the planet by reducing my footprint

3.3.1 Carbon footprint

Any human activity that uses energy has an impact on the climate.

We drive cars, travel to other cities and countries by aircraft, use the TV and computer, cook food, and put food in the refrigerator. We cut down forests to make paper and furniture. We switch on the heating in winter and air-conditioning in summer, and we use electric lights in our homes all year-round. By doing all these things, we each leave our own personal carbon footprint in the world.

The **carbon footprint** of a city or country is the total amount of all greenhouse gases that all individuals and organizations within the city or country produce by the things they do, events they take part in and products they consume directly or indirectly.

Figure 3.3.1 Examples of greenhouse gas emission sources

Environmentally responsible behaviour means thinking about how you can reduce greenhouse gas emissions and your own carbon footprint.

It is common practice to translate all GHG emissions into CO_2 equivalent for ease of understanding and calculation. This amount is shown as units of CO_2 equivalent.

Carbon footprint

- E-mail-message – 4 g
- The same message with a large attachment – 50 g
- A plastic bag from a shop – 10 g
- A 0.5-litre bottle of water (local production) – 110 g
- An average bottle – 160 g
- An ice cream – 500 g
- A pair of jeans – 6 kg

Direct emissions are the amounts of carbon dioxide generated from the use of fossil fuels – for example, the amount of greenhouse gases emitted during operation of a factory or a vehicle engine.

Indirect emissions are the amounts of CO_2 released into the atmosphere when energy is produced and transported to make the products you buy and the services you need. This is the part of the carbon footprint we can influence: we can think twice and not buy disposable cups, think twice and walk instead of going by car, think twice and not use the washing machine at half load.

Calculating the size of our carbon footprint (especially indirect emissions) is difficult, because we must consider many different factors and find a lot of information. In addition, the carbon footprint of a product will always be the same for the producer, but it will be different for different consumers because transport and other costs of delivering the product to the consumer must be considered.

For example, the carbon footprint of an apple from the garden, eaten under the tree where it grew, is 0 g of CO_2. If you buy apples grown in your region in season (i.e., in the summer and early autumn), the carbon footprint of an apple is 10g of CO_2. The carbon footprint of an imported apple (for example, one brought from Italy) will be 150 g of CO_2.

Environmentally responsible firms can offset their carbon footprint by investing in climate projects, by planting trees or obtaining certificates from reputable carbon-offsetting companies.

Products or services with low or zero CO_2 emissions, or whose emissions have been offset, can receive low-carbon or carbon-neutral labeling to demonstrate their climate-friendliness. Such labeling influences the choice of consumers in favor of this particular product or service.

Examples of carbon-neutral labels:

3.3.2 How can I help the planet? Reducing your carbon footprint

Greenhouse gases influence the planet's climate, and emissions of greenhouse gases depend on our habits. Let's see how we can reduce our carbon footprint and help the planet.

Indoor air temperature and comfortable temperatures

In countries with colder climates almost all buildings need heating and heat insulation. Most heating systems in old buildings were built at a time when prices for heat energy were low and energy efficiency was not a priority. In many cities thermal energy is generated by burning gas or coal, which causes greenhouse gas emissions that affect the climate.

Alternative ways of producing heat energy include solar collectors and heat pumps, but these technologies remain expensive and are not easy to apply for an old multistorey apartment building.

The easiest solution is to improve heat insulation. Heat loss depends on two factors: the difference in temperature between indoors and outdoors and the heat-insulating properties of walls, ceilings, windows and floors. Buildings lose a significant part of their heat through the ventilation system. Heat loss can also occur due to latent defects, design errors, poor quality of construction, and due to ageing of the building and of thermal insulation materials. It is possible to see how well walls, ceilings and windows retain heat, and to detect where leakage of heat is occurring by means of thermal imaging, carried out by a special visual recording device that shows the temperature distribution on any surface, such as the wall of a house. The temperature distribution is shown on the display (and recorded in the memory) of the device camera as a colour field, where a certain temperature corresponds to a certain colour. Alongside the image there is always a scale showing the correspondence between colours in the picture and specific temperature ranges.

The greatest heat loss in any prefabricated building occurs at the joints between the panels of the outer wall. The only remedy (short of demolition) is full-scale repair of the facade using the latest heat-retaining plasters. The quality of window installation can be decisive for levels of heat loss, even in new and renovated buildings.

Figure 3.3.2

A five-storey apartment building from the 1960s 'glows' where heat floods out at the joints between prefabricated panels

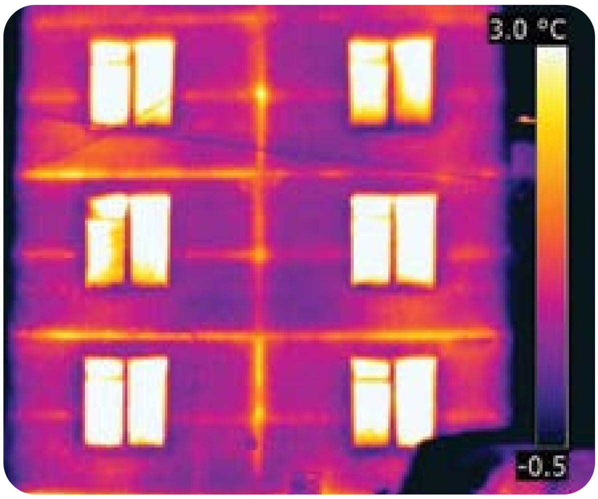


Figure 3.3.3

Heat loss on the corner of this brick building is intense at the junction of balcony glazing and the wall, and also where ceilings meet the walls

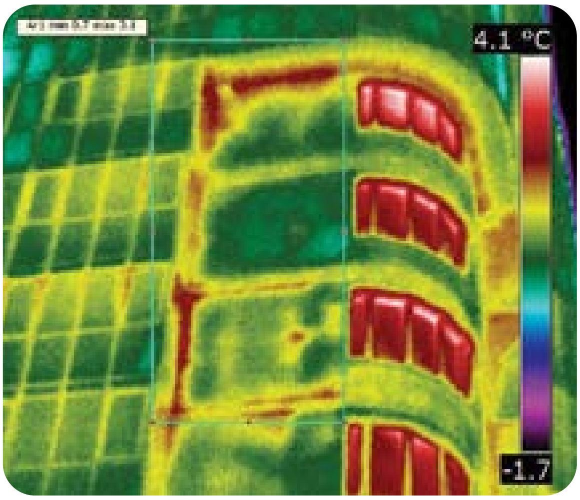
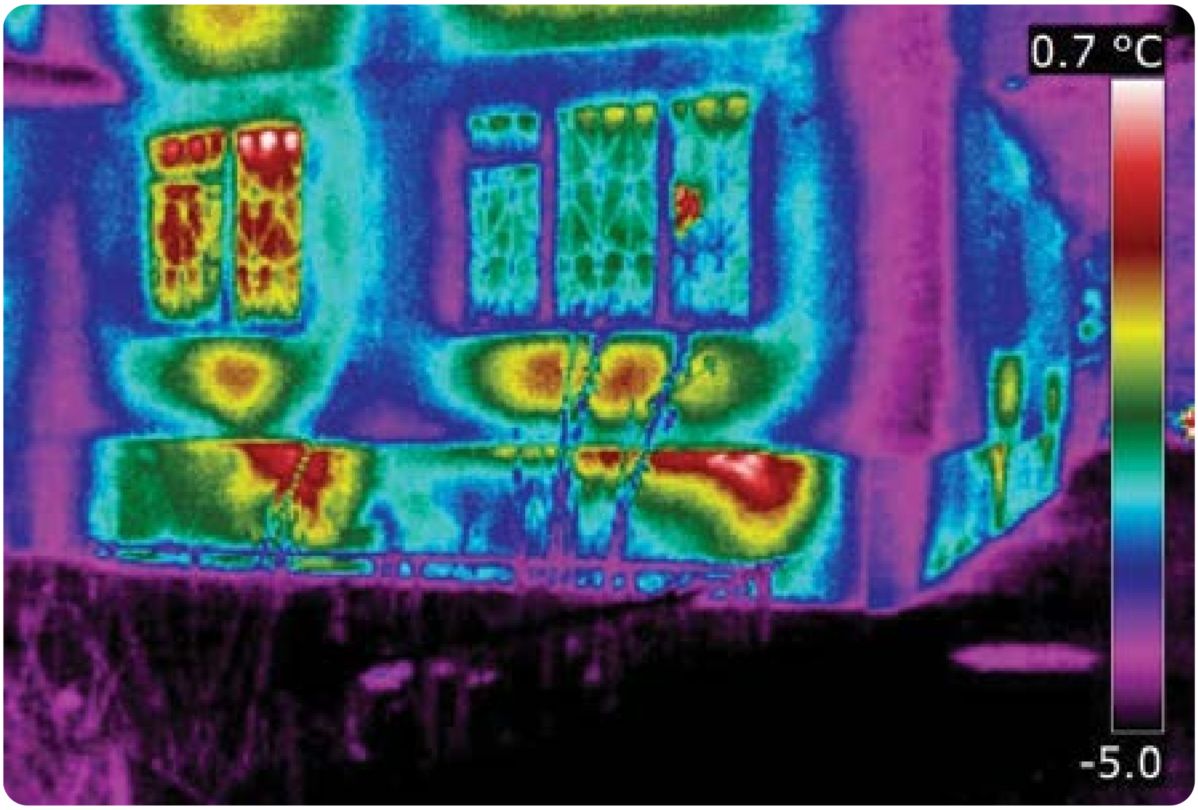


Figure 3.3.4

The red spots are where radiators are fixed to the wall in this old apartment building



Heat insulation for apartments

Options to save energy by improving heat insulation for apartments range

from replacing windows with modern that have double and triple glass packages to better doors, improved insulation of walls, floors and ceilings and replacing heating radiators with more efficient ones.

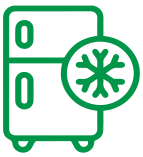
- Modern window designs, made from plastic or wood, offer excellent protection from the cold. They are easy to maintain and easy to operate.
- If you cannot replace the window with one that is more modern, do your best to insulate it. Pass a lighted candle or a thin feather along the frames and fill the gaps causing draughts. The best time to do this is in the autumn, as the plaster will not set properly if the temperature is too hot or cold. Be sure that the frame is dry when you apply it.
- Seal the windows for the winter. One advantage of modern insulation systems is that you can still open and close windows even after draught excluders have been fitted.
- If the room is still difficult to keep warm, use heavy curtains on the windows.
- You can purchase heat-reflective film that adheres to the inside of the double panes and reflects heat back into the apartment. Some of these films are removable in the summertime. However, the film lets only 80% of daylight into the room, and that can be a critical loss for apartments that are short of light (e.g., those on the ground floor, or north-facing, or with a balcony overhang from the next storey, or in the shade of a tree). But it is worth weighing the pros and cons: adults may rarely be at home in daylight hours during winter and children are at school or elsewhere, so a reflective film can be a definite advantage.
- If the front door lets in the cold, the best thing to do is to replace it, but take care to choose a good installer. There is not a great deal to choose between different doors, but the quality of their installation makes all the difference for reducing heat loss, and for noise insulation.
- If the door cannot be changed, you can improve its insulation by sticking a sheet of polystyrene or other insulating material to it and then covering it with synthetic leather. You should also close the gap under the door, through which heat escapes, by fixing a draught excluder or raising the threshold under the door.

- If it is cold inside a building, the walls require insulation. External walls can be best insulated using a 'wet facade' technology: a thermally insulating material (based on mineral or glass wool) is fixed to the wall and coated with paint or plastered over.
- Another way of retaining heat is by careful arrangement of furniture. Place wardrobes along the coldest walls: they will serve as an additional barrier against cold penetrating into the room. The furniture in the room should not hinder the circulation of warm air, so do not put any furniture near to the radiator.
- The easiest and cheapest way to insulate the floor is to put down linoleum on a felt base. But do not use glue, or the felt will lose its insulating properties. You can also lay an insulating film or a special insulating material under any floor surface.
- The most obvious way to improve the quality of heating in a room is to replace old radiators with modern bimetallic radiators. This must be done before the start of the heating season. When buying new radiators, choose those with adjusters.
- If replacement is not possible, the old radiators can be made to operate more efficiently. Remove old paint, scrape the surface, and paint them in dark colours: a dark and smooth surface gives five to 10% more heat. You can also take a sheet of plywood, paint it with silver paint or cover it with metal foil and place it behind the radiator to reflect heat back into the room instead of heating the walls. It is also important to keep radiators free of dust, which hinders heat transfer. Make sure that curtains and furniture are not preventing the flow of heat from the radiator into the room.
- Don't overheat your room! Wear something warmer rather than overheating the air.
- When you ventilate the apartment, do it quickly and completely: open the window and door wide to make air circulate.

Cooking

Your electric cooker is the most powerful appliance in your home: with all burners and the oven switched on, it can consume up to 20 kw of power, which is 10 times more than a large electric kettle or iron.

- Remember that the bottoms of the pots and pans you use on the cooker must be smooth and thick. It takes up to 40% longer to cook food in a pan with an uneven or concave bottom.
- The pan should be the same size as the burner to avoid heat loss.
- Use a lid! Energy consumption is 2.5 times greater when you cook food in an open dish.
- You can often turn off the burner on an electric cooker five minutes before the food is ready: the residual heat will complete the cooking process.
- Special appliances (coffee makers, pressure cookers, multicookers) can prepare food using 30–40% less energy than an ordinary cooker and in half the time.
- If you pour water over the cereal a few hours before cooking porridge, it will cook more quickly and contain more vitamins. Buckwheat can be soaked for about an hour, rice for longer, and beans or peas can be left to soak overnight. This also saves you time – if food cooks more quickly, you don't have to spend time watching it.
- Don't use too much water when you are boiling food.
- Don't fill the kettle to the brim if you only need water for one cup.



Refrigerators

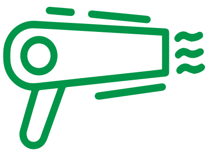
The refrigerator is the most energy-intensive appliance in your home, and the size of your electricity bill depends on how good it is and how you use it. A modern refrigerator uses three or even five time less energy than one manufactured 20 years ago with the same size and features, especially if the old seals have lost their elasticity, so that warm air is getting into the refrigerator. For an economical family of one or two people, a new refrigerator can lower electricity bills by 1.5 times.

- Before opening the fridge, think about what you need from it. Just a few seconds is enough for warm air from the room to displace the cold air inside it.
- If the fridge is large, it is a good idea to fill it up with jams and pickles: when you open the fridge warm air quickly displaces the cold air, but if the fridge is full, then less warm air gets in.
- Never put food into the fridge when it is still warm! And position the fridge as far as possible away from radiators, the cooker and direct sunlight.
- Make sure that containers with produce are covered when you put them into the fridge so that moisture does not evaporate and condense on the fridge walls.
- If the fridge needs to be defrosted manually, do it often.

Lighting

You can make energy savings of up to 40% by using modern lighting equipment and applying some practical tips.

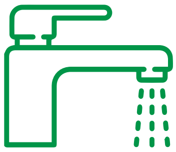
- Spotlighting in places where we work or read often works better than powerful ceiling lights. Use portable lamps and fixtures.
- A smooth white surface reflects 80% of the light directed at it, while a dark green surface reflects only 15%, and a black surface just 9%. When choosing furniture, wallpaper, and curtains for a room, give preference to lighter colours.
- There is a very simple and highly effective way of improving lighting efficiency: wipe the dust from light bulbs and glass windows regularly.
- Most of the daylight comes into a room through the upper part of the window, so it is particularly important not to block it.



Appliances

You can reduce your energy consumption by learning how to make better use of household appliances.

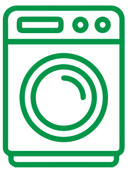
- When choosing new audio, video, or computer equipment, give preference to those with lower power consumption. Of course, purchase decisions in the family are up to parents, but you can always help them to decide by telling them what you know – they may well take notice.
- Turn all electrical appliances right off when you are not using them. When you turn off the TV using a console, it goes into 'sleep' mode, which uses less electricity, but still some electricity.
- Do not leave chargers for mobile devices permanently plugged in.
- Use high-quality plug extensions with wide-gauge cords. Narrow cords will grow warm, which means that electricity is being lost as heat instead of powering your devices.

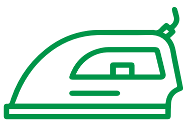


Water consumption

Actions relating to water consumption can save both, energy, and water.

- Wash in the shower and only take a bath on special occasions.
- Ten drops per minute from the tap add up to 263 litres of water in a year. Mend the leaky tap.
- There are different types of taps. Taps with rubber washers may leak more often, but that little piece of rubber is easy to replace. Ball and ceramic taps may last a very long time, but only if the pipe that carries water to them has filters installed, because the polished parts in such taps are very sensitive to rust particles in the water. Ceramic taps must be closed gently. Thermostatic taps, which appeared on the market recently, are more expensive, but they can adjust the water temperature quickly and accurately, which reduces unnecessary expense.
- Get into the habit of closing a tap when you don't need water to run continuously. Some families peel potatoes and wash them under running water, but you can do just as well using basins or buckets. Washing dishes is easier if you wash them all together and then rinse them all together. Modern sinks often have plugs, so you can use the sink itself as a basin.





Washing and ironing

Reducing emissions from washing and ironing can help to save energy, emissions, your time and keep your clothes longer.

- When you wash clothes in the washing machine, there is no need to heat the water to 90°C and run a full cycle: that is only necessary for very dirty items. For linen or only slightly soiled clothes, an economy wash cycle is quite sufficient (every machine offers a choice of economy or quick washes) and modern detergents contain enzymes that ensure a proper wash even at low temperatures. Such a wash uses nearly 10 times less power than a half-hour wash at 90°C.
- Wait until you have a full load before using the washing machine – it is uneconomical to wash one pair of jeans.
- Make sure that the items to be washed are spread evenly in the drum of the machine. Otherwise, the machine will not be able to provide rapid rotation of the drum. If the load is evenly spread, there will be less strain on the machine, the wash cycle will take less time and parts of the washing machine will last longer.
- When ironing washed clothes, sort them by different materials: you can start with lower temperatures and then move on to things that require high temperatures, and small items can be left for ironing after the iron has been turned off.
- Some things do not need ironing – it is enough to hang them neatly on clothes hangers.

Recycling and re-using

We are used to seeing an abundance of things around us, but they do not appear from nowhere. Everything we use has been produced using energy and by the work of many people. Waste from the production of things and ever larger rubbish heaps worsen our living conditions and affect the climate.

- Before you buy something new, think to yourself whether you really need it. Perhaps you only need it for a short time and would be as well borrowing it from someone else.
- Look after things to make them last longer.
- If you have something that you no longer need, think whether it could be useful to somebody else. We can give toys or clothes we have grown out of to the kindergarten, the orphanage or just to other children we know. There are sites on the Internet where people offer things they don't need for free and other people are often ready to take them. Packing tubes or boxes can be turned into something new, old dolls and toys can be restored, and there are people who can fix a broken appliance and make it work again.
- You can donate old books that you won't read again to the library or to book-exchanges, which have become popular in recent years: these are special shelves in some bookshops and libraries where you can bring any book of your own and exchange for it a book that someone else has brought there.
- If a thing is completely broken, the material from which it is made can be recycled. You can check on the Internet whether there is any reception point in your town or city for recyclable objects – you may be lucky and find such a point near to where you live. You can also put up notices to bring people in your neighbourhood together for recycling waste and unwanted items, or team up with friends, or talk to teachers at school. Together, you might gather enough plastic, paper, and metal to make a trip to the recycling centre worthwhile.
- Take your own bags when you go shopping, so that you don't have to use new ones at the checkout (save that convenience for when you really need it). Plastic bags for shopping are now freely available in shops, and they are sometimes convenient and necessary, but you can always tell the checkout staff that you don't need them. Several countries are now introducing a charge for plastic bags, which makes it worth your while to take your own bags to use.
- It makes sense to buy everyday goods that keep for a long time (detergent, shampoo, some cereals, etc.) in large bulk packages. Remind your parents of that.

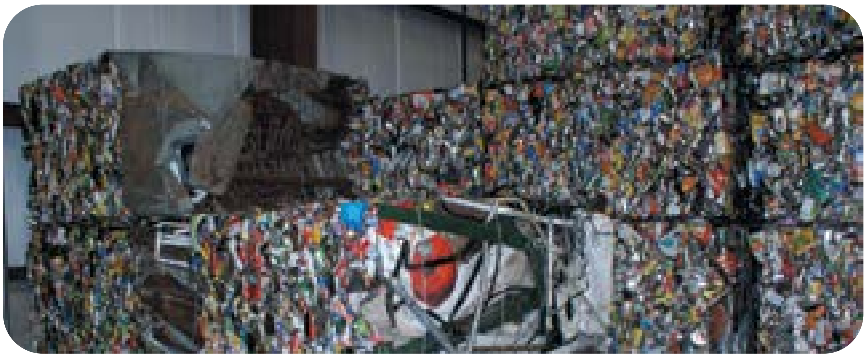


Figure 3.3.3

Metal recycling bales

Table 3.3.1 **Comparison between paper entirely produced from virgin pulp and from recycled materials (per tonne of paper)**

	Paper made entirely from virgin pulp	Paper made entirely from recycled materials	Saving
Timber	3 tonnes	0 tonnes	3 tonnes
Energy	11,140 kWh	6,450 kWh	4,690 kWh
Greenhouse gas emissions	2,581 kg of CO_2	1,625 kg of CO_2	956 kg of CO_2
Waste water	72,000 litres	39,100 litres	33,100 litres
Solid waste	1,033 kg	506 kg	528 kg

If we save one tonne of paper, we also save 13 tonnes of oil, 4,100 kilowatt-hours of electricity and 32 tonnes of water. The production and printing of one sheet of A4 paper generates 28 g of CO_2, and copying a single sheet of A4 380 g of CO_2.

Energy savings in production using recycled materials

Aluminium – 95%
Zinc – 60–70%
Paper – 64%
Copper – 70–85%
Magnesium – 95%
Plastic – 80–88%
Lead – 60–80%
Steel – 70%
Glass – 68%

So, you can reduce your carbon footprint by using less energy and not wasting energy and water, by not buying things you don't need and things with excess packaging, by getting your rubbish recycled, by walking and using a bicycle whenever possible, by buying locally produced food. And finally, remember that our main allies in helping the climate are plants. Take care of them and plant new ones whenever and wherever you can.

Figure 3.3.6 Climate change: How to reduce your carbon footprint

QUESTIONS

1 What is a carbon footprint?

2 What units are used to measure a carbon footprint?

3 Which of these has a bigger carbon footprint: strawberries grown in the garden at the local farm, or strawberries brought from abroad and beautifully packaged? Why?

4 It’s cold outside, and the heating isn’t working indoors.
Which of these would be most useful to keep warm at home and why?
a) wear a warm sweater and socks;
b) put a carpet under your feet;
c) have something to eat;
d) drink hot tea;
e) turn on an electric heater;
f) dance, jump or run;
g) light a fire in the stove or fireplace;
h) take a hot bath;
i) sit in the sun.

5 What is more economical and when is it more economical – taking a bath or taking a shower?

6 Can installation of water meters help to save energy? Why?

7 Do we use energy when we use water in an apartment building? What sort of energy do we use?

8 What do you already do in your home to save energy?

9 What important things do you need to remember when using a fridge?

TASKS

1

Test your carbon footprint

A. When you buy fruits and vegetables in a shop, what do you usually choose:
– local, unpackaged produce (1 point)
– unpackaged produce from the southern regions of your country (2 points)
– unpackaged produce from France, the Netherlands, Argentina and other countries (3 points)
– imported produce, individually pre-packed (4 points)

B. The bag you use for shopping is:
– linen or cotton (1 point)
– paper (2 points)
– a plastic bag that I take from home (3 points)
– a plastic bag that I take or buy when I pay for goods in the shop (4 points)

C. When you buy drinks, what sort of container are they usually in?
– paper (1 point)
– glass (2 points)
– aluminium (3 points)
– plastic (4 points)

D. What book do you prefer to read:
– a new one, bought in a shop (4 points)
– an electronic one (3 points)
– one that has already been read (2 points)
– one from the library (1 point)

E. When you give someone a present, do you prefer:
– bright and attractive wrapping paper, whatever it is made of (4 points)
– paper with an environmental label to show that it is recyclable (2 points)
– a used box or bag that I specially decorate (2 points)
- to give the present without packaging (1 point)

Answers

- **From 14 to 16 points:** An elephant's carbon footprint!
  Better put all that weight into saving energy.
- **From 11 to 13 points:** The carbon footprint of a horse's hoof!
  Put on your harness and get down some energy saving.
- **From 8 to 10 points:** You have the carbon footprint of a cat's paw!
  But don't sit purring – you could do even better.
- **From 5 to 7 points:** Great! You have the carbon footprint of a mouse!
  You can be proud of yourself – all you need to do now is persuade others to be like you.

2

Draw a table with four columns. Use the first column to note down cases of inefficient energy use that you see around you (on the street, at home, at school). In the second column explain how energy could be saved or used more efficiently in all these cases. In the third column, write down cases you have seen of efficient energy use. And in the fourth column, write down one occasion each day when you personally used energy more efficiently and did the planet some good. Compare your table with the tables of your classmates. Make a report on the results.

3

Go through all your things (preferably with your parents), find out where they came from and mark that place on the world map. Put things you bought or were given, but don't use, into a separate group. Calculate how far they travelled to reach you. Now you can make a chart (diagram, map) of what you have found out, showing where things were made, what use they are to you (necessary, unnecessary, useful from time to time, good for recycling, good for making something else out of, etc.).

4

Divide the class into seven groups. Each group draws a straw to select a focus group: younger students; older students; housewives; pensioners; industrialists; politicians; teachers. Each group has to develop a project to promote energy saving and energy efficiency for its focus group.

Your tasks are to:

1) think of a slogan or slogans for an information campaign
2) design a poster to encourage energy saving in your group
3) develop a programme that will help your focus group to grasp the principles of energy saving and carry them out

Put some original ideas into your programme – from a puppet show to publishing a book, to proposals for reform of the state (depending on the focus group).

After the projects have been presented, display the best posters at school.

3.4 Global cooperation on climate change, sustainable development, and all-of-society approach to deal with climate change

Global cooperation and negotiations on climate change

Until the end of the 1970s, the only people who took an interest in climate change were scientists.

In 1979, reports presented at the first World Climate Conferenceprovided evidence that human activity has major impact on climate. This attracted the attention of journalists, then of the public, and finally of governments.

In 1988, the United Nations recognized climate change as one of the most pressing global challenges for humanity.

Some of the best scientific minds in the world began to work on the issue of climate change.

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was set up by the International Meteorological Organization and the United Nations Development Programme. The panel was asked to review the available scientific evidence and show how human activity affects the climate.

The first IPCC report published in 1990 confirmed that the threat of climate change was real and that there was a direct connection between human activity and processes in the global atmosphere. Since then, five more IPCC reports have been released, the latest in 2021-2022, which assess climate change using the most recent research by scientists from around the world.

Since the first IPCC report, most scientists have increasingly agreed on the man-made nature of climate change and that we can and must find ways of combating it. This will only be possible if countries all over the world work together, and the best way of doing that is under the auspices of the United Nations.

In 1992, the countries of the world agreed at a United Nations conference dedicated to environment and development held in Rio de Janeiro, Brazil, on the need to cooperate on climate, biodiversity and forests, and desertification issues. The agreement on climate issues was reflected in an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC) that was negotiated within a record time of 18 months.

The Climate Convention entered into force in 1994, but it only set out general actions to limit and reduce greenhouse gas emissions and cooperate on adaptation to climate impacts. So, in 1995, at the first Conference of the Parties to the Convention (i.e., the countries that had signed the Convention), it was decided to prepare a further international legal instrument to regulate concrete actions by the Parties into the 21^{st} century.

The negotiations to prepare this new instrument were complex and difficult. Yet, the countries came to agreement. And in December 1997 in Japan, they adopted a new international treaty, the Kyoto Protocol to the UNFCCC, named after the city of Kyoto, where it was signed.

The Kyoto Protocol was revolutionary because it contained quantified commitments by each developed country not to exceed a certain level of greenhouse gas emissions in the period 2008-2012 relative to 1990, which was taken as the baseline. It also introduced innovative market-based mechanisms that attached a price to carbon dioxide emissions.

United Nations
Framework Convention on
Climate Change

For example, the European Union pledged to reduce its emissions by 8%, Japan by 6%, and Russia and Ukraine not to exceed the level of their emissions in 1990.

The United States, which had the largest amount of greenhouse gas emissions in the world at that time, took an active part in the negotiations on the Kyoto Protocol, but later, in 2001, did not ratify it.

At the end of 2012, there were two international treaties in force: the Climate Convention, as an international treaty defining the general strategy for humanity to combat climate change, and the Kyoto Protocol to the Climate Convention, which established specific commitments of industrialized countries, such as the European Union, and countries with economies in transition, such as Russia and Ukraine.

The period of the first commitments made by industrialized countries and countries with economies in transition under the Kyoto Protocol expired at the end of 2012 and a new round of negotiations was needed for the next period, beginning in 2013. In 2013, developed countries that remain part of the Kyoto Protocol agreed on further commitments to reduce greenhouse gas emissions in the second commitment period from 2013 to 2020, promising more substantial reductions than before.

But the attitude of several countries towards the Kyoto Protocol has changed. The USA, Canada, Japan, New Zealand, and Russia have not joined the agreement for 2013–2020. Their argument is that the world has changed since the 1990s, and that almost all the growth in emissions today comes not from developed countries, but from major developing countries with emerging economies (China, India, Brazil, South Africa, and others), whose emissions are not regulated by the Kyoto Protocol.

The solution that was found at that time was for these developed countries that are not part of the second commitment period of the Kyoto Protocol to take on voluntary commitments for emission reduction by 2020 and for developing countries to implement Nationally Appropriate Mitigation Measures in form and scope that they define by themselves.

Figure 3.4.2

Adoption of the landmark Paris Agreement at COP21 in Paris in 2015

Milestones in addressing climate change

- 1992 - Climate Convention, when countries agreed to formulate and plan actions to return emissions to 1990 levels;
- 2008-2012 - The first commitment period of the Kyoto Protocol, when 37 developed countries and the European Community committed to reduce greenhouse gas emissions to an average of 5% against 1990 levels;
- 2013-2020 – The second commitment period of the Kyoto Protocol, when developed countries committed to reduce greenhouse gas emissions by at least 18% below 1990 levels. However, the developed countries that did not participate in the second commitment period took on voluntary commitments to reduce emissions by 2020, and developing countries agreed to implement Nationally Appropriate Mitigation Measures (NAMAs).
- 2015 – Adoption of the Paris Agreement that includes Nationally Determined Contributions (NDCs) of countries, with ambitious long-term measures to curb greenhouse gas emissions.
- 2016 – Entry into force of the Paris Agreement with the first commitments to reduce emissions (NDCs) between 2020 and 2025, or 2020 and 2030.

In December 2015, the countries met at the United Nations Climate Change Conference in Paris to achieve a new universal agreement on climate that was implemented from 2020 and applied to all nations. In preparation for Paris, governments submitted their climate pledges, the **Nationally Determined Contributions' (NDCs)**, outlining their mid-term national emission reduction targets. The goal is to limit global average temperature well below 2°C and towards 1.5°C compared to pre-industrial levels.

The Paris conference looked at a broad range of climate change challenges and solutions including mitigation of greenhouse gas emissions, adaptation to climate change impacts, loss and damage from climate change as well as technological, capacity-development and financial support for such actions. The Paris Agreement is a legal framework for climate change actions beyond 2020; more detailed decisions on its implementation have been formulated and agreed upon at subsequent climate conferences.

Effective international cooperation can help the world develop along a 2°C and towards 1.5°C pathway and adapt to climate change that is already happening. It can also help countries grasp the many opportunities and benefits associated with the transition to low-carbon and climate resilient economies.

Importantly, the Paris Agreement does not impose emission limitation or reduction targets on countries. Rather, it encourages countries themselves to set targets that represent their best possible effort to contribute to the temperature goals of the Paris Agreement. Such efforts are reflected in the national climate plans that are submitted periodically by countries as NDCs. The first set of NDCs was submitted in 2015-2016, and the second in 2021-2022.

To ensure that NDCs pledged by countries collectively bring down emissions well below 2°C and towards a 1.5°C pathway, a new mechanism was introduced in the Paris Agreement, known as the Global Stock Take (GST). The GST will assess the collective progress towards the goals of the Paris Agreement, considering the best available science and equity. It will help to encourage and inform countries to increase their ambition and scale up their actions in line with what science requires when they update their NDCs. The next NDCs due in 2025 are expected to include targets for 2035.

The first GST took place in 2022-2023 and culminated at the Conference of Parties (COP28) held in December 2023 in Dubai, the United Arab Emirates. Countries reached a consensus that the world is not on track to achieve the 1.5°C goal of the Paris Agreement and must take urgent and ambitious actions on mitigation and adaptation and reflect them in the next NDCs in 2025.

The stock take recognizes the science that indicates that global greenhouse gas emissions need to be cut by 43% by 2030 and by 60% in 2035 compared to 2019 levels, to reach net zero emissions by 2050 and limit global warming to 1.5°C.

The stock take asks countries to a) take concrete actions towards achieving a tripling of renewable energy capacity and doubling energy efficiency improvements by 2030 globally and reducing methane emissions; and b) accelerate efforts towards phasing down unabated coal power, phasing out inefficient fossil fuel subsidies, and transition away from fossil fuels in energy systems in a just, orderly, and equitable manner. It calls on developed countries to continue leading the transition to an emissions-neutral and resilient future.

The COP28 also reached a consensus on stepping up support to developing countries to enable such ambitious action. For example, the GST assessment led to the establishment of funding mechanisms and tools to help deal with events such as the extreme flooding in Sylhet, Bangladesh in 2022 that led to a shortage of clean drinking water (Fig. 3.4.2). The GST outcome thus givescountries a fair chance to achieve the goals of the Paris Agreement in this critical decade for climate action.

Figure 3.4.2

Women seeking drinking water in Sylhet, Bangladesh, after extreme floods in 2022

The Paris Agreement also requires developed countries to support developing countries by providing them with financial, technological, and capacity development. As part of the GST, countries recognized the need to provide developing countries with climate finance in the range of $5.8–5.9 trillion for the pre-2030 period.

COP28 was also the first to spotlight the impact of climate change on human health. Ministers of health, environment, finance, and other related sectors set out a roadmap and opportunities for actions to deal with this issue. Countries adopted the first Declaration on Health and Climate Change, where they committed to join forces and work to transform health systems to be climate-resilient, low-carbon, sustainable and equitable, and to better prepare communities and the most vulnerable populations for the impacts of climate change.

Climate change and sustainable development

International cooperation on climate change is closely linked with the other principal concern of humanity – how to achieve sustainable development for global prosperity. Sustainable development requires mutually supporting actions in three domains: economic, social, and environmental. And climate change impacts all three of them.

At the United Nations General Assembly in September 2015, 193 countries adopted the 2030 Development Agenda and its 17 **Sustainable Development Goals (SDGs)**. Goal 13 aims at 'Taking urgent action to combat climate change and its impacts' (Fig. 3.4.3).

Figure 3.4.3 17 Sustainable Development Goals of the United Nations

Many other SDGs also address climate change, for example, Goal 7, 'Ensure access to affordable, reliable, sustainable and modern energy for all'.

In our modern world of technological progress, about 1.3 billion people, 80% of them in rural areas, have no access to electricity. These people, the world's poorest, make up more than 16% of the eight billion people now living on the planet.

Even more people, about three billion, use traditional biomass (wood and firewood) for cooking and heating. Pollutants emitted into the atmosphere from the combustion of biomass in inefficient cooking devices may be causing the premature deaths of 1.5 million people every year, or more than 4,000 a day. That is more than the total number of people who die each day from malaria, tuberculosis and AIDS combined. These poor people live in Africa, south of the Sahara Desert (the largest desert in the world), South Asia and Latin America.

This problem has been called **'energy poverty'**.

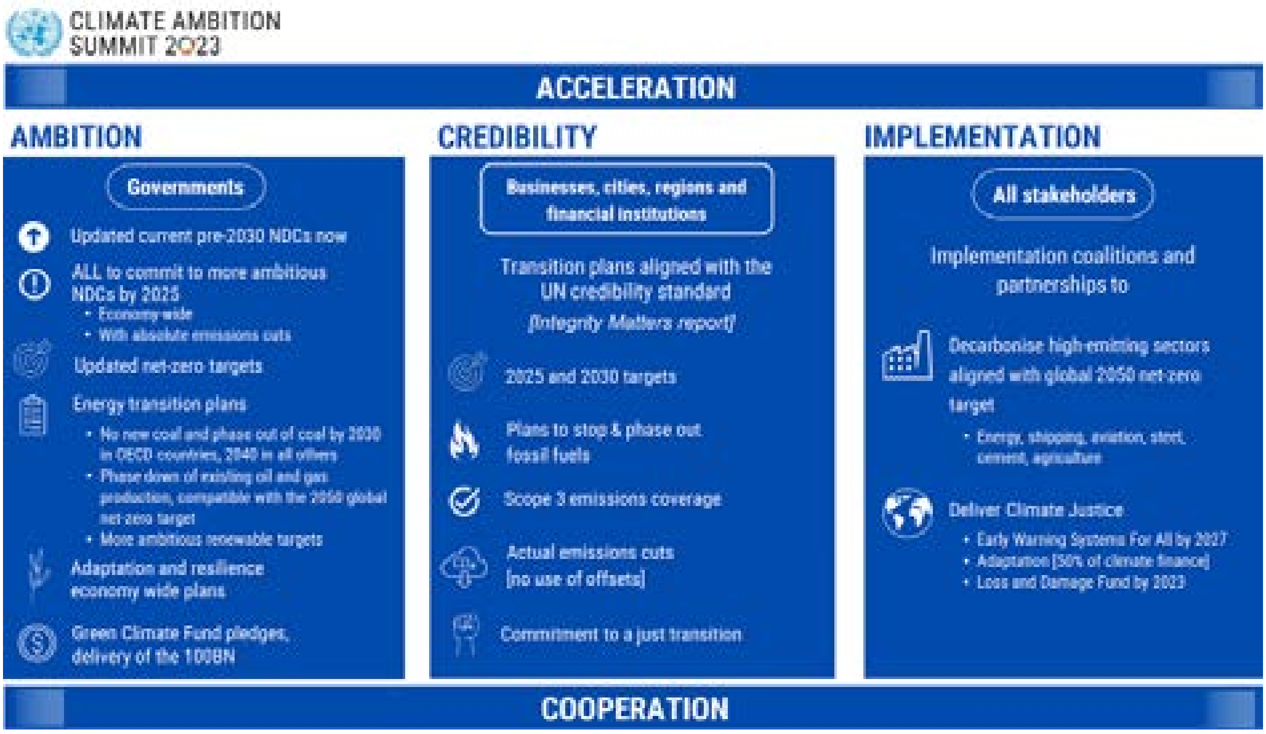
Achieving climate change goals and the goal of providing electricity access to all is mutually reinforcing. Clean, efficient, affordable, and reliable energy is key to global health and prosperity, and the efficient use of energy resources combats climate change. This is why it is vitally necessary to promote the rational and efficient use of energy resources.

All-of-society approach to climate change

Representatives of business, cities, regions, investors, civil society, academia, and organizations of women, youth, and indigenous peoples, or non-governmental actors, have been increasingly engaged in climate change negotiations since the 1990s.

It was at COP21 in Paris that governments formally agreed that it was urgent to mobilize stronger and more ambitious climate action to achieve the goals of the Paris Agreement. Everyone has a role to play. Society and other non-governmental actors engage in climate action by creating their own climate plans, setting goals to reduce emissions, disclosing climate risks, enhancing technical proficiency and capacity, and assisting with the local execution of national policy objectives. They also work together and often with national governments in transnational climate initiatives or international cooperative initiatives. The United Nations Climate Ambition Summit in 2023 gave particular attention to the roles of governments, business, cities, regions, and financial institutions, and how they can work jointly in making the decarbonization of society and economy a reality (Fig. 3.4.4).

Figure 3.4.4 **How different stakeholders join efforts to fight climate change: UN Climate Ambition Summit 2023**



The UNFCCC provides information on more than 32,000 initiatives and actors engaged in climate action. In October 2023, these included 15,590 companies, 1,654 investors, 3,443 organizations, 282 regions, 11,354 cities and 194 countries. High-level champions at the UNFCCC guide actions by non-governmental actors to enable collaboration between governments and the cities, regions, businesses, and investors that must act on climate change. Most notable recent initiatives are the 2030 Breakthroughs, the Sharm-el-Sheikh adaptation agenda, Race to Zero and Race to Resilience campaigns.

Recognizing the importance of engaging young people in climate action, COP28 in Dubai created the position of a Youth Climate Champion. The champion is tasked with enhancing the meaningful participation and representation of young people in future COPs.

TASKS

1 In this set of tasks, you can try playing the role of an international negotiator. Read these ten tips and learn them by heart.

Ten tips for an international negotiator

1. Focus on the issue that is being discussed. Don't get diverted and don't pursue sidetracks or jump to other topics.

2. Try to find and distinguish the key idea, and focus on content, not on form. However, when engaging with others, do not forget that in diplomacy, the form or the way you present your ideas matters a lot.

3. Paraphrase what the other person has said and check that you understood them correctly ('If I'm not mistaken, you mean that...', 'Do I understand rightly that ...').

4. Ask questions.

5. Respect the silence of the person you are talking to, don't rush to fill pauses in the conversation.

6. Interpret information both from the point of view of your own culture, and from the point of view of a culture of your counterpart.

7. Try not to read your own meaning into someone e se's behaviour.

8. Don't hurry to make assessments and value judgments.

9. Learn to recognize non-verbal messages of the person you are talking to (facial expressions, gestures, posture, intonation, etc.).

10. Don't jump to conclusions based on a single gesture or sign.

It is interesting that one of the most successful strategies in dealing with people from other cultures is simply to imitate them. Copying the way your negotiating partner behaves significantly increases the chances of a positive outcome for both sides. So being a chameleon can help you to succeed in international negotiations. In any case, courtesy, respect for the person you are talking to and their culture, and openness in communication can work wonders. (The same applies in daily life.)

2

Game
Imagine that you are taking part in a United Nations Conference on Climate Change, and you are going to discuss the problems of different countries related to climate change.

Prepare a brief welcome speech that the head of your state will read to conference participants. The speech should mention:

– the climate and main natural resources of your country

– how people in your country live

– the chief sectors of your country's economy

– the impact of climate change on nature, people and the economy

– what your country expects the conference to achieve

After the welcome speech the conference participants express their views on how to prevent the negative impacts of climate change on the environment and people in the countries taking part in the conference.

At the end of the game, the participants select a winner – the student who contributed the most to the discussion, and who said the most relevant, well-argued, and interesting things

3

You are a governmental officer in a small island state in the Pacific region. You are preparing a proposal to apply for international financial support to help your country cope with the negative impacts of climate change. Include the following issues in your funding proposal:

1) What expected effects of global warming represent the greatest threat to your country?

2) What is to be done if rising sea levels threaten to engulf the whole of your island?

3) What international organizations and states will you apply to for help?

4) How do you plan to preserve the culture of your country, if your island disappears under the sea?

4

Guidelines for teachers on the use of the Climate Box toolkit in schools

4 Guidelines for teachers on the use of the Climate Box toolkit in schools

The Climate Box toolkit, an interactive set of educational materials and games on climate change, is addressed to teachers of natural sciences, social studies, and the environment in Grades 1-11.

The materials have been prepared by UNDP with the support of the Global Environment Facility, the Ministry of Natural Resources and Environment of the Government of the Russian Federation, and the Coca-Cola Company. Climate Box is the third of a series of toolkits for school students prepared and presented by UNDP and its partners, following Black Sea Box and Baikal's Little Treasure Chest.

The objectives of the Climate Box toolkit are to:

- Inform students about the world around them and the relationships between human beings and the environment
- Promote ideas of conservation and respect for nature
- Instil an environmental culture of responsible consumption by young people and develop energy- and resources-saving skills among them
- Help teachers prepare and conduct lessons on subjects directly or indirectly related to climate change

The interactive toolkit contains:

An illustrated textbook for students with educational materials and a variety of questions and tasks for individuals and groups, along with guidelines for teachers on the use of the toolkit in lessons for students in different age groups (as a chapter in the textbook and a standalone supplement)

The Climate Quiz, a set of game cards

A wall map illustrating the possible effects of climate change on nature and humanity in various parts of the world by the end of the 21^{st} century

A poster with tips on how to reduce your carbon footprint

A poster with recommendations on how to resist and adapt to climate change impacts that are hard to mitigate

climate-box.com – a website with all toolkit materials

The Climate Box textbook

The textbook consists of three sections: 'The problem of climate change'; 'How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?'; and 'How to prevent dangerous climate change'.

It helps students to distinguish between different types of climate and natural zones; explains the relationship of the geographical components of natural systems; teaches them how to understand essential geographical features and weather phenomena and how they can change as a result of natural and manmade impacts; explains the use of alternative energy sources; teaches rules of conduct in case of extreme weather; and tells them how to make sparing use of resources at home and school and outdoors. Each section contains information that can usefully supplement many aspects of educational programmes.

The textbook contains interesting and informative facts about natural anomalies, examples of the consequences of climate change impacts on coastal, mountain and Arctic regions, forests, cities, and countries. It gives students an opportunity to independently analyze the information and build hypotheses and forecasts about natural processes and phenomena relevant to the region where they live.

The textbook helps students to view the world from the point of view of an astronomer, geographer, or ecologist. Colourful and attractive illustrations, charts and graphs help to consolidate their understanding of evolution (by reference to climate change events in the past and the shape of our planet today), spatial differences in the processes of climate formation, geographical features of the natural complexes of different continents and oceans, conservation practices, natural and manmade causes of environmental problems, measures to preserve the natural world and protect people from natural and man-made disasters, the greenhouse effect and biodiversity, and the carbon footprint of human beings on Earth.

Questions and tasks offer students an opportunity to use all this knowledge in practice The textbook can be used in work with students eight years and older and is particularly suitable for students aged 10–13 years, both as part of the main curriculum and in extracurricular activities.

Teachers are advised to use the textbook materials taking account of what their students are currently focused on, and their needs, interests, and abilities. Some children will find the entire textbook interesting, while others may be attracted by specific facts and illustrations, or ideas for experiments.

The tables below indicate how to link the Climate Box to national curricula. Although focused on the Russian educational programme, these suggestions could be relevant to similar curricula in other countries.

We are optimistic that every student will find something new and interesting in the textbook. We suggest that teachers take a creative approach to the toolkit, using the materials in activities outside the classroom and in extracurricular activities: these may be outdoor activities, environmental actions, subject weeks, competitions and quizzes, and study circles. The team of authors sincerely hopes that the Climate Box toolkit will encourage students, teachers, and parents to alter their lifestyles towards greater environmental awareness.

Educational programmes

Primary education

National programme for primary education “The World Around Us” (for grades 1–4)

Secondary education

National programmes for basic secondary education in subjects:

- Geography (for grades 5-11)
- Biology (for grades 5-11)
- Chemistry (for grades 8-11)
- Physics (for grades 7-11)
- Social studies (for grades 6-11)
- Safety basics (for grades 8-11)

PRIMARY EDUCATION				
Section in the Climate Box textbook	The World Around Us Programmatic and thematic content			
	1st grade	2nd grade	3rd grade	4th grade
PART 1. The problem of climate change				
1.1. Climate and weather	• Monitoring the weather in your region. Weather and thermometer. Determination of air (water) temperature using a thermometer. Observing seasonal changes in nature.	• How does the Earth differ from other planets? Living conditions on the Earth.	• Properties of air. The importance of air for plants, animals, and humans.	• The Sun is the closest star to us, a source of light and heat for all life on Earth. • The rotation of the Earth around the Sun and the change of seasons.
1.2 Climate types and climate zones	–	–	–	• Climate zones of your country: general idea, main climate zones (climate, flora and fauna, peculiarities of work and life of people, human influence on the nature of the studied zones, nature conservation). Connections in climate zones.
1.3. How and why the climate changed in the past	–	–	–	• Methods to understand nature: observations, comparisons, measurements, experiments to study natural objects and phenomena.
1.4. Climate change today	–	–	–	• Ecological issues of interaction between human beings and nature.

PRIMARY EDUCATION				
Section in the Climate Box textbook	The World Around Us Programmatic and thematic content			
	1st grade	2nd grade	3rd grade	4th grade
PART 2. How climate change affects the natural world and human beings Can we adapt to the inevitable consequences of climate change?				
2.1. How climate change affects the weather	–	–	–	–
2.2. How climate change affects plants and animals	• Plants. Plants in the immediate environment. Deciduous and coniferous plants. Wild and cultivated plants. Houseplants, rules of maintenance and care. • Animals. Domestic and wild animals (differences in living conditions). • Inanimate and living nature. Relationships between human beings and nature. Rules of ethical and safe behaviour in nature.	• Diversity of plants (flora). • Diversity of animals (fauna). • Connections in nature. The annual course of changes in the life of plants and animals • The Red List, its meaning, individual representatives of plants and animals of the Red List. Reserves, natural parks. Protection of nature. Rules of ethical behaviour in nature.	• Dependence of the life cycle of organisms on environmental conditions. • Conditions necessary for plant life (light, heat, air, water). • Conditions necessary for animal life (air, water, heat, food). • Plants and animals of our region. • Human influence on natural communities.	• Protection of natural resources: water, air, minerals, flora, and fauna. International Red List (selected examples).
2.3. How climate change affects forests	• Plants. Plants in the immediate environment. Deciduous and coniferous plants. Wild and cultivated plants. Houseplants, rules of maintenance and care. • Animals. Domestic and wild animals (differences in living conditions). • Inanimate and living nature. Relationships between human beings and nature. Rules of ethical and safe behaviours in nature.	• Diversity of plants (flora). • Diversity of animals (fauna). • Connections in nature. The annual course of changes in the life of plants and animals • The Red List, its meaning, individual representatives of plants and animals of the Red List. Reserves, natural parks. Protection of nature. Rules of ethical behaviour in nature.	• Dependence of the life cycle of organisms on environmental conditions. • Conditions necessary for plant life (light, heat, air, water). • Conditions necessary for animal life (air, water, heat, food). • Plants and animals of our region. • Human influence on natural communities.	• Protection of natural resources: water, air, minerals, flora, and fauna. International Red List (selected examples).

PRIMARY EDUCATION				
Section in the Climate Box textbook	The World Around Us Programmatic and thematic content			
	1st grade	2nd grade	3rd grade	4th grade
PART 2. How climate change affects the natural world and human beings Can we adapt to the inevitable consequences of climate change?				
2.4. How climate change affects water resources	• Plants. Plants in the immediate environment. Deciduous and coniferous plants. Wild and cultivated plants. Houseplants, rules of maintenance and care. • Animals. Domestic and wild animals (differences in living conditions). • Inanimate and living nature. Relationships between human beings and nature. Rules of ethical and safe behaviour in nature	–	• Water. Distribution of water in nature, significance for living organisms and human life. The water cycle in nature. Water protection.	• Reservoirs, their diversity (ocean, sea, lake, pond, swamp); river as a stream of water; human use of rivers and reservoirs. Reservoirs and rivers of our region (names, brief description based on observations).
2.5. How climate change affects agriculture	–	–	• Soil, its composition, significance for wildlife and human economic life.	–
2.6. How climate change affects coastal regions	–	• Continents and oceans.	–	–
2.7. How climate change affects mountain regions	–	–	–	–
2.8. How climate change affects Arctic regions	–	–	–	–
2.9. How climate change affects cities and human health	–	–	–	–
2.10. How climate change affects social problems	–	–	• Countries and nations of the world.	–

PRIMARY EDUCATION				
Section in the Climate Box textbook	The World Around Us Programmatic and thematic content			
	1st grade	2nd grade	3rd grade	4th grade
PART 3. How to prevent dangerous climate change				
3.1. 'Green' energy sources **3.1.1. What is energy?** **3.1.2. The main sources of energy**	–	–	–	–
3.1.3. Fossil fuels	–	–	• Rocks and minerals. Their importance in the human economic activities and use of minerals in a sustainable way. Minerals of our region (2–3 examples).	–
3.1.4. Nuclear energy	–	–	–	–
3.1.5. Renewable energy sources	–	–	–	–
3.1.6. Advantages and disadvantages of different energy sources	–	–	–	–
3.2. Energy efficiency and energy saving **3.2.1. Environmentally friendly transport** **3.2.2. Household appliances and electrical devices**	–	–	–	–
3.2.3. Green construction. Passive and active buildings **3.2.4. Green cities**	–	–	–	–
3.3. Carbon footprint and how I can help the planet by reducing my carbon footprint	• Careful attitude towards things and taking good care of them.	–	–	• Rules of ethical behaviour in nature.
3.4. Global cooperation on climate change and sustainable development	–	–	–	• Rules of ethical behaviour in society, attitude towards people regardless of their nationality, social status, religious beliefs.

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 1. The problem of climate change						
1.1. Climate and weather	• Geographical methods of studying objects and phenomena. • Phenological observations in nature.	• Air temperature. Average daily, average monthly, average annual temperature. Annual variation of air temperature. • Water in the atmosphere. Types of precipitation. • Weather and its indicators. Causes of weather changes. • Climate and climate-forming factors. • Dependence of climate on geographical location and altitude of the area above sea level. • Human adaptation to climate conditions. • Meteorologist as a profession. • Basic meteorological data. • Natural phenomena in the atmosphere.	–	• Factors determining the climate of our country. • The influence of geographical location on the climate of a country.	–	–
1.2 Climate types and climate zones	–	• Global, Regional, and Local Natural Complexes. Natural complexes of the local area.	• Diversity of climate on Earth. Climate forming factors. • Characteristics of the main and transitional climate zones of the Earth.	• Climatic zones and types of climates in our country, their characteristics.	–	–

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 1. The problem of climate change						
1.3. How and why the climate changed in the past	• The Earth in the solar system. • The movement of the Earth around the Sun. • Change of seasons on the Earth. Uneven distribution of sunlight and heat on the Earth's surface. • Tropics and polar circles. • The rotation of the Earth around its axis.	–	–	• Ancient and modern glaciations.	–	–
1.4. Climate change today	–	• Ways to study and monitor global climate. • Climatology as a profession. • Remote methods in the study of human influence on the Earth's atmosphere.	• The influence of modern human economic activities on the Earth's climate. • Global climate change and different points of view on its causes.	• Ancient and modern glaciations. • Climate change caused by natural and anthropogenic factors. • Observed climate changes on the territory of our country and their consequences. Ways of adaptation to climate change. • Features of the climate of our region. • Predicted impacts of climate change on different natural and economic systems in our country.	–	• Modern directions of geographical research. • Human adaptation to various natural conditions and their changes over time.

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?						
2.1. How climate change affects the weather	–	· Natural phenomena in the atmosphere, methods of observation and protection.	–	· Dangerous and adverse meteorological phenomena.	–	· Natural hazards, climate change.
2.2. How climate change affects plants and animals	–	· Biosphere. · Diversity of flora and fauna. Adaptation of living organisms to their habitat in different climate zones. · Research and environmental issues.	–	· The wealth of flora and fauna in our country: species diversity, factors that determine it. · Features of the flora and fauna of various natural and economic systems of our country. · Specially protected natural areas of our country and our region. UNESCO World Natural Heritage Sites; plants and animals listed in the Red List of your country.	–	· Specially protected natural areas as one of the objects of sustainable development goals.
2.3. How climate change affects forests	–	· Natural environment. · Protection of nature. · Specially protected nature areas.	–	· Forest industry and the environment. Problems and prospects for development.	–	· Forest reserves of the World. · Deforestation - its causes and affected areas.
2.4. How climate change affects water resources	–	· Hydrosphere and methods of its study. Parts of the hydrosphere. · Rivers. Nutrition and regime of the river. · Lakes. Origin of lakes. Nutrition of lakes. · Natural phenomena in the hydrosphere, methods of observation and protection.	· Salinity of surface waters of the World Ocean, its dependence on the ratio of precipitation and evaporation, the desalinating influence of river waters and glacier waters. · Ecological problems of the World Ocean.	· Aquatic natural systems of the: rivers in your country, seas, lakes. · Dangerous hydrological natural phenomena and their distribution across the territory. · Uneven distribution of water resources. Increase in their consumption and pollution. Ways to preserve the quality of water resources.	–	· Supply of fresh water. · Hydropower resources of the world. · The role of the natural resources of the World Ocean (energy, biological, mineral) in our life and the prospects for their use.

SECONDARY EDUCATION

Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?						
2.5. How climate change affects agriculture	–	• Soil formation and soil fertility. Soil protection.	• Types of economic activities: agriculture.	• Agroclimatic resources. • Soil resources in your country. Measures to preserve soil fertility: land reclamation, combating soil erosion and soil pollution.	• Agriculture. • Land, soil and agroclimatic resources. • Agriculture and environment. • Features of the agro-industrial sector of your region.	• Agroclimatic resources of the world. • The impact of agriculture and its individual activities on the environment. • Geographical differences in land availability. • Organic farming. Crop farming. Animal husbandry.
2.6. How climate change affects coastal regions	–	• The World Ocean. • Movements of the waters of the World Ocean: waves; currents, ebbs, and flows. • Natural phenomena in the World Ocean.	• Changes in ice cover and sea level, their causes, and consequences. • Patterns of changes in ocean salinity. • Main fishing areas.	• The wealth of flora and fauna in our country: species diversity, factors that determine it. • Features of the flora and fauna of various natural and economic systems of our country. • Specially protected natural areas of our country and our region. UNESCO World Natural Heritage Sites; plants and animals listed in the Red List of your country.	–	• Rising sea levels. • Fisheries and aquaculture: geographical features.
2.7 How climate change affects mountain regions	–	• Altitudinal zone. • Preservation of the most important biotopes of the Earth.	• Glaciers. • Altitudinal zones in the mountains in your country.	–	–	–

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?						
2.8. How climate change affects Arctic regions	–	• Permafrost.	• Antarctica is a unique continent on the Earth. • Human exploration of Antarctica. Modern research in Antarctica.	• Glaciers. • Permafrost.	• Arctic zone. • State programme for the socio-economic development of the Arctic zone.	–
2.9. How climate change affects cities and human health	–	–	• Current world population. Factors influencing population growth. • Location and density of population.	• Geographical features of population distribution. • Urban and rural population. • Urbanization in your country. Largest cities and urban agglomerations.	–	• The concept of urbanization; its features in countries of various socio-economic types. • Urban agglomerations and megalopolises of the world.
2.10. How climate change affects social problems	–	–	• The influence of climatic conditions on people's lives. • Cities and rural settlements.	• The influence of climate on the life and economic activities of the population. • External and internal migrations. Reasons for migration and main directions of it.	–	• Climate refugees. • Geographical features of population distribution and factors that determine it. Population migrations: causes, main types, and migration routes.

SECONDARY EDUCATION

Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 3. How to prevent dangerous climate change						
3.1. 'Green' energy sources **3.1.1. What is energy** **3.1.2. The main sources of energy**	–	–	–	• Classifications of natural resources. Natural resource capital and environmental potential of your country. • Mineral resources of the country and their rational use.	• Energy sector. Oil, gas and coal industries. • Electric power industry.	• Natural resource capital of world regions and large countries. Provision of countries with oil, gas, uranium, ore and other minerals.
3.1.3. Fossil fuels						
3.1.4. Nuclear energy						
3.1.5. Renewable energy sources	–	• Hydrosphere and people. Use of water energy by the humankind.	–	–	• Power plants using renewable energy sources, their features and share in electricity production.	• Global energy sector: main stages of development, energy transition. • Leading countries in the development of renewable energy.
3.1.6. Advantages and disadvantages of different energy sources	–	–	–	• Principles and methods of rational environmental management.	• Main types of power plants (nuclear, thermal, hydroelectric, power plants using renewable energy sources). • Impact of the energy sector on the environment.	• World power industry. Current trends and geographical features in the development of the industry. • Environmental impact of the power industry and various types of power plants, including renewable energy power plants.

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 3. How to prevent dangerous climate change						
3.2 Energy efficiency and energy saving **3.2.1. Environmentally friendly transport** **3.2.2. Household appliances and electrical devices**	–	–	–	–	• Sea, inland waterway, rail, road, air transport. • Transport and environmental protection.	• Main international highways and transport hubs.
3.2.3. Green construction. Passive and active buildings **3.2.4. Green cities**	–	–	–	–	• Economic development and the state of the environment. • State documents reflecting issues of environmental protection of your country and government measures supporting energy transition and sustainable development.	• The concept of urbanization; its features in countries of various socio-economic types. • Urban agglomerations and megalopolises of the world.
3.3. Carbon footprint and how I can help the planet by reducing my carbon footprint	–	–	• Changes in nature caused by human economic activities.	–	–	–

SECONDARY EDUCATION						
Section in the Climate Box textbook	Geography Programmatic and thematic content					
	5th grade	6th grade	7th grade	8th grade	9th grade	10th grade
PART 3. How to prevent dangerous climate change						
3.4. Global cooperation on climate change and sustainable development	–	–	• Interaction between human beings and nature on different continents. • The need for international cooperation in the use of nature and its protection. Development of environmental protection activities at the present time. • Global sustainability problems and international efforts to tackle them. • United Nations and Sustainable Development Goals. • UNESCO World Heritage: natural and cultural sites	–	–	• Global issues: global climate change, natural disasters, shortage of water resources and deterioration of it quality, desertification of land and soil degradation, biodiversity conservation. • Contamination of the World Ocean and the use of its resources. • Possible ways to address global issues. Your country`s contribution to solving global issues.

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 1. The problem of climate change					
1.1. Climate and weather	**5th grade** • Scientific methods for studying living nature: observation, experiment, description, measurement, classification. • Seasonal changes in plant life. **7th grade** • Seasonal changes in the life of the plant community. **11th grade** • Abiotic factors: light, temperature, humidity. Adaptation of organisms to the abiotic factors. Biological rhythms.	**7tth grade** • Physics. Natural phenomena. • Physical quantities. Measurement of physical quantities. • Aggregate states of things. Features of the aggregate states of water. • Earth's atmosphere and atmospheric pressure. Reasons for existence of the atmosphere of the Earth. Measuring atmospheric pressure. Dependence of atmospheric pressure on altitude above sea level. Instruments for measuring atmospheric pressure. **8th grade** • Air humidity. **9th grade** • Reflection of light. Law of light reflection.	**8th grade** • Physical properties of substances. Aggregate state of substances. • Air is a mixture of gases. Air composition. • Oxides. • The water cycle in nature.	–	–
1.2 Climate types and climate zones	**5th grade** • Natural zones of the Earth, their inhabitants. Flora and fauna of natural zones. **7th grade** • Plants of natural zones of the Earth. Flora. **8th grade** • Animals of natural zones of the Earth. Basic patterns of distribution of animals on the planet. Fauna.	–	**8th grade** • The water cycle in nature.	–	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 1. The problem of climate change					
1.3. How and why the climate changed in the past	**7th grade** • "Living fossils" of the plant kingdom. **8th grade** • Paleontology. Fossil remains of animals, their study. "Living fossils" of the animal world. **11th grade** • The sequence of appearance of species in the fossil record. • The main stages of the evolution of the organic world on Earth, the development of life by eras and periods.	**9th grade** • Rectilinear propagation of light. Eclipses of the Sun and Moon. • Reflection of light. Law of light reflection. **11th grade** • Solar system. • Sun. Solar Activity.	**8th grade** • Classification of chemical reactions (compounds, decomposition, substitution, exchange).	–	–
1.4. Climate change today	**6th grade** • Photosynthesis. • Plant respiration. • Formation of growth rings in trees. **9th grade** • Civilization. • Technogenic changes in the environment. **11th grade** • Cycles of substances (carbon, nitrogen).	–	**8th grade** • Classification of chemical reactions (compounds, decomposition, substitution, exchange). • Fuel: coal and methane. Air pollution, increased greenhouse effect, destruction of the ozone layer. **9th grade** • Carbon, distribution in nature, physical and chemical properties. Carbon cycle in nature. • Environmental problems associated with carbon monoxide, global climate change, greenhouse effect.	**6th grade** • The connection between humans and nature. **10th grade** • The contradictory nature of progress.	**8-11th grades** • The influence of human activities on the natural environment. • Environmental literacy and rational resources management.

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.1. How climate change affects the weather	**7th grade** • Seasonal changes in the life of the plants. **9th grade** • Dependence of human health on the state of the environment. • Environmentally conscious behaviour and behaviour in dangerous and emergency situations.	**8th grade** • Vapourization and condensation. Evaporation.	**8th grade** • Physical and chemical phenomena. • The water cycle in nature. **9th grade** • Carbon cycle in nature. • Carbon oxides, their physical and chemical properties. Environmental problems associated with carbon monoxide, global climate change, greenhouse effect.	–	**8-11th grades** • Meteorological emergencies: storms, hurricanes, tornadoes, torrential rains, hail, frost, heat. • Possibilities of forecasting, warning, mitigation of consequences. Informing and alerting the population about emergency situations. • Rules for safe behaviour. Consequences of meteorological emergencies. • Evacuation of the population in emergency situations, the procedure for the population.

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.2. How climate change affects plants and animals	**5th grades** • Adaptation of organisms to their environment. Seasonal changes in the life of organisms. • The concept of natural systems. • Human influence on wildlife throughout history. • Ways to preserve biological diversity. Protected areas (reserves, sanctuaries, national parks, natural monuments). Red List of your country. **7th grade** • Evolutionary development of the plant world on Earth. • Protection of flora. Restoring the number of rare plant species: specially protected natural areas. The Red List of your country. Measures for the conservation of flora. **8th grade** • Diversity of the animal world. • Evolutionary development of the animal world on the Earth. • Extinct animals. • Restoring the number of rare animal species. • Measures for the conservation of wildlife. **11th grade** • Evolution of species. • Community of organisms – biocenosis. Connections in the biocenosis. • The concept of ecosystem and biogeocenosis. • Biodiversity as a factor in the sustainability of ecosystems. Preservation of biological diversity on Earth. • Conservation of biodiversity as the basis for the sustainability of the biosphere.	–	**8th grade** • Physical and chemical phenomena. • The role of solutions in nature and in human life. • The water cycle in nature. **9th grade** • Chemical pollution of the environment with nitrogen compounds (acid rain, air, soil and water pollution). • Carbon cycle in nature. • Carbon oxides, their physical and chemical properties, effects on living organisms.	**11th grade** • Environmental legislation. • Environmental violations.	**8-11th grades** • Rules of conduct necessary to reduce the risk of encountering wild animals, the procedure for action when encountering them; what to do in case of bites from wild animals, snakes, spiders, ticks, and insects.

SECONDARY EDUCATION					
Section in the Climate Box textbook	**Programmatic and thematic content**				
	Biology	**Physics**	**Chemistry**	**Social Sciences**	**Safety basics**
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.3. How climate change affects forests	**6th grade** · Photosynthesis. · Plant respiration. **11th grade** · Ecosystem of coniferous or deciduous forest. · The basis of rational use of natural resources.	–	**8th grade** · The water cycle in nature. **9th grade** · Carbon cycle in nature. · Carbon oxides, their physical and chemical properties, effects on living organisms.	**11th grade** · Environmental legislation. · Environmental violations.	**8-11th grades** · Wildfires. Forecasting and warning capabilities. Rules for safe behaviour. Consequences of wildfires for people and the environment.
2.4. How climate change affects water resources	**8th grade** · Adaptation of fish to environmental conditions. · The importance of fish in nature and human life. Economic importance of fish. **11th grade** · Ecosystems of rivers and lakes.	–	**8th grade** · Physical and chemical phenomena. · Acids and salts. · Oxides. Properties of oxides. · Physical properties of water. · Water is a solvent. Chemical properties of water. · The role of solutions in nature and in human life. · The water cycle in nature. · Water contamination. Protection and purification of fresh waters. · Solubility of substances in water. **9th grade** · Chemical pollution of the environment with nitrogen compounds (acid rain, air, soil, and water pollution). **11th grade** · The medium of aqueous solutions of substances: acidic, neutral, alkaline.	–	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.5. How climate change affects agriculture	**5th grade** · Changes in nature due to the development of agriculture. **6th grade** · Plant nutrition. · Soil, its fertility. **7th grade** · Agriculture. Cultivated plants of agricultural land. **8th grade** Domestication of animals. Farmland animals. **11th grade** · Agroecosystems. · Biological and economic importance of agroecosystems. · The basis of rational use of natural resources.	–	**8th grade** · Physical and chemical phenomena. · Acids and salts. · Water is a solvent. · Chemical properties of water. · The water cycle in nature. · Waters contamination. · Solubility of substances in water. **9th grade** · Chemical pollution of the environment by nitrogen compounds (acid rain, air, soil, and water pollution).	**6th grade** · The connection between human beings and nature.	–
2.6. How climate change affects coastal regions	**8th grade** · Game animals (fishing, hunting).	–	**8th grade** · Water is a solvent. Chemical properties of water.	**6th grade** · The connection between human beings and nature.	**8-11th grades** · Hydrological emergencies: floods, tsunamis. · Possibilities for forecasting, warning, mitigation. · Rules for safe behaviour. Consequences of hydrological emergencies

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.7. How climate change affects mountain regions	–	–	–	**6th grade** • The connection between human beings and nature.	**8-11th grades** • Geological emergencies: earthquakes, volcanic eruptions, landslides, mudflows, rockfalls, avalanches. • Possibilities for forecasting, warning, mitigation. • Rules for safe behaviour. • Consequences of geological emergencies.
2.8. How climate change affects the Arctic region	–	**7th grade** • Aggregate states of matter: structure of gases, liquids and solid (crystalline) bodies. Features of the aggregative states of water.	**8th grade** • Physical properties of substances. Aggregate state of substances. • Physical and chemical phenomena. • Chemical properties of water. • Solubility of substances in water.	**6th grade** • The connection between human beings and nature.	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 2. How climate change affects the natural world and human beings. Can we adapt to the inevitable consequences of climate change?					
2.9. How climate change affects cities and human health	**7th grade** • Plants of the city, a feature of the urban flora. Parks, forest parks, botanical gardens. **8th grade** • The city as a special artificial environment created by man. • Synanthropic species of animals. Their living conditions. • Recreational pressure on wild animals in the city. **9tth grade** • Urbanization. **11th grade** • Urban ecosystems. Biological and economic importance of urban ecosystems.	**10th grade** • Technologies for producing modern materials, including nanomaterials, and nanotechnology.	**8th grade** ·The water cycle in nature. • Water contamination. • Solubility of substances in water. **9th grade** • Carbon oxides, their physical and chemical properties. • Environmental problems associated with carbon monoxide, global climate change, greenhouse effect.	–	**8-11th grades** • Methods of protection against overheating and hypothermia in different conditions. First aid for overheating, hypothermia, and frostbite.
2.10. How climate change affects social problems	–	–	**9th grade** • Chemical pollution of the environment by nitrogen compounds (acid rain, air, soil and water pollution).	**6th grade** • The connection between society and nature. • Social communities and groups. The position of a person in society. **11th grade** • Social inequality. • Migration processes in the modern world.	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 3. How to prevent dangerous climate change					
3.1. 'Green' energy sources **3.1.1. What is energy?** **3.1.2. The main sources of energy**	**7th grade** • The role of ancient ferns in the formation of coal.	**8th grade** • Fuels. Operating principles of heat engines. Heat engines and environmental protection. **11th grade** • Production, transmission, and consumption of electrical energy.	**11th grade** • The role of chemistry in ensuring environmental and energy security.	**6th grade** • Resources and economy of your country.	–
3.1.3. Fossil fuels	–	–	**8th grade** • Fuel: coal and methane. Air pollution, increased greenhouse effect, destruction of the ozone layer. **9th grade** • Initial concepts of organic substances as carbon compounds (methane, ethane, etc.) • Natural sources of hydrocarbons (coal, natural gas, oil), their processed products (gasoline), their role in everyday life and industry. **10th grade** • Natural sources of hydrocarbons and their processing. • Natural gas. Associated petroleum gases. Oil and its origin. Oil refining methods: distillation, cracking (thermal, catalytic). Petroleum products, their use in industry and everyday life. • Coal and products of its processing.	**6th grade** • Resources and economy of your country.	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 3. How to prevent dangerous climate change					
3.1.4. Nuclear energy	–	**9th grade** · Nuclear energy. **11th grade** · Problems and prospects of nuclear energy.	–	–	–
3.1.5. Renewable energy sources	–	**8th grade** · Methods of electrical energy generation. · Power plants using renewable energy sources.	–	–	–
3.1.6. Advantages and disadvantages of different energy sources	–	**9th grade** · Effects of radiation on living organisms. **10th grade** · Environmental problems of the power industry. **11th grade** · Environmental risks during electricity generation. · Environmental aspects of nuclear energy.	**9th grade** · Natural sources of hydrocarbons (coal, natural gas, oil), their processed products (gasoline), their role in everyday life and industry.	**6th grade** · Resources and economy of your country.	–

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 3. How to prevent dangerous climate change					
3.2. Energy efficiency and energy saving **3.2.1. Environmentally friendly transport** **3.2.2. Household appliances and electrical devices**	–	**8th grade** · Electrical circuits and consumers of electrical energy in everyday life. · Use of electric motors in technical devices and transport. **10th grade** · Electric heating and electric lighting devices – technical design and practical application. · Technical devices and practical application: internal combustion engine, household refrigerator, air conditioner. **11th grade** · The culture of using electricity in everyday life.	**9th grade** · Natural sources of hydrocarbons and products of their processing (gasoline), their role in everyday life and industries.	**10th grade** · Worldview, its role in human life. · Rational economic behaviour. · Economic activities and sustainable development. **11th grade** · Environmental legislation. · Environmental violations.	**8-11th grades** · The influence of human activities on the natural environment. · Environmental literacy and rational environmental management.
3.2.3. Green construction. Passive and active buildings **3.2.4. Green cities**	**7th grade** · Plants of the city, a feature of the urban flora. Parks, forest parks, botanical gardens.	–	**9th grade** · The most important building materials: ceramics, glass, cement, concrete, reinforced concrete. Problems of safe use of building materials in everyday life. · Alloys (steel, cast iron, duralumin, bronze) and their use in everyday life and industry. **11th grade** · General physical properties of metals. The use of metals in everyday life, nature, and technology. Metal alloys.	**6th grade** · The connection between human beings and nature. **11th grade** · Environmental legislation. Environmental violations.	**8-11th grades** · The influence of human activities on the natural environment. · Environmental literacy and rational environmental management

SECONDARY EDUCATION					
Section in the Climate Box textbook	Programmatic and thematic content				
	Biology	Physics	Chemistry	Social Sciences	Safety basics
PART 3. How to prevent dangerous climate change					
3.3. Carbon footprint and how I can help the planet by reducing my carbon footprint	**11th grade** · Methods of environmental research. · Ecological worldview of modern people.	**11th grade** · The culture of using electricity in everyday life.	**8th grade** · Physical and chemical phenomena. **10th grades** · Plastics. · Natural and synthetic rubbers. · Fibre: natural (cotton, wool, silk), artificial (acetate fibre viscose), synthetic (nylon and lavsan). **11th grade** · Humans in the world of substances and materials. · Household chemical literacy.	**6th grade** · The connection between human beings and nature. **7th grade** · Moral assessment of people's behaviour and your own behaviour. **10th grade** · Worldview, its role in human life. · Rational economic behaviour.	**8-11th grades** · The influence of human activities on the natural environment. · Environmental literacy and rational environmental management
3.4. Global cooperation on climate change, sustainable development and all-of-society approach to deal with climate change	**9th grade** · The importance of environmental protection for the preservation of humanity. **11th grade** · Anthropogenic changes in the biosphere. Global ecological problems.	–	**8th grade** · Protection and purification of fresh water. **9th grade** · Environmental problems associated with carbon monoxide, global climate change, greenhouse effect.	**6th grade** · Strengthening the relationships between countries and people in modern society. · Global problems of our time and the possibilities of solving them through the collaboration of the international community and international organizations 9th grade Global problems and possibilities for their solution. The environmental situation and ways to improve it.	**8-11th grades** · Environmental emergencies. Possibilities of forecasting, warning, mitigation of consequences.

LIST OF ILLUSTRATIONS

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