2024 Edition

Trend Compendium **2050**

Megatrend 3

Environment & Resources

The Roland Berger Trend Compendium 2050 focuses on stable, long-term developments …

- The **Roland Berger Trend Compendium 2050** is a global trend study compiled by **Roland Berger Institute (RBI)**, the think tank of Roland Berger. Our Trend Compendium 2050 describes the **most important megatrends** shaping the world between **now and 2050**
- Our **trend views are based on most recent studies, data and analyses.** We critically examine the results for relevance, plausibility and reliability
- We deliberately use **publicly available sources** to make our analyses verifiable
- To incorporate today's uncertainties into strategic planning, we recommend **combining the megatrends of the Roland Berger Trend Compendium 2050** with the **Roland Berger scenario planning approach**

Is it worth dealing with megatrends when globally impactful events such as the COVID-19 pandemic or the war in Ukraine are taking place?

Of course! The coronavirus pandemic and the war in Ukraine have far-reaching consequences and deeply affect people, economies, and politics but neither event has derailed the megatrends analyzed herein – such is the inherent nature of megatrends: climate change, societal aging, or technological innovations do not lose their momentum, their direction, or their importance. To cope with such challenges and to master resulting opportunities, our awareness and our understanding of megatrends is vital – not least to develop sustainable answers.

… and covers six megatrends that shape the future development of our world to 2050

1 People & Society	2 Politics & Governance	3 **Environment & Resources**	4 Economics & Business	5 Technology & Innovation	6 Health & Care
Population	Global Risks	Climate Change & Pollution	Global Trade & Value Chains	Value of Innovation	Global Health Challenges
Migration	Geopolitics	Biodiversity	Power Shifts	Frontier Technologies	Healthcare of the Future
Education & Labor	Future of Democracy	Water	Energy Transformation	Humans & Machines	Caregiving
Values		Resources & Raw Materials	Debt Challenge		

Accelerating the mitigation of global climate change effects is a must – In the future, biodiversity, water, and resources & raw materials face critical issues

Subtrends of megatrend "Environment & Resources"

1


Climate Change & Pollution

2


Bio-diversity

3

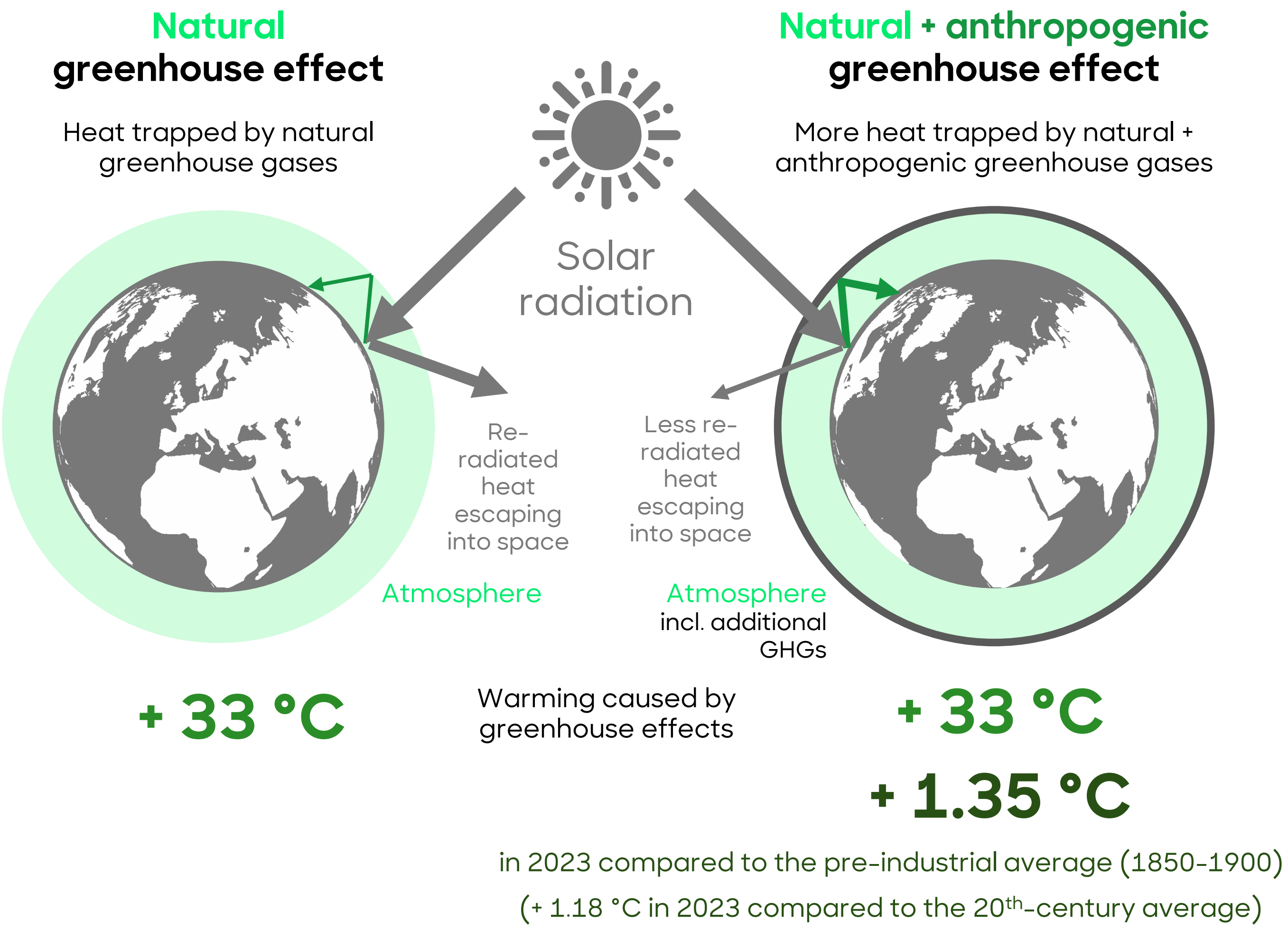

Water

4


Resources & Raw Materials

To address the climate change challenge, it is necessary to recognize that humans have added a critical layer to the natural greenhouse effect

Illustration of the natural and anthropogenic greenhouse effect



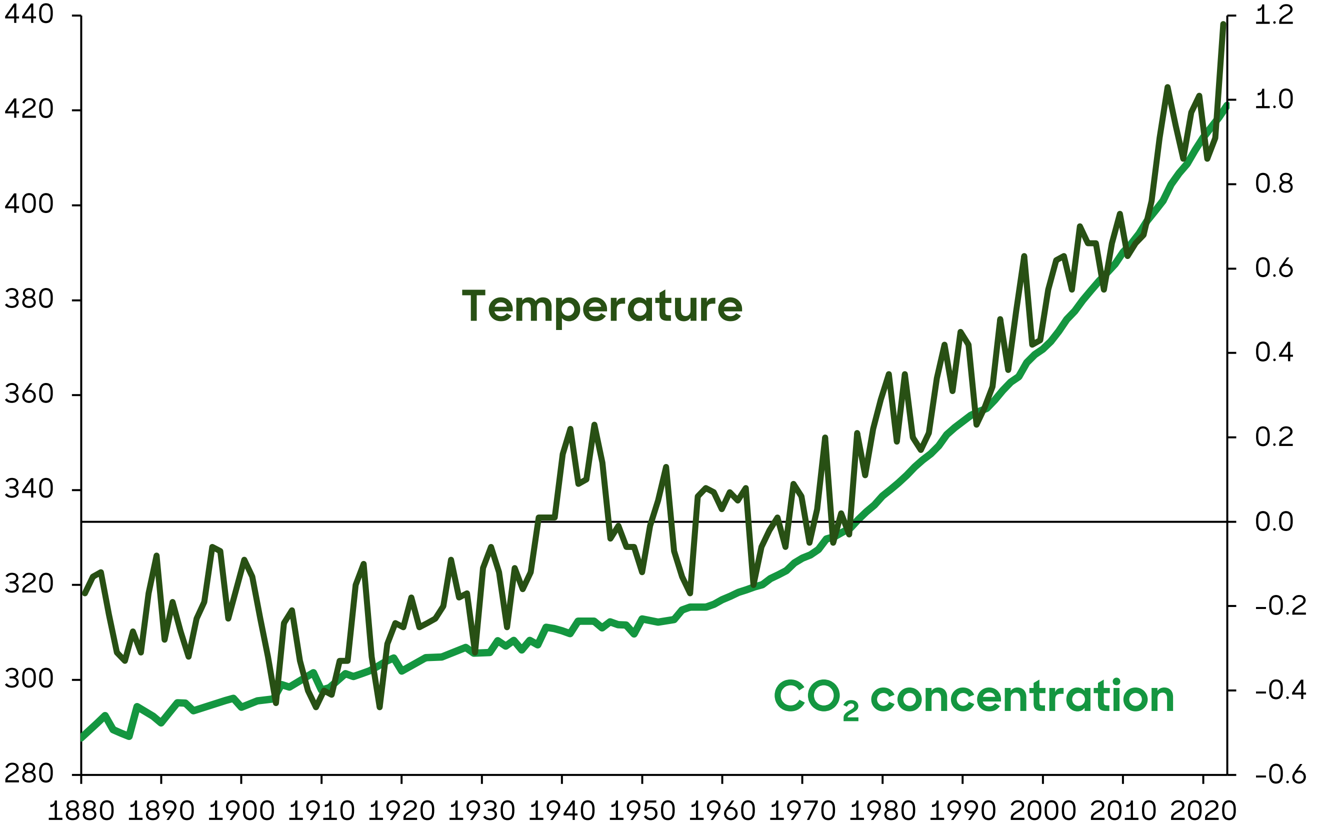
- The **greenhouse effect** is a process that **heats the Earth's surface.** When solar radiation reaches the Earth, some of it is re-radiated into space, while some is trapped by greenhouse gases in the atmosphere, warming the Earth
- The **natural greenhouse effect,** caused by water vapor and natural levels of carbon dioxide (CO_2), methane, nitrous oxide, and ozone in the atmosphere, **keeps the Earth's temperature about 33 °C warmer than otherwise** (15 °C average surface temperature instead of -18 °C). Water vapor accounts for 36-85% of the overall greenhouse effect, depending on sky and regional conditions
- **Human activities** – particularly activities such as the burning of fossil fuels (coal, oil, natural gas), agriculture, and land clearing at scale – **are increasing the concentration of greenhouse gases,** in particular CO_2, methane, and nitrous oxide. This is the anthropogenic greenhouse effect, causing an additional warming of the Earth of **1.35 °C (2023)** above the pre-industrial average
- Compared to the natural greenhouse effect, the **anthropogenic greenhouse effect** looks small. But it **appeared very fast,** so that Earth's natural systems (e.g. ecosystems, ocean currents, jet stream, etc.) and civilization could not adapt at the same rate

Source: NOAA/Climate.gov; NRDC; Real Climate; Niwa; Roland Berger

CO_2 levels and global temperatures have risen over the last century, with both trends persisting into this century

CO_2/Temperature increase nexus

CO_2 concentration in the atmosphere [left scale, ppm] **and global temperature anomalies compared to the average global temperature in the 20th century** [right scale, °C]

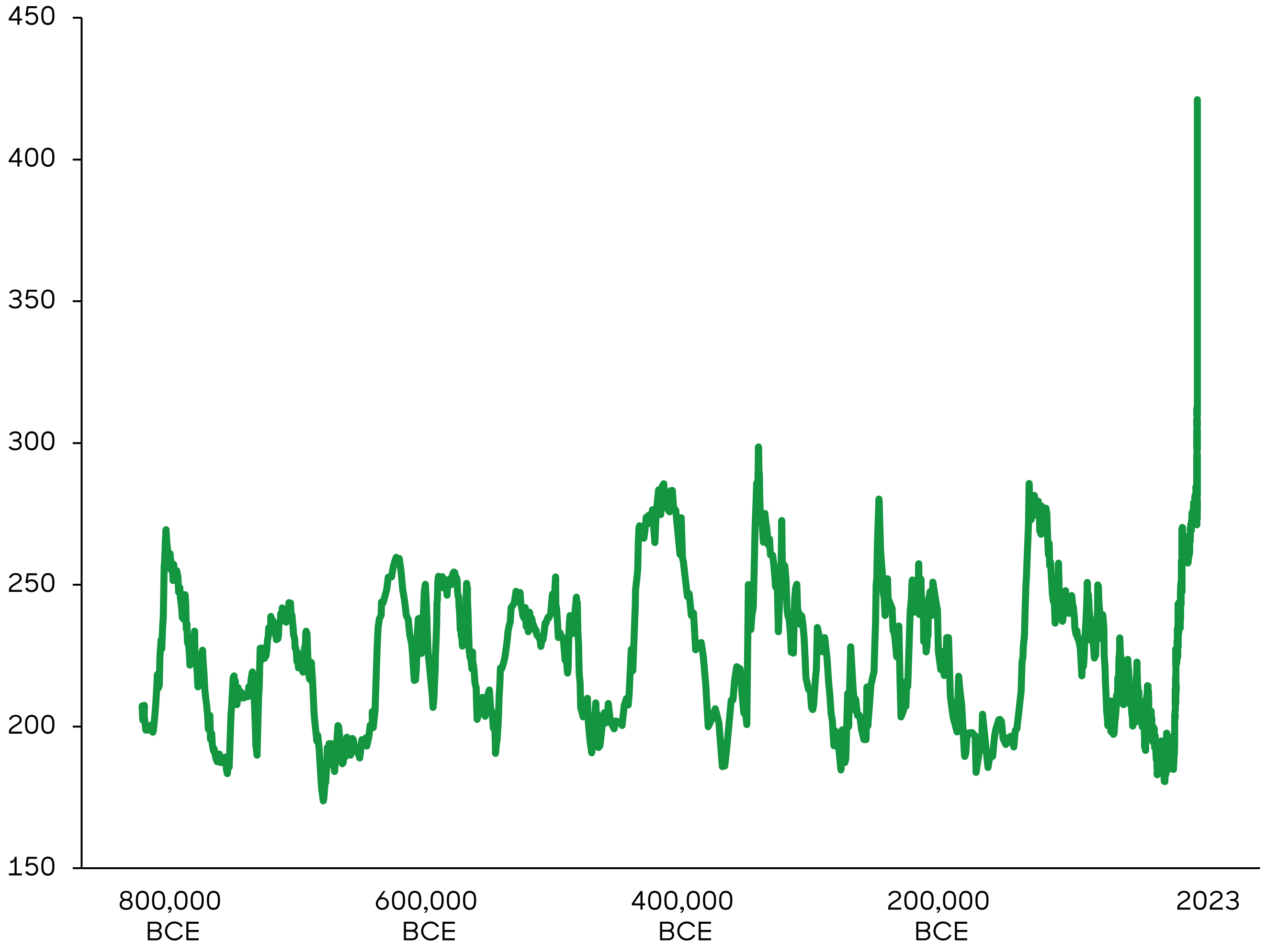


- **Since the 1880s, carbon dioxide** (CO_2) **concentration in the atmosphere has increased** significantly, rising **even more rapidly within the past 60 years.** Today, it is well above 400 parts per million (ppm)
- In parallel to the rise in CO_2 concentration, the global average temperature increased by **1.18 °C above the 20th century average** (2023), which is 1.35 °C above pre-industrial levels
- **Globally,** the ten most recent years (2014-2023) were the warmest on record, herein **2023 was the warmest**
- **May 2024** was the **twelfth month in a row** that was the **warmest** for the respective month of the year. The average global temperature in the 12-month period between **June 2023 and May 2024 exceeded pre-industrial levels by 1.63 °C**
- The graph only shows CO_2 concentration. Other **greenhouse gases** (GHG) **also contribute to the greenhouse effect** and human-induced climate change: besides CO_2, **methane** (CH_4) and **nitrous oxide** (N_2O) also play an important role
- **CO_2's lifetime cannot be represented with a single value** as some of the excess CO_2 is absorbed quickly (e.g. by the ocean surface) while some will remain in the atmosphere for thousands of years; **methane** lasts about **12 years** and **nitrous oxide** around **109 years**

Source: NOAA; Climate Action Tracker; NASA; EU EEA; EPA; IPCC; Roland Berger

CO_2 concentration – the main GHG contributor – has reached its highest level on record at an accelerated rate

Long-term atmospheric concentration of CO_2 [ppm]



- The **current concentration levels of CO_2** in the atmosphere are the **highest for at least 800,000 years.** Such long-term trends in CO_2 concentration can be measured through means of preserved air samples from ice cores
- Historic **peak and trough cycles of CO_2 concentrations** comprise intervals of ice ages (lower CO_2 concentration) and warmer interglacial periods (higher CO_2 concentration). During these cycles, CO_2 concentrations **did not exceed 300 ppm** in the last 800,000 years – but they are well **above 400 ppm today**
- Even if the global community achieves a decrease in carbon emissions, this will not have an immediate impact on lowering atmospheric concentrations because **CO_2 remains in the atmosphere for a long time – until it is removed by natural processes,** such as **absorption** through land vegetation, soils, and the ocean acting as so-called natural **carbon sinks**
- **Natural absorption processes last from less than five years to thousands of years.** Thus, even if CO_2 emissions were completely stopped today, we would still be faced with higher CO_2 concentrations for several hundred years

Source: Our World in Data; NOAA; SIO; Roland Berger

Climate change is a complex topic – Analysis of human-made effects date back to the late 19th century

Background information and frequently asked questions on climate change

How is the global temperature measured?

Scientists measure global temperature by **combining sea surface and land surface air temperatures,** calculating temperature anomalies relative to a standard period. This method accounts for daily and seasonal variations across different regions, providing a consistent way to track Earth's climate trends

If carbon dioxide hits a new high every year, why isn't every year hotter than the last?

Earth's temperature doesn't rise instantly with each increase in carbon dioxide due to the ocean's ability to absorb and store heat, causing a lag in warming. Over time, the correlation between higher CO_2 and temperature is evident, but **year-to-year variations occur due to natural climate patterns** like El Niño and La Niña, volcanic activity, solar variability, and other factors

If the globe is still warming, then why are some locations not warming while others have experienced cooling?

Global warming means an increase in Earth's overall average temperature over extended periods, yet this warming is not evenly distributed. **Variations in regional factors such as sunlight exposure, cloud cover, atmospheric circulation, and land surface characteristics** can lead to some areas not warming or even experiencing cooling, despite the general upward trend in global temperatures. According to the latest data, Europe is the fastest warming continent in the world

How do we know the build-up of carbon dioxide in the atmosphere is caused by humans?

The surge in atmospheric CO_2 levels is consistent with human activity, especially the burning of fossil fuels. The **high and quick increase of atmospheric CO_2 levels far exceeds natural rates.** In addition, CO_2 stemming from the burning of fossil fuels has a **characteristic isotopic fingerprint** which can be detected in today's atmosphere

When was anthropogenic global warming mentioned the first time?

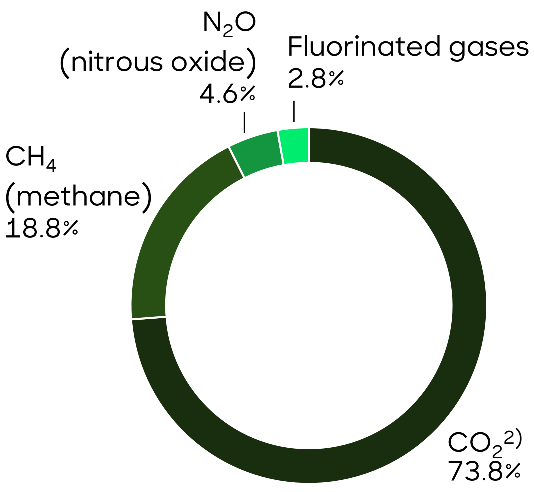
In **1896, Swedish chemist Svante Arrhenius** estimated the extent to which **increases in atmospheric CO_2** are responsible for the **Earth's increasing surface temperature** through natural as well as human-made greenhouse effects. In **1975, geochemist Wallace Broker** coined the term **"global warming".** In **1988, NASA scientist James E. Hansen** reported a **clear cause and effect** between excess CO_2 and global warming. In the same year, the Intergovernmental Panel on Climate Change (IPCC) was formed to collect and evaluate evidence on climate change

Source: NOAA; Roland Berger

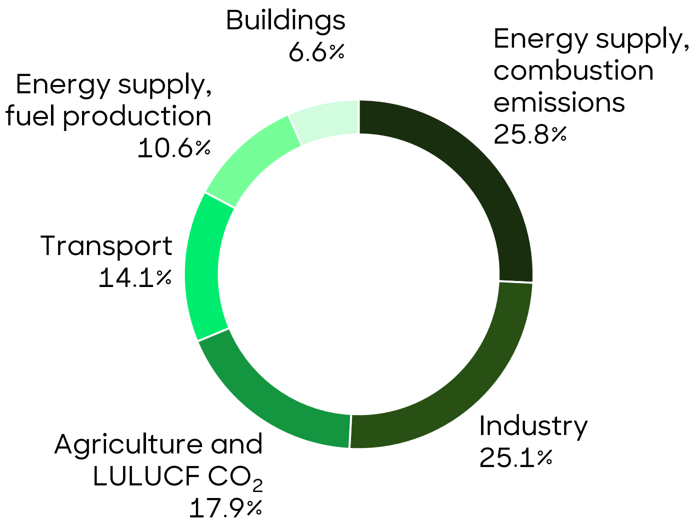
CO_2 leads GHG emissions, comprising nearly 75% in 2022 – Sector breakdown highlights critical areas for emission reductions

Global greenhouse gas emissions

Composition of global greenhouse gas emissions 2022[1] [%]



Sector breakdown of global greenhouse gas emissions 2022[3] [%]



Global GHG emissions 2022: 57.4 Gt CO_2e

- To make emissions from greenhouse gases (GHG) like CO_2, methane (CH_4), nitrous oxide (N_2O) and fluorinated gases comparable, scientists evaluate the **Global Warming Potential** (GWP), measuring the contribution to global warming of a specific mass of a GHG relative to the same mass of CO_2
- Over 100 years, the GWP of **methane and nitrous oxide are nearly 30 and 273 times higher,** respectively, than the GWP of CO_2
- Due to the sheer mass of its emissions **CO_2 contributes nearly 3/4 to GHG emissions** measured in CO_2 equivalents (CO_2e), followed by methane, nitrous oxide and fluorinated gases
- **Energy supply** (combustion emissions in the power sector and emissions from fossil fuel production) **and industrial combustion and processes** are responsible for more than **60%** of all **GHG emissions.** Some industries, like steel and cement producers, emit high amounts of CO_2
- **Agriculture and land-use, land-use change** (e.g. deforestation for farmland) and **forestry, transport** and **buildings** together emit almost **40%** of GHGs
- The **sector breakdown** shows where the **biggest levers** are to decrease GHG emissions

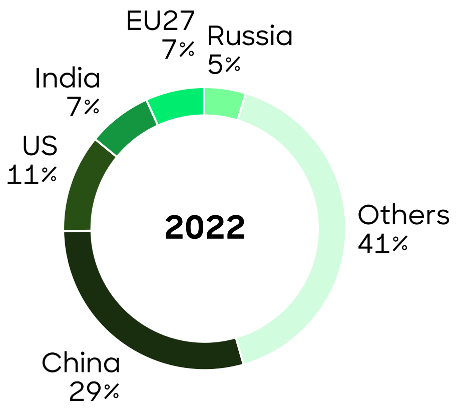
1) According to their Global Warming Potential; 2) The bigger part (67.0% of total GHG emissions) of CO_2 emissions is from burning fossil fuels; the smaller part (6.7% of total GHG emissions) stems from land use, land-use change, and forestry (LULUCF GHG emissions); 3) Sum is 100.1% due to roundings

Source: UNEP; European Commission; Roland Berger

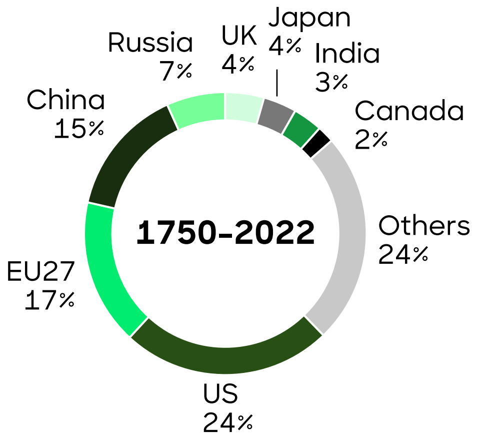
Comparing GHG emissions reveals national disparities and high carbon efficiency pathways for reducing emissions

GHG emissions

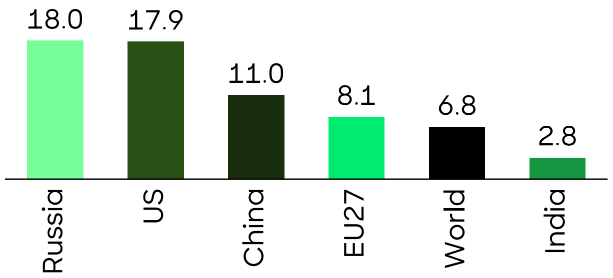
Share of GHG emissions[1] [%]



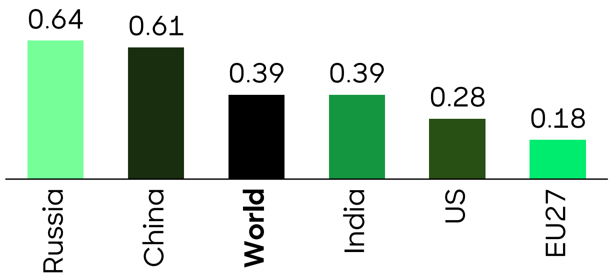
Cumulative share of CO_2 emissions[2] [%]



Per capita emissions of GHG 2022 [t CO_2e/capita]



Per GDP emissions of GHG 2022 [t CO_2e/('USD GDP)]

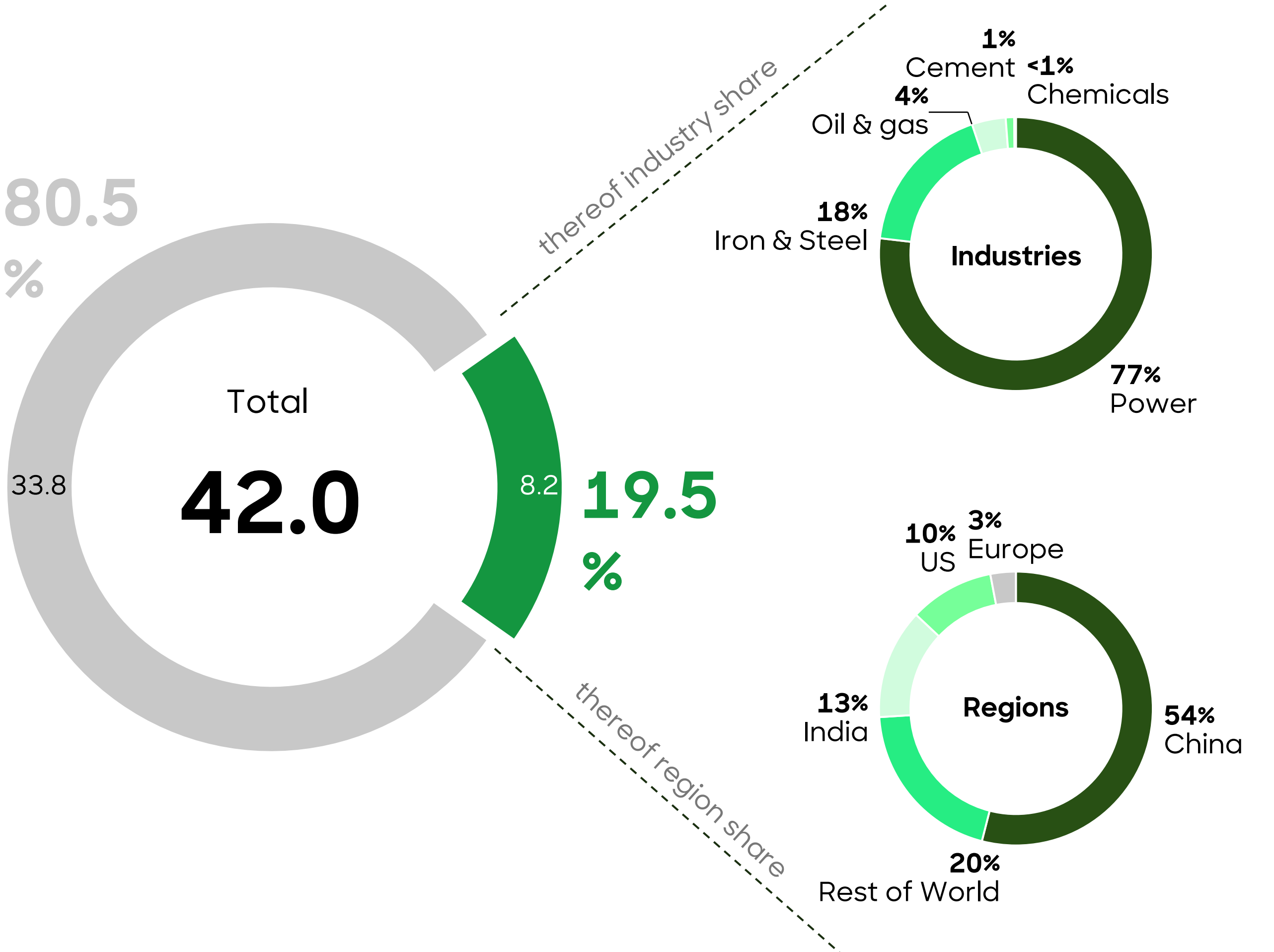


- According to the **most recent data (2022) China is by far the biggest emitter of GHGs,** followed by the US, India, EU27 and Russia. These economies account for 59% of all GHG emissions globally, showing their **big lever for emission reductions**
- The **US and Europe's** (notably including the **UK**) **historical CO_2 emissions** exceed those of China and other emerging and developing nations, underscoring **debates on climate responsibility** and the need for **equitable treatment** in global climate policies that **reconcile past and present contributions**
- The **current per capita emissions** reflect **significant disparities,** with Russia and the US registering high per capita emissions indicative of energy-intensive economies. In stark contrast, India's per capita emissions are quite low, pointing to its **developmental stage** and **population size**
- The EU27 figures suggest **a balance between industrial activity and energy efficiency.** These variances emphasize the challenge of equitably addressing climate change, respecting **each nation's development pathway,** and **emission reduction potential**
- **Emissions in relation to GDP** show significant disparities as well, with the **EU27** establishing **high carbon efficiency** at 0.18 t CO_2e per GDP unit, while **Russia and China** exhibit less efficiency, indicating **room for economic greening**

1) GHG emissions from all anthropogenic activities except land use, land-use change, forestry and large-scale biomass burning;
2) Historically, only data from CO_2 emissions are available
Source: European commission; Global Carbon Budget (2023) with major processing by Our World in Data; Roland Berger

1,000 of the most CO_2-intensive assets are responsible for nearly 20% of all global CO_2 emissions – A concrete lever for action

Global CO_2 emissions, 2021 [Gt CO_2, %]



1,000 most CO_2-intensive assets | Other assets

- In 2021, the **1,000 most CO_2-intensive assets** emitted **19.5% of all CO_2 emissions** worldwide
- Roland Berger's Global Carbon Restructuring Plan (GCRP) outlines the pathway for owners of the **world's major carbon emitters** to enact substantial climate protection measures
- **Power-related facilities,** notably **coal**-based power plants, **emerge as the primary culprits,** emitting approximately 0.9 tons of CO_2 per megawatt hour (MWh), **double the emissions of gas-fueled power plants,** highlighting the power sector's urgency of transitioning away from fossil fuels
- **54% of the 1,000 assets are in China,** 13% stem from India, 10% from the US, only 3% from Europe
- **Ownership** of major **carbon emitters** is concentrated among a select group of companies, with **40 companies responsible for half of the emissions** analyzed in the GCRP study
- **Nearly half of these 40 companies are based in China (48%),** with a fifth coming from the Rest of the World. The US, India, and Europe each account for just under 10%

Source: Roland Berger; IEA

Climate action is a long-standing global effort, culminating in the 2016 Paris Agreement

Selection of climate change negotiations

- **1972** – United Nations conference on the Human Environment is held
- **1988** – The Intergovernmental Panel on Climate Change (IPCC) is set up
- **1994** – The UNFCCC enters into force
- **1997** – The Kyoto protocol is adopted
- **2001** – The Marrakesh accords take place
- **2005** – The EU's Emissions Trading System (ETS) is launched; The Kyoto protocol enters into force
- **2010** – The Cancun agreements are adopted
- **2015** – The **Paris Agreement** is adopted at COP 21[1)]
- **2016** – The **Paris Agreement** enters into force
- **2020** – The EU pledges to become climate-neutral and adopts the Green New Deal – other countries to follow suit
- **2021** – COP 26: Glasgow Climate Pact adoption
- **2022** – COP 27: Agreement to establish a "loss and damage" fund
- **2023** – COP 28: Agreement on global transition away from fossil fuels
- **2024** – COP 29 (11/24): Encouraging cities and communities to adopt climate strategies

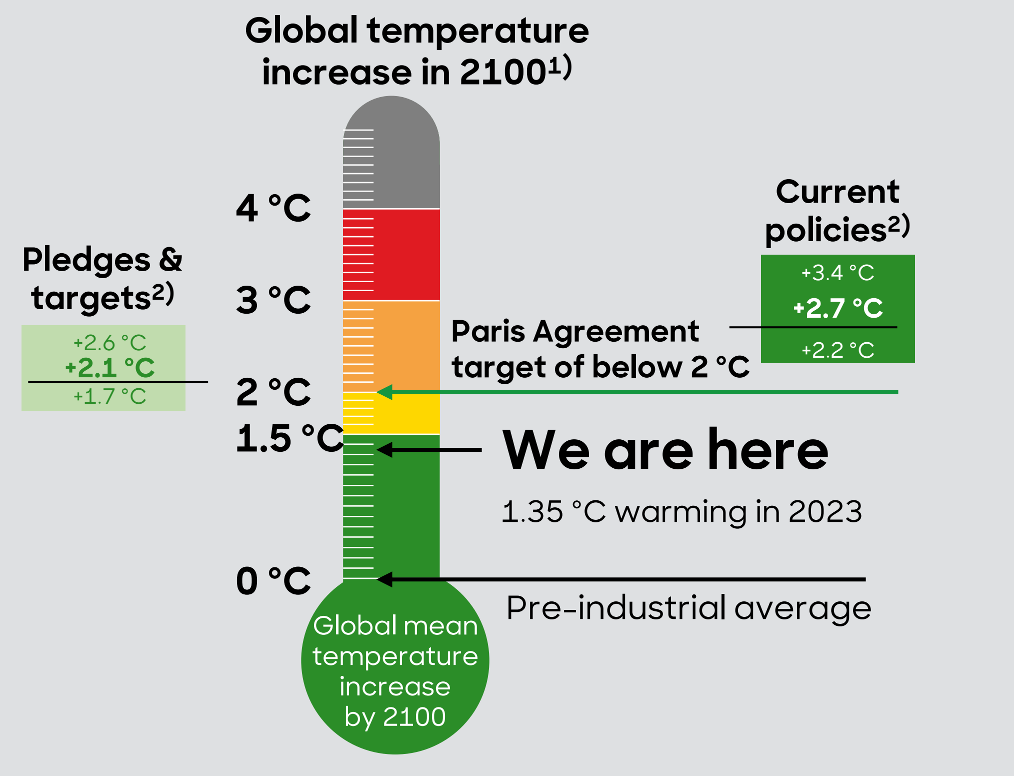
The **Paris Agreement** combating climate change is the first truly universal, legally binding global climate agreement. The goal of the agreement is to hold the rise in global average temperature to **well below 2 °C** above pre-industrial levels, while pursuing **efforts to limit the rise to 1.5 °C.** The deal aims to ensure that global greenhouse gas **emissions peak as soon as possible** and that emissions and removals are balanced in the second half of this century

1) COP 21 stands for "21st session of the Conference of the Parties", COP is the supreme governing body of an international convention; COP 21: UN Framework Convention on Climate Change

Source: European Parliament; Roland Berger

The Paris Agreement's objective is to keep the global temperature rise below 2 °C above pre-industrial levels

Paris Agreement target and status quo of global temperature increase



Is the limit of 2 °C enough?

For some time, keeping global warming below 2 °C had been regarded as the main benchmark in terms of risk limitation. More recently, **1.5 °C is being considered safer**. However, in 2023, **experts believe this target is becoming increasingly hard to achieve.** To keep the 1.5 °C goal viable, rapid and extensive changes across all societal sectors are necessary, coupled with immediate, substantial reductions in greenhouse gas emissions

- The **Paris Agreement,** with 195 signatory parties, endorses the **collective fight against climate change,** setting ambitious global temperature targets
- **In 2023,** the average temperature rise already reached about **1.35 °C above pre-industrial levels,** indicating significant challenges ahead
- Projections based on **existing policies** suggest a possible warming of **2.7 °C by 2100;** however, with **stronger commitments,** this could be reduced to an average of **2.1 °C**
- Scientists from the International Energy Agency emphasize that to limit global warming to **1.5 °C by 2100,** global emissions must reach **net zero by 2050**
- While progress in sectors like electric vehicle sales is promising, the Climate Action Tracker reports that overall efforts fall short, and a **substantial increase in action this decade is crucial** to meet the 1.5 °C target

"There is no 'Plan B' because we do not have a 'Planet B.' We have to work and galvanize our action."

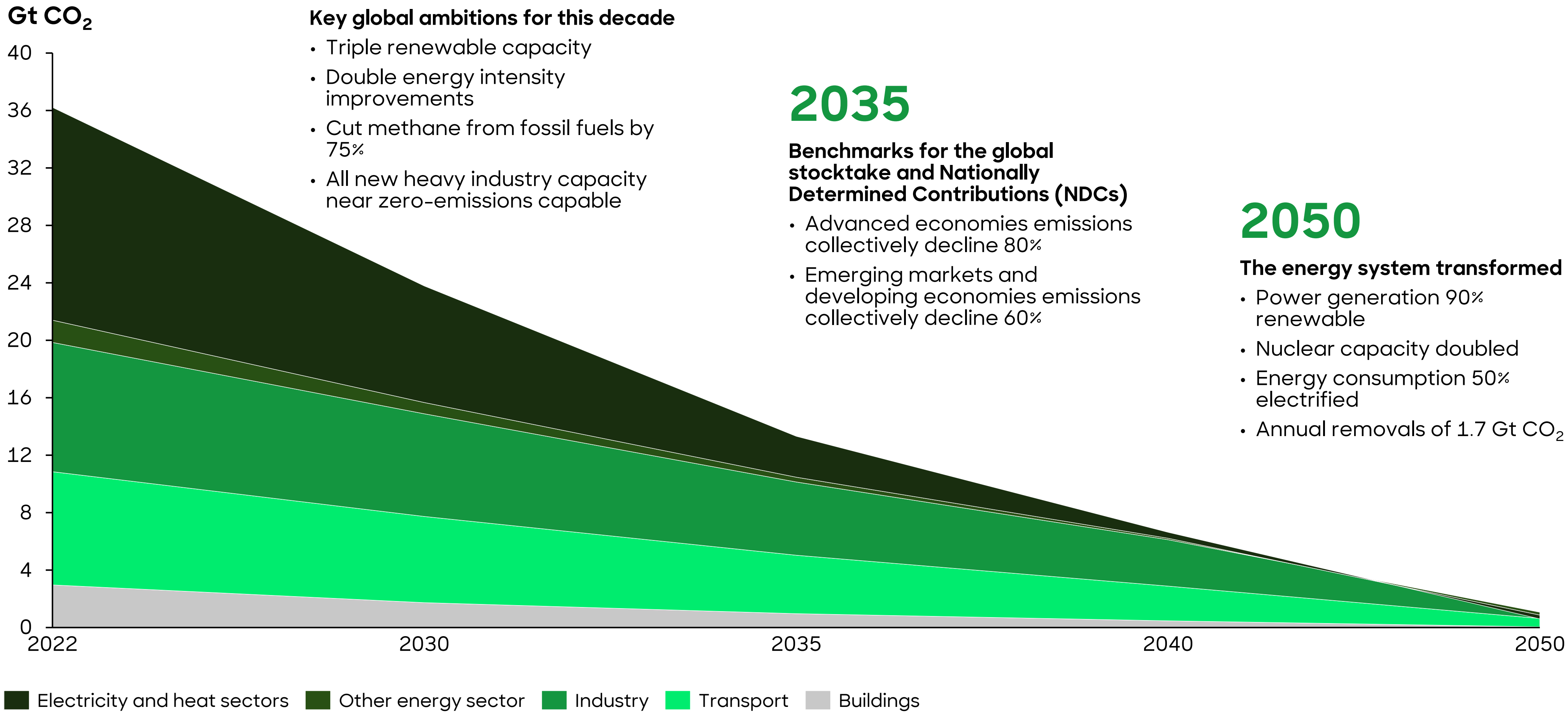
Former UN Secretary-General Ban-Ki Moon

1) Compared to pre-industrial temperature level average; 2) Probability range; 50% probability in bold

Source: Climate Action Tracker; UNFCCC; IEA; Roland Berger

From agreement to an actionable way forward: IEA's Net Zero Emissions (NZE) initiative maps a path to a CO_2-neutral year 2050

Selected global milestones for policies, infrastructure, and technology deployment in the NZE scenario



2030

Key global ambitions for this decade

- Triple renewable capacity
- Double energy intensity improvements
- Cut methane from fossil fuels by 75%
- All new heavy industry capacity near zero-emissions capable

2035

Benchmarks for the global stocktake and Nationally Determined Contributions (NDCs)

- Advanced economies emissions collectively decline 80%
- Emerging markets and developing economies emissions collectively decline 60%

2050

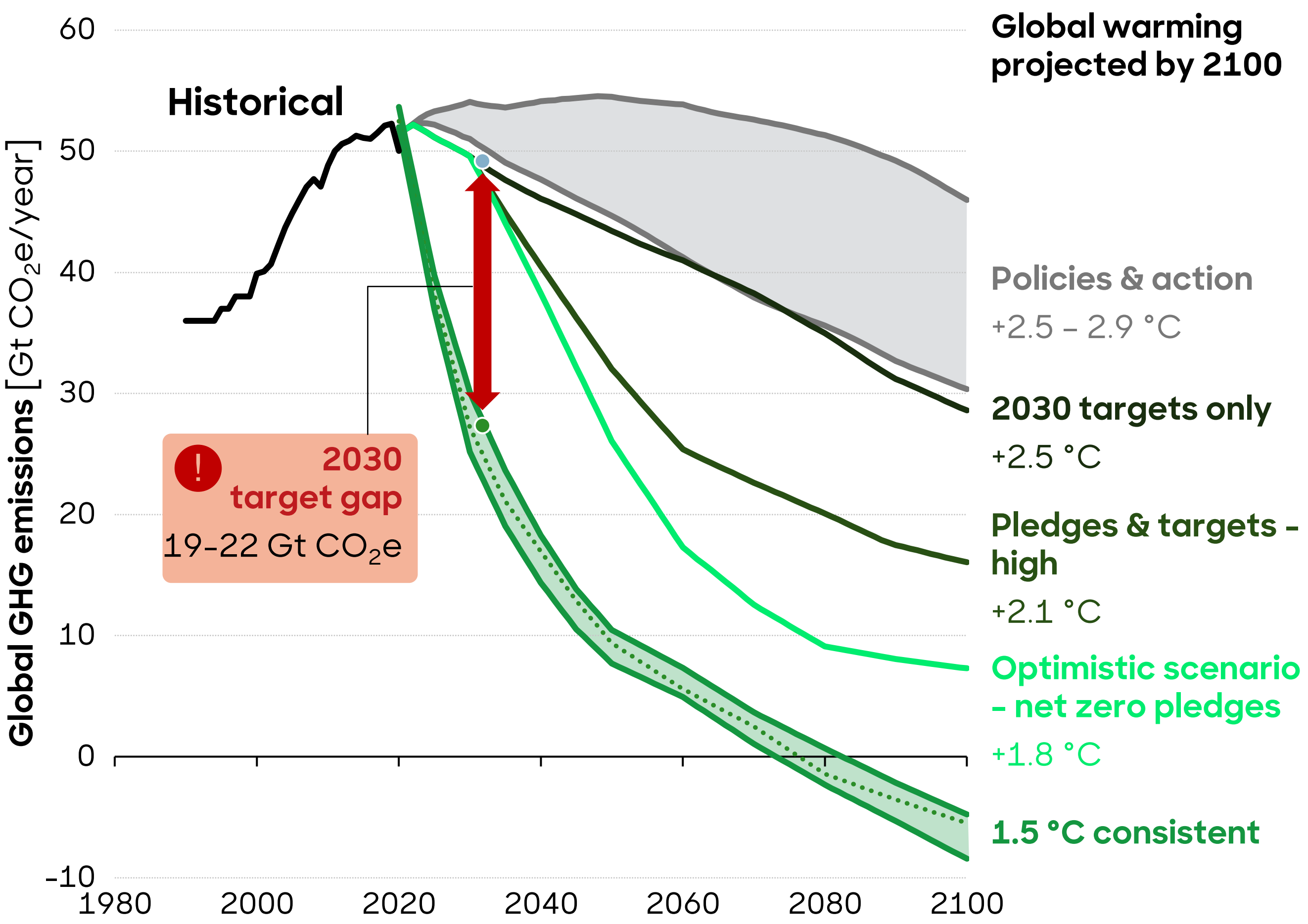
The energy system transformed

- Power generation 90% renewable
- Nuclear capacity doubled
- Energy consumption 50% electrified
- Annual removals of 1.7 Gt CO_2

Source: IEA; Roland Berger

Limiting human-induced global warming to 1.5 °C requires substantial efforts to accomplish carbon neutrality by 2080

2100 global warming projections under different scenarios



The **Climate Action Tracker (CAT)** visualizes various **scenarios** to show the effects of **different efforts to limit global warming**[1)]

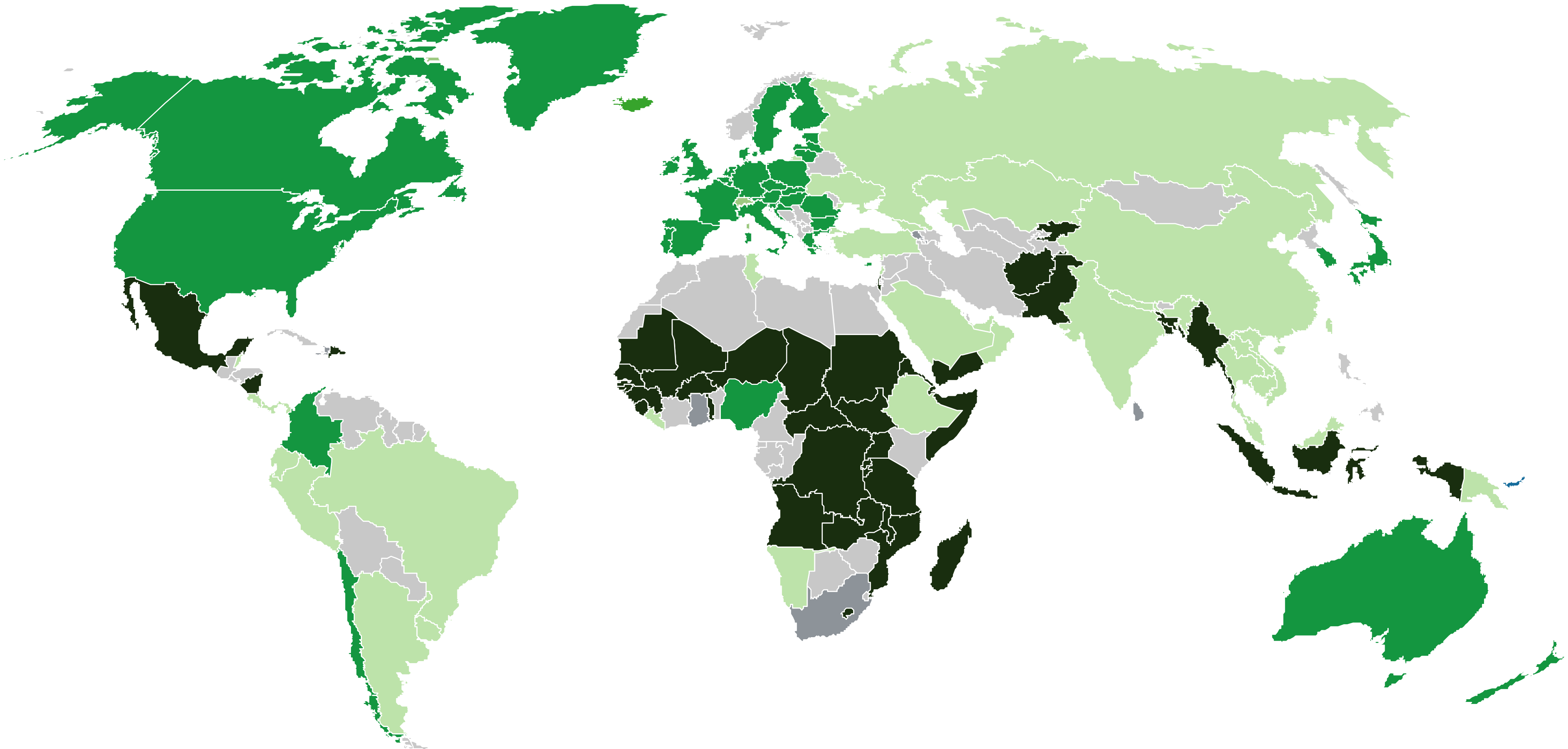
- The scenario **"Policies & action"** refers to **laws which are currently in place** and will most likely result in a global warming of **2.5-2.9 °C**
- **"2030 targets only"** scenario refers to (intended) **nationally determined contributions of governments** within the **Paris Agreement.** This would lead to a global warming of **2.5 °C**
- If **binding long-term or net-zero targets** are included (**"Pledges & targets" scenario**) global warming could be limited to **2.1 °C**
- The **"optimistic scenario"** analyzes the effect of **net-zero emissions targets** that are either adopted or under discussion in around 140 countries. Here, the median warming estimate is **1.8 °C.** As a warming above 2 °C cannot be ruled out, this scenario is not Paris Agreement compatible
- The **dotted green line** is the only case that is **1.5 °C compatible:** in this scenario, **GHG emissions** need to be reduced rapidly to be brought to **zero between 2070 and 2080**
- The **consequences of global warming** are **evident:** rising sea level, ice-free summers in the Arctic, mel-ting glaciers, coral bleaching, heat waves, floods, storms, lower crop yields, extinction of species. The **intensity and irreversibility** of these impacts depend on the **level of the temperature rise**

1) The CAT is an independent scientific project that tracks government climate action and measures it against the globally agreed Paris Agreement aim of "holding warming well below 2 °C, and pursuing efforts to limit warming to 1.5 °C"

Source: Climate Action Tracker; Roland Berger

National laws paving the way to net zero emissions are scarce – Policy documents, pledges, and proposals are more common

Global net zero carbon emission targets as of January 2024



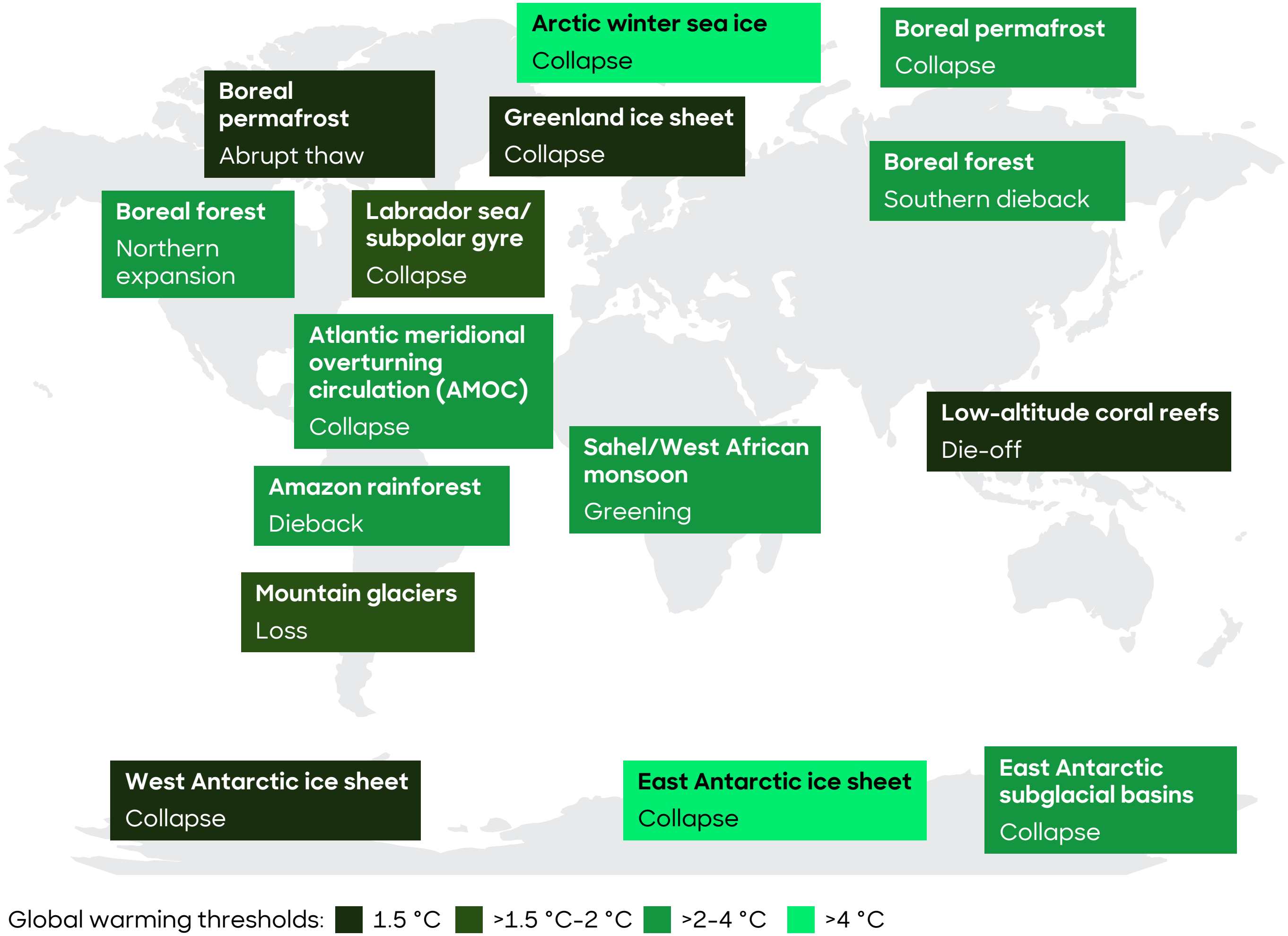
- In law: 29/44[1)]
- In policy document: 49
- No declaration
- Declaration/pledge: 10
- Proposed/under discussion: 54

1) The number of nations with net zero targets enshrined in law if EU Member States are included. The European Climate Law binds EU nations to take the necessary domestic measures to meet climate neutrality by 2050, taking into account the importance of promoting fairness and solidarity among Member States

Source: ECIU; CCPI; Roland Berger

Critical change to Earth systems is looming, as the breaching of tipping points becomes more likely

Examples of global and regional tipping elements



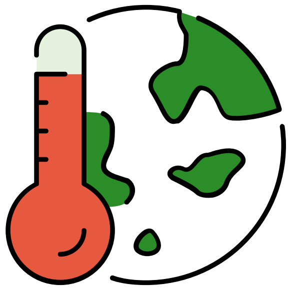
- **Tipping elements** are large-scale, relevant **components of the Earth's systems,** which are characterized by a threshold behavior
- There are three categories of tipping elements: **oceanic** and **atmospheric circulation patterns** (e.g. that of the Atlantic ocean), **cryosphere entities** (e.g. Arctic/Antarctic ice melting), and **biosphere components** (i.e. large-scale ecosystems such as coral reefs)
- Large-scale discontinuities in the climate system have a **temperature change threshold** – a **tipping point;** once tipped, transition (abrupt or gradual) can continue without further forcing
- **Tipping points vary:** For example, coral reefs are more susceptible to rising temperatures than the Amazon rainforest
- Information from most recent IPCC reports suggests that **tipping points could be exceeded even between 1 and 2 °C of warming** – not at 5 °C as was previously thought. Four elements (low-latitude coral reefs, the Greenland and West Antarctic ice sheets and boreal permafrost) are expected to tip at 1.5 °C
- At the current trajectory of global warming, at **least one tipping point could be passed in the coming 10 years,** with climate scientists noting that **cascading effects** might be common

Source: WEF; ESA; Roland Berger

Is it worth undertaking the highest efforts to limit the temperature increase? There is a clear difference between the impact of a 1.5 °C or a 2 °C increase

Climate risks: Impact of **1.5 °C** versus **2.0 °C** of global warming

Climate risk



Arctic sea ice

1.5 °C	2.0 °C
Ice free summers in the Arctic at least **once every 100 years**	Ice free summers in the Arctic at least once every 10 years

People

1.5 °C	2.0 °C
9% of the world's population or 700 million people will be exposed to extreme **heat waves** at least once every 20 years	28% of the world's population or 2 billion people will be exposed to extreme heat waves at least once every 20 years

Food

Every half degree of warming will steadily lead to **lower yields** and lower nutritional content in tropical regions

Oceans

Lower risks to marine biodiversity, ecosystems and their ecological functions and services **at 1.5 °C** compared to 2°C

Water availability

1.5 °C	2.0 °C
350 million city dwellers are exposed to severe drought by 2100	140 million urban residents are exposed to severe drought by 2100

Species

1.5 °C	2.0 °C
6% of insects, **8%** of plants and **4%** of vertebrates will be affected	18% of insects, 16% of plants and 8% of vertebrates will be affected

Sea level rise

10 cm higher at 2 °C than at 1.5 °C in 2100. This difference would expose up to **10 million more people to risks**

Coral bleaching

1.5 °C	2.0 °C
1.5 °C: 70% of the world's coral reefs are lost by 2100	2 °C: Virtually all coral reefs are lost by 2100

Costs

Lower economic growth at 2 °C than at 1.5 °C for many countries, esp. low-income countries

Extreme weather events

1.5 °C	2.0 °C
100% increase in flood risk	170% increase in flood risk

Scenarios: **1.5 °C** global warming; **2.0 °C** global warming

Source: WWF; Roland Berger

If the temperature increase exceeds 2 °C, cities will be faced with tough, new climate conditions

Impact on cities, if global temperature increases above 2 °C by 2100

Global impact on major cities (more than 1 m inhabitants) in 2050

77%

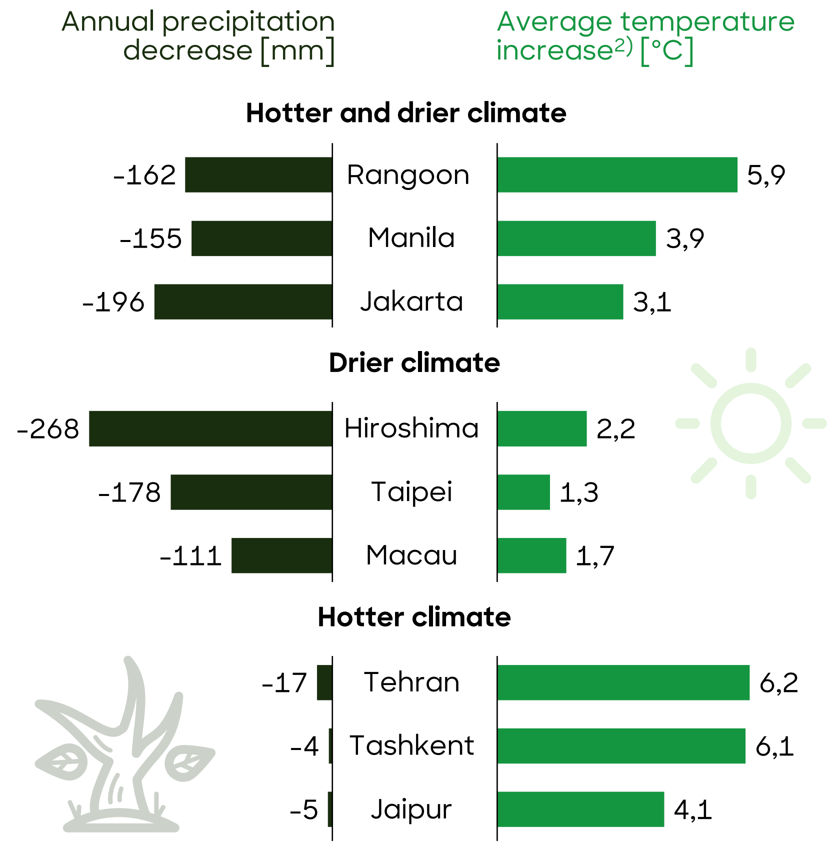
Share of major cities being faced with **striking shifts in their climate,** e.g. in **2050**

Madrid will have the climate of **Marrakech**
London will have the climate of **Barcelona**
San Francisco will have the climate of **Lisbon**

22%

Share of major cities shifting to a **climate** regime that **does not currently exist** on Earth[1)]

Example of climate extremes: Annual precipitation decrease [mm] and temperature increase [°C] until 2050 in selected Asian cities



- Under the IPCC scenario **RCP 4.5** it is more likely than not that global warming **exceeds 2 °C**
- RCP 4.5 is one of two **intermediate scenarios,** i.e. between a stringent mitigation scenario (RCP 2.6) and a scenario with very high emissions (RCP 8.5)
- In RCP 4.5, **CO_2** emissions will **peak around 2040** and then decline. In 2100, it will reach about 50% of 2050 levels. Methane (CH_4) emissions will stop increasing by 2050
- It is expected that **many plant and animal species** will be **unable to adapt** to the effects of RCP 4.5

1) The 22% are included in the 77%; 2) In warmest month of the year
Source: Bastin et al; IPCC; Roland Berger

Mitigating climate change requires switching energy supply to renewables, electrification, increasing energy efficiency, and GHG capture/use/storage

Methods to reduce greenhouse gas emissions

Renewable energy

- Hydro power
- Photovoltaics
- Concentrated solar power
- Solar thermal
- Wind power
- Bioenergy
- Geothermal energy
- (Nuclear energy)

Electrification

- Buildings heating
- Industry, services, agriculture, other business sectors
- Transport

Reduce greenhouse gas emissions

Greenhouse gas (GHG) capturing, usage and storage

- GHG capturing: industrial sources, direct air capturing
- GHG usage: e.g. fertilizers, oil recovery, synthetic fuels, chemicals, building aggregates
- GHG storage: e.g. in exhausted oil or gas fields, in saline formations, in unmineable coal seams

Energy efficiency

- Energy supply
- Processes in industry, services, agriculture, other business sectors
- Transport
- Buildings
- Private households

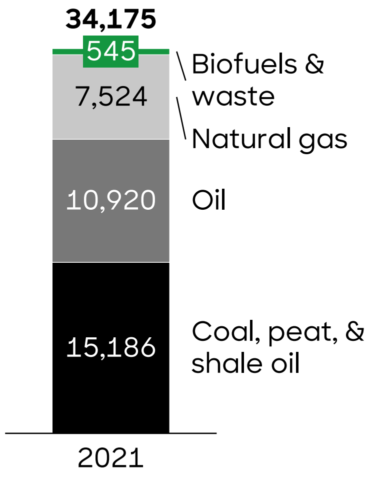
- **Four methods help to combat climate change:** increased use of **renewables**, **electrification** of end-use-sectors, higher **energy efficiency,** and **greenhouse gas (GHG) capturing, usage and storage** all lower the impact of GHG emissions
- **Renewable forms of energy** need to replace fossil-fuel based energy production. Sites can be **central** (e.g. hydro power, concentrated solar power or PV power plants) or **decentral** (like PV or solar thermal on rooftops)
- **Electrification of end-use-sectors,** e.g. by switching to electric vehicles or heat pumps, is a crucial measure to reduce the use of fossil fuels. To be carbon neutral, the power needs to be produced by renewables
- Increasing **energy efficiency** is necessary wherever energy is produced and used. As outlined, **power plants** and certain **industrial processes hold great reduction potential** – but other sectors also need to improve their energy efficiency
- **GHG capturing, usage and storage** is needed whilst energy production and industrial **processes emit GHGs**
- **Applying all four approaches in tandem** boosts overall effectiveness
- However, all four methods **carry associated costs and require energy** (e.g. for the production and installation of PV panels). **Technological progress and scaling** can lower costs as well as energy inputs
- In a system with **emission certificates** the certificate **price** will be a crucial factor in the cost-benefit comparison of the four methods

Source: IEA; Roland Berger

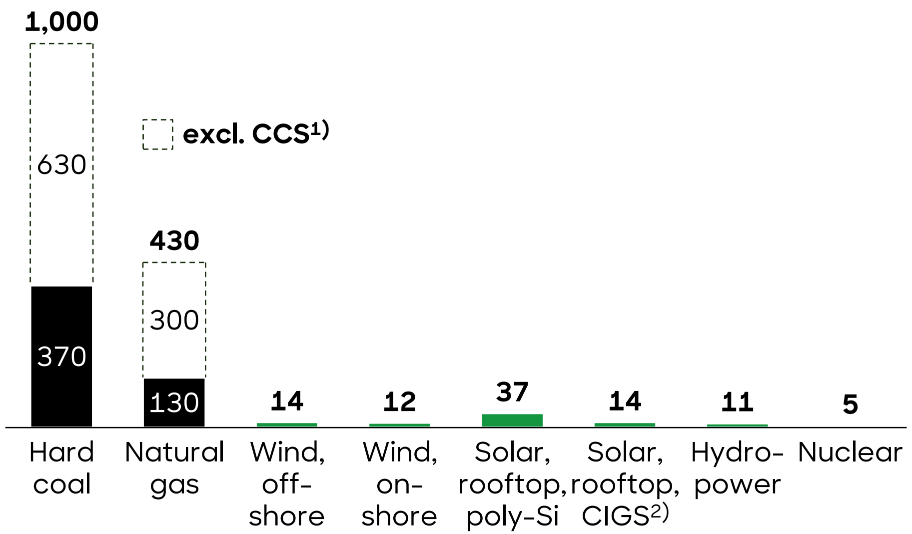
Renewable energy sources are essential for the energy transition – Fossil fuels emit up to 150 times more CO_2e than renewables

GHG mitigation potential of shifting to renewables

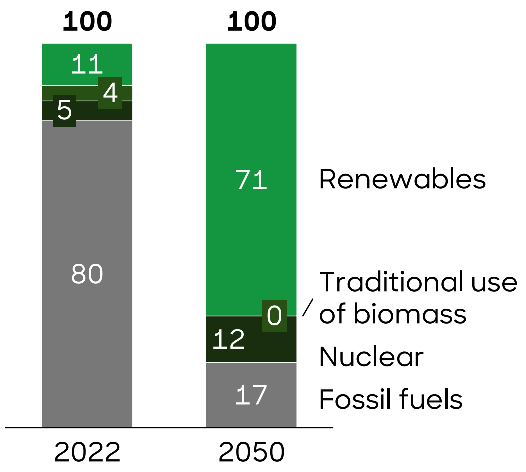
Total global GHG emissions from fuel combustion per fuel
[Mt CO_2e]



Lifecycle GHG emissions per kWh by energy source
[gr. CO_2e per kWh]



Total global energy supply according to the NZE scenario[3]
[%]

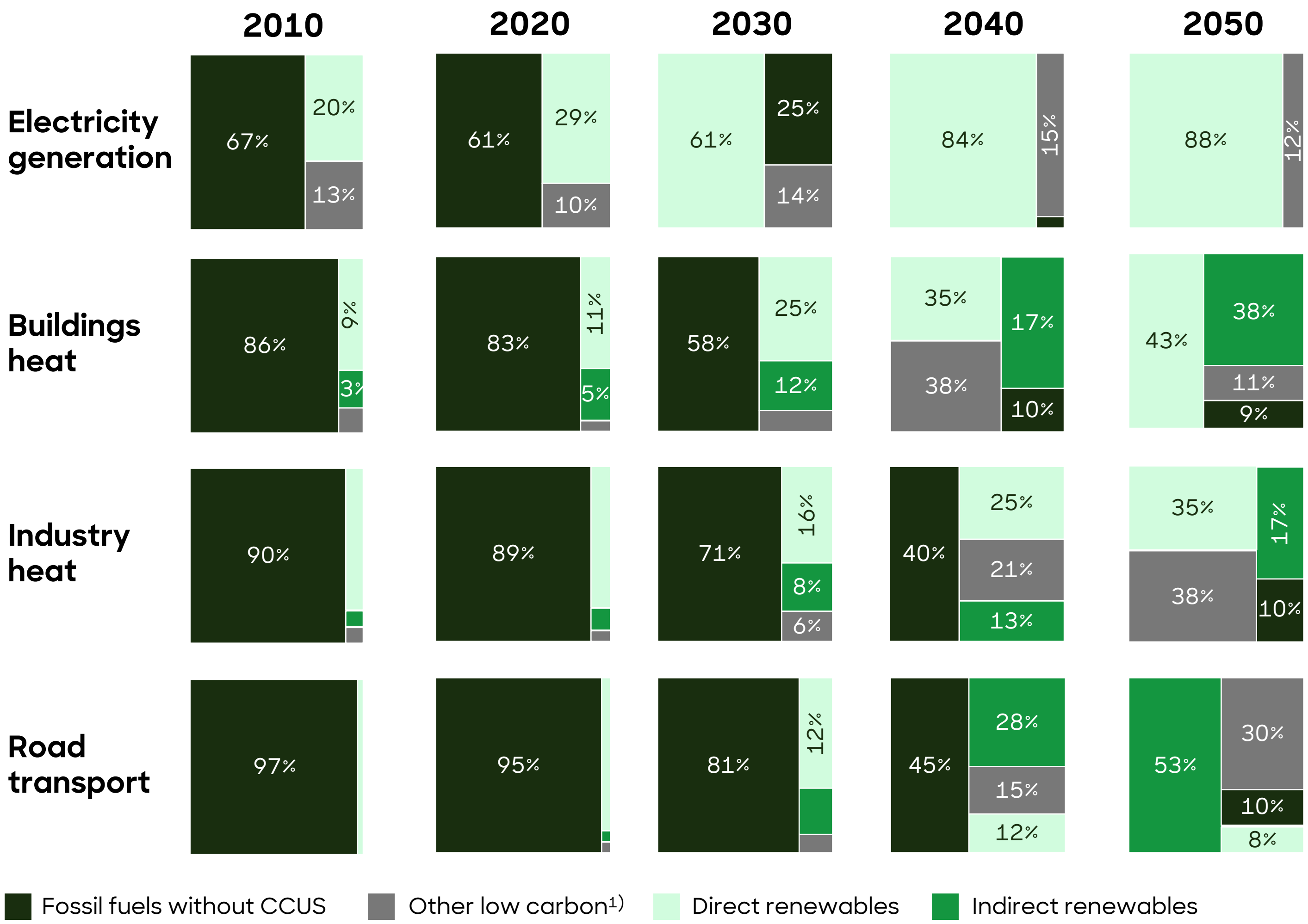


- **Fossil fuels** such as coal, peat, shale oil, oil and natural gas **still are the main sources of energy** and emit vast amounts of CO_2 compared to renewables
- **Renewable** energy sources such as solar, wind, hydropower, biofuels, and similar alternatives play a **pivotal role in reducing GHG emissions**
- **Renewables produce up to 150 times less CO_2e per kWh than fossil fuels** – a promising alternative supporting energy transition ambitions of the international community
- To reach net zero emissions by 2050 the **share of renewables of total energy supply must increase from 11% in 2022 to 71% by 2050**
- While renewable electricity generation is already advanced, **renewable energy sources** will have to play **a bigger role in transportation and heating**

1) CCS: Carbon Capture and Storage; 2) Copper Indium Gallium Diselenide solar cells; 3) IEA Net Zero Emissions by 2050 scenario
Source: IEA; IRENA; UNECE; Roland Berger

Electrification of end-use sectors requires replacing the use of fossil fuels with renewables in all areas of application

Fuel shares in total energy use in selected applications in IEA's Net Zero Emissions by 2050 scenario [%]



- **Electrification of end-use sectors** is a key measure to become carbon neutral by 2050. Examples are electric vehicles instead of those with an internal combustion engine, heat pumps instead of natural-gas powered heating, and industrial machines powered by electricity instead of fossil fuels
- To be carbon neutral, the power needs to be **produced by renewables.** Thus, today's global energy mix needs to undergo **drastic changes across various fields of applications**
- On a global scale, renewable energy technologies are pivotal to lowering emissions: **Hydropower has been a leading** low-emission energy source over many decades; the **expansion of wind and solar power** will triple renewable power generation by 2030 and provide an **eightfold boost by 2050** in the Net Zero Emissions by 2050 roadmap
- Its accomplishment will require **annual additions of wind and solar capacity** to be **five times higher between 2020 and 2050** than the average of the years 2018-2020
- Energy use from renewables differs: **Direct renewables** guarantee a use of energy without the need to transformation into a further form of energy (e.g. biofuels for road transport). The **indirect use of renewables,** however, requires the initial energy form to be transformed into another, as is the case in electric vehicles powered by renewables

1) Other low-carbon refers to nuclear power, facilities equipped with CCUS (carbon capture, usage & storage), and low-carbon hydrogen and hydrogen-based fuels
Source: IEA; Roland Berger

Environment & Resources

3.1 Climate Change & Pollution

3.2 Bio-diversity

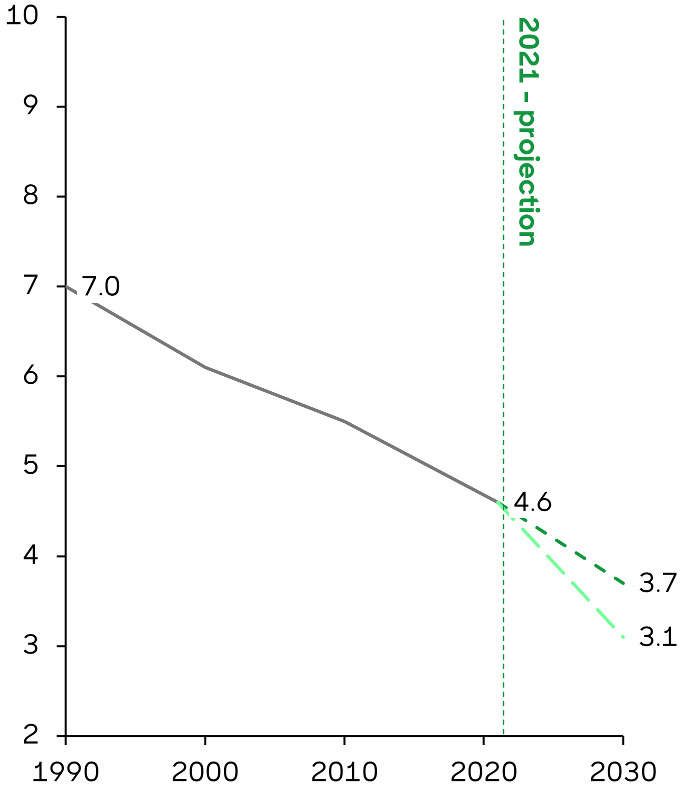
3.3 Water

3.4 Resources & Raw Materials

Energy efficiency provides some of the fastest and most cost-effective CO_2 mitigation options, lowering energy bills and improving energy security

Energy efficiency requirements

Global energy intensity measured in terms of primary energy and GDP
[MJ per 2017 USD PPP]



World - - - Stated policies scenario — — Net zero emissions scenario

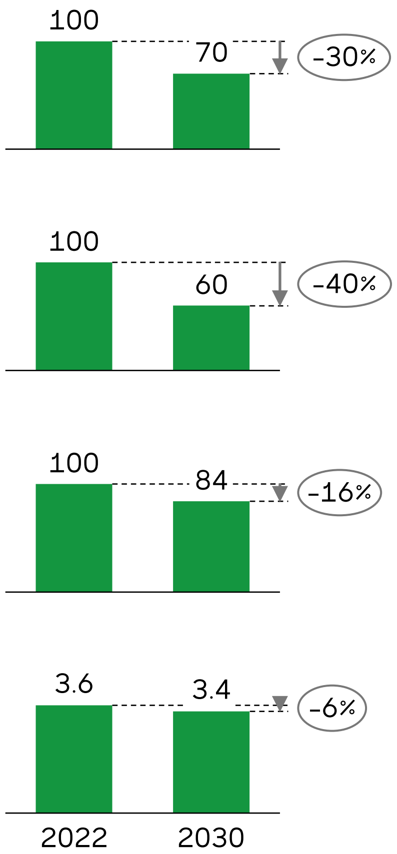
Key milestones in energy efficiency to achieve net zero

Unit electricity consumption of new air conditioners
[Index, 2022 = 100]

Unit electricity consumption of refrigerators
[Index, 2022 = 100]

Fuel consumption of new trucks
[Index, 2022 = 100]

Energy intensity of clinker production
[GJ/t]

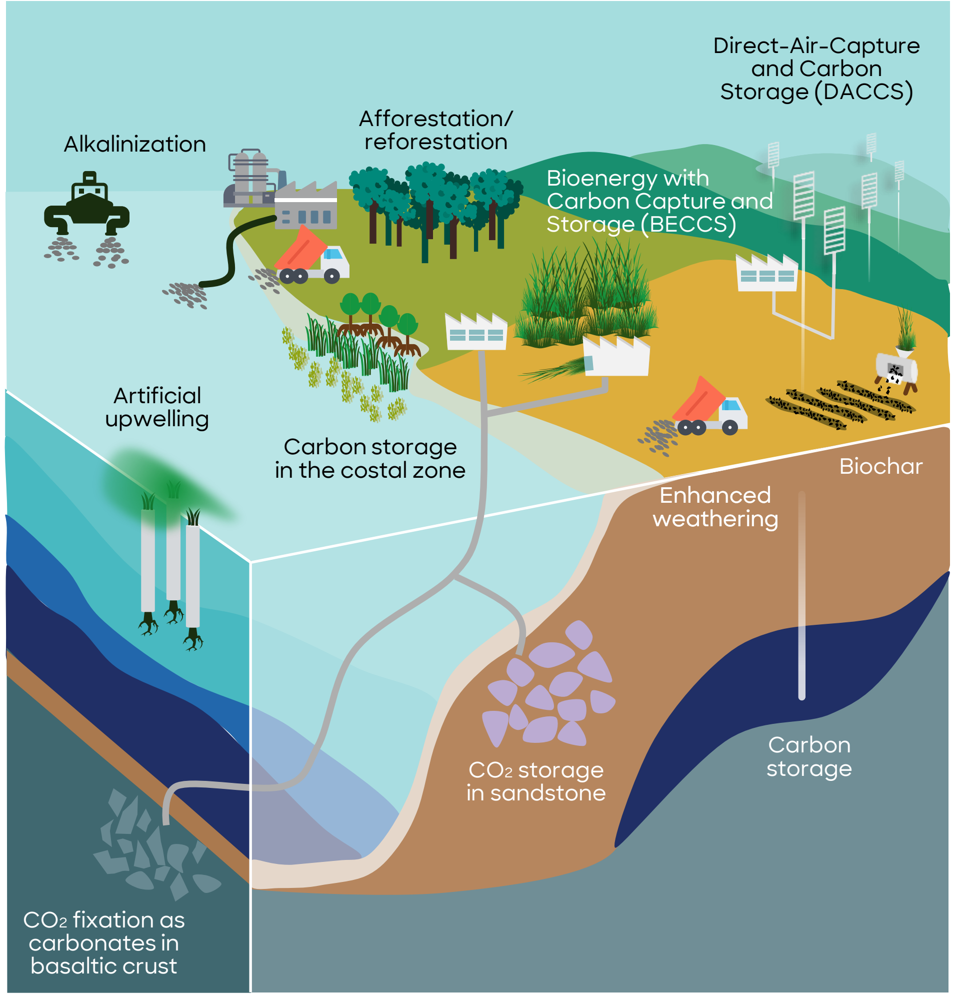


- **Energy efficiency** is a **key measure** for curbing energy demand in IEAs Net Zero Emissions by 2050 scenario
- Collectively, **energy efficiency, electrification, behavioral shifts, and digitalization** contribute to shaping **global energy intensity** – the **amount of energy needed to generate a unit of GDP**, a key measure of the economy's energy efficiency
- **Significant progress** has been made in this area over the **past 30 years.** In 1990, 7 MJ were needed to produce 1 USD of GDP globally. **By 2020**, this figure has decreased to 4.6 MJ. To reach the net zero target, this number **needs to be reduced further,** to just 3.1 MJ by 2030
- Most **efficiency initiatives yield cost savings for consumers,** reducing energy expenses and mitigating the impacts of unexpected energy price surges, for example as witnessed following Russia's invasion of Ukraine
- To **achieve the ambitious 1.5 °C Paris target, energy efficiency needs to be increased in all areas** such as households (e.g. by power-saving air conditioners or refrigerators), transportation (e.g. by reducing fuel consumption of vehicles), and industry (e.g., by more efficient production processes)

Source: IEA; Roland Berger

Whilst greenhouse gases continue to be emitted, their removal from the atmosphere is vital – Usage and storage options of GHGs differ widely

Selected methods of CO_2 removal from the atmosphere

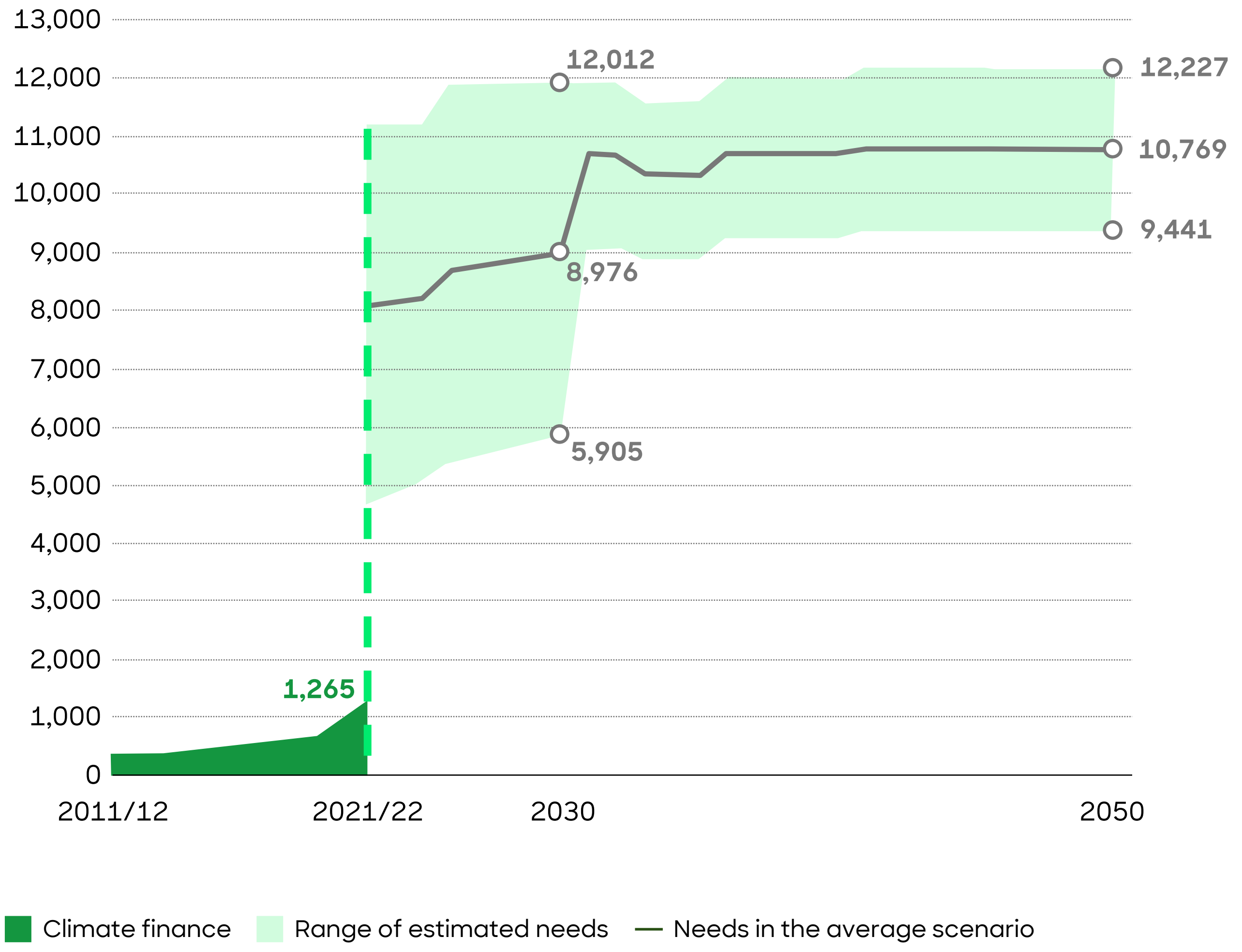


- **Greenhouse gas capturing, usage and storage** is a **crucial method** to fight climate change. In contrast to the increased use of renewables and a higher energy efficiency, the **target** here is not to reduce GHG emissions, but **to lower their impact**
- As **CO_2** has the highest share of GHG emissions, efforts focus on carbon(dioxide) capturing, usage and storage. It can be captured from **industrial sources** and then used or stored (**CCUS,** Carbon Capture, Usage and Storage) or be captured from the **air** and then stored (**DACCS,** Direct Air Capture and Carbon Storage)
- CO_2 **usage** includes applications as enhanced oil recovery and the transformation into products like **urea (for fertilizers), synthetic fuels, chemicals,** and **building aggregates**
- Bioenergy with Carbon Capture and Storage **(BECCS)** involves capturing and storing CO_2 from processes where **biomass is converted into fuels** or **directly burned** to generate energy
- If not used, **CO_2** can be **stored in different places underground**
- **Biochar carbon removal** uses heating without oxygen (pyrolysis) to transform biomass into biochar which can store CO_2 for extended periods
- **Enhanced weathering** is a method to store CO_2 in rock material and spread it out across extensive land areas, beaches or the sea surface
- **Plants** are natural CO_2 stores. **Afforestation/reforestation** on land or at coastal zones contribute to the removal of CO_2 from the atmosphere
- As the **ocean** is a major player in mitigating climate change – absorbing about 25% of human-made CO_2 emissions – there are several **options to enhance the binding of atmospheric CO_2,** e.g. the **increasing of the alkalinity of seawater** (e.g. by inserting rock powder) to enhance the ocean's CO_2 uptake from the atmosphere or artificially **upwelling** of deep, nutrient-rich water to increase the binding of atmospheric CO_2 in algal biomass

Source: IEA; Geomar; WEF; MIT; Roland Berger

Climate finance surges to USD 1.3 trillion in 2019/2020, yet a seven-fold increase by 2030 is crucial to align with Paris Agreement objectives

Global tracked climate finance and estimated annual needs through 2050 [USD bn]

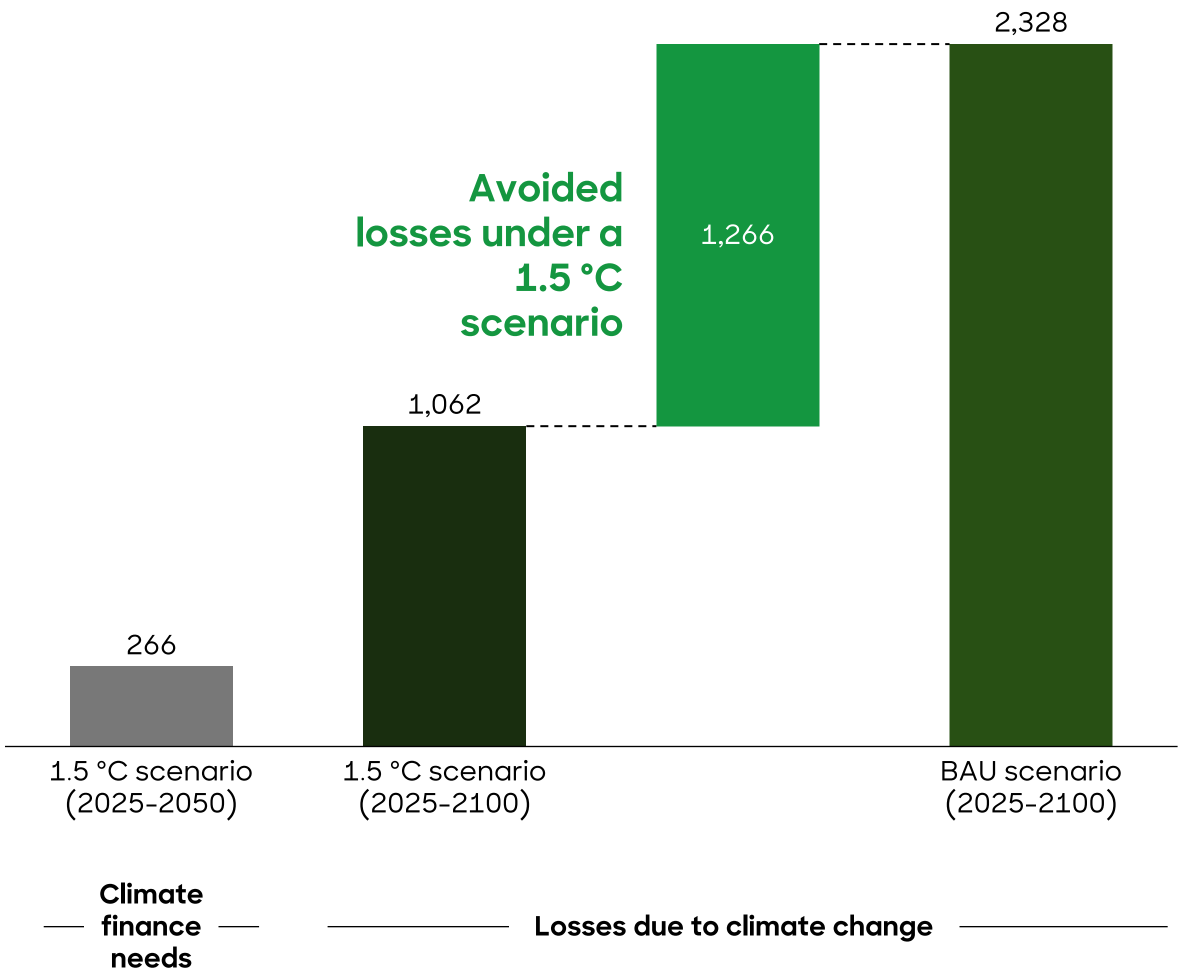


- The Climate Policy Initiative's (CPI) **Global Landscape of Climate Finance 2023** report synthesizes data from diverse scenarios to estimate the range **of investments required to meet international climate goals**
- As of 2021/2022, average **annual climate finance has nearly doubled since 2019/2020,** reaching around USD 1.3 trillion, with projections indicating **a need to increase annual climate finance to USD 9 trillion by 2030** and over USD 10 trillion from 2031 to 2050 **to meet the objectives of the Paris Agreement**
- **Climate finance** is categorized into two main types: **mitigation finance,** which focuses on reducing emissions to slow climate change, and **adaptation finance,** aimed at helping communities cope with its effects. **Mitigation finance is growing,** particularly in renewable energy and transporta-tion. **Adaptation finance** – though increasing – **remains insufficient**, with a **heavy reliance on public funds** and less private sector involvement
- The **distribution of climate finance remains uneven,** being heavily concentrated in certain geographies and sectors. There is **a pressing need for strategic initiatives to leverage private finance** in underfunded areas and to support climate-vulnerable and high-emission countries in their transition to low-carbon economies

Source: CPI; Roland Berger

The cost of inaction would turn out to be much higher than the financing required to fight the impacts of climate change

Cumulative climate finance needs vs losses 2025-2100 under 1.5 °C and BAU scenarios [USD trillion]

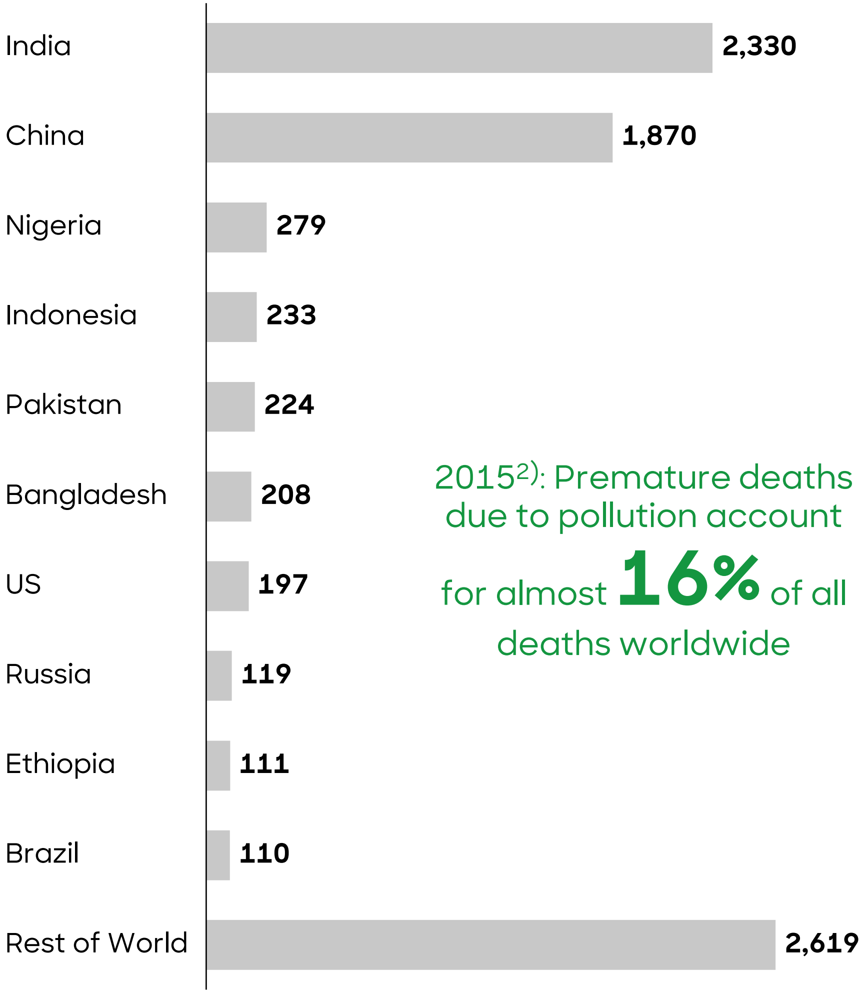


- The projected **social and economic costs of global warming** will far **exceed the costs of the transition.** Meanwhile, the cost of inaction is mounting
- Increasing **climate investments** to the levels **required by 2050** (**USD 266 trillion** cumulatively), will result in a significant **reduction in social and economic losses by 2100: USD 1,266 trillion** lower compared to a business-as-usual (BAU) scenario
- The estimated losses are based on **direct economic impacts** of increased (extreme) **weather**-related and other uninsurable damages, **increased production costs, productivity losses, and health costs.** Likely to be **vastly under-estimated** these figures do not capture capital losses caused by stranded assets, losses of nature and biodiversity, or increased conflict and human migration
- While the **data and methods** for estimating future losses are **still rudimentary,** they paint a picture that illustrates the **economic imperative** to invest now, while highlighting the immense **opportunities for businesses** to pursue increasingly low-carbon and climate resilient paths

Source: CPI; Roland Berger

Pollution, a significant environmental threat, contributes to approximately 8.3 million deaths globally

Estimated number of premature pollution-related deaths per year, 2019[1] ['000]



2015[2]: Pollution costs the global economy **6.2%** of economic output

2015[2]: Premature deaths due to pollution account for almost **16%** of all deaths worldwide

2015[2]: **>90%** of pollution related deaths occur in low- and middle-income countries

- **Pollution** is considered the world's **most ubiquitous environmental threat** to human health – but also to other living organisms
- Pollution takes on many forms and **combinations**, such as land and water pollution
- Certain types of pollution are more **easily recognizable** than others, depending on severity: **Air pollution** in urban areas can be seen as smog, yet rural areas can also suffer from bad air due to farming practices; **light pollution** can be seen from outer space; **water pollution** can manifest as debris swept up at coastal areas
- Some types, such as air or noise pollution can be measured by a handful of **parameters**, while others, such as water pollution, face an abundance of metrics, from a growing number of relatively **novel pollutants** such as microplastics or pharmaceutical products (hormones, antibiotics)

1) Fatalities after exposure to toxic air, water, land, and chemical pollution; 2) Most recent data available
Source: Global Alliance on Health & Pollution; Roland Berger

Pollutants harm the environment and the health of all living species – Targeted reduction and mitigation efforts are vital

	Air pollution	Water pollution	Land pollution	Noise pollution	Light pollution	Space pollution
Selected origins	Fuel combustion for energy production/ transportation, heating, non-exhaust vehicle emissions, natural/ chemical/nuclear catastrophes	Industry and household sewage, mines, vehicles & vessels, agricultural runoff, spillages, fracking, natural oil seeps, natural/nuclear/ chemical catastrophes	Industry and household waste, mines, agriculture, natural/ chemical/nuclear catastrophes	Vehicles, aviation, industrial/construction/ mining activities, leisure pursuits	Public and private infrastructure, vehicles, industrial and leisure activities	Old rocket stages, discarded satellites, lost equipment, collisions or orbit explosions caused by surface launched missiles or remaining energy sources like fuels or batteries
Examples	Fine dust, sulfur dioxide, carbon monoxide, nitrogen oxides, ozone, chemicals vapors, pollen, radioactive air pollutants	Waste (esp. plastics) and sewage, bacteria, oil, chemicals, fertilizer, pesticides, herbicides, tire abrasions, metals, drugs	Liquid, solid or sludge waste (open dump or landfill), microplastics in sewage sludge used as fertilizer, pesticides, herbicides, heavy metals	Traffic noise, flight paths, heavy machinery, music and video streaming, concerts	Over-illumination of streets/places/buildings/industrial plants and facilities	Human generated space junk such as pieces of spacecraft or defunct satellites, tiny flecks of paint of old spacecraft
	99 out of 100 people breathe air that exceeds WHO air pollution guidelines – Air pollution is responsible for 1 in 8 deaths worldwide	**The Great Pacific Ocean Garbage Patch contains 1.8 trillion pieces of plastic in an area of 1.6 million km^2 – 3x the size of France**	**Globally, 33% of waste is still openly dumped and approx. 40% goes to landfills**	**In middle- and high-income countries, 1 of 2 young people (aged 12-35 years) listen to unsafe levels of sound**	**83% of the world's population live under light-polluted skies**	**Space debris is travelling at about 7 times the speed of a bullet, posing a massive threat to operating spacecraft and satellites**

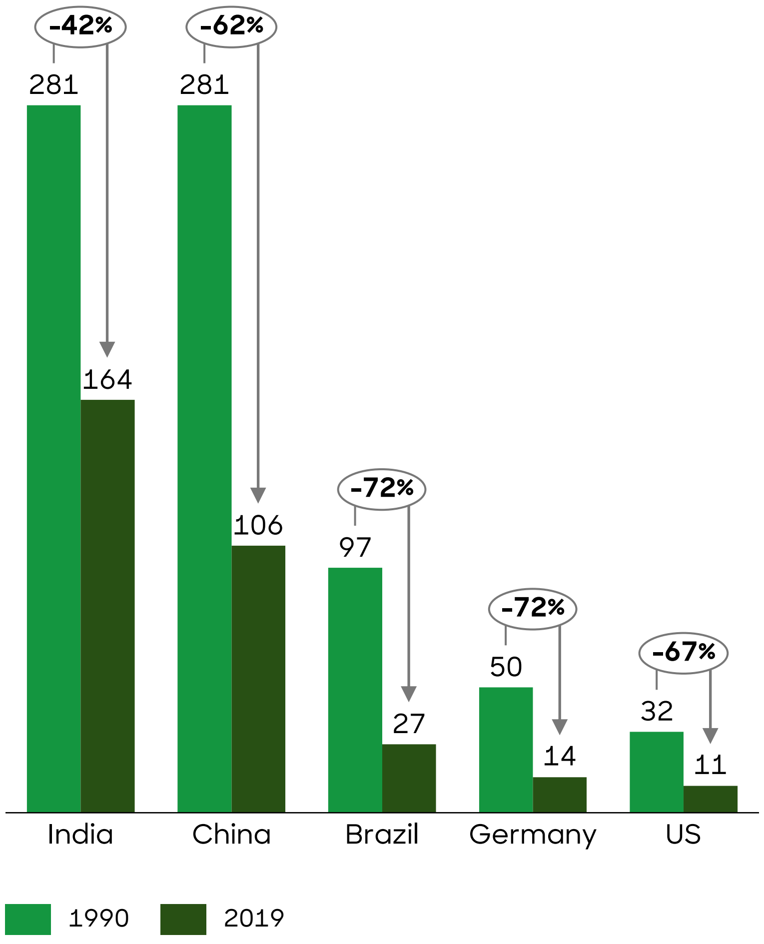
Pollution reduction and mitigation approaches

- Ban (more) harmful pollutants
- Set tighter pollution limits across all types of pollution
- Implement emission-free/lower emission energy production and industrial processes
- Switch to circularity approaches and durable, more sustainable products
- Inform and improve better land use, waste, and light management practices

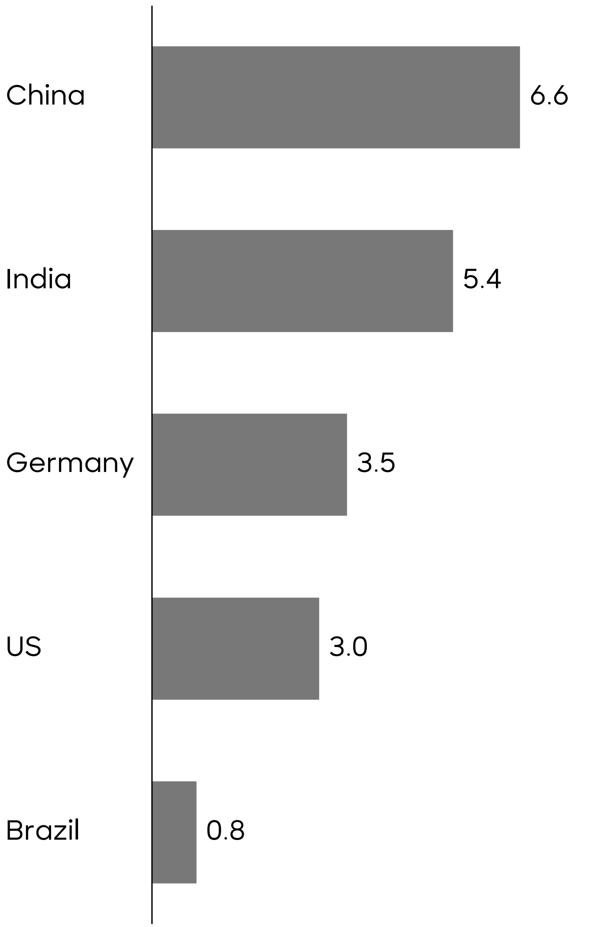
Source: LiveScience; WHO; WWF; Ocean Cleanup; World Bank; National Geographic; International Journal of Science and Research; NASA; ESA; Roland Berger

Air pollution is causing fewer deaths today than in 1990 – However, economic costs remain significant

Age-standardized deaths/100,000 population attributable to air pollution



Economic costs of air pollution as a share of GDP, 2018 [%]

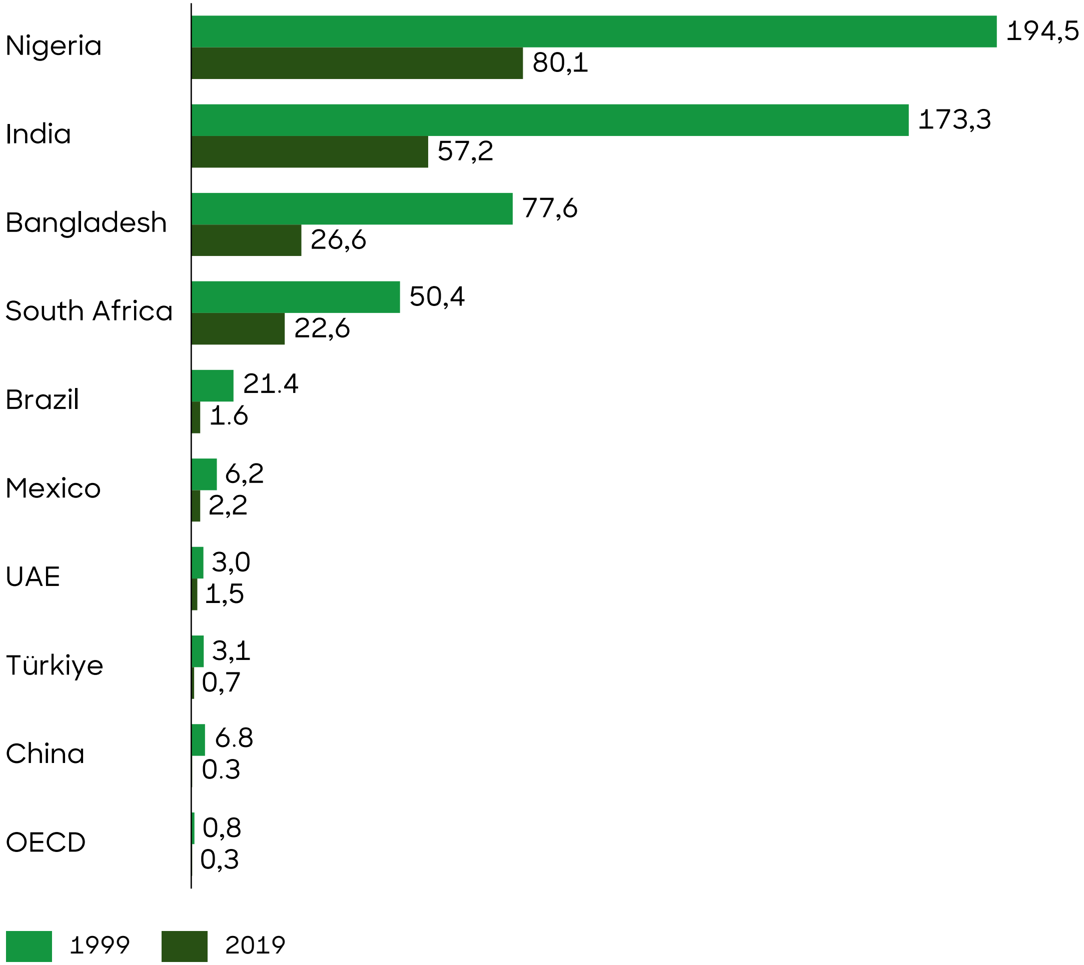


- **Air pollution** refers to the prevalence of chemicals or compounds in the air that are **not normally present** and that **degrade air quality,** or cause adverse changes in quality of life (e.g. damage to the ozone layer or global warming)
- Although air pollution is displaying an improvement in terms of steadily declining numbers of attributable deaths, **air pollution still shortens lives more than any other external cause** – by 2.2 years (global average per person)
- Around **99% of the world's population** breathe **air that exceeds WHO guideline limits** regarding selected air pollutants
- **Total costs of air pollution** on a global scale are estimated at around **3.3% of global GDP**, accounting for disabilities from chronic diseases, asthma, preterm births, sick leaves, and deaths

Source: State of Global Air; CREA; WHO; Roland Berger

Water pollution as a cause of death has decreased significantly in developing countries – A positive development supporting people and economies

Number of deaths per 100,000 population from unsafe water sources, selected countries



Can the economic cost of bad water quality be determined?

Biochemical oxygen demand[1)]

Polluted water harms economies: Studies found, that in regions where **BOD is high, GDP growth** is **lowered by up to 1/3**

Oxidized nitrogen

Nitrates are **lethal for babies;** nitrates **increase childhood stunting** by **11-19%** and **decrease adult earnings** by **1-2%**

Salinity

Salts degrades land. Due to saline water, enough **food is lost each year** to feed **>170 million people,** equivalent to the population size of Bangladesh

1) Biochemical oxygen demand (BOD) represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic (oxygen is present) conditions at a specified temperature

Source: IHME; World Bank; Roland Berger

3.1
Climate Change & Pollution

3.2
Bio-diversity

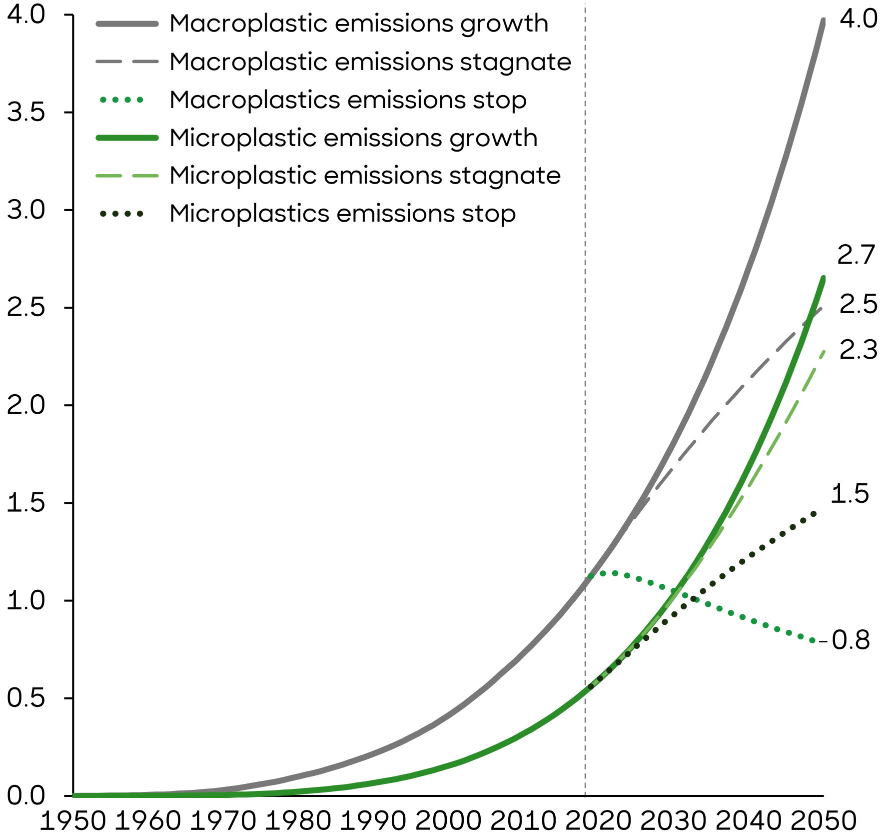
3.3
Water

3.4
Resources & Raw Materials

Even if we stopped emitting plastics into the ocean today, plastic particles would persist in our surface waters for many decades

Amount of micro- and macroplastics in the surface ocean & scenarios[1, 2] [m tons]

Forecast for different scenarios



Breaking the plastic wave could[3) ...

... save **government cost** of up to **USD 70 billion**

... save **costs to corporates** of up to **USD 1.3 trillion**

... generate **1 million new jobs**

... **reduce GHG emissions** by **500 million tons of CO_2e**

How to break the plastic wave?

- We must **stop plastic waste entering our waterways** as a matter of urgency: Most of the plastic that pollutes the oceans is due to **poor waste management** practices – particularly in low-to-middle income countries
- Efforts must also be focused on **recapturing and removing existing plastics** from our offshore waters and from shorelines

- Past assumptions postulated that **plastics in the ocean** have a **short lifespan**, quickly degrade into microplastics, and sink to greater depths – however, **this is incorrect**
- Macroplastics can **persist even for decades** – even if we were to **stop emitting plastic waste** into the ocean today, macroplastics would persist **in our surface waters** for many **decades** to come
- **By 2050**, there could be **more plastic** in the ocean **than fish** (by weight)
- In fact, this is partly because there is a **massive legacy of plastics buried along our shorelines** which could re-surface and be transported to nearshore regions
- The **level of microplastics** in the oceans will **increase under any scenario** as the existing larger plastics **continue to degrade.** Any additional plastic waste acts as a further contribution

1) Macroplastics are defined as buoyant plastic materials >0.5 cm in diameter, microplastics are buoyant plastic materials <0.5 cm in diameter; 2) The three scenarios are defined as follows: emissions stop – emissions to the oceans stop in 2020; emissions stagnate – emissions stagnate at 2020 emission rates; emissions growth – emissions continue to grow until 2050 in line with historical plastic production rates; 3) According to Pew Trusts "System Change scenario"

Source: LeBreton; The Pew Charitable Trusts; Roland Berger

Land pollution threatens the health of humans, animals, and the environment through soil, food, and water contamination

Quantifiable economic losses due to soil pollution

Soil contamination is responsible for **agricultural productivity losses** of **15-25%**

Global annual **pesticide usage** increased by **more than 80%** in three decades[1)]

Soil pollution is estimated to cause annual **agricultural economic losses** worth **USD 20 bn** in China

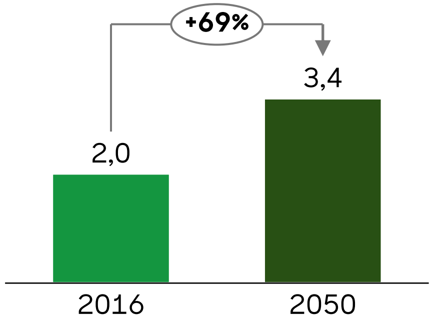
- Land pollution refers to the **deterioration of the Earth's land surfaces at and below ground level.** It is caused by the accumulation of solid and liquid waste materials that **contaminate ground-water and soil** – a component of land – **posing a threat to human health** and/or the **ecosystem**
- The **cost of remediating** polluted land/soil **is site specific** and **future use dependent:** cost factors include size of the affected area, pollutant concentration, reme-diation depth, technology used, civil protection measures, etc.
- There are additional, often overlooked and therefore **underestimated indirect costs** related to land pollution regarding the natural world: **Biodiversity losses** and **degradation** of **ecosystems** affect **long-term soil productivity** and **resilience**
- For humans, **illnesses** stemming from unsafe water and food grown on polluted soil affect **workforce productivity**

1) 1990-2017
Source: FAO; Pesticide Atlas; Roland Berger

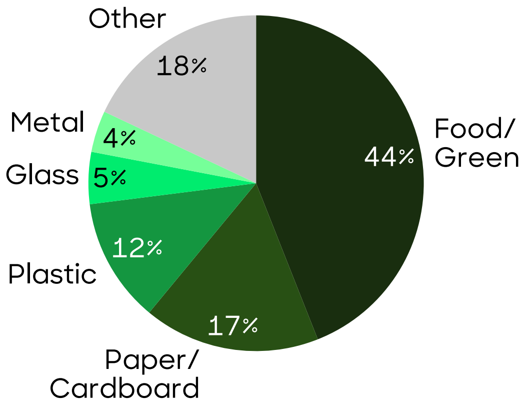
Land pollution is linked to our globally increasing levels of waste generation – Non-food waste is the dominant issue for waste management systems

Annual municipal solid waste, globally and regional

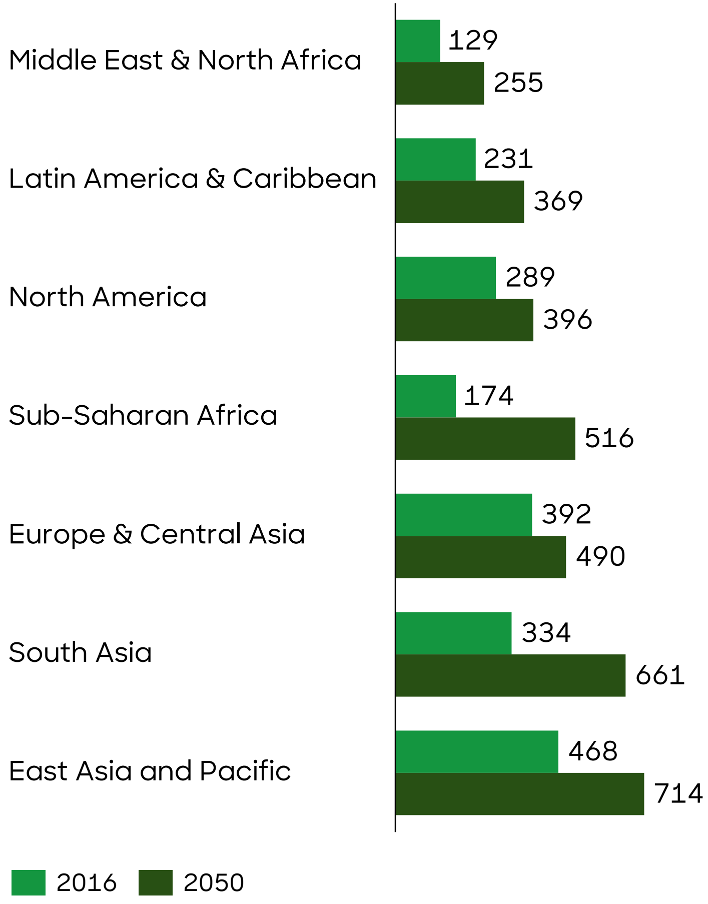
Global [trillion tons]



Main types of waste generated [%]



By region [bn tons]



- In line with a rising global population increasingly living in urban areas is the rise of **municipal solid waste** (MSW) generation; further factors are **related to life-style** and easy access to packaged products
- MSW **includes household waste** such as food scraps, garden waste, packaging, furniture, clothes, paper and cardboard, household appliances, paint and batteries
- **Improper management** of MSW landfills increases the **potential for soil pollution** from leachate as well as **CO_2 emissions into the atmosphere. Soil contamination** reduces soil fertility and crop yields, impacting food security
- **Although non-food waste constitutes more than half of the waste we produce, food waste also carries a heavy environmental burden:** the **energy** that goes into producing, harvesting, transporting, and packaging of food that is wasted **generates more than 3.3 billion metric tons of CO_2** – if food waste **were a country,** it would be the **world's third largest emitter of GHGs,** behind the US and China
- In **low-income countries, 90%** of waste is **mismanaged**

Source: World Bank; FAO; National Geographic; Roland Berger

Environment & Resources

3.1 Climate Change & Pollution

3.2 Bio-diversity

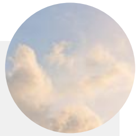
3.3 Water

3.4 Resources & Raw Materials

Well over 8 billion tons of plastic have been produced over the past 70 years – Today plastic particles pollute our air, water, and land

Plastics threatens our environment ...

... in the **air**



Airborne microplastics threaten air quality

- Plastic waste **breaks down** into smaller particles until it becomes **microscopic,** gets **swept up into the atmosphere,** and travels – carried by the jet stream – across continents
- **84%** of atmospheric microplastics come **from roads, 11% from oceans** and **5% from agricultural soil dust**

... in the **ocean**

Increasing threat of "plastic islands" e.g. in the Great Pacific Garbage Patch

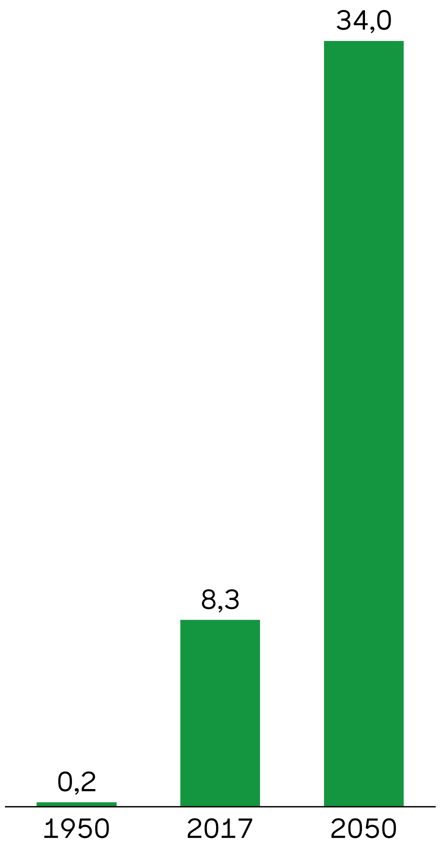
- There are about **80.000 tons** of plastic in the northern Pacific ocean, the area equals **1.6 million km²** – equivalent to **3x the size of France**
- Plastic trash is found **in the guts** of more than **90% of the world's sea birds** and in more than **half of the world's sea turtles**

... on **land**

Microplastics in soils, sediments and freshwater have a long-term, negative effect on our ecosystems

- Less than **9% of all plastic waste** ever produced has been **recycled.** Roughly **12% was combusted,** while the **rest** (79%) is accumulating in **dumps, landfills or the natural environment**
- Estimates suggest, that **1/3 of all plastic waste** ends up in **soils or freshwater.** Most of it disintegrates into particles smaller than five millimeters

Cumulative plastic production volume, globally [bn metric tons]



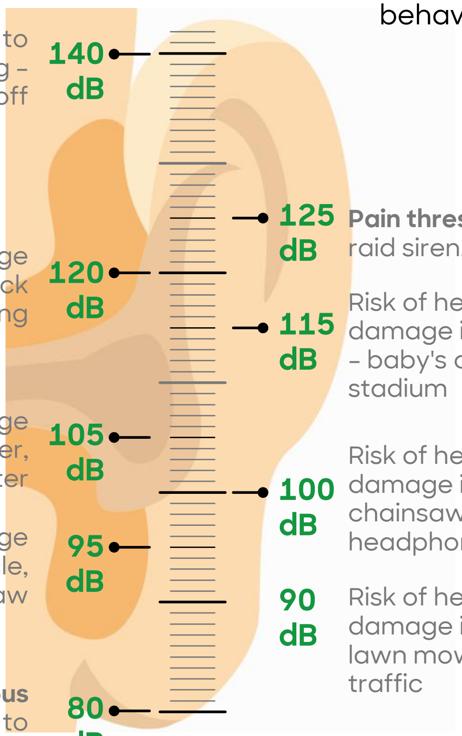
- **Plastic** particles are now found **everywhere,** even in rainwater and as far as the Arctic: **plastic pollution** has become one of the most **urgent environmental challenges** as the rapidly expanding production of single-use plastic products exceeds the world's ability to manage this kind of waste product
- **400 million tons of plastic** are produced annually of which **40% are single-use** products
- The post-war production boom and the development of thousands of new plastic products has changed the modern age to such an extent that **life without plastics** would be **almost inconceivable** today
- **Today's plastic** is largely **non-biodegradable:** it doesn't rot (like paper or food) and can linger in the environment for hundreds of years
- Research trials using **plastic-eating microbes** are underway in several countries while endeavors to clean up large marine areas have launched innovative techniques such as **artificial coastline** waste traps and in-water **seabins**

Source: University of California/Geyer R.; Media research; Roland Berger

Noise pollution is ubiquitous yet often less noticeable than other forms of pollution causing health problems for people and wildlife

Noise pollution/health nexus

Risk of hearing damage at selected decibel levels



An estimated **USD 1 trillion** is lost each year due to failures in adequately addressing hearing loss – this includes genetic and biological but also behavioral and environmental factors

Around **16%** (7-21% across different regions) of hearing loss in adults results from **exposure to excessive noise** in the **workplace** – which is responsible for over 4 million disability adjusted life years (DALYs)

Of persons aged 12-35 years, **1 billion** are at **risk of hearing loss** due to **exposure** to unsafe levels of sounds in **recreational settings**

- **Noise** pollution is any **unwanted or disturbing sound** that **affects the health** and well-being of humans and other living species
- **For humans**, loud sounds can be encountered in the **workplace,** in the overall **living environment,** or as part of **recreational** activities
- Sounds that reach **80 decibels (dB) or higher can harm a person's ears.** Sound sources that exceed this threshold are, for example, truck traffic (90 dB) and rock concerts (110-120 dB)
- The most common health problem to do with loud sounds is **Noise Induced Hearing Loss (NIHL)** but also high blood pressure, heart disease, sleep disturbances, and stress. These **health problems** can affect all age groups
- Noise pollution also impacts the health and well-being of **wildlife:** as animals use sound for a wide variety of reasons – including to navigate, find food, attract mates, and avoid predators – (human made) noise pollution makes it difficult for them to accomplish these tasks, **affecting** their **ability to reproduce, feed** and – ultimately – **survive**

Source: ProtectEar; WHO; Roland Berger

Light pollution is widespread and increasing, leading to problems for humans and wildlife, also indicating a waste of precious energy

Rapid brightening of the night sky affects people and ecosystems and is a waste of energy resources

Rapid growth of light pollution

Between 2011 and 2022, **global sky brightness increased by an estimated 9.6% per year.** Previously, studies had estimated that light pollution was growing by approx. 2% per year[1)]

Stars

The Milky Way is hidden for more than **1/3 of humanity,** including 60% of Europeans and nearly 80% of North Americans

People

More than **80% of the world** and more than **99% of the US and European populations** live under **light-polluted skies**

35% of light is wasted

due to poorly designed or unnecessary outdoor lighting – **equivalent to USD 3 bn p.a. worth of energy**

Land

23% of the world's land surfaces between 75°N and 60°S, i.e. 88% of Europe, and almost 1/2 of the United States, **experience light-polluted nights**

- Light pollution commonly refers to **excessive, misdirected or obtrusive artificial light.** It includes **glare, sky glow, light trespass, over-illumination** and **light clutter**
- Light pollution is any unwanted or disturbing light/illumination that affects the **health and well-being of humans and other living species**
- Light pollution **generates significant costs** including **negative impacts:** Excessive and misdirected light not only **interferes with nighttime ecosystems,** wildlife, health and sleep habits of humans and animals, and leisure pursuits (stargazing) but also with professional astronomy and other physical sciences; it also entails economic effects through the **vast amount of energy wasted**
- There is strong evidence that economic activity and urban density are correlated with the existence of light pollution, and – with the advent and rising numbers of satellites – **light pollution from satellite constellations** is another form of human action obscuring starlight – causing considerable problems for the scientific community
- **Five guiding principles help to mitigate** light pollution: lighting should be **useful, targeted, low level, controlled,** and **warm-colored**

1) Globe at night/Skyglow study, based on human observation (vs satellite observations measuring a limited spectrum of light)

Source: International Dark-Sky Association; Science Advances; Ecological economics; Roland Berger

Space pollution in the form of space debris is a growing problem due to the rising number of satellite launches and other space activities

Origins of space debris

As private space companies have excelled in launch efficiency, **more satellites** have been **launched** into space **in 2022 and 2023 than in the six decades** of space exploration before

6,050 total rocket launches since 1957[1)]

↓

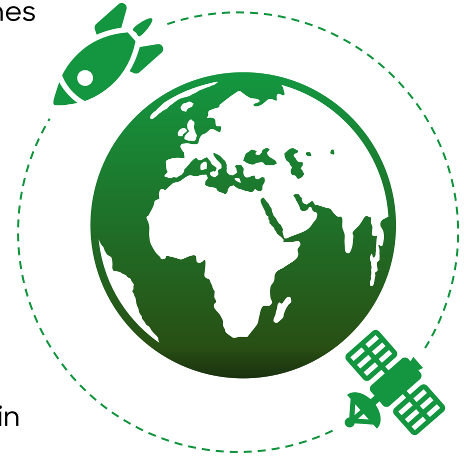
16,990 deployed **satellites**

↓

11,500 still in space

↘

9,000 still functioning



Size of space debris:

36,500 objects	> 10 cm
1,000,000	1 cm - 10 cm
130,000,000	1 mm – 1 cm

↑

Space debris
6,500 tons[2)]

Making up for more than 50% of total mass of space objects in Earth's orbit[3)]

↑

About **35,150** debris objects are being tracked

↑

A total of **640** anomalous events caused fragmentation

→

Average impact speed at collision:

10 km/s

↓

Threats originating from space debris

Collision with operating satellites or spacecraft

Space debris crashing on Earth's surface; on average one object returns to Earth each week

Light pollution affecting scientific discoveries, public astronomical observation, and ecosystems

↓

Tackling space debris

Prevent space debris generation

Remove space debris from orbit

Regulate commercial space companies

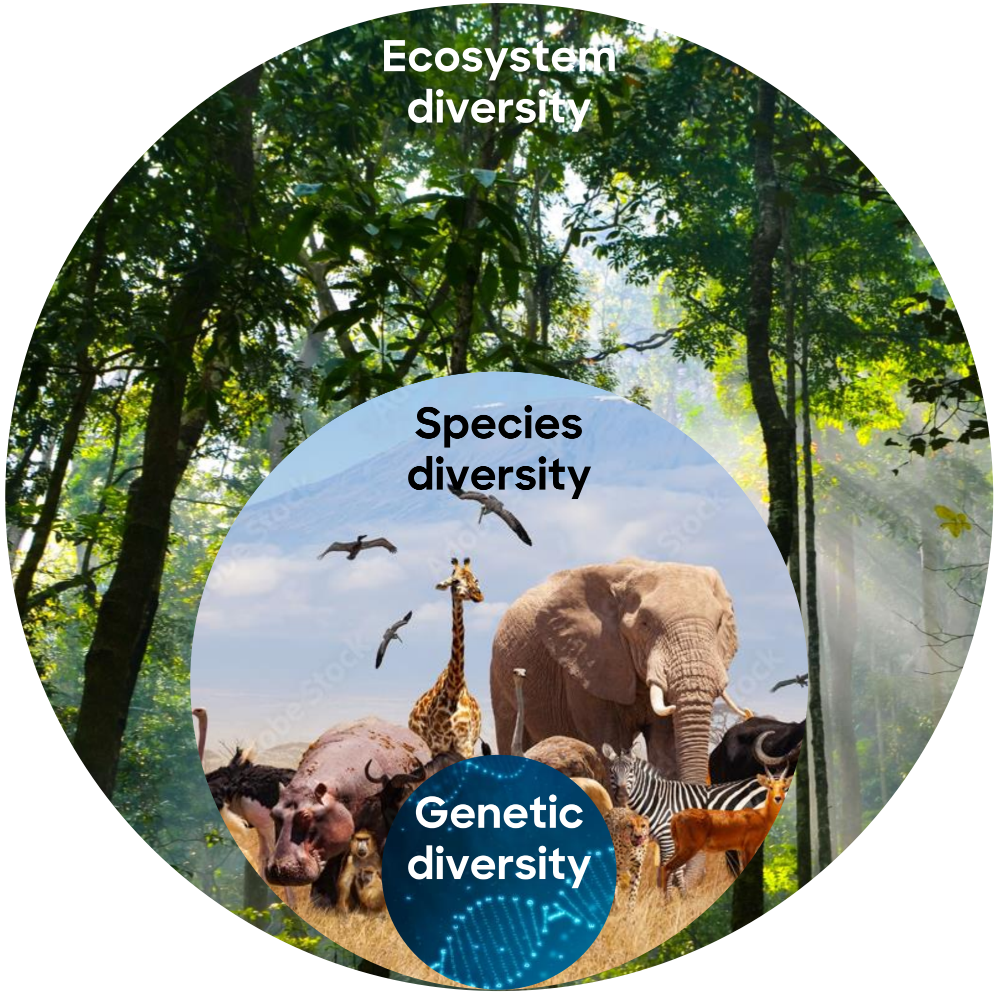
- **Space debris** consists of man-made **non-functional space objects** such as pieces of spacecraft or defunct satellites, tiny flecks of paint of old spacecraft. They are mainly in LEO[4)]
- The so-called **Kessler Effect** sets out the **dangers of an unstable debris environment,** where beyond a certain critical mass of debris a **chain reaction** is triggered resulting in more collisions and debris, **rendering space activities and the use of satellites** in certain orbital ranges **increasingly difficult**
- In the absence of a globally agreed space pollution frame-work, **ESA's "zero debris approach"** aims to limit the agency's debris production as a first step towards more responsible and sustainable use of LEO
- Besides defunct objects, planned **mega constellations of commercial satellites** will massively add to the risk of collision

1) October 4, 1957: Soviet Union launches Sputnik 1, the first artificial Earth satellite, marking the start of the space era; 2) As of January 2022; 3) Total mass of space objects in Earth's orbit is estimated to be at 11,500 tons in 2023; 4) Lower Earth Orbit

Source: ESA; NASA; Roland Berger

Biodiversity has rightly become as important as climate change – It is essential to our life and can be explored at three interdependent levels

Biodiversity levels

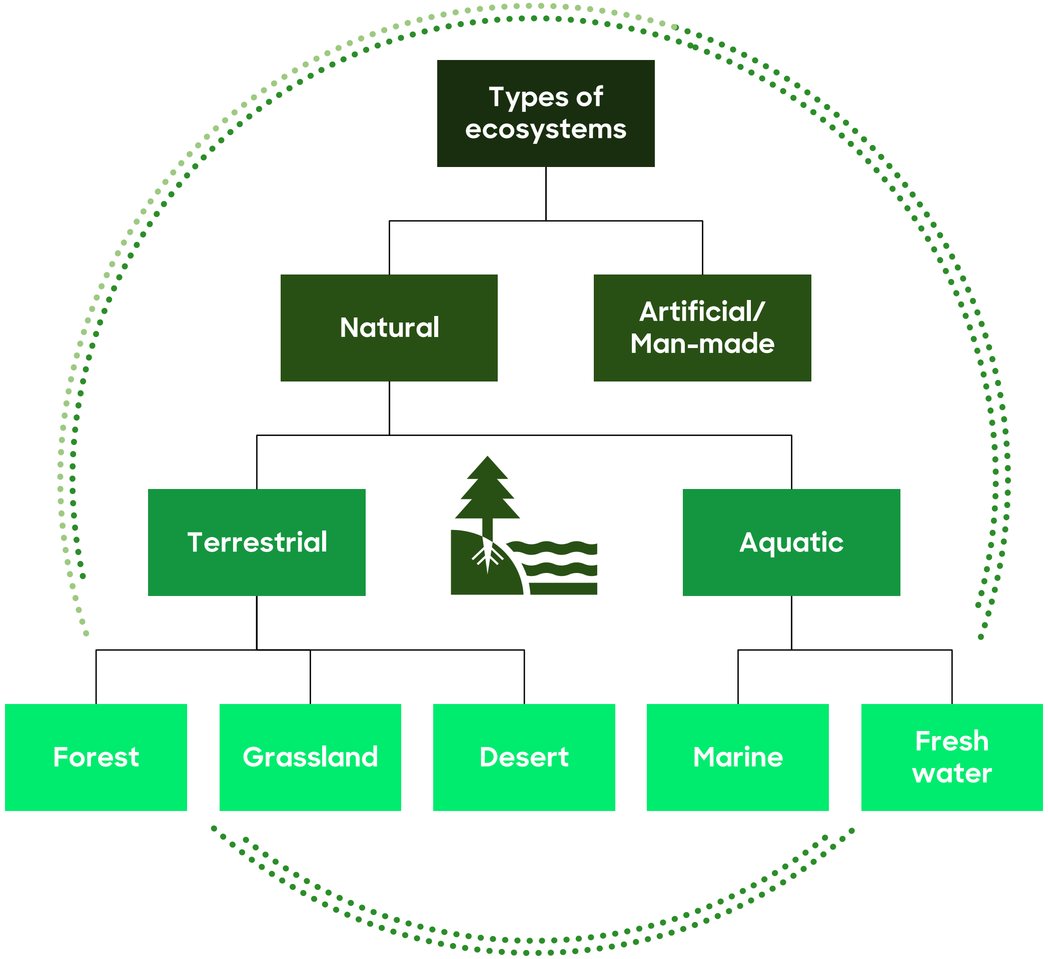


- In recent years, the topic of **biodiversity,** a term first coined in 1985, has gained the **same importance as climate change** – a view long overdue as biodiversity is **essential for all life** on Earth
- While biodiversity is commonly understood as the diversity of species, including animals, plants, fungi, and bacteria that are living on Earth, there are **three distinct levels of biodiversity** that interact with each other
- Genetic diversity is the **variety of genes within a species.** Each species is made up of individuals that have their own genetic composition. This means a species may have different populations with different genetic variability
- Species diversity is the **variety of species within a habitat or a region.** Some habitats, such as rainforests, have many species. Others, especially polluted or depleted habitats, have fewer. **Species are grouped into families** according to shared characteristics
- **Ecosystem diversity** is the variety of ecosystems in a place. An ecosystem is a community of organisms and their physical environment interacting together. **The area covered by an ecosystem can vary greatly,** from large forests to lakes and ponds
- **Countries** with **very high levels of biodiversity** are described as **megadiverse.** Twelve of these megadiverse countries, including e.g. Ecuador, Madagascar, and Australia, contain around 75% of our Earth's biodiversity
- Interaction between species and natural events are key to maintaining biodiversity. Ecosystems and species **adapt to disturbances** that occur on a regular basis, with some of them relying on disturbances such as floods and fires for replenishment and reproduction

Source: The Australian Museum; LSE; Roland Berger

Ecosystems comprise our ambient environment – The surface of the Earth is a series of connected ecosystems

Classification of ecosystems

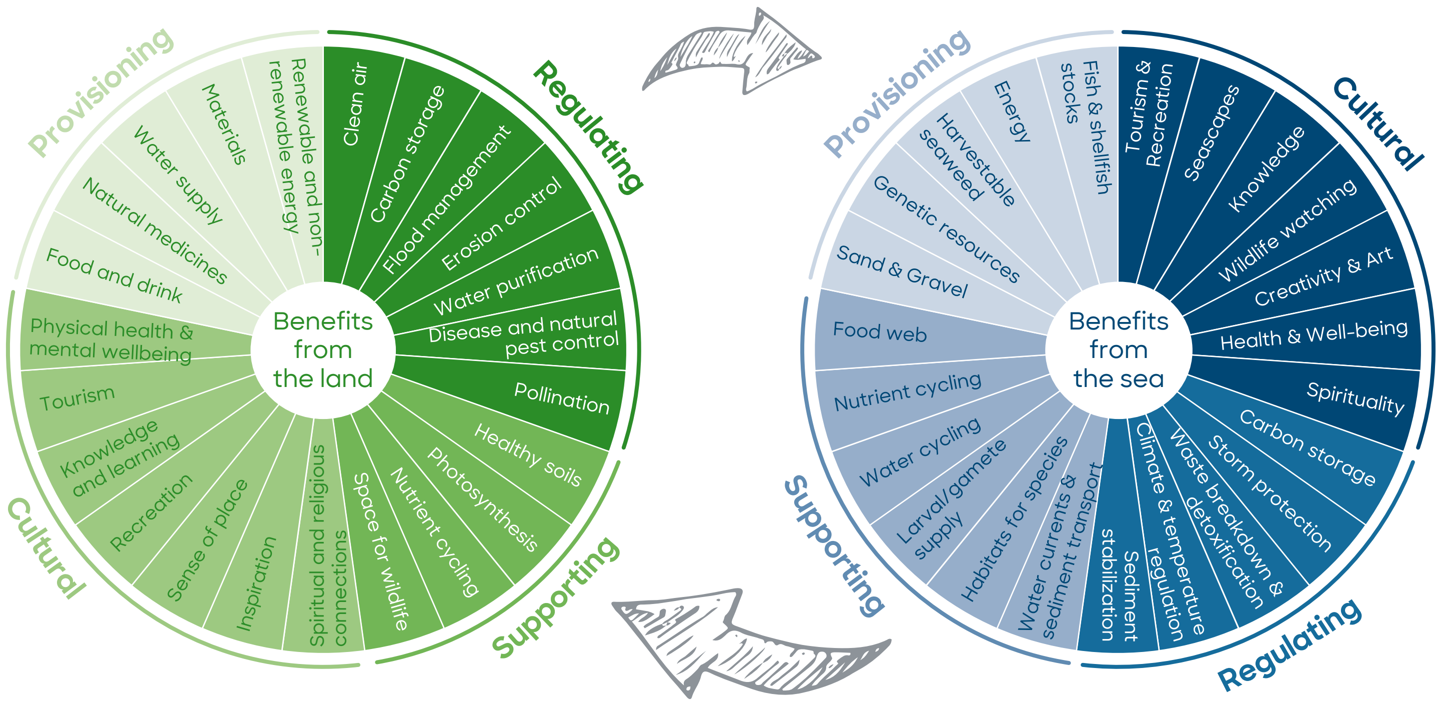


- An **ecosystem** is the **systematic interaction of a set of** living (biotic, i.e. animals, plants, and other tiny organisms) and non-living (abiotic, i.e. rocks) components of an area engaging within a particular **habitat;** a **habitat** is specific to a **species** or population of organisms – its main components are **shelter, water, food,** and **space**
- Covering around **71% of the planet's surface area, aquatic ecosystems** are the Earth's biggest ecosystem: **Aquatic ecosystems** broadly comprise **marine** (saltwater) **ecosystems** like the ocean, coral reefs, and mangroves, **and freshwater environments** such as rivers, freshwater lakes, estuaries, and wetlands
- **Terrestrial ecosystems** cover the remainder (around **29%**): Key categories of terrestrial ecosystems include **forests, grasslands, and deserts**
- Any number of ecosystems and habitats make up a **biome:** A **biome covers a wider physical area than an ecosystem or habitat** and has a relatively large 'geographical zone' defined mainly by its **climate** (**precipitation** and **temperature**). The same biome (e.g. tundra, tropical rainforest) may reoccur in several other locations around the world that share similar conditions. Because biomes are largely shaped by climate, **if the climate changes so does the biome**
- **Ecosystems** differ enormously depending on **a range of factors** other than climate, namely underlying geology, soil status, nutrients, plant and animal life, hydrology, and many more – all **prone to human-made activity and manipulation**

Source: National Geographic; Dasgupta Review; Roland Berger

Ecosystem services are the benefits humans derive from nature – Over half of the world's GDP is dependent on nature's services

Terrestrial and aquatic ecosystem services – Illustrative



- Ecosystem services are understood as the **benefits people obtain from nature** – the direct and indirect contributions provided for human wellbeing and quality of life
- Ecosystem services can be categorized into **provisioning, regulating, cultural, and supporting services.** While some are more tangible, others are complex to quantify and are only experienced indirectly
- **Provisioning services** are tangible goods that can be directly used for consumption or the production of other goods. They include the delivery of food, fresh water, wood, fuel, fiber, and medicine
- **Regulating services,** like carbon sequestration, pollination, and erosion control support ecosystem stability and lead to benefits such as climate regulation and flood management
- **Cultural services** benefit people's wellbeing through opportunities for recreation, ecotourism, and education
- Finally, **supporting services** are more ambiguous but form the basis for the other types of services. They support the functioning of ecosystems through nutrient and water cycling, habitat provision, and the formation of healthy soils
- Humanity depends on natural capital assets and ecosystem services: WEF research shows that **USD 44 trillion of economic value generation** – more than half of total global GDP(2019) – **is moderately or highly dependent on nature and its services,** and thus directly exposed to risks from nature loss

> ***Over half of the world's GDP is moderately to highly dependent on ecosystem services and biodiversity,*** *such as pollination, soil health, water quality and provision of natural resources.*
>
> **World Economic Forum**

Source: Nature Agency Scotland; WEF; Roland Berger

Multiple pressures affect the state of ecosystems and their species

Drivers of pressures on ecosystem services

Indirect drivers: Demographic & sociocultural; Economic & technological; Institutions & governance; Conflicts & epidemics

↓

Direct drivers: Land/sea use change; Direct exploitation; Invasive alien species; Pollution; Climate change

↓

Biodiversity impact: Terrestrial; Marine; Freshwater

↓

Ecosystem services: Provisioning services; Regulating services; Supporting services; Cultural services

- Due to multiple **direct and indirect pressures** – and despite long-standing local, national, and international environmental protection efforts – **ecosystems are under threat worldwide,** with the rate of change in direct and indirect drivers differing among regions and countries
- **Indirect drivers** affecting ecosystems arise from societal behaviors and values that influence global production and consumption patterns, population dynamics, and technological progress
- Chief causes are **land and sea use changes** and (over)**exploitation, pollution, invasive alien species,** and **climate change**
- These five direct stressors result from an array of **underlying causes** across major sectors which are, in turn, linked to and driven by human population dynamics, societal behaviors, production and consumption patterns, resource use, and governance
- At least a quarter of the global land area is **managed by indigenous and local communities.** While generally declining less rapidly in these areas, nature managed by these communities is under increasing pressure due to **resource extraction, commodity production,** and new **transport and energy infrastructure**

Source: WWF; IPBES; Roland Berger

Environment & Resources


3.1 Climate Change & Pollution

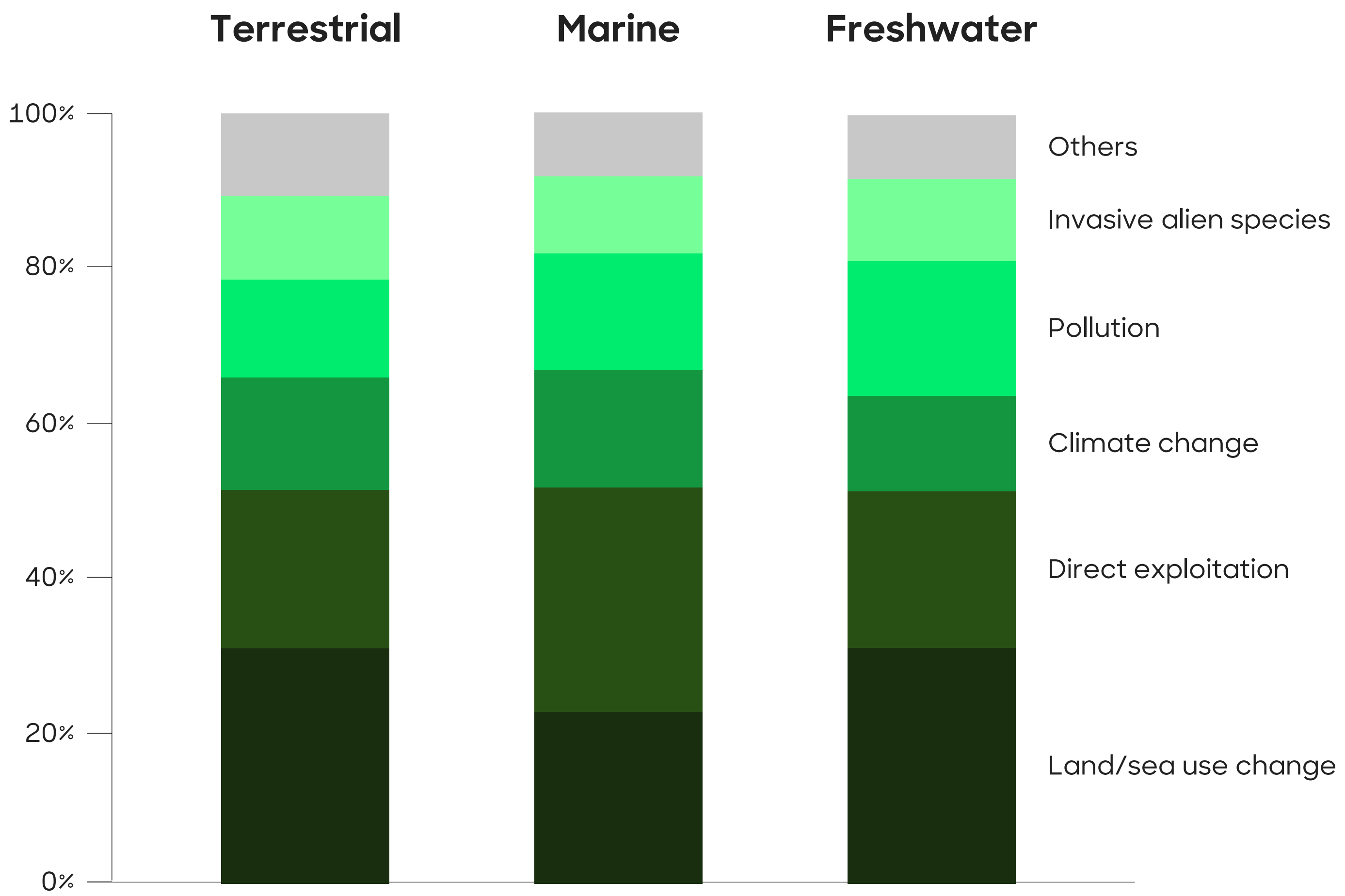

3.2 Bio-diversity


3.3 Water


3.4 Resources & Raw Materials

Changes in land and sea use and direct exploitation account for more than 50% of the global impact on ecosystems

Relative global impact of direct drivers on ecosystems[1)]



- **Direct drivers** (natural and anthropogenic) are drivers that **unequivocally influence biodiversity and ecosystem processes**
- **Natural drivers** cannot be influenced by human activity; these include, for example, volcanic eruptions, earthquakes, tsunamis, and tropical cyclones
- **Anthropogenic drivers**, resulting from human decisions and activity, include habitat conversion, e.g. degradation of land and aquatic habitats, deforestation and afforestation, exploitation of wild populations, **climate change, pollution of soil, water and air,** and species introductions. Some of these drivers, such as pollution, can have negative impacts on nature; others, as in the case of habitat restoration, or the introduction of a natural enemy to combat invasive species, can have positive effects
- According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), **land- and sea-use change and direct exploitation account for more than 50% of the global impact on land and aquatic ecosystems** – but each driver is dominant in certain ecosystem contexts

1) The color bands represent the relative global impact of direct drivers on terrestrial, marine, and freshwater nature, as estimated from a global systematic review of studies published since 2005

Source: IPBES; Roland Berger

Across ecosystems, human activity continues to severely erode the world's ecological foundations

Illustrative findings on ecosystem damage

> *"Human actions have already severely altered around 3/4 of the land surface and 2/3 of the ocean area."*
>
> **IPBES**

Terrestrial ecosystems

- **More than 85% of wetlands** have been lost
- **1/3 of the world's topsoil** has been degraded
- **32% of the world's forest area** has been destroyed
- The **Amazon has lost 17% of its size** in the past 50 years

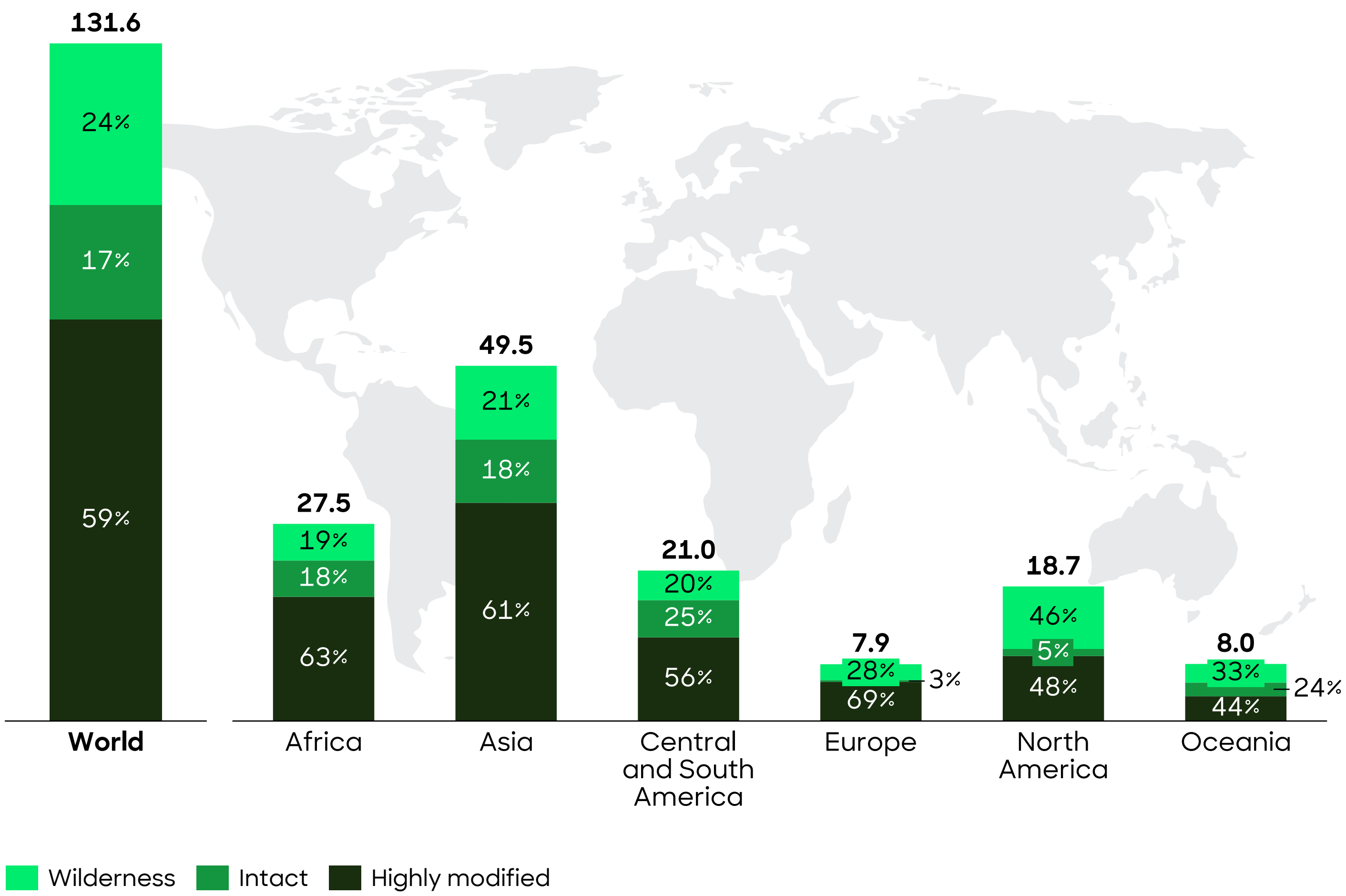
Aquatic ecosystems

- **Seagrass meadows** decreased in extent by over **10% per decade**
- **More than 55% of ocean area** is covered by industrial fishing
- **33% of fish stocks** are overfished
- **50% of the world's coral reef system** has been destroyed

Source: WEF; IPBES; Roland Berger

Our land areas are highly modified: Almost 60% of the Earth's terrestrial area is under moderate to intense pressure

Share of anthropogenic disturbances and total surface on continents[1)] [%, m km²]



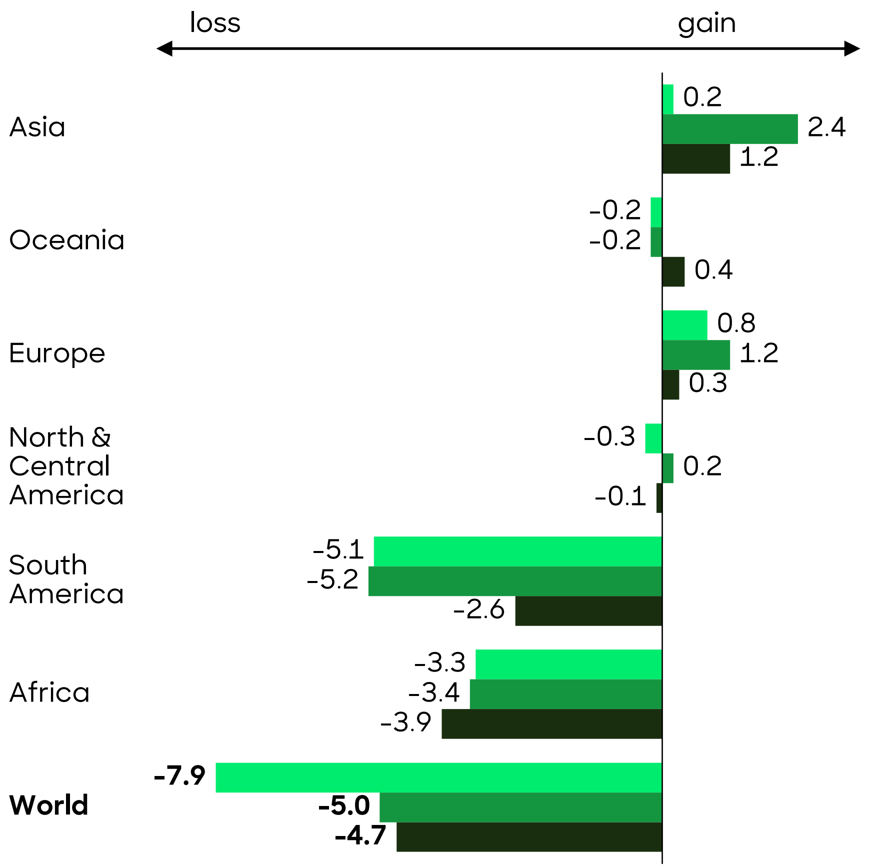
- Based on data from recent surveys, **less than half (41.6%) of the Earth's surface was intact or wilderness,** i.e. with a human footprint below the threshold to being highly modified (<4) – meaning it was assessed as being **ecologically intact**
- However, this includes mostly **wilderness** (24%). Other **ecologically intact areas** (17%) include areas with low density **transitory human populations,** for example, as well as low intensity grazing pastures
- The remaining area **(59%)** – with a human footprint of ≥4 – was under **moderate or intense human pressure** and is therefore regarded as **highly modified**
- This highly modified area encompasses **over half the area of 11 of Earth's 14 biomes**
- The ≥4 **threshold** has been found to be **robust** from a **species conservation perspective** because, once surpassed, species extinction risk increases dramatically, and several **ecosystem processes are altered**

1) Human Footprint: Study uses a human footprint threshold of <4 (on a 0-50 scale) to identify where land is considered ecologically intact (below the threshold) or highly modified and thus ecologically degraded (equal to or above the threshold). Areas below this threshold are ecosystems that may be subject to some level of human pressure, but still contain most of their natural habitat and maintain their ecological processes. Due to rounding the sum of the percentages does not always equal 100%

Source: One Earth/Brooke; Roland Berger

Globally, the annual rate of forest loss has eased – Nevertheless, the scale of deforestation in Africa and South America poses a threat

Annual forest area net change by decade and region (1990-2020) [m ha p.a.]



1990-2000 | 2000-2010 | 2010-2020

Deforestation projections from 2010 to 2030 (selective)

	Amazon	Greater Mekong	Borneo	Cerrado	Congo Basin
Projected loss of forest [m ha]	**23-48**	**15-30**	**22**	**15**	**12**
Livestock	Primary	Not a cause	Not a cause	Primary	Less important
Large-scale agriculture	Primary	Primary	Primary	Primary	Secondary
Small-scale agriculture colonization	Primary	Secondary	Secondary	Not a cause	Primary
Unsustainable logging	Less important	Secondary	Secondary	Not a cause	Secondary
Pulp plantations	Not a cause	Secondary	Secondary	Not a cause	Not a cause
Fires	Secondary	Not a cause	Secondary	Not a cause	Not a cause
Charcoal and fuelwood	Not a cause	Less important	Not a cause	Less important	Primary
Mining	Secondary	Not a cause	Not a cause	Less important	Secondary
Hydroelectric power	Primary	Less important	Less important	Secondary	Secondary
Infrastructure	Primary	Less important	Secondary	Less important	Not a cause

Primary cause of forest loss | Secondary cause of forest loss | Less important cause of forest loss | Not a cause of forest loss

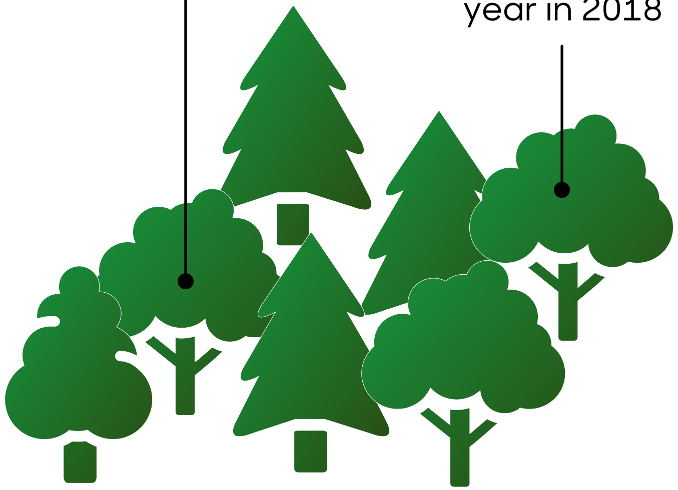
Source: FAO; WWF; Roland Berger

Global forest ecosystems are a major carbon sink – Reforestation could greatly increase their capacity for absorption of CO_2 emissions

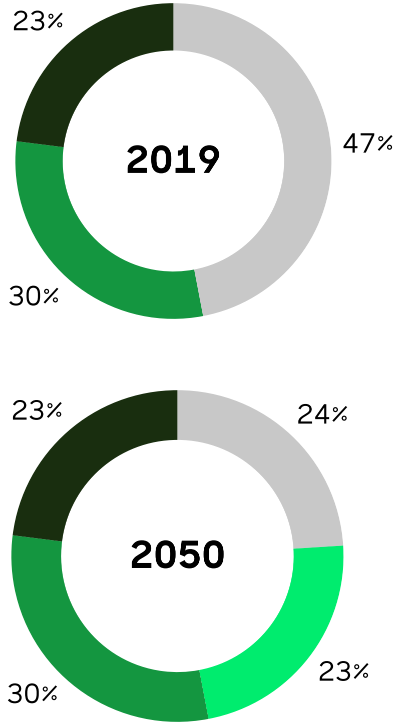
Forest ecosystem services – Forest ecosystem value

USD 16.2 trillion is the estimated **value of ecosystem services** provided by forests in 2018

The formal forest sector account for an estimated **45 m jobs**, generating **labor income** of **USD 580 bn** per year in 2018



Share of CO_2 emissions absorbed by forests in 2019 and potential impact of natural forest regrowth until 2050[1)]



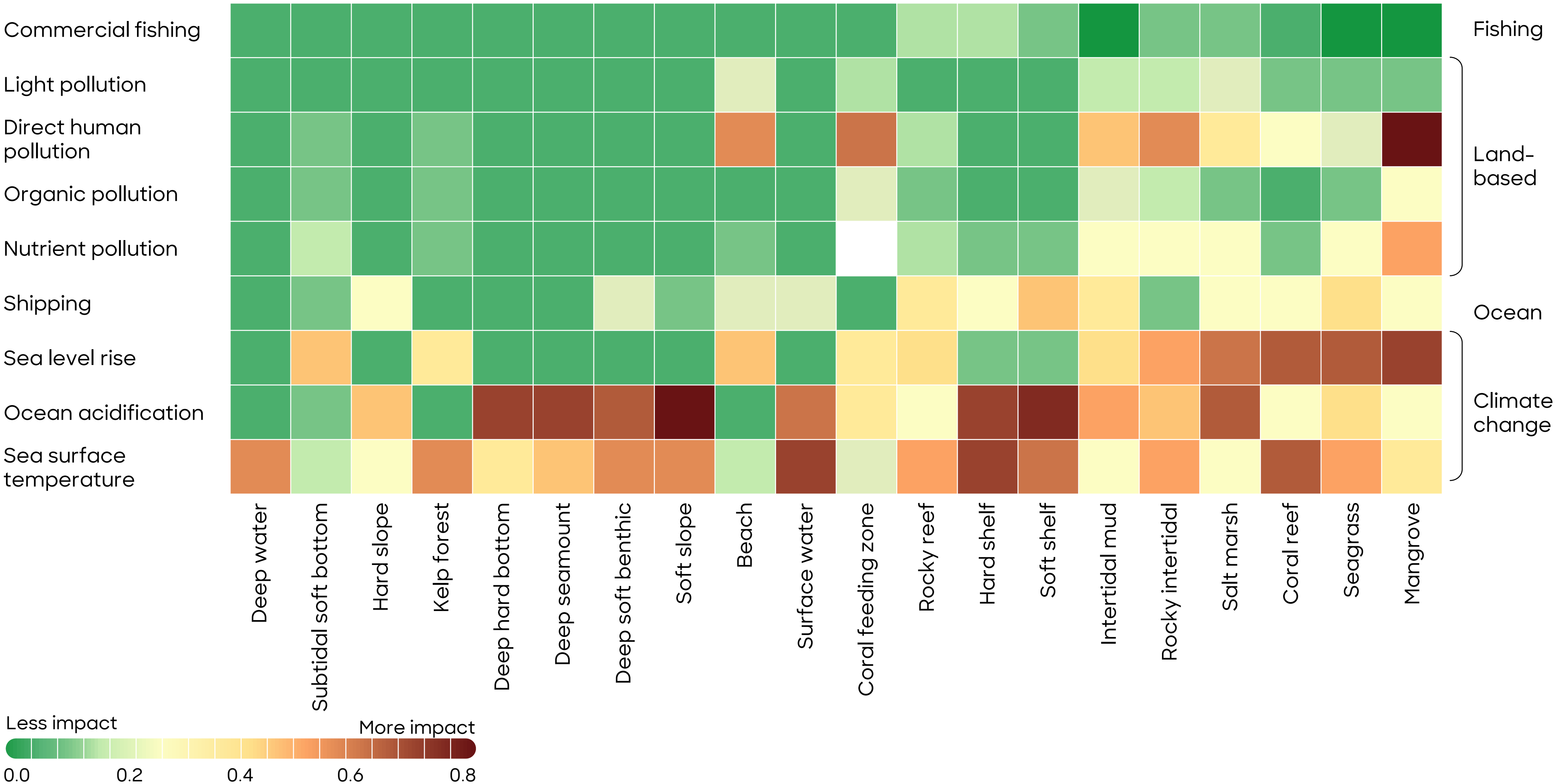
- **Humans** are reliant on what nature provides; this includes **terrestrial ecosystems such as forests**
- In terms of **biodiversity,** the world's forests contain **60,000 different tree species,** 80% of amphibian species, 75% of bird species, and 68% of the world's mammal species
- According to the FAO, around **30% of CO_2 emissions are absorbed by forests,** around 23% by the oceans and the remainder is absorbed by the atmosphere
- Through actions that **encourage natural forest regrowth until 2050, a 23% increase** in the **absorptions of CO_2** emissions by such areas could be achieved (31% of the carbon is stored in the biomass and 69% in the soil) while helping to increase biological diversity across all species
- Reforestation is not a silver bullet: proper selection of tree species and locations is critical – if not, it can do more harm than good. It is more important to **protect existing, natural forests and natural regrowth**

1) Based on ground and Earth observation data to map annual forest-related GHG emissions and removals globally for the period 2001-2019

Source: FAO; UN; UNEP; WRI; Roland Berger

Oceans are threatened by human activity – 59% of marine ecosystems are under cumulative pressures

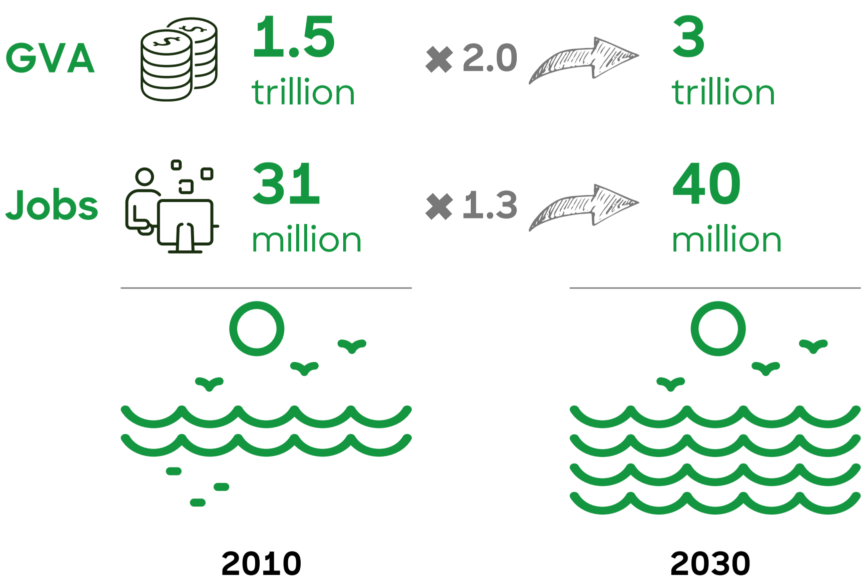
Different marine environments and their exposure to and impact of a range of human activity pressures



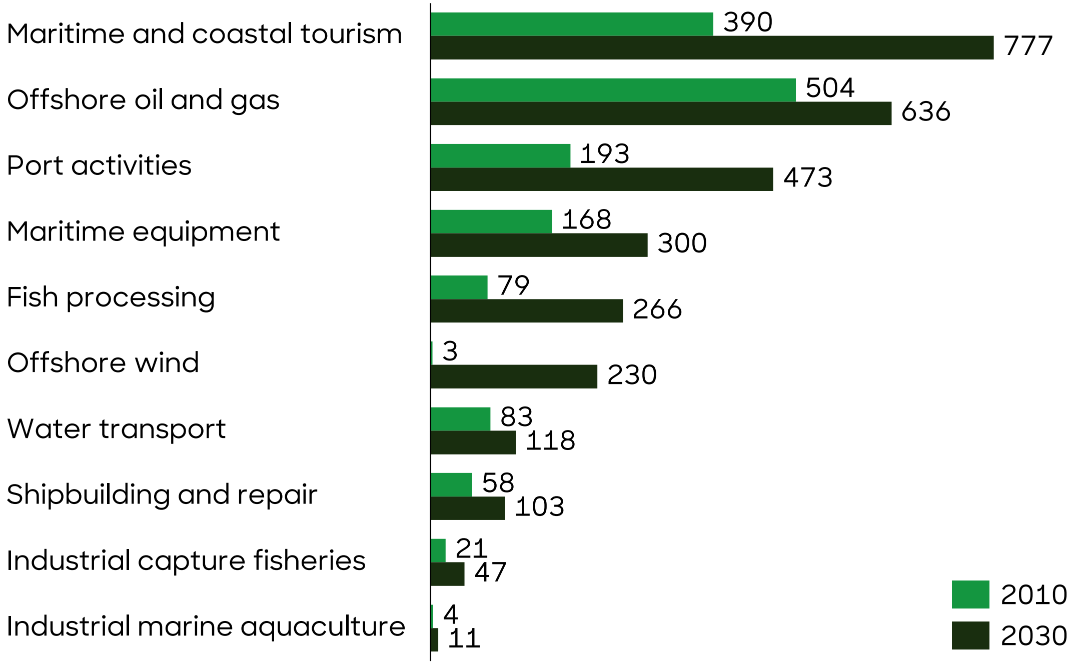
Source: Nature; Roland Berger

Oceans produce at least half the oxygen we breathe, and their ecosystems add considerable value to the global economy

Global value added and jobs in the ocean economy in 2030 [constant 2010 USD]



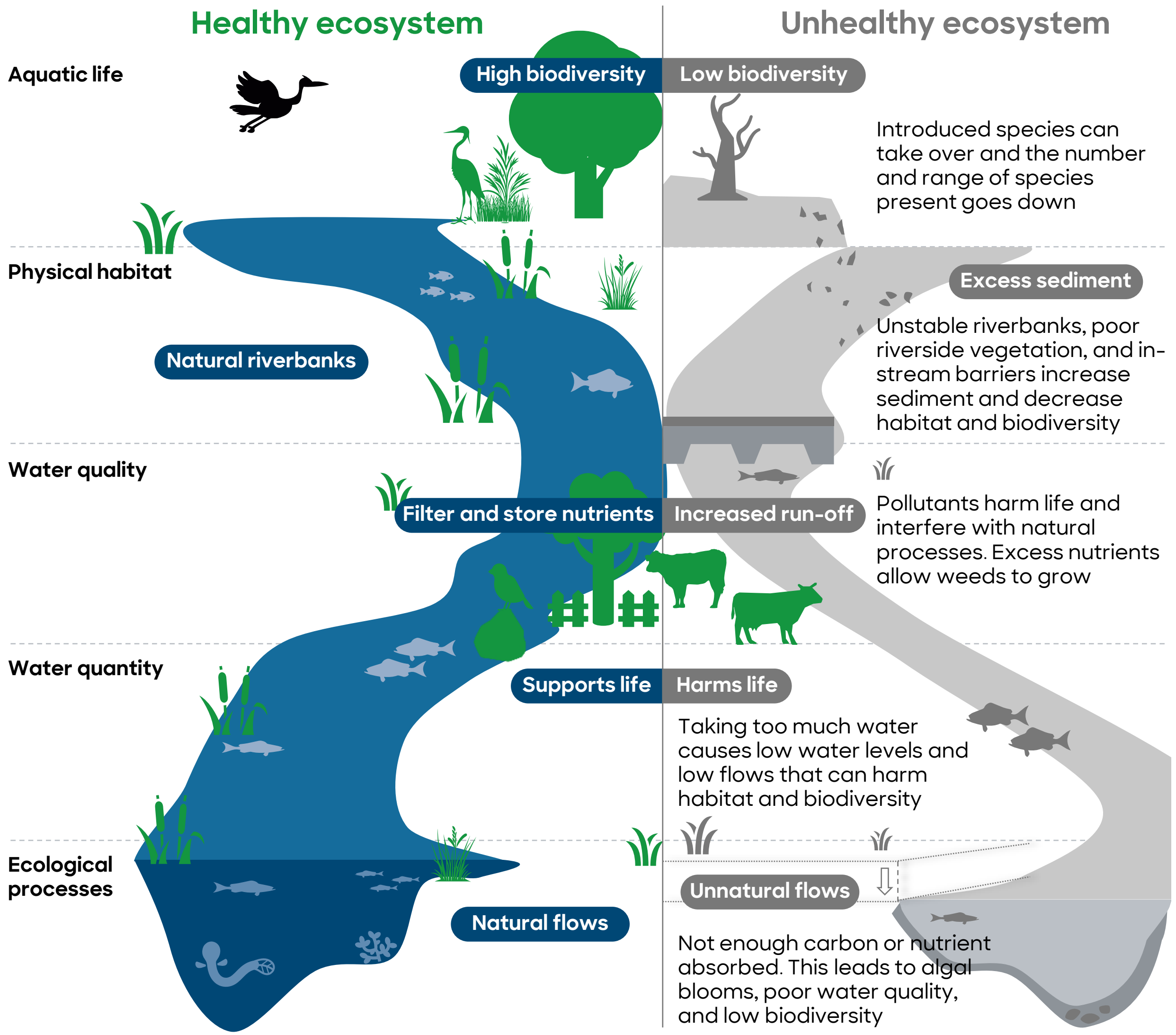
Overview of industry-specific value added in the ocean economy [constant 2010 USD bn]



- Ocean ecosystem services: The ocean produces at least **half the oxygen we breathe (50-80%)** and **absorbs more than a quarter (>25%) of the anthropogenic emissions of carbon dioxide (CO_2)** and around **93% of the added heat** arising from human-driven changes to the atmosphere
- Ocean economy value: Prior to the COVID-19 pandemic, **OECD projected a doubling of the ocean economy from 2010 to 2030, to reach USD 3 trillion and employ 40 million people**
- The ocean economy spans **multiple sectors** – including oil and gas, fishing, aquaculture, shipping, ports, tourism, offshore wind energy, and marine biotechnology – and is growing rapidly

Source: OECD; EarthSky; Ocean-Climate; Roland Berger

Freshwater ecosystems are key to biodiversity and human wellbeing, but their declining health poses a threat

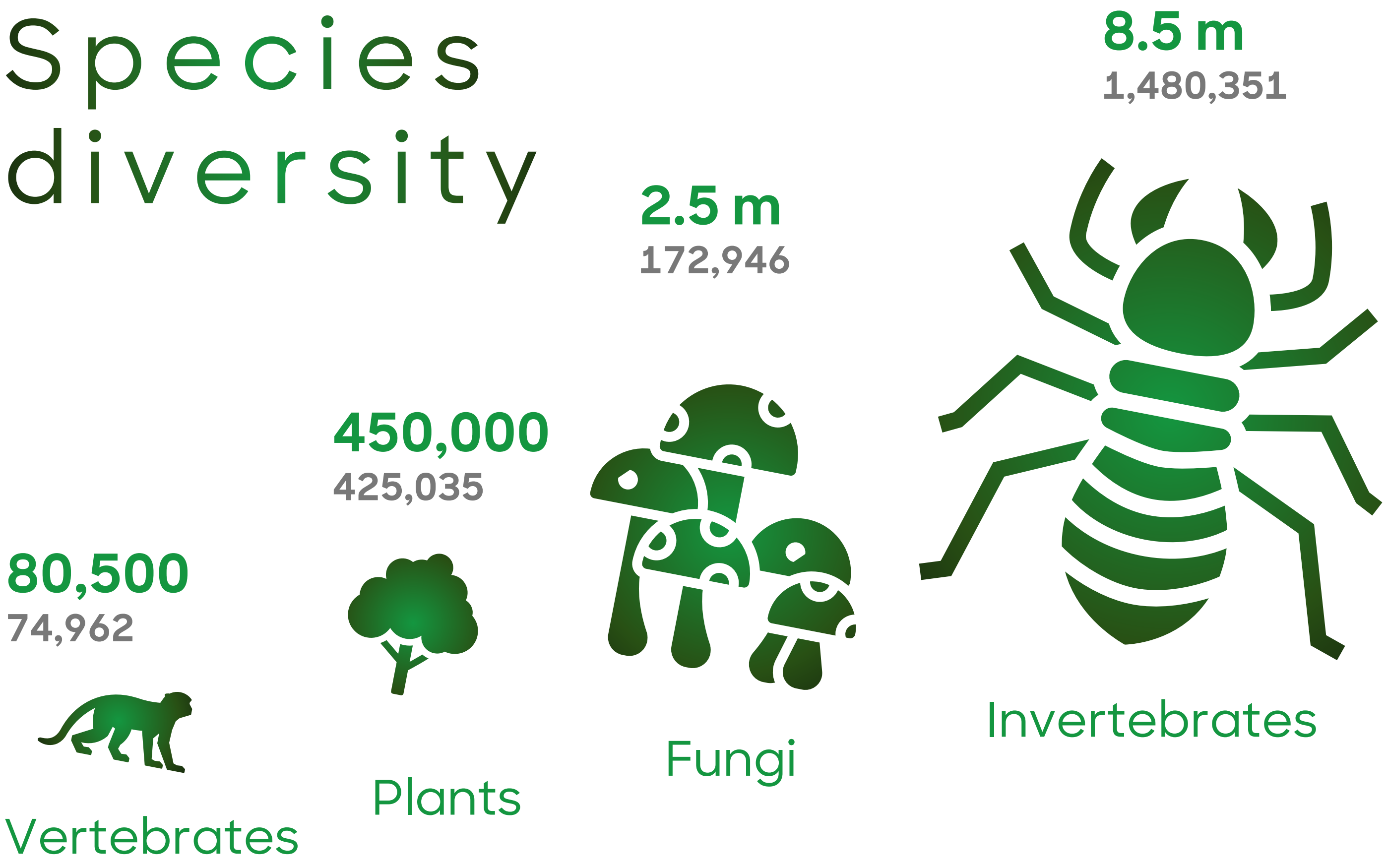


- **Freshwater ecosystems** can include rivers, streams, lakes wetlands, estuaries, and underground aquifers
- Despite covering less than **1% of the Earth's total surface,** these ecosystems are critical for biodiversity as they provide habitat for one third of all vertebrate species, including **40% of all fish species**
- Freshwater ecosystems are under immense pressure: **resource extraction, power generation** as well as **pollution** from plastic, chemicals and waste have led to high levels of degradation. There has been an average decline of 35% in the area of natural inland wetlands since 1970 with a total loss of 87% since 1700
- The **connectivity** of freshwater ecosystems has also suffered, particularly from barriers to migration routes like **dams and reservoirs.** Only 37% of rivers longer than 1,000 km remain free-flowing over their entire length. This poses a threat to the survival of fish species that need to migrate to feed and breed
- Freshwater **ecosystem health** can be assessed along five categories: the state of **aquatic life, habitat condition** including connections to groundwater, physical and chemical measures of **water quality, water quantity** including variability of flow levels and connections to different water bodies, and the **ecological processes** – the interactions between species and their habitat
- Comprehensively assessing ecosystem health remains a challenge and measuring components varies according to the type of ecosystem. A proposed measurement approach is the **Freshwater Health Index (FHI)**

Source: UNEP; New Zealand Ministry for the Environment; Conservation International; WWF; ZSL; Roland Berger

The diversity of species living on Earth is enormous, with many species yet to be discovered

Estimated number of species and number of described species[1)]



XXX: Estimated xxx: Described

- The diversity of species in the three major kingdoms of life – animals, plants, and fungi – showcases the remarkable **variety of life forms that exist on Earth.** As more species are being discovered and described, many, especially among fungi and invertebrates, are still not known to us
- Estimates suggest that **animals** exhibit **a wide range** of species richness, with global numbers ranging from 3 to 30 million species. In contrast, **plants** are estimated to have a **more constrained diversity,** with approximately 450,000 to 500,000 known species
- **Fungi,** on the other hand, indicate high estimates, ranging from 0.5 up to 19.4 million species, highlighting the vast number of **unknown fungal diversity.** This wide range is primarily due to specific challenges associated with documenting fungal diversity such as their **taxonomic complexity** but also the fact that fungi have historically been under-researched
- Over time, our knowledge of species diversity has advanced significantly, driven by interdisciplinary collaboration, technological innovations, and a **growing recognition of the importance of biodiversity conservation**

1) The numbers of described species should be used with caution as these are not always up to date for all taxonomic groups

Source: Niskanen et al.; IUCN; Roland Berger

Sustainable biodiversity is a 'must have' for our planet and for our economy – More than half of global GDP is dependent on nature

Economic value of selected species

USD 235-577 billion p.a.

> USD 1 trillion

USD 15.2 billion p.a.

- Methods to quantify the **economic value of biodiversity** are highly complex yet important as biodiversity is under extreme pressure worldwide, with **one million animal and plant species threatened with extinction** according to UN estimates
- WEF research shows that **USD 44 trillion of economic value generation** – more than half of the world's total GDP (2019) – is **moderately or highly dependent on nature and its services** and is therefore directly exposed to risks from nature loss

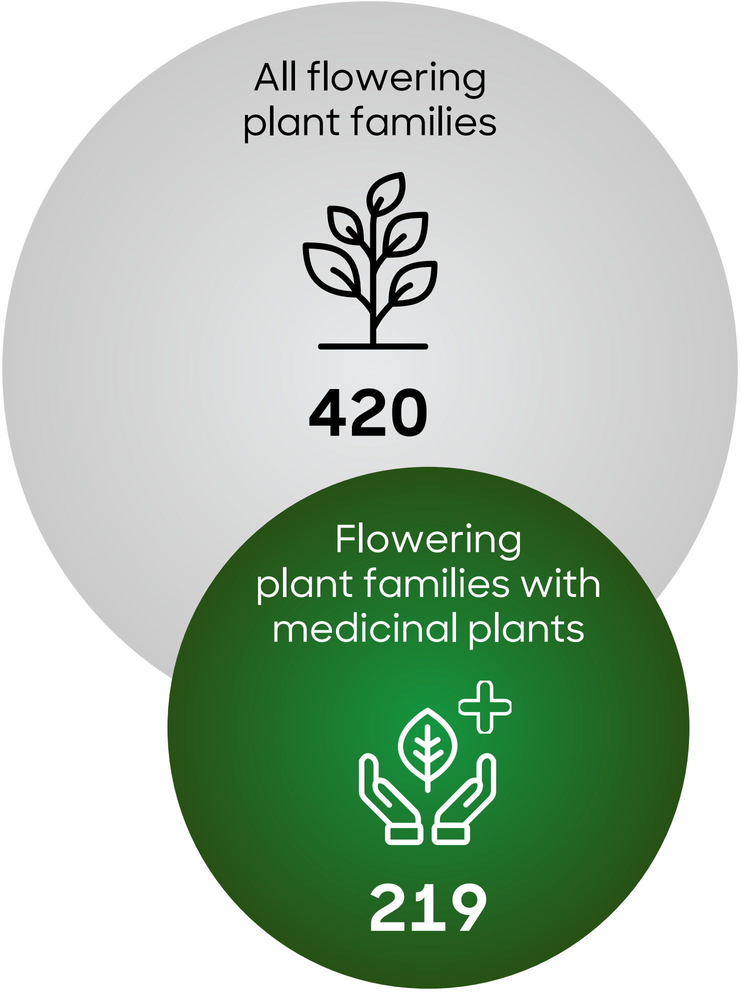
Three illustrative examples

- More than 75% of global food crops are dependent on **insect pollinators,** thus contributing 35% of global food production. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) the **annual value** of global crop output **at risk** due to **pollinator loss** is estimated at **USD 235-577 billion**
- **Great whales** sequester 33 tons of CO_2 on average over their lifetime. Together with other economic effects such as fishery enhancement, ecotourism, and phytoplankton productivity **(capturing 37 billion tons CO_2 p.a.),** the IMF estimates the average value of a great whale at more than USD 2 million and the **value for the current stock of great whales at over USD 1 trillion**
- **Antarctic krill** in the Antarctic Peninsula and Scotia Sea region deliver **carbon sequestration services** with an estimated (lower bound) value of **USD 15.2 billion annually**

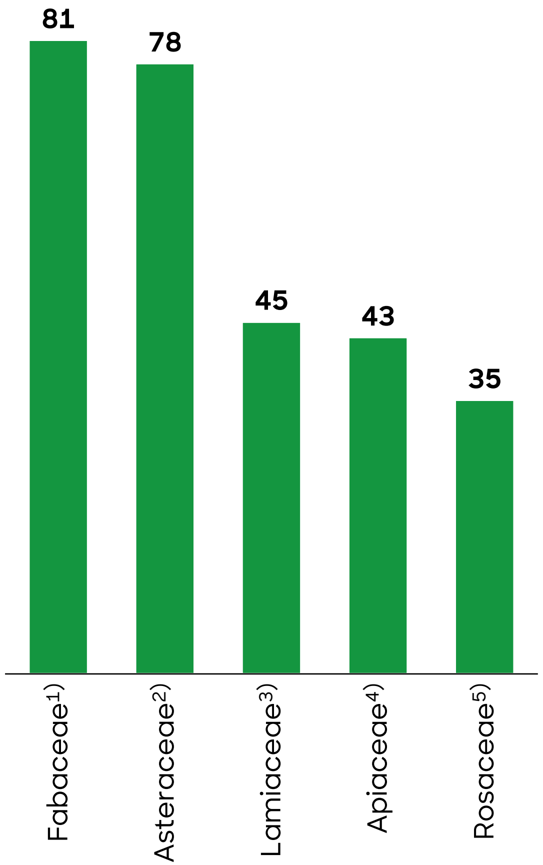
Source: UN/IPBES; WEF; IMF; WWF; Roland Berger

Biodiversity is essential for medical research – Natural products are a core part of drug discovery

Flowering plant families with medicinal plants and with the most medicinal genera



Flowering plant families with the most medicinal genera



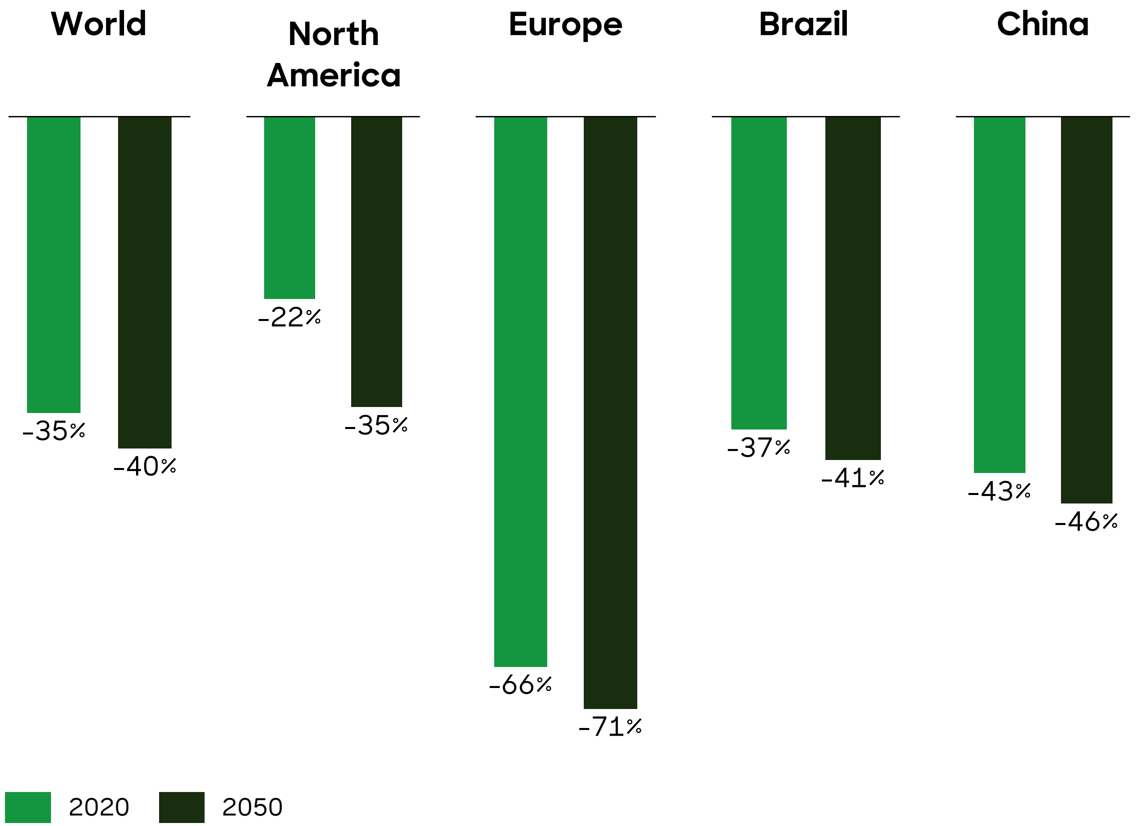
- **Plants** are **ingredients** for both traditional as well as **modern medicines.** For example, Taxol, a compound used in **chemotherapy drugs** was originally discovered in the bark of a certain type of yew tree, while a compound used in **aspirin** originated from the bark of the willow tree
- Roughly **70% of all cancer drugs are natural or "bioinspired"** and chemicals originally discovered in plants are also used to treat **Alzheimer's, malaria or Parkinson's**
- Overall, **more than 40% of pharmaceutical formulations** are derived from nature
- Interdisciplinary research on medicinal plants conceptualizes **plants and humans as symbiotic partners,** integrates traditional knowledge and disciplines such as evolutionary ecology to foster innovation
- This approach to medicinal research allows for **discovery of new therapeutic compounds** and applications of medicinal plants, emphasizes protecting plant diversity and the responsible use of plant resources, and recognizes the value of indigenous and traditional knowledge

Selected examples for each family: 1) Chickpea, clover, liquorice; 2) Artichoke, echinacea, sunflower; 3) Mint, rosemary, sage; 4) Anise, cumin, fennel; 5) Almond, blackberry, rose
Source: Davis and Choisy; WEF; WHO; Roland Berger

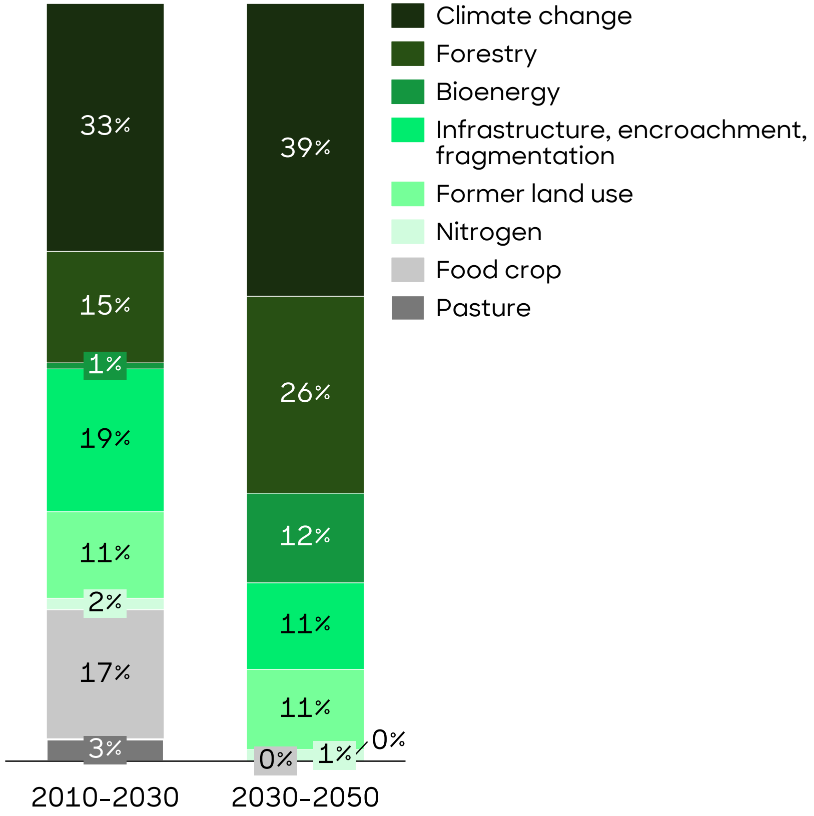
Biodiversity is declining: So far, more than one third of terrestrial species have been lost

Terrestrial species abundance and biodiversity loss

Terrestrial mean species abundance loss 2020 and 2050 for selected regions and countries[1)]
[% loss compared to pristine ecosystem]



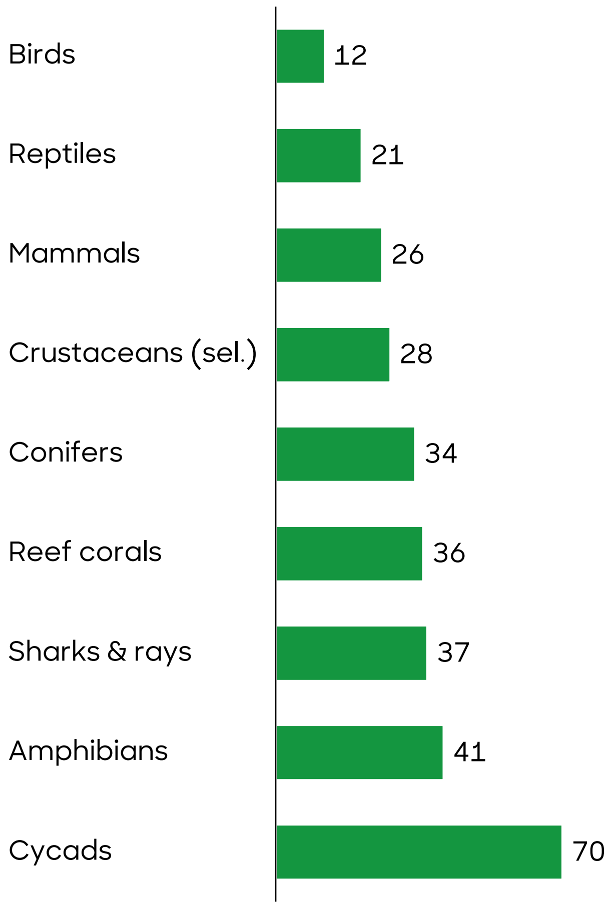
Relative share of pressures to additional terrestrial biodiversity loss 2010-2030 and 2030-2050[1)]
[%]



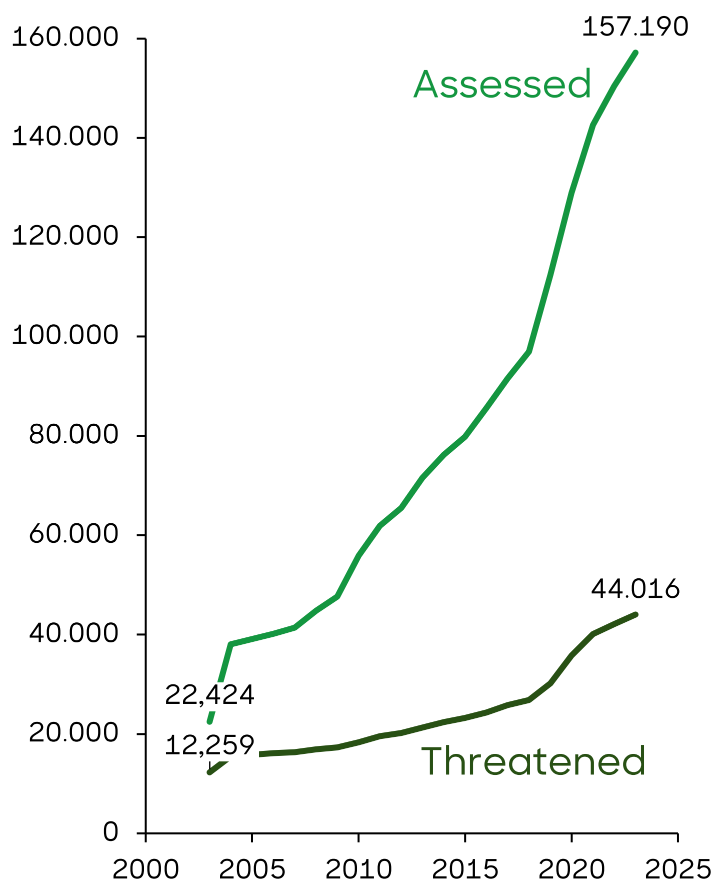
1) According to the Baseline scenario of the OECD, which includes steady GDP growth and a strong ongoing use of fossil fuels
Source: OECD; Roland Berger

Over the past two decades the number of species classified as threatened has more than tripled

Share of threatened species in selected categories 2023[1] [%]



Number of assessed and threatened species 2003-2023[1]



- The **Red List** published by the International Union for Conservation of Nature (**IUCN**) is the most acknowledged source of information on the global **status and development of species and their threat of extinction**
- It categorizes species into seven main categories ranging from least concern (LC) to extinct (EX), considering factors such as **their geographic area, the population size, and the rate of decline.** Species categorized as threatened have reached a **high risk of extinction in the wild,** while species categorized as near threatened are likely to become endangered in the near future
- As of 2023, more than **44,000 species** are threatened with extinction, meaning that **28% of all assessed species are under threat**
- Notably, the number of assessed species increased even more rapidly, meaning that the **share of threatened species has decreased** over time
- The **number of species** in each category can **fluctuate** because species are continuously being **reassessed** and moved between categories

1)Threatened species comprise those being assessed as critically endangered, endangered or vulnerable

Source: IUCN; Roland Berger

Biodiversity Intactness Index is an indicator of biodiversity loss under human pressures – Improvements necessitate a sustainability lens

Biodiversity Intactness Index (BII) of selected countries in 2020[1] [0-100%]; BII changes to 2050 under a middle-of-the-road scenario (SSP2) and a sustainable scenario (SSP1) [percentage points (PP)]

Country	2020BII[1]	Change to 2050 under SSP2[1]		Change to 2050 under SSP1[2]	
Papua New Guinea	100%	0 PP	→	0 PP	→
Canada	92%	-1 PP	↓	0 PP	→
Finland	88%	-11 PP	↓	-8 PP	↓
Brazil	80%	-2 PP	↓	0 PP	→
Japan	79%	-1 PP	↓	0 PP	→
Indonesia	73%	-2 PP	↓	+1 PP	↑
Australia	71%	0 PP	→	+1 PP	↑
US	67%	0 PP	→	+1 PP	↑
China	67%	0 PP	→	+2 PP	↑
Germany	61%	-1 PP	↓	+5 PP	↑
India	57%	-3 PP	↓	0 PP	→
Ireland	56%	+7 PP	↑	+8 PP	↑
South Africa	55%	0 PP	→	+1 PP	↑
UK	54%	+2 PP	↑	+3 PP	↑
Nigeria	52%	-2 PP	↓	0 PP	→

>90% – Safe limit: Threshold for areas to have **enough biodiversity** to be a **resilient** and **functioning ecosystem** (line between Canada and Finland)

Globally, biodiversity intactness is measured at 75% (line between Japan and Indonesia)

<30% signals depleted biodiversity to an extent of what is needed for a functioning ecosystem (line below Nigeria)

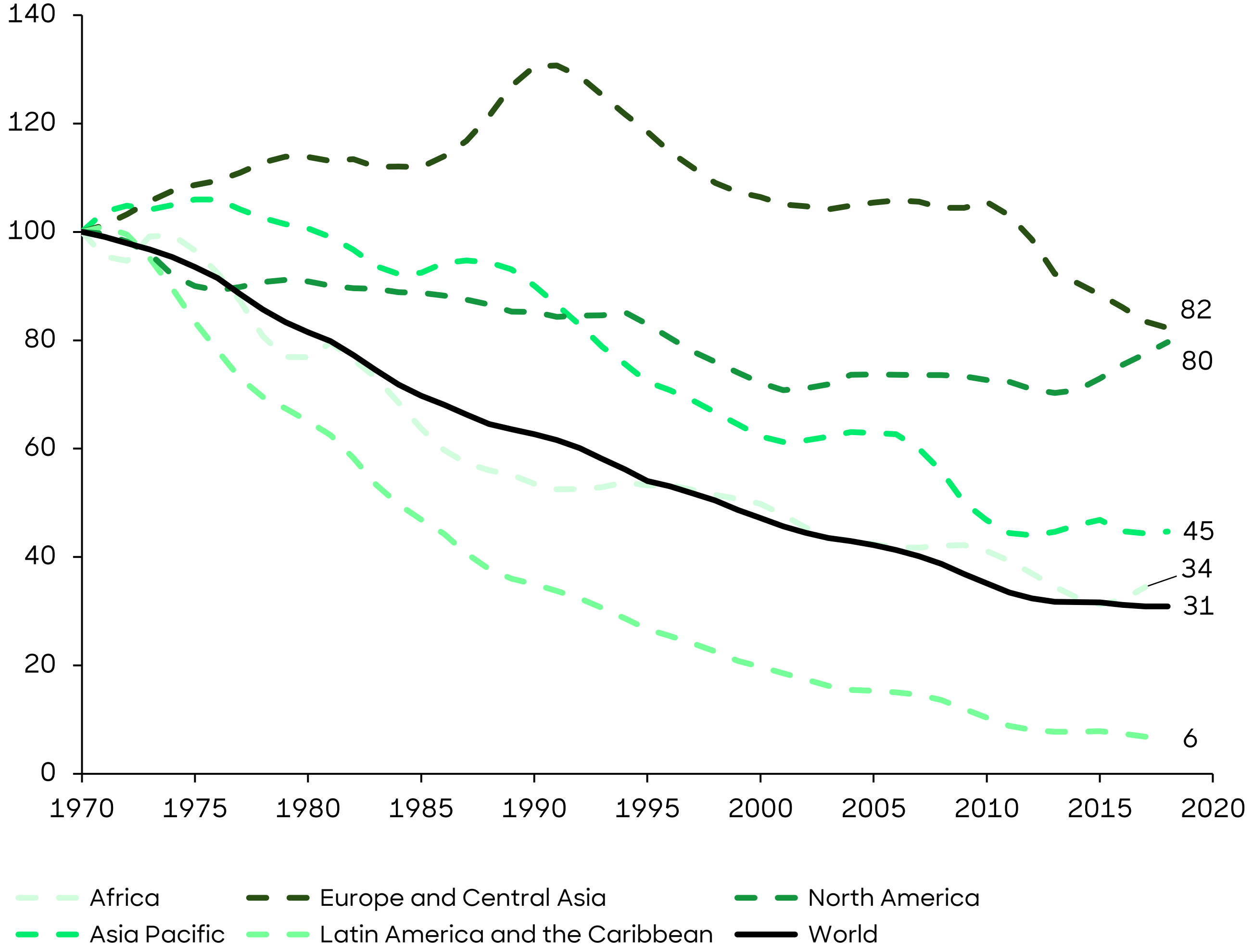
- Biodiversity intactness is defined as the modeled **average abundance of originally present (i.e. pre-modern times) species,** relative to their abundance in an intact ecosystem after land use change or human impacts. The Biodiversity Intactness Index[3] (**BII**) estimates **how much of an area's natural biodiversity remains**
- At **country level,** the BII can be used to show how **terrestrial biodiversity has fared under pressures** from humanity nationally
- The BII concept also helps to demonstrate **plausible improvement to 2050** under sustainability development aspects (sustainable scenario) – or not, as is the case in the middle-of-the road scenario
- The **middle-of-the road scenario** of the Shared Socioeconomic Pathways[4] (SSPs) assumes that there is no marked shift in social, economic and technological trends and institutions only make slow progress in achieving sustainable development goals. In the **sustainable development scenario,** the world gradually shifts toward a more sustainable path and there is increasing commitment to achieving sustainable development goals
- The underlying database is the **largest and most geographically and taxonomically representative of spatial comparisons of bio-diversity** collated to date – including around 54,000 species of birds, mammals, plants, fungi and insects across 26,000 locations
- All **major organizations** concerned with environmental issues (e.g. UN, CBD, IPBES) have **adopted the BII** as a **core ecological indicator**

1) Based on the "middle-of-the-road" scenario; 2) Based on the "sustainable development" scenario; 3) Developed by the Natural History Museum PREDICTS-project; 4) SSPs are projected socioeconomic developments used in climate change scenarios (see Riahi et al., 2017)

Source: Natural History Museum; Riahi et al.; Roland Berger

Global abundance of wildlife populations has steeply declined – A bad sign for biodiversity and ecosystem health

Living Planet Index by region 1970-2018[1)] [1970 = 100]



- The **Living Planet Index (LPI)** aims to track **changes in the relative abundance of wildlife species** populations and includes over 30,000 terrestrial, freshwater and marine **vertebrate populations** representing 5,230 species
- Trends in relative abundance provide a snapshot of changes within an ecosystem and can act as **early warning indicators** of overall ecosystem health. Additionally, population trends respond relatively quickly to successful conservation and policy efforts
- On the global level, the Index shows an **average 69% decline in monitored populations** since 1970. The decline was most drastic in **Latin America** and the **Caribbean** where there was an average decline of 94% across studied population. This can partially be explained by the intensification of agricultural activity and deforestation as well as the existence of many **highly specialized species that are sensitive to changes**
- In Europe and Central Asia, the **state of wildlife populations temporarily improved,** reaching a peak in the early 1990s. Since then, a decline followed – as in all other regions
- Like the Red List, the **LPI is dynamic** and since the last report in 2020, 838 species and 11,011 populations were added to the dataset

1) Change in the relative abundance of wildlife species 1970-2018
Source: WWF; ZSL; Roland Berger

The introduction of invasive species has been one of the main drivers of biodiversity losses

Categorization of species by invasive behavior

Native species
A species within its natural range, including shifting its range, without human involvement

Alien species
A species whose presence in a region is attributable to human activities that have enabled it to overcome the barriers that define its natural range

Established alien species
A subset of alien species that have produced a viable self-sustaining population

Invasive alien species
A subset of established alien species that spread and have a negative impact on biodiversity, local ecosystems, and species

Biological invasion process

Transport
Human activities move a species through introduction pathways beyond barriers that define its natural range

Introduction
Arrival at a new location outside of its natural range through human activities

Establishment
Production of a viable, self-sustaining population

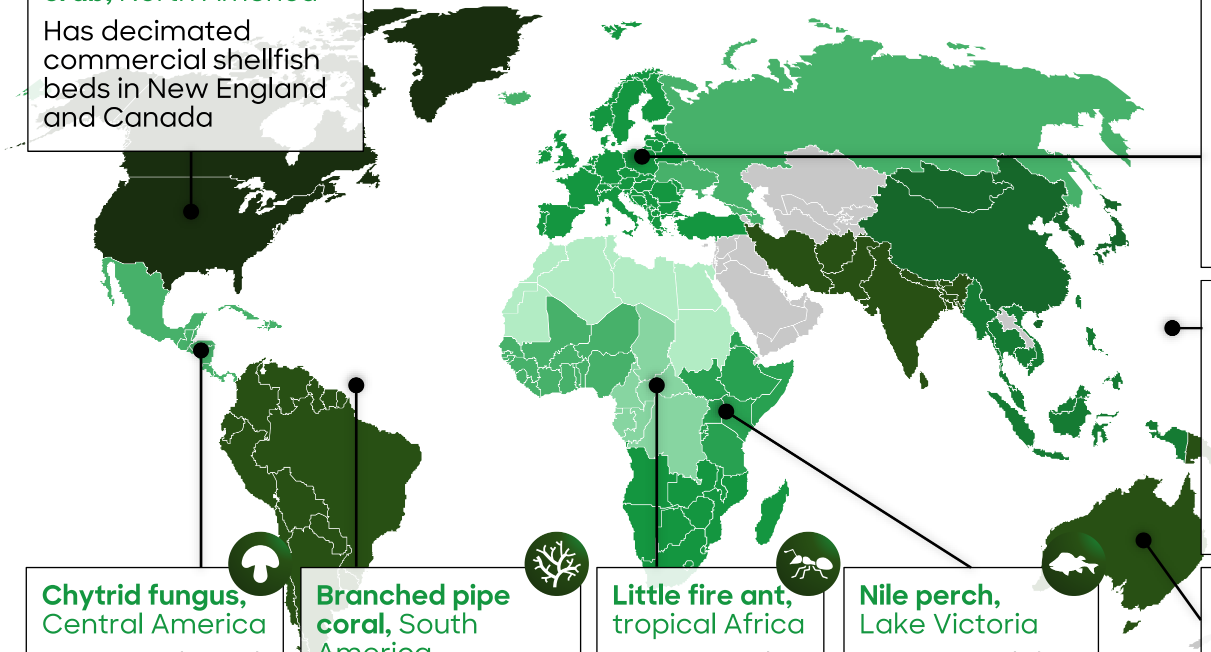
Spread
Dispersal and/or movement in a new region or range

- There are **different pathways** by which humans transport species from one location to another. Historically, invasive species were often **introduced on purpose for their perceived benefits** as pets, in agriculture or horticulture. For example, 35% of alien freshwater fish in the Mediterranean Basin have arisen from aquaculture
- Pathways for the unintentional introduction of invasive species often are the **contamination** of traded goods and **stowaways** in ballast, water, and sediments. More recently, the **online trade in animals and plants** has contributed to the spread of invasive species
- Some factors both cause changes to nature and facilitate biological invasion: **climate change, pollution** and the **fragmentation of ecosystems** through human activity can **drive species beyond their natural range**
- Commonly **known invasive species** are the **red fox,** the **Pacific oyster,** the giant African land snail, the red imported fire ant and the lantana
- On islands, invasive alien species are a major cause of biodiversity loss. Islands, and particularly **remote islands with high endemism,** are **more susceptible to impacts** from invasive alien species
- In its 2023 **Assessment on Invasive Alien Species,** the IBPES records an **unprecedented rise** in the number of alien species in the last decades, with 37% of all known alien species having been reported since 1970. The faster spread of invasive alien species within countries can mainly be attributed to direct drivers such as **changes in land and sea use,** with transport and utility infrastructure facilitating their spread

Source: IPBES; Roland Berger

Across the world, invasive alien species are a major cause of extinction and economic losses

Selected examples of damage caused by invasive alien species



European shore crab, North America
Has decimated commercial shellfish beds in New England and Canada

Japanese knotweed, Central and Northern Europe
Reduces abundance and species richness of native plant and soil-inhabiting species

Brown tree snake, Guam
Has caused the local extinction of most resident populations of Guam's 25 bird species

Chytrid fungus, Central America
Has contributed to severs global declined of amphibians, including global extinctions

Branched pipe coral, South America
Overgrows native corals, causing community-wide mortalities and local extinctions

Little fire ant, tropical Africa
Has caused local extinctions of forst floor and leaf-chewing invertebrates

Nile perch, Lake Victoria
Has caused the global extinction of many endemic cichlid fish species

Buffle grass, Australia
Restricts access to culturally important sites, making it difficult to transmit tradi-tional knowledge

Cumulative documented costs of biological invasions 1970-2017 [USD bn]: 1 | 10 | 100 — No data

- **Invasive alien** species have **adverse impacts on nature,** its contributions to **people, and the quality of life.** They adversely impact good quality of life in 85% of cases, mainly by impacting material and immaterial assets and health
- Many species have **negative cross-cutting impacts:** 16% of invasive alien species adversely impact both nature and nature's contributions to people
- Invasive species have played a role in **60% of recorded global extinctions,** 90% of which have occurred on islands. 218 invasive alien species alone have caused **1,215 local extinctions** of native species, with vertebrates causing the most extinctions (50.9%)
- The **economic costs** caused by biological invasions have **increased fourfold** every decade since 1970. The estimated global annual economic cost in **2019** was **USD 423 billion**
- The **management of invasive species** can range from measures for **prevention** and **early detection** to **containment** and **eradication** but also emphasizes fostering **public understanding**

Source: IPBES; Roland Berger

Genetic diversity is the foundation of biodiversity – It describes the genetic variability within and across populations of species

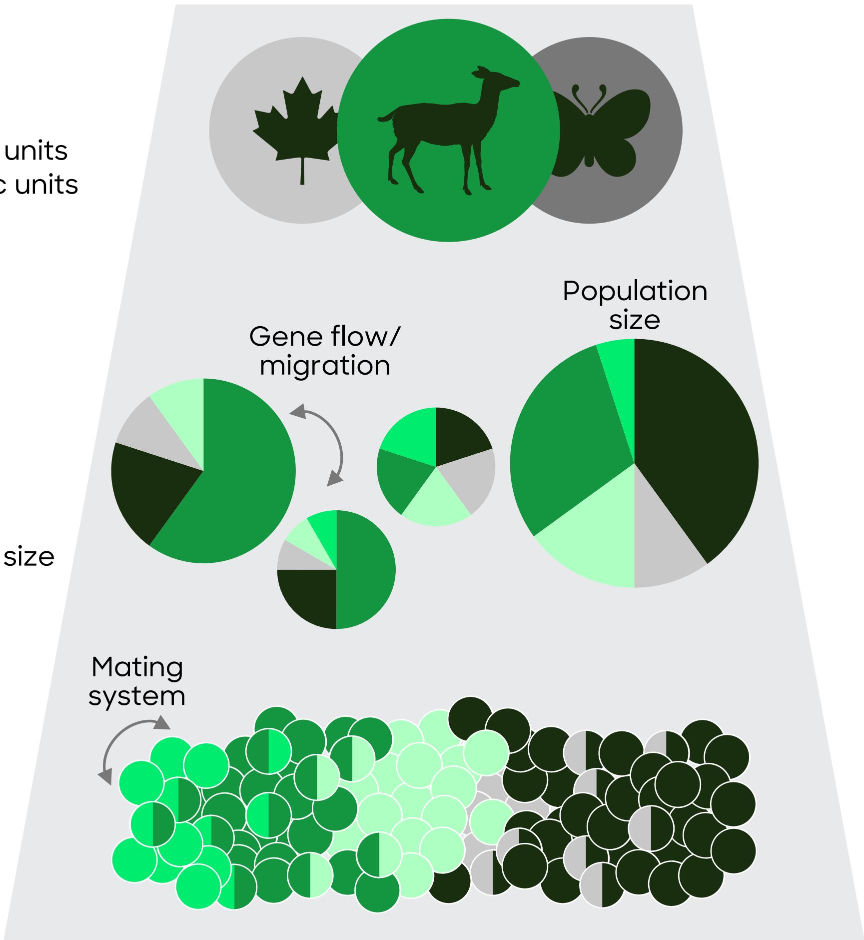
Three levels of biological organization and their respective genetic essential biodiversity variables[1)]

Genetic composition

Species
- Differentiation
  - Number of genetic units
  - Distance of genetic units

Populations
- Diversity
  - Richness
  - Heterozygosity
- Inbreeding
- Effective population size

Individuals
- Diversity
  - Heterozygosity
- Inbreeding



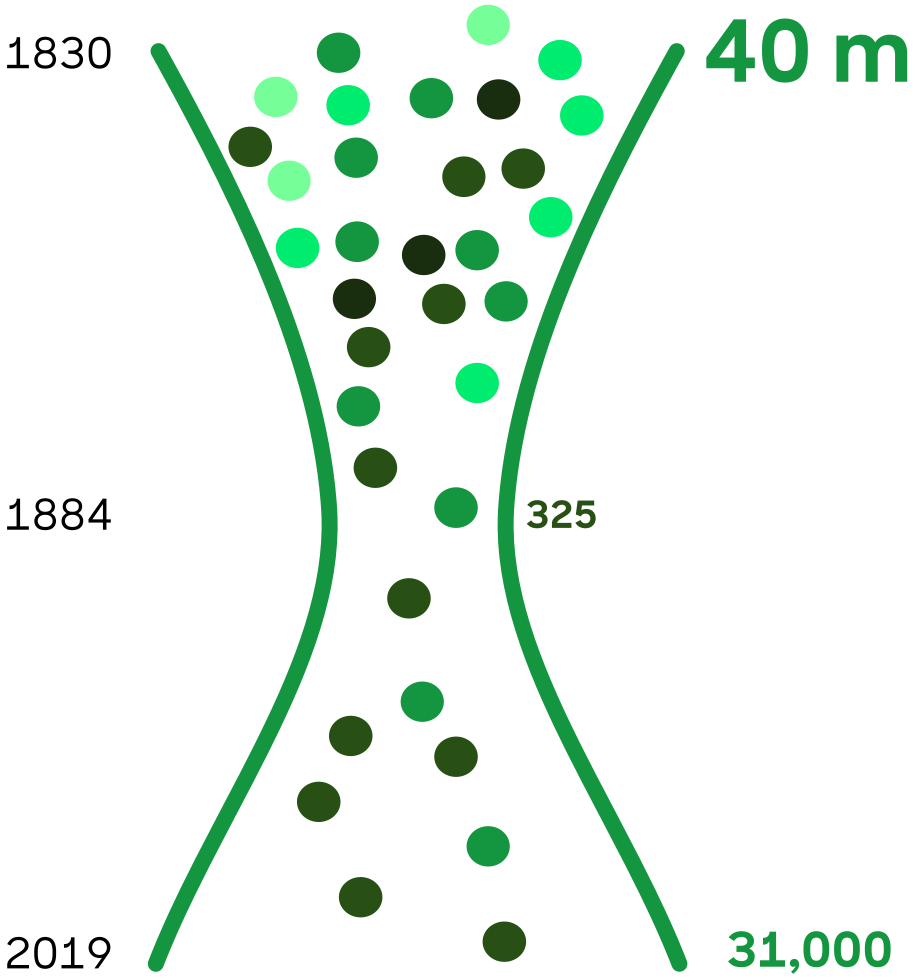
- **Genetic diversity** describes the level of **genetic variability within a population and across populations.** It is the foundation of the three levels of biodiversity, supporting and complementing species and ecosystems diversity
- Genetic diversity can be observed both **at the population and the individual level, comprising two components,** richness and evenness: **richness** relates to the number of genetic variants in a population while **evenness** expresses the probability that two randomly drawn alleles (DNA sequences at a given genomic location) from a sample are different
- Genetic diversity is **one of the four genetic essential biodiversity variables** determining **genetic composition,** a measure of **within-species diversity.** The others include **genetic differentiation** (divergence in genetic composition between multiple populations of the same species), **inbreeding** (level of diversity within individuals), and **effective population size** (change of genetic diversity due to random change in the frequency of an existing gene variant in the next generation)
- Genetic diversity provides **resilience** against abrupt changes and **allows species and ecosystems to adapt** to changing climates, environments, and other challenges, such as diseases. Ultimately, genetic variation allows species to develop into distinct and new lineages
- Genetic diversity within and across populations **supports ecosystem functions** and contributes vital resources to society (e.g. mangroves that serve both to protect coastal habitats and as nurseries for fish), and other services, such as carbon capture

1) The species level corresponds to the combined genetic diversity of the species. The population level pie charts reflect the relative population sizes and the proportion of genotypes in each population (i.e. population genetic structure resulting from gene flow and migration); the smallest circles represent unique individuals with the colors depicting their genotypes

Source: Hoban et al.; Roland Berger

Genetic diversity increases chances of survival – Small populations are at risk of extinction

Genetic bottleneck as seen in the American bison population (estimate)[1)]



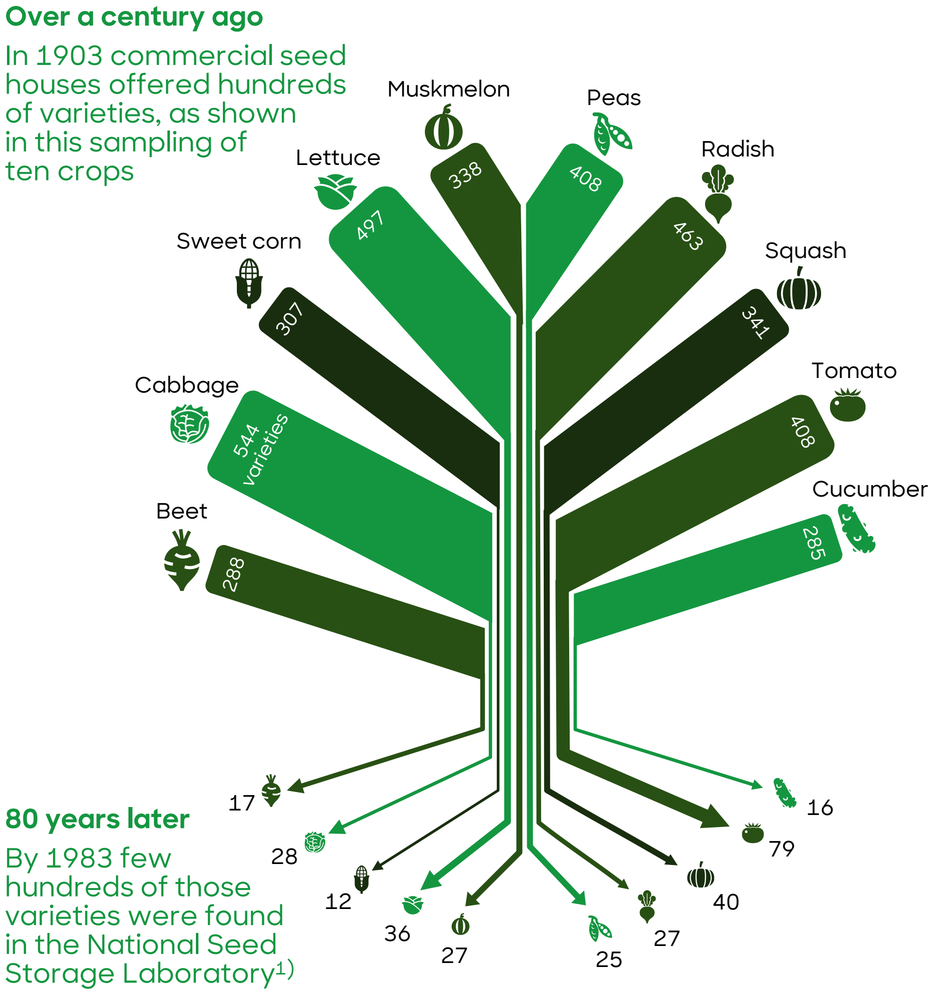
- Low levels of genetic diversity can be caused by **genetic bottlenecks,** arising mainly in small and isolated populations following events that drastically reduce the size of the local population. Causes include **human activity** (culling, selective breeding, pollution) or **natural events** such as natural disasters and famines
- In the case of the **American bison,** a combination of **commercial hunting** and the spread of **diseases** from cattle almost led to its extinction. Later, conservation efforts in **parks and reserves** and the **reintroduction** into the wild led to a rise in Bison numbers
- A key instrument in **combating extinction** and increasing the chance of long-term survival of species is **maintaining the variation of genetic material: Conservation genetics** aims to characterize and advance the preservation of biodiversity by applying genetic principles and methods
- Experiments show that **genetically diverse populations** have **lower extinction rates,** and that the injection of new genetic variants has the potential to **boost the fitness** of threatened species. But examples of highly successful species that lack such genetic variation are often **invasive species,** with short reproduction cycles and a lack of natural predators and competitors
- Domesticated species such as **dogs** often display a high degree of **morphological diversity.** However, only a small fraction of all genes determine looks. Overall, **selective breeding** and **small population size** have unintentionally increased the numbers of harmful genetic variants within dogs
- The study of genetic diversity has led to **new strategies** to prevent extinctions such as **genetic rescue** – the introduction of new genetic material into a population – or the **translocation of individuals from different populations.** An example of the former is the **Przewalski's horse.** By cloning individuals using a cryopreserved cell line, researchers were able to **reintroduce genetic variation** that was lost from the living gene pool

1) Excluding commercial herds

Source: FAO; University of Melbourne; phys.org; Kardos; Revive & Restore; Marsden et al.; Roland Berger

The loss of crop diversity has wide-ranging implications for global food security

Change in number of crop varieties in the US, 1903-1983



- Genetic diversity is a key element in dealing with varying production environments. **Crop diversity** directly impacts food security and agricultural sustainability, with the genetic composition contributing to **crop resilience and productivity**
- **Crop genetic erosion** refers to the gradual loss of genetic diversity within crop species, including traditional landraces (local cultivars), modern cultivars, and wild relatives
- **Common drivers** of crop genetic erosion are the **displacement** of traditional landraces by high-yielding modern cultivars, **shifts in agricultural practices** that alter natural habitats, and **ecological conditions.** Furthermore, market dynamics and development processes can lead to the **abandonment of commercially unviable cultivars** and the **displacement of traditional crop varieties.** Lastly, crop diversity is lost because there is **limited access to quality seeds** and a lack of support for local seed saving practices
- This process can be illustrated by the replacement of maize landraces with modern cultivars in the US corn belt - a transition leading to the **displacement of unique alleles and traits** that were characteristic to the locally well-adapted crop population
- The **decrease in crop diversity** reduces the resilience of crops to pests, diseases, and changing environmental conditions. One of the factors causing the **Irish potato famine** was a **lack of genetic diversity** due to "Lumper" potato monocultures
- A more **modern example is the Cavendish banana** which currently dominates world markets: each banana plant is genetically identical to the previous generation making it highly susceptible to disease. In fact, its predecessor, Gros Michel, was wiped out by a fungus in the 1950s. Now, a new strain is threatening existing banana plantations in South America
- Due to its global importance, **maintaining the genetic diversity of seeds,** cultivated **plants**, and farmed/domesticated as well as related wild **species** is part of the **UN sustainable development goal** to end hunger

1) Changed its name in 2001 to the National Center for Genetic Resources Preservation
Source: Khoury et al.; Gro Intelligence; RBGK; Roland Berger

Environmental protection has been on the global agenda for decades – Efforts are intensifying to halt and revert nature loss

Timeline of major environmental and biodiversity milestones

1948
International Union for the Conservation of Nature **IUCN**

1961
WWF

1969
Green-peace

1972
UN conference on Human Environment Stockholm – **UNEP** founded

1992
UN **Rio Earth Summit**

1993
Convention on Biological Diversity (**CBD**) treaty

1995
World Business Council for Sustainable Development **WBCSD**

2000
The UN's Millennium Development Goals to 2015 incl. goal 7: **Environmental sustainability**

2001
Millennium Summit & global **Millennium Ecosystems Assessment** 2004, findings presented in 2005

2005
Group on **Earth Observations (GEO)**/Biodiversity Observation Network – nature data network

2007
G8 environment ministers + 5 main newly industrialized countries meet in Potsdam

2010
First report of the Economics of Ecosystems and Biodiversity (**TEEB**) initiative; UN International Year of Biodiversity; Aichi Biodiversity Targets 2011-2020

2012
IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services); **latest global assessment published in 2019**

2015
UN **Sustainable Development Goals 2030**, including multiple environmental goals

2019
G7 Metz Charter on Biodiversity

2020
UN Biodiversity Summit, 70 world leaders **pledge to reverse nature loss by 2030; EU 2030 Biodiversity Strategy** (as part of Green Deal); **"Nature-positive to 2030"** – Global goal for nature[1)]

2021
Dasgupta Review – The Economics of Biodiversity; **COP15** meeting (part 1) for the Convention on Biological Diversity **CBD**

2021
G7 leaders – **2030 Nature Compact**

2021-2030
UN **Decade of Ecosystem Restoration**

2022
COP15 meeting (part 2) – **Kunming-Montreal Global Biodiversity Framework (GBF)** is adopted. Progress evaluation to take place at **COP16** in Cali, Columbia in **October 2024**

2023
UN **Agreement on Biodiversity beyond national jurisdiction (BBNJ, "High Seas Treaty")** covering marine biodiversity in international waters

1) Proposed by a select group of internationally renowned scientists and ecology experts

Source: Roland Berger

The 2023 Global Biodiversity Framework agreed at COP15 is guiding global concerted action on nature to 2030

The Kunming-Montreal GBF agreement: 4 goals, 23 targets to 2030

1 – Halting human-induced extinction of threatened species and **reducing** the rate of **extinction** of all species **tenfold** by **2050**

2 – **Sustainable use** and management of **biodiversity** to ensure nature's contribution to people are valued, maintained and enhanced

3 – **Fair distribution** of the **benefits from** the utilization of **genetic resources** and digital sequence information on genetic resources

4 – **Accessibility** of adequate **means of implementing the GBF** to all parties, particularly LDC[1)] and Small Island Developing States

The GBF also features 23 targets to achieve by 2030, including

1. **Effective conservation and management of at least 30% of the world's land, coastal areas and oceans. Currently, 17% of land and 8% of marine areas are under protection**
2. Restoration of 30% of terrestrial and marine ecosystems
3. Reduce to near zero the loss of areas of high biodiversity importance and high ecological integrity
4. Halving global food waste
5. Phasing out or reforming subsidies that harm biodiversity by at least USD 500 bn per year, while scaling up positive incentives for biodiversity conservation and sustainable use
6. Mobilizing at least USD 200 bn per year from public and private sources for biodiversity-related funding
7. Raising international financial flows from developed to developing countries to at least USD 30 bn per year
8. Requiring transnational companies and financial institutions to monitor, assess and transparently disclose risks and impacts on biodiversity via operations, portfolios, supply and value chains

And others ...

- **Biodiversity** is now treated as an important **standalone issue,** not simply as an afterthought of climate change and pollution
- In 2022, COP15 ended with a major agreement on biodiversity. The **Kunming-Montreal Global Biodiversity Framework** (KMGBF) includes ambitious goals not only for the tackling of biodiversity loss but also plans to restore ecosystems and protect the rights of indigenous peoples. Overall, it includes **4 main goals and 23 individual targets.** The most well-known is the **30x30 goal,** aiming to put **30% of land and sea ecosystems under protection by 2030** – a mere 6 years from now
- These ambitions add specific commitments to the **UN Sustainable Development Goals** for 2030, i.e. goals 14 and 15, on **Life below Water** and **Life on Land**
- The next biodiversity conference, **COP16,** is scheduled to take place in October 2024 in Colombia

1) Least Developed Countries

Source: UNEP; Roland Berger

With 50% of global GDP dependent on nature, strategies to maintain and restore biodiversity are crucial for future prosperity

The EU 2030 biodiversity strategy provides an exemplary framework focused on two approaches

1 Establish protected areas

30% of land in Europe by 2030

30% of sea in Europe by 2030

2 Restore degraded ecosystems at land and sea

- **Increase organic farming** and biodiversity-rich landscape features on agricultural land
- Halting and reversing the **decline of pollinators**
- Restoring at least **25,000 km of EU rivers** to a free- flowing state
- Reducing the use and risk of pesticides by **50% by 2030**
- Planting **3 billion trees** by 2030

- The **EU 2030 Biodiversity Strategy** - introduced in May 2020, and embedded in the EU Green Deal - contains long-term commitments and action plans that aim to **build societies' resilience to future threads** such as the impacts of climate change, forest fires, food insecurity, and disease outbreaks while protecting wildlife and fighting illegal wildlife trade
- Parts of the plan were later also adopted in the 2022 **COP 15 biodiversity** commitments, for example the so-called **30x30 goal**
- This framework is accompanied by various other approaches such as **rewilding efforts** and **nature restoration targets**

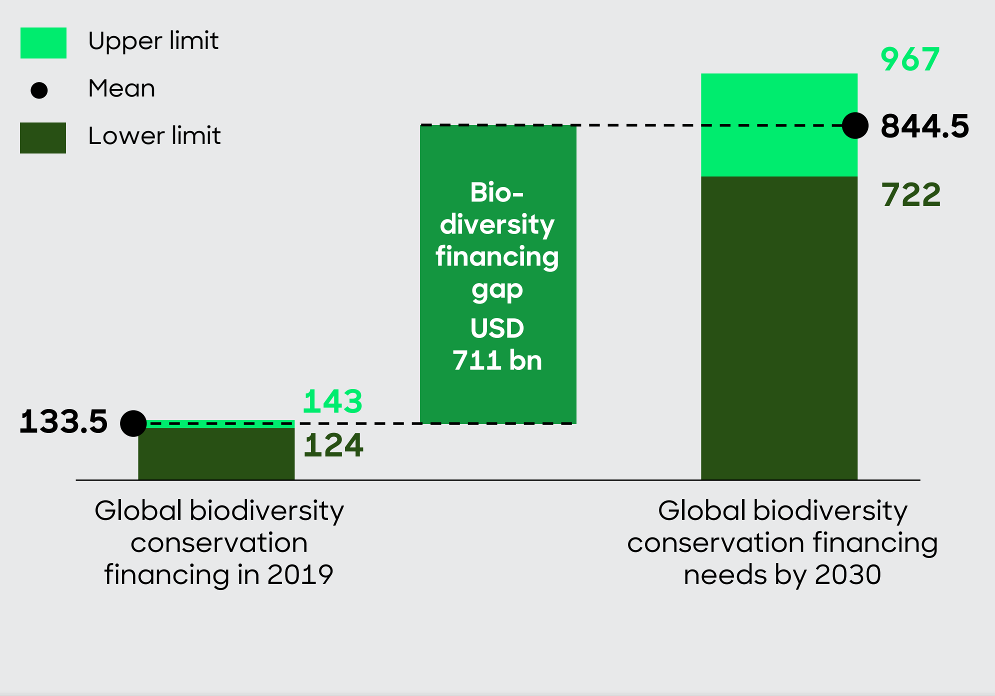
Source: European Commission; Roland Berger

Less than 1% of annual global GDP could close the USD 711 billion per year biodiversity funding gap thus conserving the planet's environment

Global biodiversity conservation financing vs. global biodiversity conservation needs [USD bn]

Current biodiversity financing flows

- In 2019, the total **global** annual flow of funds toward **biodiversity protection** amounted to approx. **USD 124-143 billion p.a.**
- Meanwhile, annual **government expenditure on activities harmful to biodiversity** in the form of agricultural, forestry, and fisheries subsidies – USD 274-542 billion p.a. in 2019 – is **two to four times higher than annual capital flows toward biodiversity conservation**



Future biodiversity spending needs

- To **halt the decline** in global biodiversity requires **USD 722-967 billion p.a.** in spending between now and 2030
- This leaves an estimated global **biodiversity financing gap of** USD 598-824 billion p.a. (average: **USD 711 billion p.a.)** – equal to **under 1%** of **annual global GDP**

The **Kunming-Montreal Global Biodiversity Framework (GBF),** agreed at the 15th meeting of the Conference of Parties (COP15) to the UN Convention on Biological Diversity (CBD) in December 2022, has addressed **key biodiversity funding issues at the global level** by targeting two areas

- **The reduction of harmful subsidies:** progressively **phase out or reform by 2030 subsidies** that harm biodiversity **by at least USD 500 billion p.a.,** while scaling up positive incentives for biodiversity's conservation and sustainable use *(Target 18)*
- **The mobilization of resources and effectiveness of funding flows:** by 2030, **at least USD 200 billion p.a.** in domestic and international biodiversity-related funding from all sources (public and private); to **raise international financial flows from developed to developing countries** to at least USD 20 billion p.a. by 2025, and **to at least USD 30 billion p.a. by 2030** *(Target 19)*

Source: Paulson Institute/Cornell/Nature Conservancy; UN COP15; Roland Berger

Tackling biodiversity loss and climate change is an investment that could yield over USD 10 trillion in business opportunities annually

15 transitional actions across 3 socio-economic systems to tackle biodiversity loss and climate change

Energy and extractives

Circular and resource efficient models
Nature-positive metals and minerals extraction
Sustainable materials supply chains
Nature-positive energy transition

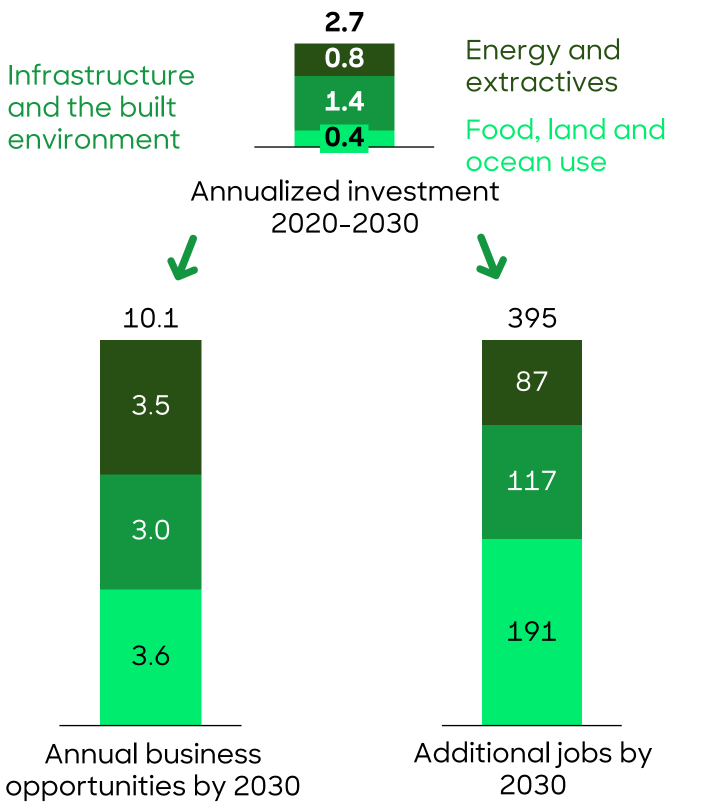
Infrastructure and the built environment

Densification of the urban environment
Nature-positive build environment design
Planet-compatible urban utilities
Nature as infrastructure
Nature-positive connecting infrastructure

Food, land and ocean use

Ecosystem restoration and avoided expansion
Productive and regenerative agriculture
Healthy and productive ocean
Sustainable management of forests
Planet-compatible consumption
Transparent and sustainable supply chains

Annualized investment required 2020-2030 to scale the transition [USD trillion]**, annual business opportunities** [USD trillion]**, and additional jobs by 2030** [m]



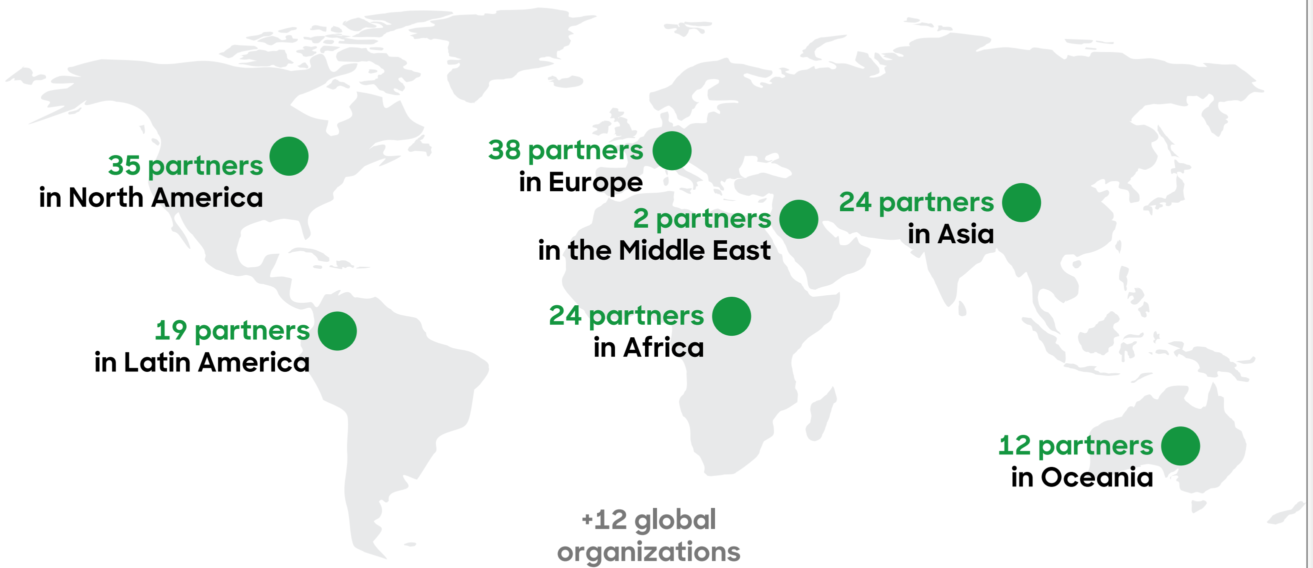
- Combatting climate change by decarbonizing the economy is important but other **direct drivers of biodiversity loss must also be tackled**
- According to estimates from the World Economic Forum (WEF), **three economic systems are responsible for nearly 80% of nature loss,** namely energy and extractive sectors, infrastructure and the built environment, and food, land and ocean use
- Transforming these large systems along 15 transitional actions is necessary not just for nature's sake but to meet the **growing demands of business stakeholders** to **lead in a nature-conscious manner**
- It is expected that such a transformed, **nature-positive economy can unlock USD 10 trillion** of annual business opportunities and **create 395 million jobs by 2030**

Source: WEF; Roland Berger

Progress is underway: Global networks are being built – Rewilding is a more recent strategy aimed at boosting biodiversity

Since 2020, the Global Rewilding Alliance is partnered with the UN's Decade of Ecosystem Restoration to 2030

Global Rewilding Alliance – Terrestrial & Marine (177 partners and growing)



*"To restore stability to our planet, we must restore its biodiversity, the very thing that we've removed, it's the only way out of this crisis we've created – **we must rewild the world."***

Sir David Attenborough

- **Protect the best – rewild the rest: The Global Rewilding Alliance,** brings together 100+ organizations from over 70 countries, now also in partnership with the UN and its agenda of the Decade on **Ecosystem Restoration to 2030**
- The work of the alliance is based on four pillars: making the point for rewilding by **gathering scientific evidence, influencing policy** by advocating for rewilding as key nature-based solution, **building networks** by connecting organizations with local communities, and **inspiring communities** by educating and raising awareness
- **Let nature lead:** All **rewilding** is also restoration, but not all restoration is rewilding – **rewilding aims for resilience in nature, ultimately without human intervention.** A newer approach to **increase biodiversity** without clearly defined end goals and metrics
- **Restoration,** on the other hand, refers to a **wide spectrum of activities such as reforestation,** erosion control, removal of non-native species, etc. – all efforts often requiring regular human intervention
- **Work at nature's scale: Initiatives** include efforts to **reintroduce wolves** to Yellowstone, **jaguars** to the marshlands of Argentina, and **beavers** to the British Isles; restore free-roaming **bison herds** on the Great Plains of North America and parts of Europe; **restore tigers** to the forests of India; designate **new marine national parks** in the South Atlantic Ocean; bring back missing **megafauna** to wildlife conservancies in southern Africa; replenish the Scottish **forests,** and many more

Source: Global Rewilding Alliance; Roland Berger

Impressive success stories underline the importance of rewilding and other approaches to improve biodiversity

Recently successful projects in rewilding and wildlife conservation

Global amphibian assessment
Re:wild

Lasting 8 years and engaging 1,000 experts, Re:wild assessed 8,000+ amphibian species, providing valuable insight for future conservation

GBP 400,619 to rewilding projects
Rewilding Britain

The Rewilding Innovation Fund continues to support initiatives that promote biodiversity and rewilding across the UK

Cinereous vulture milestone
Rewilding Europe

The release of 14 cinereous vultures in 2022 and another 13 in 2023, contributes to reinforcing the natural cycle of life and biodiversity

Large Carnivore Monitoring informs policy
Wildlife Conversation Trust

The Large Carnivore Monitoring Project in Central India preserves biodiversity through a five-year commitment, protecting 8,778 km² of forestland

Friend of the Parks
Rewilding Chile

The Friends of the Parks Program fosters environmental education, local identity, and economic development around Chile's national parks

70 km elephant proof fence protects elephants & humans
Peace Parks Foundation

Human-wildlife conflict has since reduced by over 90% at Vwaza Marsh Wildlife Reserve in Malawi

Virtual fencing reduces wildlife roadkill
Great Eastern Ranges & WWF-Australia

A virtual fence (using technology rather than physical fences) along the New South Wales South Coast has drastically reduced wildlife roadkill from 5 kangaroos and wallabies a week to 5 in 8 months

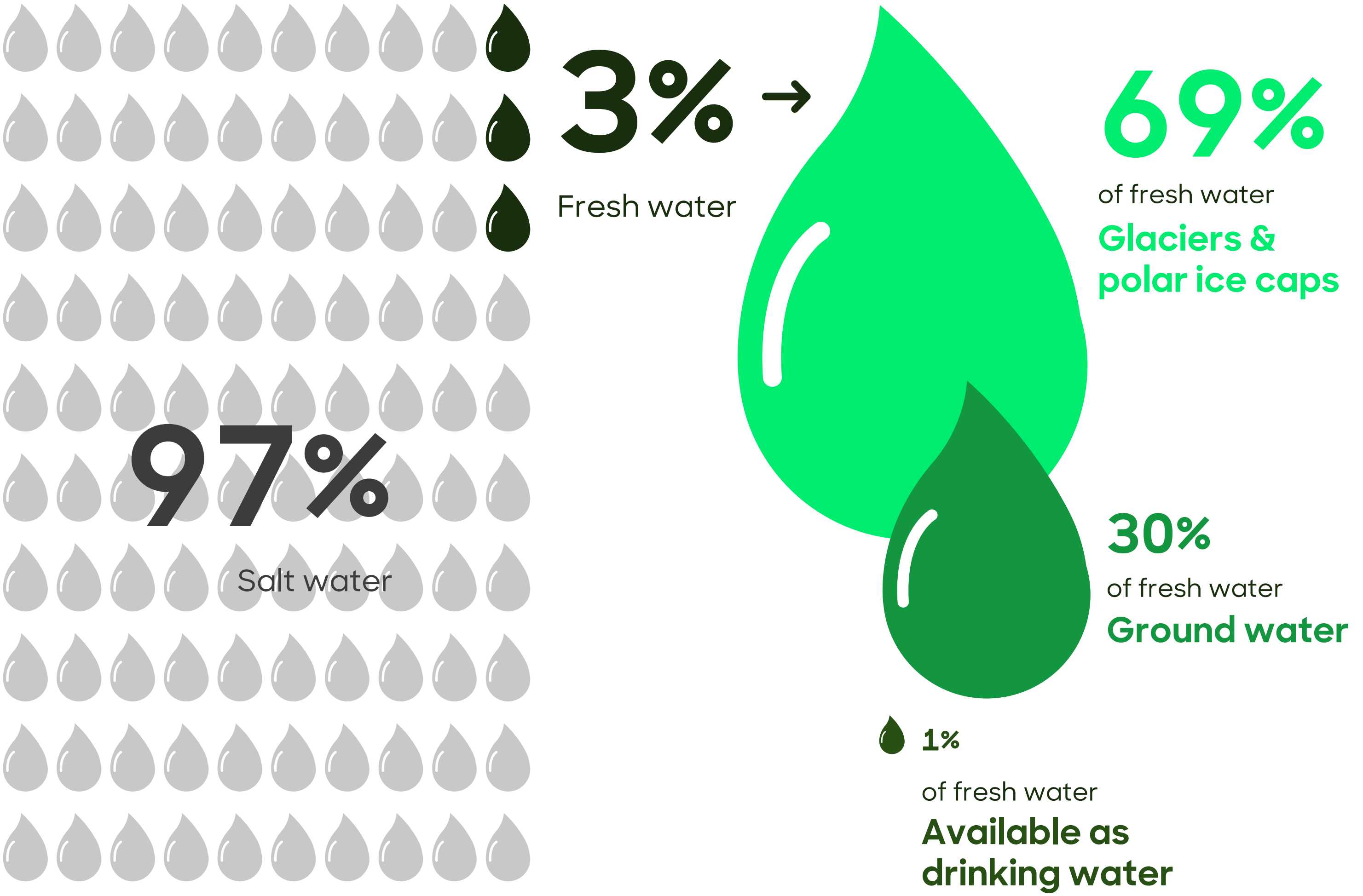
Peninsula Mitre protection law
Rewilding Argentina

A successful 30-year effort has achieved legislation to protect the Peninsula Mitre and its surrounding sea – an essential carbon sink

Source: Global Rewilding Alliance; Roland Berger

As a vital component of life, fresh water continues to be a scarce resource globally – Fresh drinking water is a precious good

Facts around global water supply

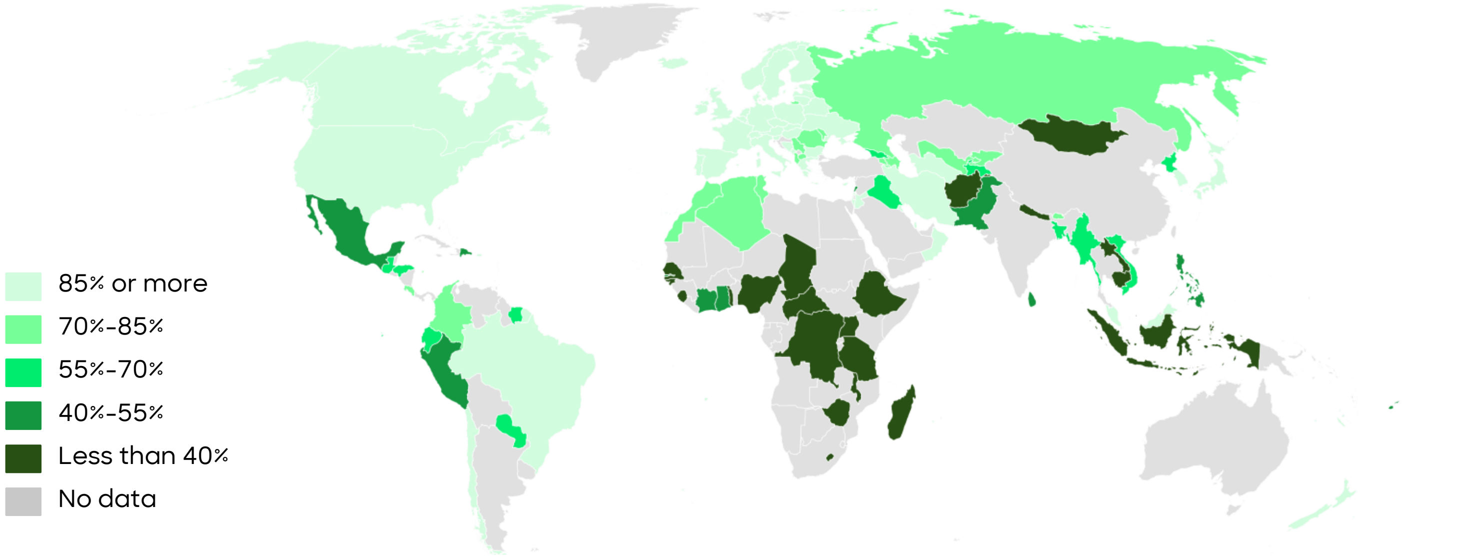


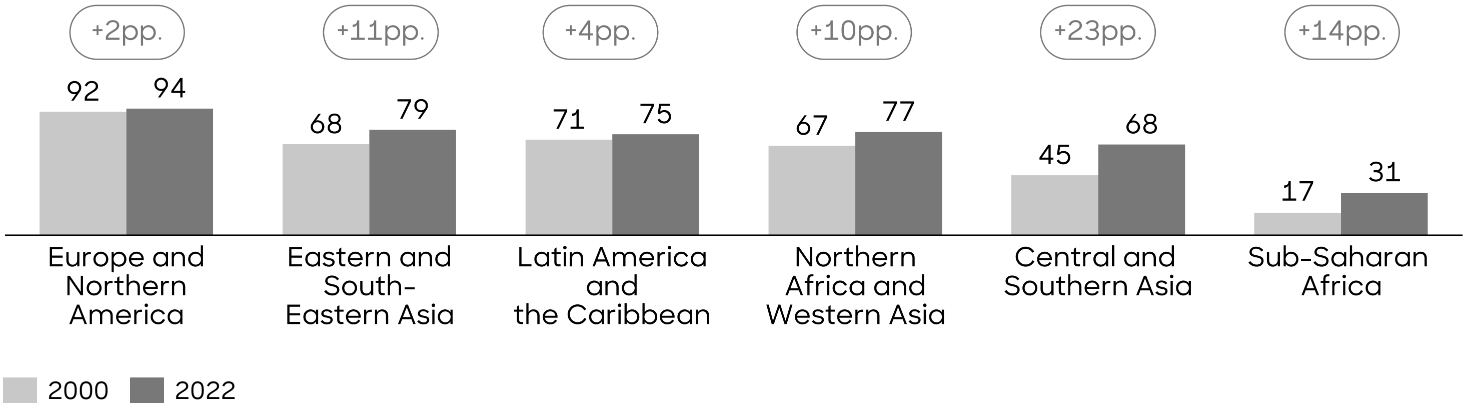
- In an era marked by exceptional global challenges and changing raw material needs, **one resource stands at the forefront of sustainability and resilience – fresh water**
- As a **critical component** of Earth's ecosystem, the **availability and management of freshwater resources** have become **central** to the **well-being** of our planet and its inhabitants
- Despite covering around 70% of the Earth's surface**,** only a **very small fraction of water is fresh water** and **suitable for human consumption**
- The **scarcity** of this vital resource poses a **significant challenge** as the world's **population continues to grow,** and **climate change** disrupts traditional weather patterns, exacerbating droughts and water stress
- Presently, a **quarter of the global population lacks access to safe drinking water,** posing a significant health hazard. Effects of **unsafe water** result in **over a million deaths annually**

Source: USGS; UNESCO; World Bank; National Geographic; Roland Berger

Millions of people still lack access to safely managed drinking water, although the situation has improved in recent decades

Share of the population using safely managed drinking water services, 2022 [%]





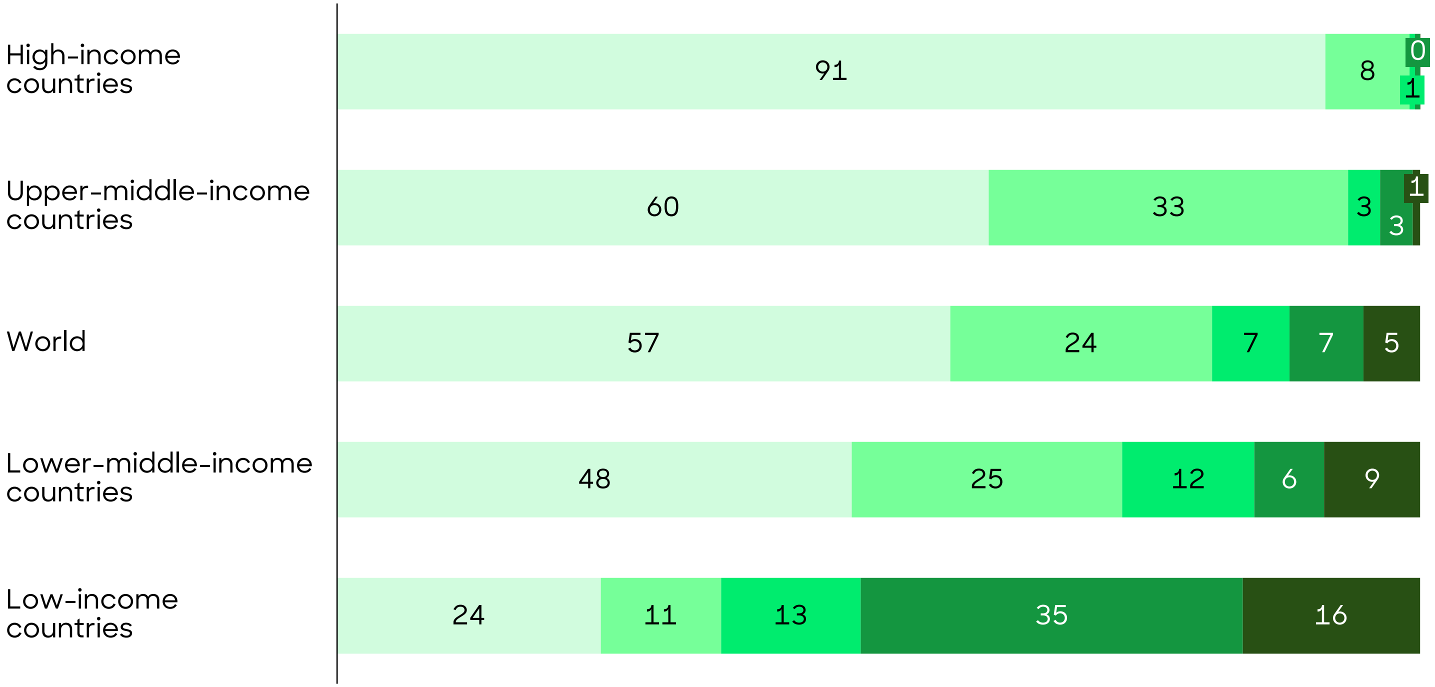
- Despite universal access to safe drinking water being a **fundamental necessity and a human right, millions** of individuals worldwide still **lack access**
- The WHO defines **safely managed drinking water** as drinking water from an **improved source[1]),** that is **located on premises, available when needed, and free from fecal and priority chemical contamination**
- While there have been **advances** in recent decades across all regions, the situation remains **precarious in Sub-Saharan Africa,** where less than a **third of the population** has access to safely managed drinking water. Globally, **2.2 billion people continue to lack access to safely managed water services,** including 1.5 billion with only basic services (improved source, collection time ≤ 30 minutes), 292 million with limited access (improved source, collection time > 30 minutes), 296 million relying on unimproved sources (unprotected dug well or spring), and **115 million** obtaining **drinking water directly from rivers, lakes, and other surface water sources**

1) Improved sources include piped water, boreholes or tube wells, protected dug wells, protected springs, rainwater, and packaged or delivered water

Source: WHO/UNICEF; Roland Berger

Globally, safely managed sanitation is also still in a poor state, particularly in low-income countries

Share of the population using different forms of sanitation, 2022 [%]



Share of population …

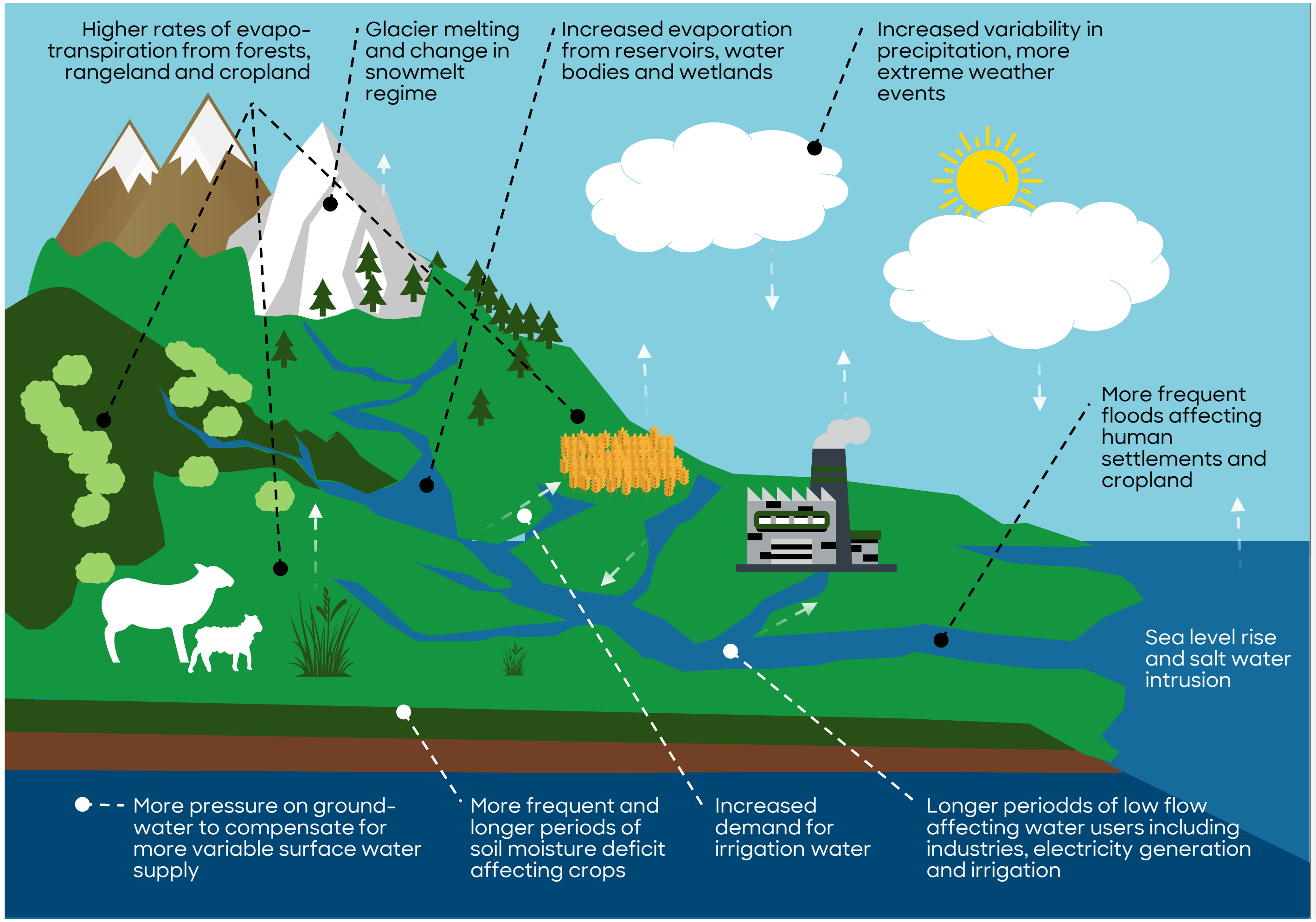
- … using safely managed sanitation services
- … using only basic sanitation services, improved sanitation facilities which are not shared
- … using limited sanitation services, improved sanitation facilities which are shared
- … using unimproved sanitation facilities
- … practicing open defecation

- Safe sanitation systems are **essential for safeguarding public health and socioeconomic advancement.** Hence, sanitation has been acknowledged as a **distinct right** and is included as a Sustainable Development Goal (SDG)
- However, despite its importance, approximately **40% of the global population lack access to safely managed sanitation facilities** due to various obstacles, including availability, affordability, and cultural norms
- This poses a significant health hazard, as unsafe sanitation contributes to **hundreds of thousands of deaths annually.** Unsafe sanitation is a major risk factor **for infectious diseases** such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio. Additionally, it **exacerbates malnutrition** and is particularly **detrimental to childhood growth** and development
- Although **advances have been made,** progress has been **insufficiently slow.** A significant portion of the global population still lacks access to safely managed sanitation, highlighting the urgent need for **continued efforts** to address this critical issue

Source: WHO/UNICEF; Roland Berger

As the water cycle is influenced by climate change, rising global warming is expected to make water management more challenging

How climate change affects various elements of the water cycle



- Water is constantly in motion. It exists in the atmosphere, on land, in oceans, and underground. It travels between these places through the **water cycle,** which **is changing as the climate changes**
- One major effect of climate change is the **increase in evapotranspiration rates.** Higher temperatures cause more water to evaporate from forests, rangelands, and croplands. This intensified evapotranspiration **reduces soil moisture levels,** which in turn affects **plant growth** and **agricultural productivity**
- Climate change also brings **more variability in precipitation patterns** and **more frequent extreme weather events.** This increased variability means that some regions will experience more intense **storms** and **heavy rainfall**, while others may suffer prolonged **droughts**
- **More frequent floods** are another consequence of climate change. Increased precipitation and extreme weather events result in flooding that can **devastate human settlements, cropland, and infrastructure**
- These **unpredictable changes complicate water resource management** and make it challenging to maintain reliable water supplies

Source: FAO; World Bank; Roland Berger

Water and climate change are inextricably linked: Extreme weather events increase challenges regarding water supply

Climate change and water

9 out of 10 **climate change events** are **water-related,** such as floods or droughts

Over a fifth of the **world's basins** have recently **experienced** either **rapid increases** in their surface water area indicative of **flooding,** a **growth in reservoirs** and **newly inundated land,** or **rapid declines in surface water area** indicating **drying up** of lakes, reservoirs, wetlands, floodplains, and seasonal water bodies

The **current Arctic sea-ice cover** (both annual and late summer) is at its **lowest level since at least 1850** and is **projected to reach near ice-free conditions** at its summer minimum at least once before 2050

A timeline on how climate change may worsen the water situation globally

2023

2030

Water scarcity in some places will **displace** between **24 – 700 million people**

Climate impacts could push up to **132 million people into poverty**

2040

600 million children globally will be living in areas of **extremely high water stress**

2050

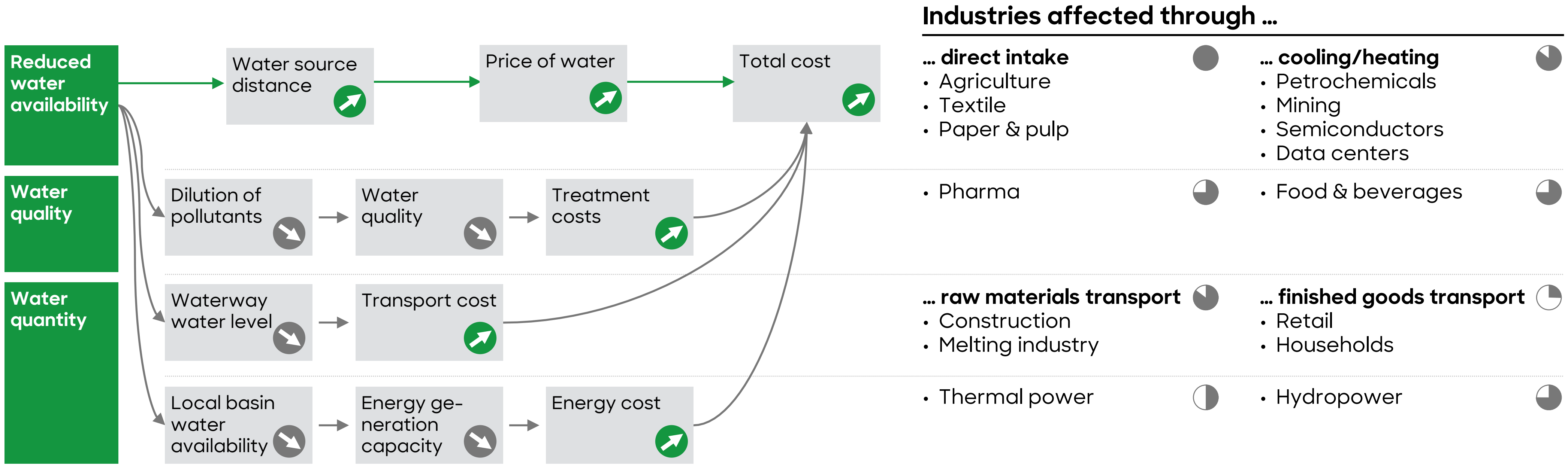
The number of people **living in potential severely water scarce areas** will increase from 2.7 bn to 3.2 bn

The number of **people at risk from floods** will **increase** from 1.2 bn to 1.6 bn

Source: FAO; World Bank; UN; Roland Berger

For businesses, water scarcity can have detrimental effects, affecting raw materials sourcing, production processes, and transportation

Water scarcity effect on the cost of business



- Water is **essential across many industries,** from agriculture to data centers, serving as a **direct and indirect input** that ensures business productivity. It is vital in **sourcing raw materials,** during **production processes,** in **energy generation,** and for the **transportation** of goods
- Shortages have significant **economic consequences.** Industries directly reliant on water in production or secondary processes will feel the immediate impact of scarcity. With water becoming scarcer, **costs will rise** disproportionately due to additional transportation and purification requirements. **Low water levels also put a strain on energy generation capacity,** affecting both thermal and hydropower plants, which supply roughly 85% of global electricity
- Companies operating in **water-scarce regions face rising cost inflation and decreased competitiveness.** Long-term water scarcity may prompt water-intensive industries to **relocate** to water-abundant areas, **exacerbating economic challenges** in regions with water shortages

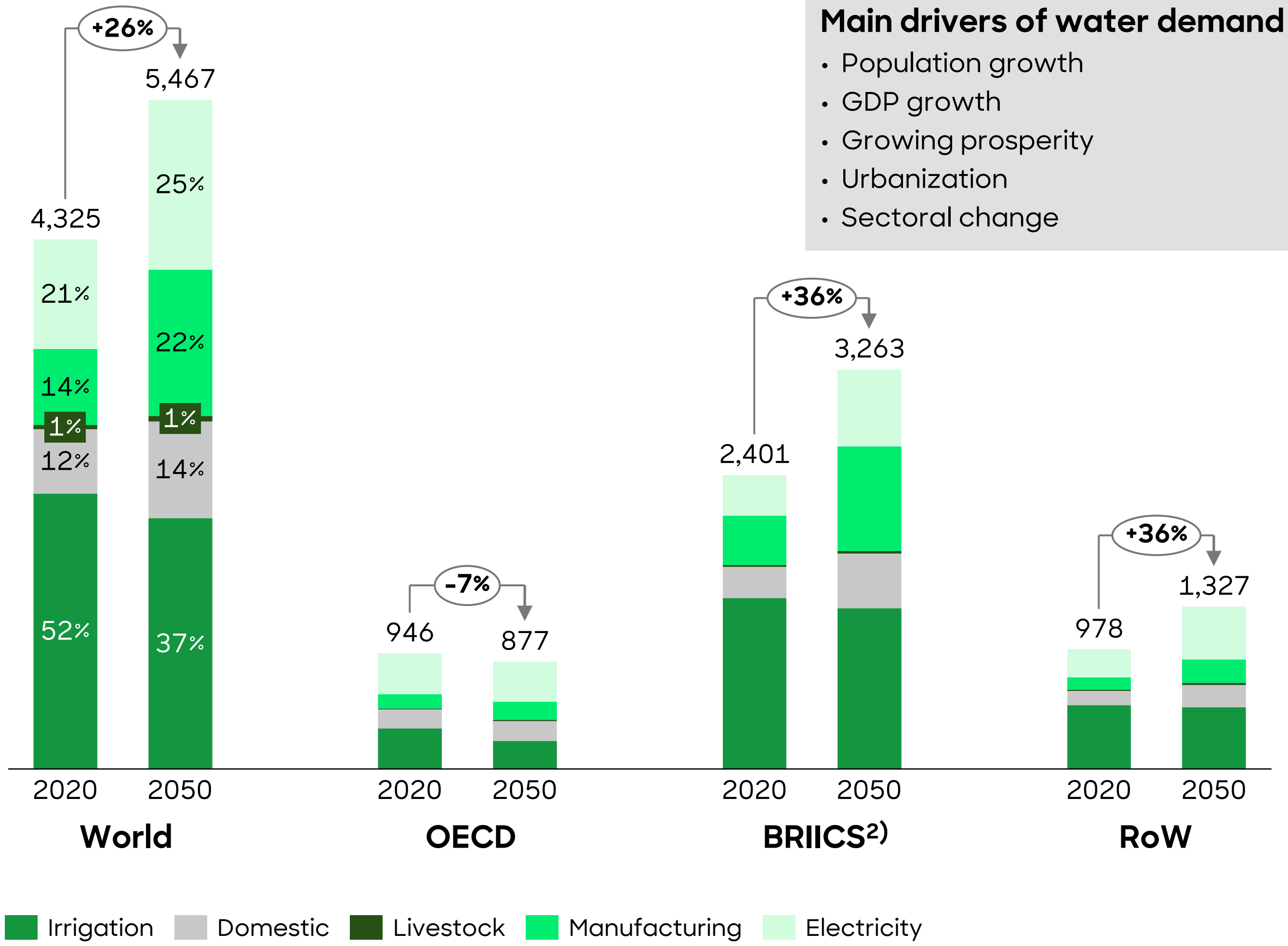
Direct impact | Indirect impact | Increase | Decrease | Large bottom-line impact on industry | Small bottom-line impact on industry

Source: Roland Berger

Demand for water is expected to rise further to 2050 driven by population growth and the desire to increase prosperity

Global water demand 2020 vs. 2050[1)] [km³]

Main drivers of water demand
- Population growth
- GDP growth
- Growing prosperity
- Urbanization
- Sectoral change

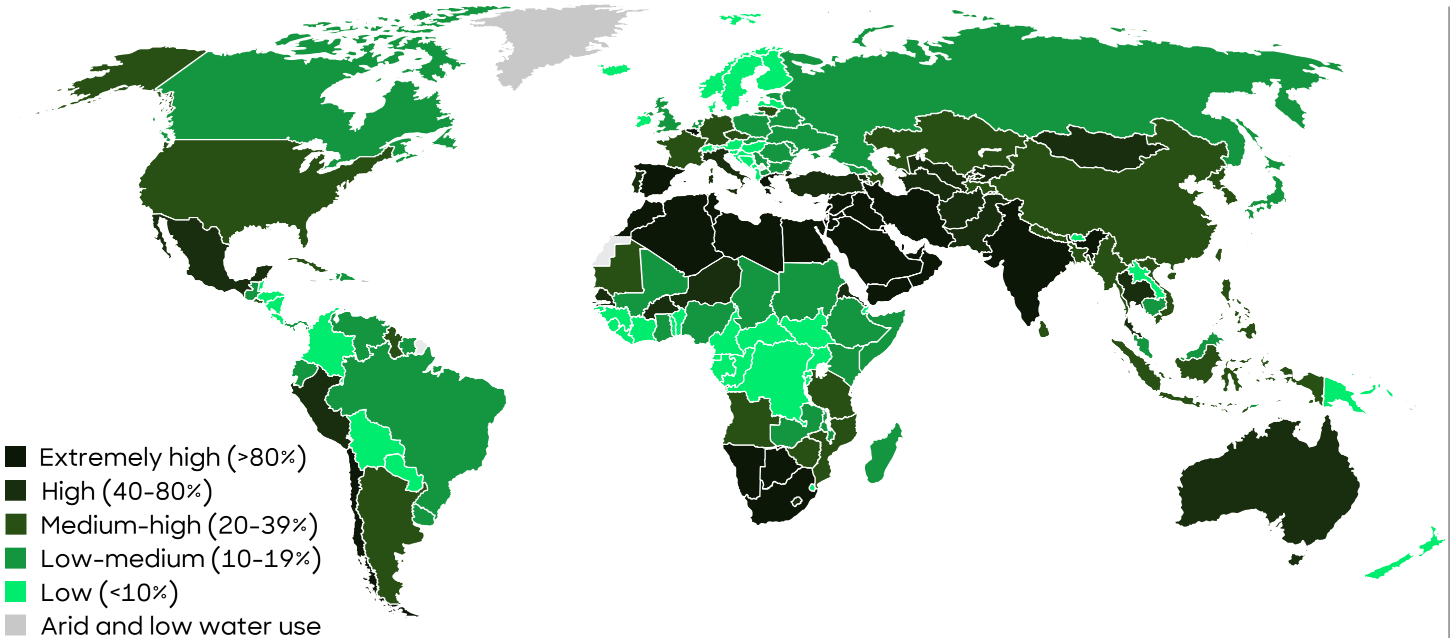


- Globally, **water demand** is forecast to **significantly rise** by 2050. This surge will be primarily **fueled by** heightened demand from the **manufacturing, domestic** usage, and **thermal electricity** generation, as well as increasing demand from emerging and developing regions
- Freshwater **reserves are depleting faster than they are replenishing.** Specifically, freshwater levels in aquifers – underground areas that hold water – are declining in many locations: of the **37 aquifers across the world, 21 are getting smaller**
- A **major aquifer in distress** is for example the **Ganges-Brahmaputra basin** in India. Other major basins in distress can be found in China, the US or the Middle East, for example
- **Climate change** is expected to further exacerbate water demand, particularly for irrigation, as droughts become more frequent, while the **availability of freshwater is anticipated to decline**
- Conversely, **higher evaporation rates,** altered **precipitation patterns,** and **melting snowpacks** are projected to **reduce the supply of freshwater** in river systems and groundwater, limiting consumption further
- The confluence of increased demand and dwindling supply is anticipated to **intensify water stress** across numerous regions globally by 2050

1) Linear extrapolation of 2000 and 2050 data; 2) Brazil, Russia, India, Indonesia, South Africa
Source: OECD; Nature; Roland Berger

Disturbing the water cycle leads to water stress with severe consequences

Projected water stress levels in 2050[1)]



"Water is essential to nearly every crisis we face, because when we don't have enough water, we don't produce enough food or energy."

World Resources Institute

- The **level of water stress** is defined as the proportion of **total freshwater withdrawal** by all major sectors (agricultural, industrial, municipal) in relation to **total renewable freshwater resources** after considering environmental flow requirements. Glaciers, lakes, rivers, and groundwater are all considered as freshwater
- The World Resources Institute's Aqueduct Water Risk Atlas 2023 shows that **25 countries – housing one quarter of the global population – face extremely high water stress each year**, regularly using up almost their entire available water supply (e.g. Bahrain, Cyprus, Kuwait, Lebanon, Oman)
- At least **50% of the world's population – around 4 billion people – live under highly water-stressed conditions for at least one month of the year;** this will rise to **60% by 2050.** Short-term draughts have recently affected Mexico, parts of the UK, South Africa, Iran, and India
- Increased water demand is often the result of growing populations and industries but living with this level of **water stress jeopardizes people's lives, jobs, food and energy security**

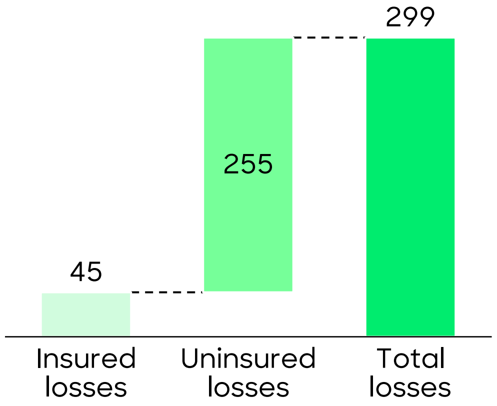
1) Water stress level: Ratio of withdrawals to water supply; baseline water stress measures the ratio of total water demand to available renewable surface and groundwater supplies. Water demand include domestic, industrial, irrigation, and livestock uses. Higher values indicate more competition among users. A country facing "extreme water stress" means it is using at least 80% of its available supply, "high water stress" means it is withdrawing 40-80% of its supply

Source: World Resources Institute; WEF; Roland Berger

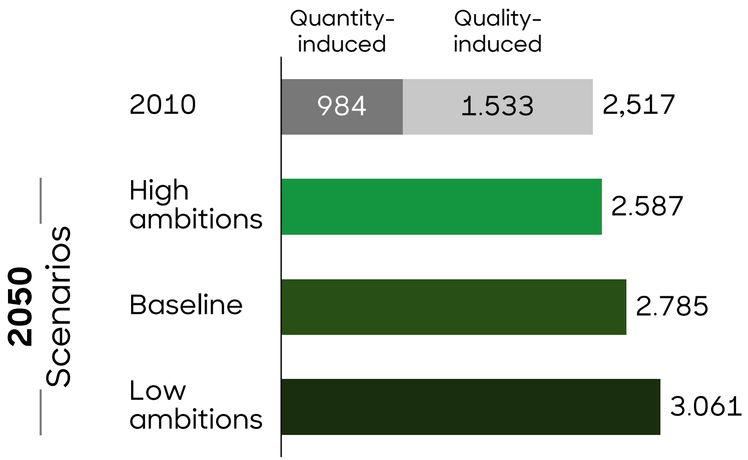
Water risks do not only stem from a lack of accessible water – Flooding and pollution also pose major water-related risks

Economic damage due to flooding and water pollution

Economic losses caused by floods worldwide
[from 2018 to 2022, USD bn]



Number of global river sub-basins facing severe scarcity of clean water[1]



High ambitions
This scenario assumes a future focusing on sustainable socio-economic development, high-ambition nitrogen policies, and an ambitious diet shift to a low meat diet

Baseline
This scenario assumes a socio-economic development following the historical trends, moderate-ambition nitrogen policies, and a medium meat and dairy diet

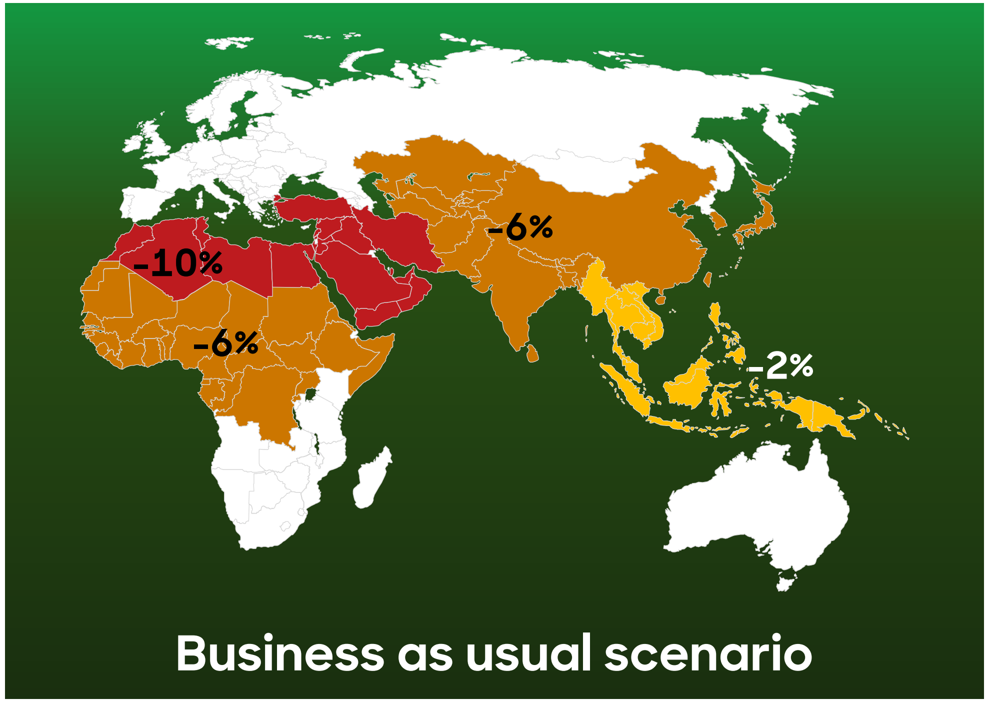
Low ambitions
The scenario assumes an urbanized future with fossil-fuel-driven socio-economic development, low-ambition nitrogen policies, and a meat- and dairy-rich diet

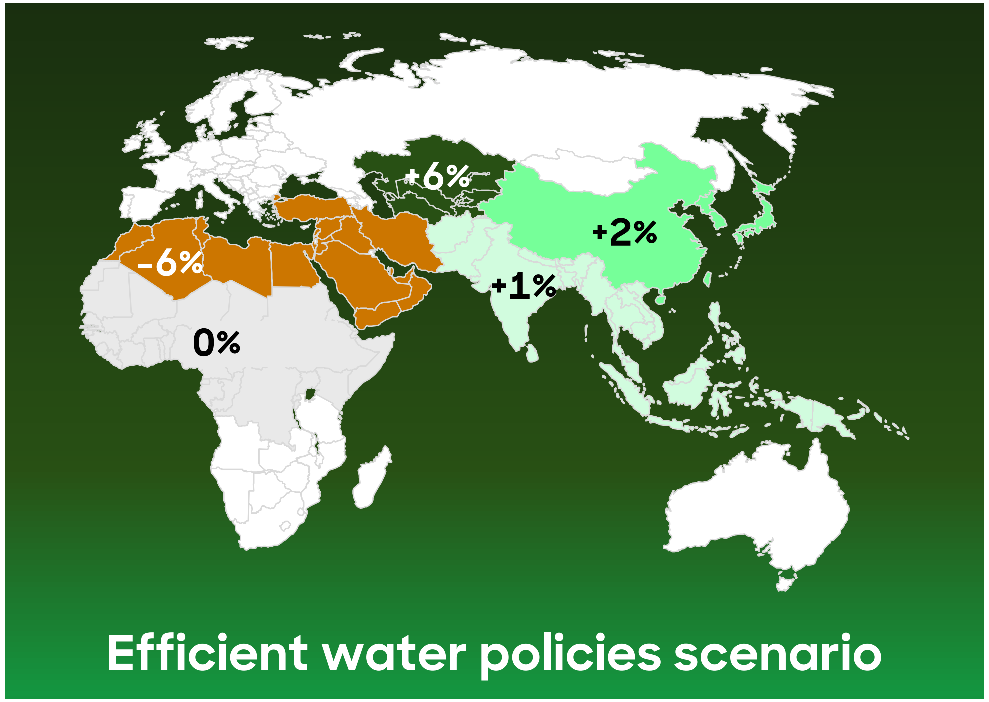
- Water-related risks for humanity extend beyond mere shortages; **deteriorating water quality** and **increased flooding** are also pressing concerns. Since 1990, flood occurrences have been on the rise due to climate change, while water quality is declining globally
- Each year, **floods destroy assets worth billions of dollars.** From 2018 to 2022 alone, losses from flooding worldwide amounted to USD 300 billion. Only a small portion of the losses are insured - and not just in poorer countries; the bulk of flood risks in industrialized countries are also not insured. Many losses involve **public infrastructure** (e.g. roads, railways, dykes, bridges) that is generally uninsured
- Furthermore, **pollution** poses significant harm, impacting the economy and public health. A comprehensive global analysis projected that by the 2050s, the number of sub-basins facing water scarcity could triple in the worst-case scenario, **when factoring in future nitrogen pollution** alongside traditional assessments of water quantity-induced scarcity
- In 2010, 984 sub-basins faced water scarcity due solely to quantity-induced factors, whereas 2,517 sub-basins were impacted by both quantity and quality-induced scarcity. By 2050, this is projected to rise to 3,061 sub-basins in the worst-case scenario. This escalation equates to an additional 40 million km^2 of basin area and an **additional 3 billion people potentially encountering water scarcity by 2050**

1) River sub-basins are smaller working units of river basins, which are a large source of drinking water but also remain locations of large scale urban and economic activities
Source: MunichRe; Nature.com; Roland Berger

Water shortages not only cause human suffering, but are also quantifiable in terms of GDP losses – Efficiency levers mitigate losses

Estimated change in 2050 GDP due to water scarcity in water-scarce areas



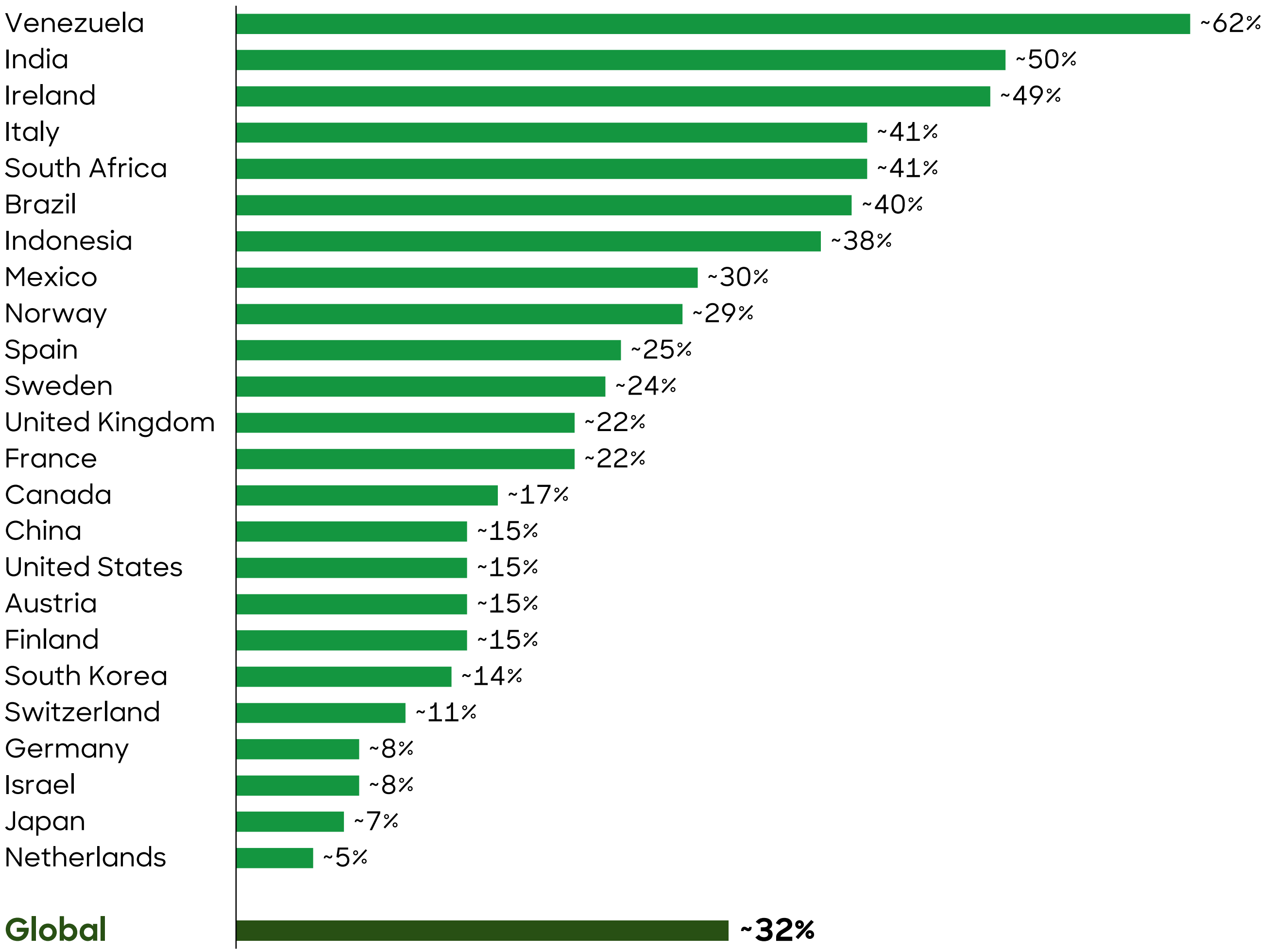


- If existing water management strategies continue and climate predictions hold true, **water scarcity will spread to regions currently unaffected** while exacerbating significantly in areas already grappling with water shortages. Especially countries from **North Africa** and **Middle East** will be hit markedly by water scarcity, seeing their **GDP growth rates decline by as much as 10% of GDP by 2050** due to water-related losses in agriculture, health, income, and property
- With **improved, efficient water resource management,** negative impacts can be mitigated. In some regions, efficient water policies may even lead to increased growth. According to WRI research, **economic gains originating from effective water management surpass associated costs:** Each dollar invested in water access and sanitation generates an average return of USD 6.80. In the period leading up to 2030, **sustaining a reliable water supply** may necessitate a **modest investment of slightly over 1% of global GDP,** equivalent to roughly **USD 0.29 per person per day** from 2015 to 2030

Source: World Bank; World Resources Institute; Allianz Global Investors; Roland Berger

To increase efficient water usage, many countries can start by doing more to avoid water leakages

Water leakages in selected countries, 2022[1] (or most recently available)

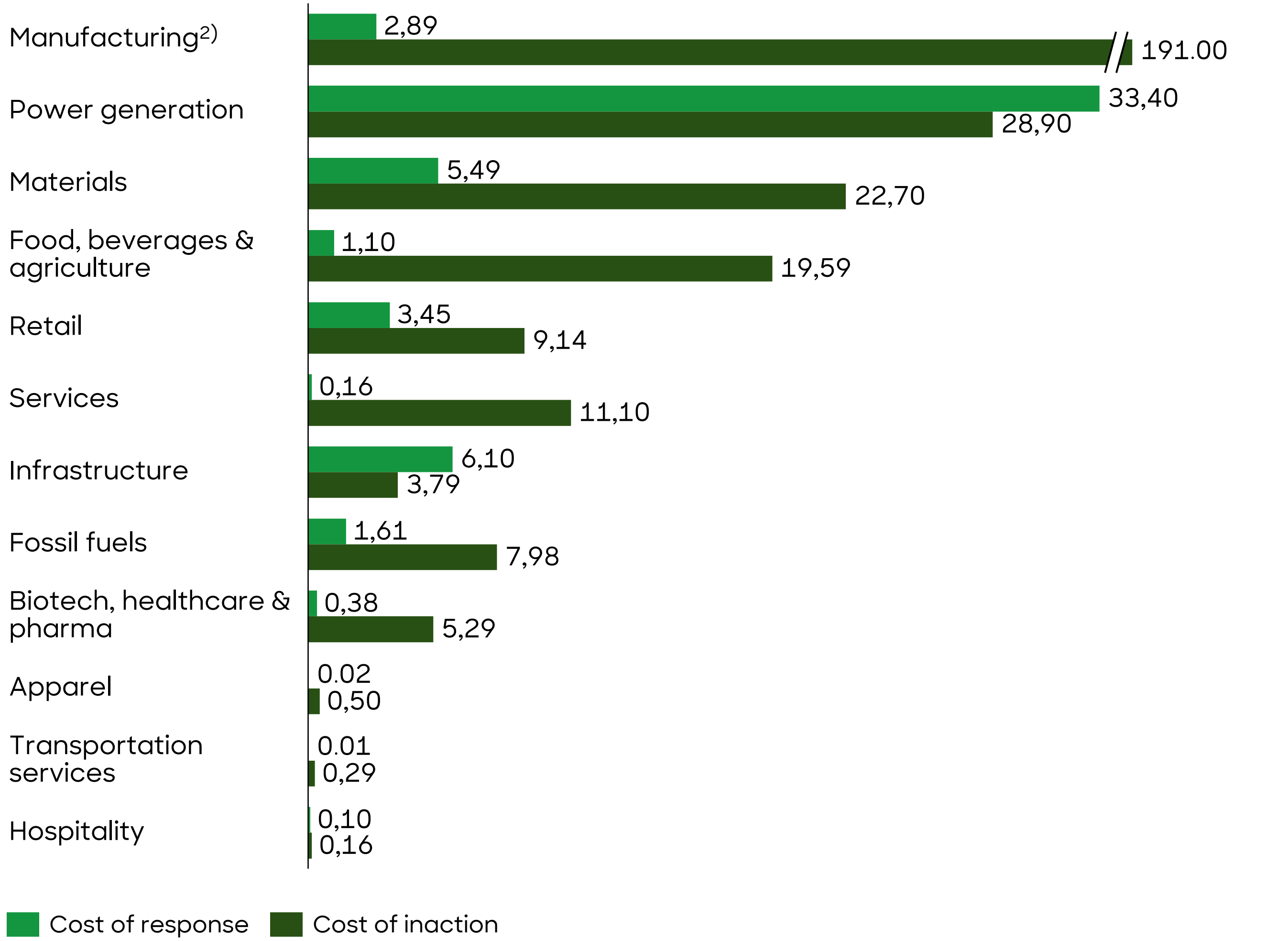


- A **significant amount of water is lost to leakages** in the water distribution network
- Average water losses in **developing countries** are estimated to be as high as **35%.** However, **developed countries** are not necessarily doing much better: for instance, France and the United Kingdom lose just over **20%** of their water in the distribution network, while Norway loses nearly **30%**
- One of the **main reasons** why water **leakages aren't tackled,** is that the **price of water** does not necessarily **reflect its true (environmental) cost**
- To limit distribution losses, pipes, pumps, and valves are being **digitalized and enhanced with smart technologies** that can measure and report real-time consumption, also enabling targeted leakage identification and repair
- While upfront investment costs of digitally enhanced water networks can be huge, around **USD 42 billion in revenue per year are estimated to be lost through leakages and other non-revenue (un-billable) water** by water utilities around the world

1) Water leakages are measured as percentage of non-revenue water (NRW), i.e. water that has been produced and is "lost" before it reaches the customer
Source: GWI; Roland Berger

With a huge imbalance between the cost of inaction and response in terms of addressing water related risks, mitigation is the way forward

Costs of addressing water-related risks vs costs of inaction, 2020[1, 2] [USD bn]



- Given the **dwindling water resources,** compounded by climate change and environmental degradation, companies must **invest in mitigating water-related risks** such as scarcity, flooding, and pollution **to bolster resilience and minimize impacts**
- The potential **financial impact** of water risks for businesses **surpass the costs associated with addressing them** in nearly all sectors
- In 2020, reported water risks had a total potential financial impact of up to USD 301 billion, whereas the **estimated cost of mitigation** stood at only **USD 55 billion**
- Across most sectors, **taking action** to address water risks proves **more economical** than inaction, **except for power generation and infrastructure** where **substantial capital expenditure is needed** to transition energy portfolios
- In these sectors, the costs reported for addressing water-related risks **are reflecting the cost of decarbonization**
- **Power generation** companies are allocating **around a third** out of the total USD 33.4 billion water-related investment in this way, while **infrastructure** companies are spending **more than half** out of the total USD 6.1 billion in this manner

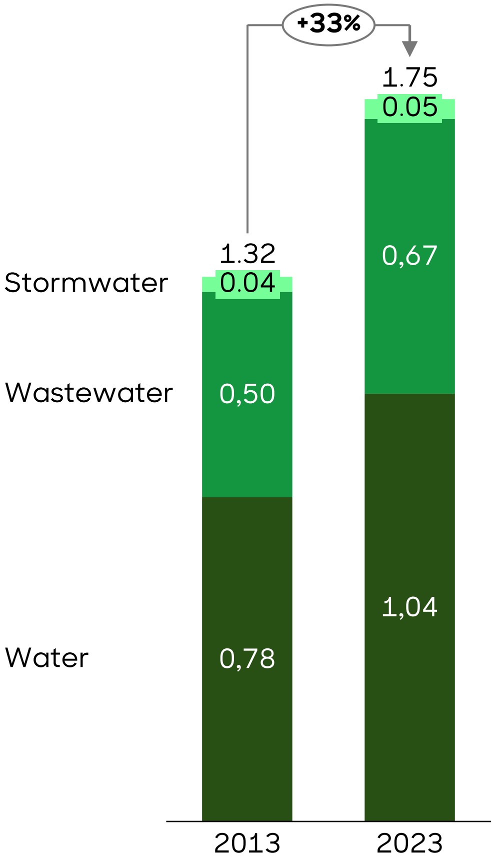
1) Survey of 5,500 companies worldwide, conducted by CDP; 2) The maximum potential financial impact in manufacturing is high in part due to the large number of respondents compared to other sectors and two significant financial impacts (>USD 50 bn) reported: one linked to flooding, another linked to reputational risk associated with pollution

Source: CDP; Roland Berger

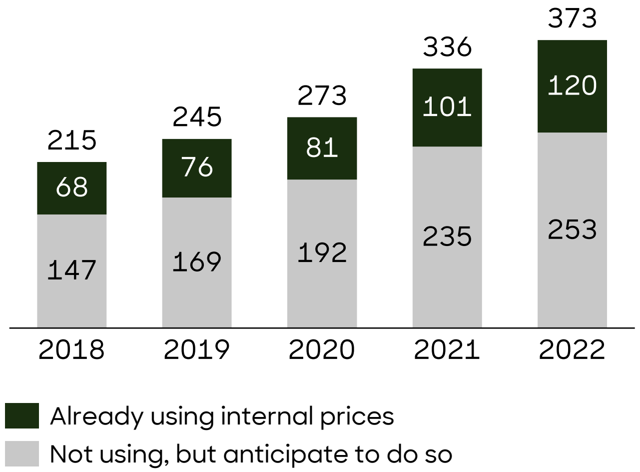
A key lever to improve water use efficiency would be the application of a fair price for water, internalizing the external cost of water overuse

The price of water doesn't match the true cost of water

Combined tariff for water globally[1] [USD/m³]



Number of publicly listed companies using internal water pricing globally[2]

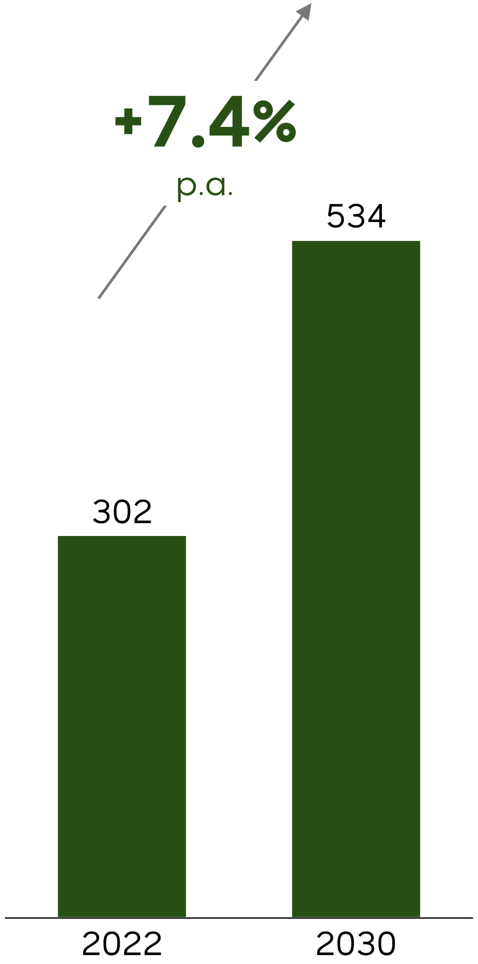


- Over the past decade, the **price of water has increased globally in most countries** that report data on water tariffs. Only in 11 of the 115 reporting countries water tariffs decreased, e.g. in the UAE or Switzerland
- However, **prices paid** for water by private households and companies for water **do not account for its true cost**
- While many customers typically **consider only the direct costs** associated with **accessing water and establishing infrastructure,** they often overlook **additional expenses** related to managing externalities, reflecting the true cost of water. The "hidden" costs of water account for environmental considerations, among others
- As of 2022, **only a few publicly listed companies use** internal hypothetical "shadow" water prices – an approach comparable to internal carbon pricing. Out of 30 companies that disclose their shadow water price, it can be observed that the price falls significantly below the actual cost of water. This circumstance allows companies to capitalize on water being considered a human right, resulting in **subsidies** and **a lack of factoring in true environmental costs**
- Analysis indicates that if a **realistic, higher cost of water were applied** across industries with high water usage, it could, in theory, **eradicate the profitability** of certain companies

1) Average tariff for water in 115 countries that provided data in 2013 and 2023; 2) Analyzed were all ~2,800 companies in the MSCI All Country World Index (ACWI)
Source: GWI; DWS; Barclays; Roland Berger

Huge investments are necessary to replace degraded water infrastructure to avoid service disruptions

Global water and wastewater treatment market value [USD bn]



USD 200-400 bn p.a.

of **additional investments** in low and middle-income countries would be needed just to achieve universal access to clean drinking water, sanitation, and hygiene by 2030

Top challenges facing the water industry

- Lack of funding
- Leakage management
- Artificially low pricing
- Control of contaminants
- Extreme weather

- **Water infrastructure needs vary regionally,** driven by factors such as population growth, urbani-zation, and environmental conditions: **urban areas** face strained water supplies, while **rural regions** struggle with higher distribution costs. Additionally, **wet regions** may face flooding, and **arid areas** experience extreme drought
- Around the world, **water infrastructure** is in dire need of **repair** as well as **expansion** to support the resilience of water networks. **Aging distribution networks** in many regions contribute to **significant losses** through leaks, breaks, and contamination
- To make the water **infrastructure more resilient as well as future-proof,** utility companies must invest heavily over the next decade to replace aging infrastructure to prevent service disruptions
- Globally, the market for **water treatment** is **expected to grow** by more than 7% p.a. to 2030 – utilities can **rely on steady or even rising demand** for decades to come
- **Developing economies** will **require improved distribution and treatment systems,** driving substantial investment in centralized infrastructure. Moreover, **decentralized solutions** are expected to gain traction, presenting further opportunities for startups and innovative technologies

Source: NASDAQ; Fortune Business Insights; Global Commission on the economics of water; Roland Berger

Beyond water, the world's sustainable development depends on the provision of food, raw materials, and energy

Globally essential resources between abundance and scarcity

Food

- **Access to food** – one of life's most basic resources – **is unevenly distributed**
- Thanks to continuous efforts, **progress** to improve the situation for the most affected can be observed over past decades: the global prevalence of **undernourishment in the general population** dropped from **13% in 2001 to 9% in 2021**
- Still, too many people are exposed to **famine** around the world. The overarching **goal** should not only be to **feed everyone,** but to do so **in a sustainable way**
- Specifically, this includes **lowering the consumption of land-intensive foods,** and to lower GHG emissions caused by food production

Raw materials

- **Raw materials,** such as metals and minerals, are **limited** in terms of availability as well as access
- **Global distribution** but also **total raw material reserves determine general availability** – this can change over time
- To **overcome these limitations,** and moving away from a 'produce-consume-discard' cycle, **waste** should be more universally **understood as a raw material;** increasingly, waste can be recycled, re-processed, and re-integrated into production cycles, thus moving from a linear to a **circular economy** model

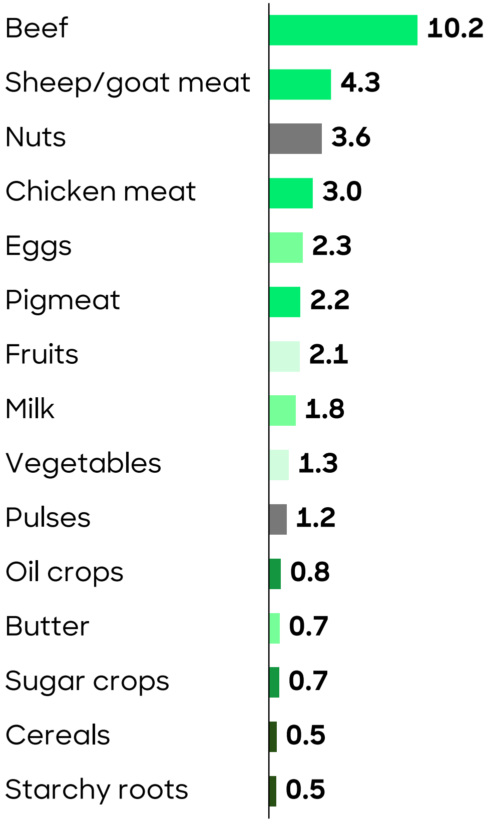
Energy

- All **processes** – in the economy, in transportation, in households, etc. – **depend on energy**
- As described here in subtrend 1, **current energy generation causes most GHG emissions,** making the **transition to renewable energy sources** a pressing concern
- Major aspects of the energy transition involve **replacing fossil fuels,** the **electrification** of the economy, and **energy generation** from **renewable sources**
- But replacing fossil fuels with renewable energy sources is not enough. In addition, a considerable **improvement in energy efficiency** is necessary to meet future energy demand

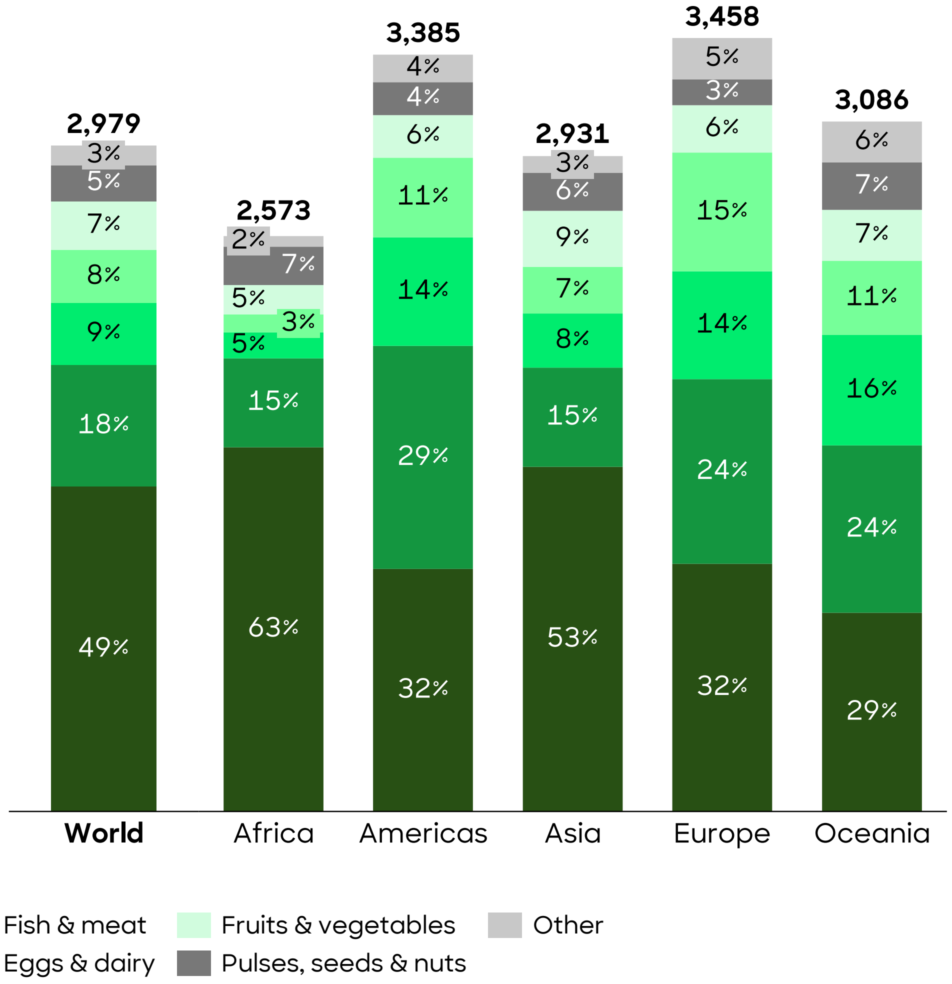
Source: UN Foundation; Roland Berger

Water is also essential for food production – Water requirements per kilocalorie differ fundamentally depending on food category

Water requirement of production [l/kcal]



Daily dietary intake, world and regions, 2021 [kcal/capita]

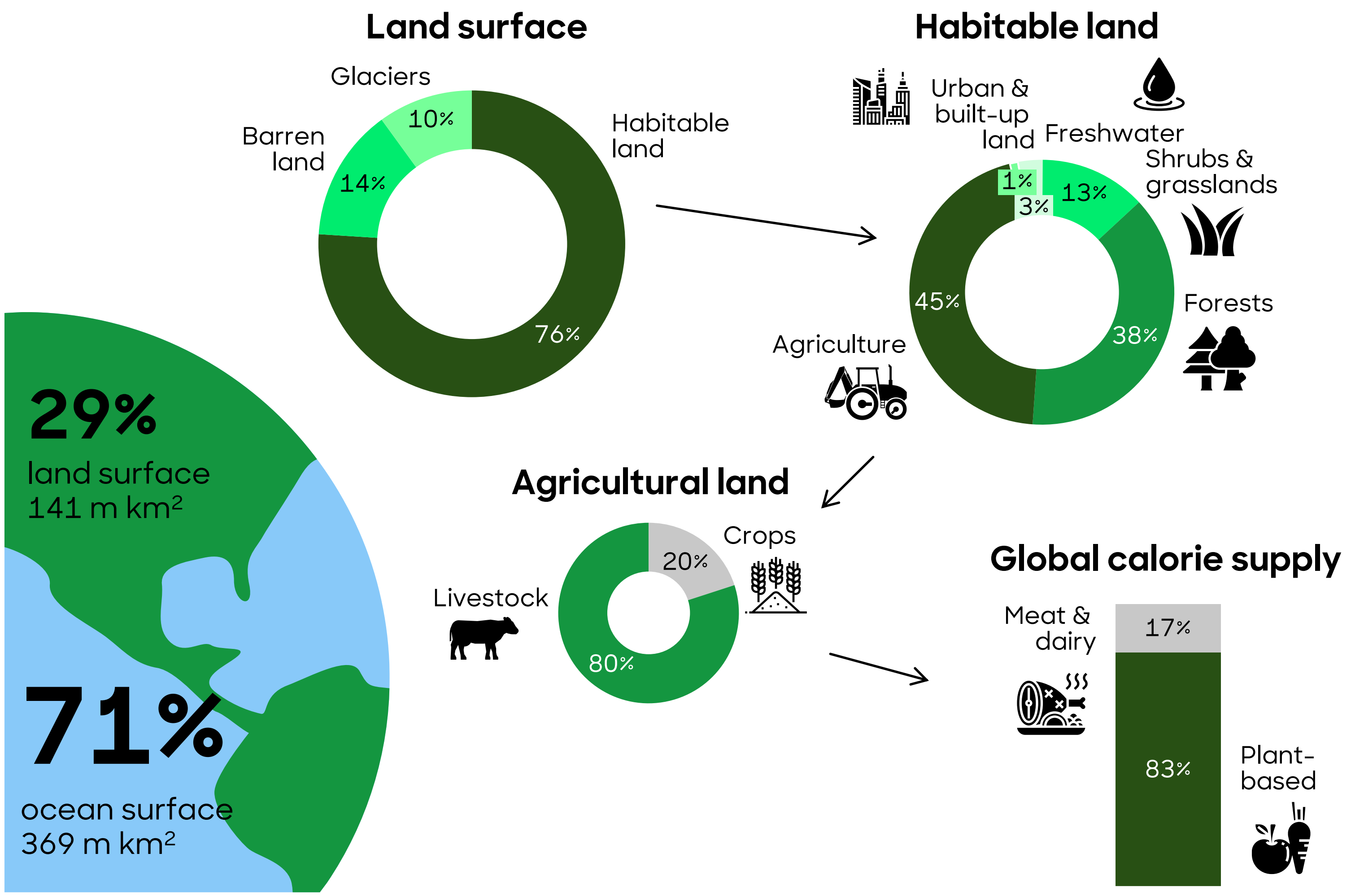


- **Water extraction and food production** are closely **intertwined.** Producing water-intensive food carries disadvantages, especially in arid regions where there is a shortage of water and a shortage of food
- Most notably, **meat products** fall under the category of **water-intensive products,** as do other animal products such as **eggs and dairy. Tree nuts** (almonds, walnuts, pistachios, cashews) are some of the **most water-intensive crops** grown today
- **Dietary intake** is deeply dependent on a country's **standard of living.** High-income countries can supply a **calorie intake** of more than 3,300 kcal per person, whereas low-income countries can only supply two thirds of that
- **Meat consumption is related to income,** too – hence the resulting water consumption. While in high-income countries, **livestock products,** such as **meat, dairy and eggs,** take up a large share of the calorie intake, in poorer countries, these foods make up a much smaller part

Source: Unesco-IHE; FAO; Roland Berger

Nearly half of the Earth's habitable land area is now used for agriculture, most of which is used for livestock

Facts concerning global land use



- Only **29% of the Earth's surface is land,** the remaining majority is water. Of the entire landmass, only **76% is habitable**, the remainder being barren land and glaciers
- **Agriculture constitutes the majority** of habitable land (45%). Another 38% is covered by forests, and 13% consists of shrubs and grassland
- By contrast, **urban and built-up areas occupy only 1%** of habitable land
- Roughly 80% of agriculturally used land is primarily **dedicated to livestock farming,** while only 20% is allocated to crops
- This **contrasts with the global calorie** supply, where only 17% originates from meat and dairy/eggs, while 83% of calories are derived from plant-based foods

Source: FAO; Roland Berger

The demand for food to 2050 is expected to rise substantially – Multiple levers can help address the future food gap …

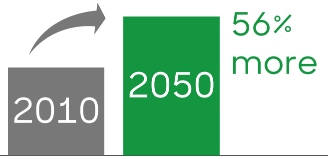
Gaps to be closed to achieve a sustainable food future in 2050

Food
Main drivers of demand

- Population growth
- Growing prosperity leading to a shift in diets

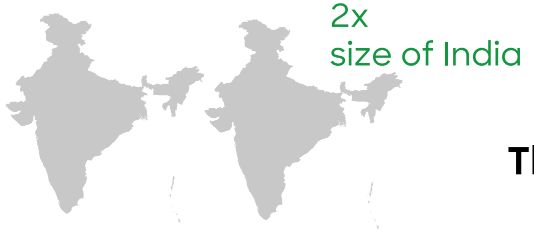
To meet the higher demand for food in 2050 we need (compared to 2010) …

… **56% more** crop calories being produced



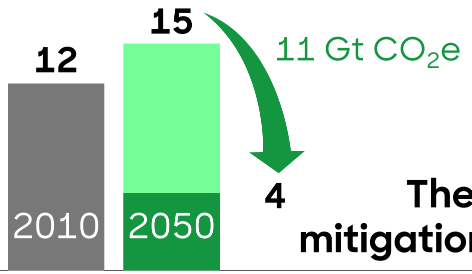
The food gap

… **593 million ha** more agricultural land – twice the size of India



The land gap

… **an 11 Gt CO_2e** GHG emission reduction in 2050 from agriculture and land-use change to meet the 2 °C Paris goal[1)]



The GHG mitigation gap

Food
Main levers to close the gaps

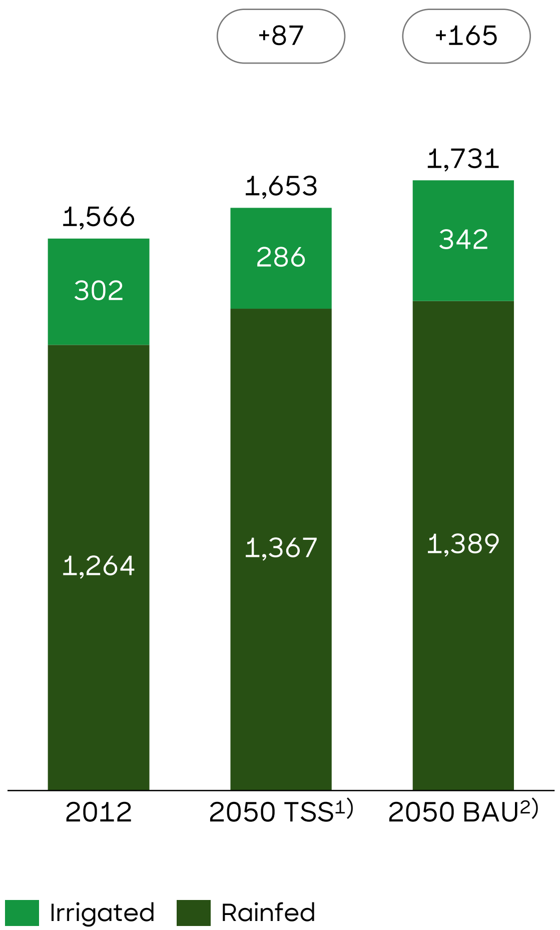
- Raise **productivity**
- Manage **demand**
- Link agricultural intensification to natural **ecosystems protection**
- Moderate **ruminant meat consumption**
- Target **reforestation** and peatland **restoration**
- Require production-related **climate mitigation**
- Spur technological **innovation**

1) Under current rate of productivity gains, emissions from agriculture and land-use change will increase to 15 Gt CO_2e per year in 2050

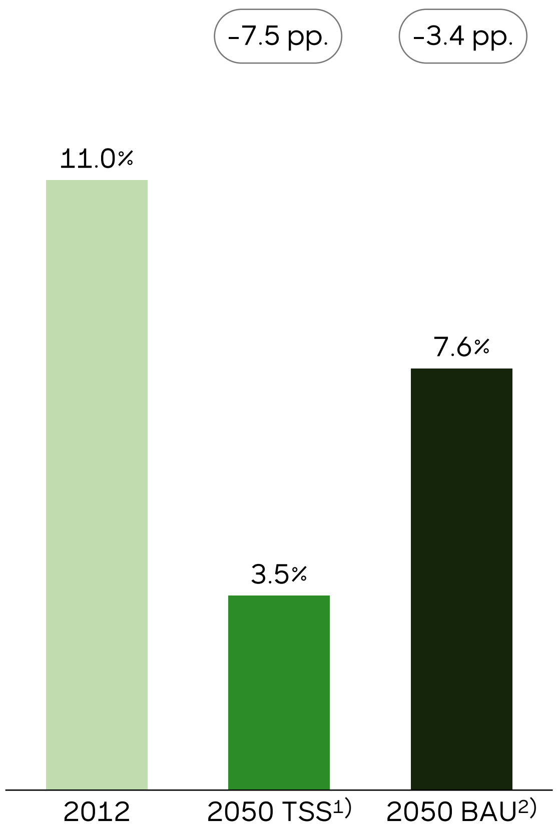
Source: World Resources Institute; Roland Berger

... however, closing all three gaps at once will be challenging – More action is needed to feed the global population

Arable land worldwide [m ha]



Global prevalence of under-nourishment [% of population]



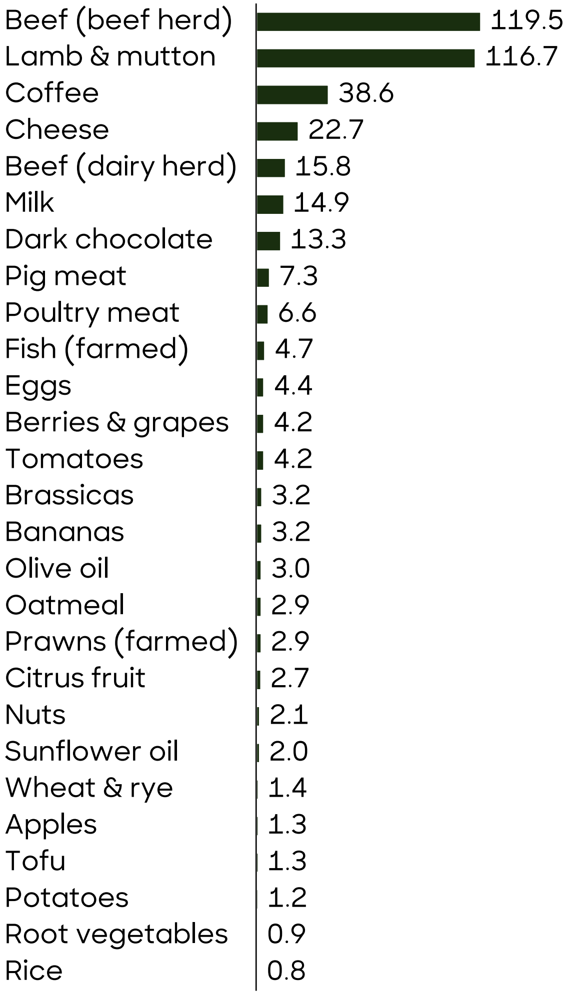
- The reconciliation of **social, economic and ecological needs** appears to be one of the most challenging tasks. However, these aspects should not be considered mutually exclusive, but should be pursued as **complementary goals**
- In the so-called **"Towards sustainability scenario" (TSS),** the anticipated **decrease in yield growth** resulting from **sustainable agricultural practices** would necessitate larger land areas to produce equivalent food quantities, all else being equal
- However, **sustainability considerations result in reduced food loss and waste,** as well as **decreased food consumption,** particularly of **animal products** compared to the **Business as usual scenario (BAU).** Additionally, there is an **increase in cropping intensity,** which helps restrict the rise in arable land use to just 6% from 2012 to 2050
- The aim is to comply with the requirements of all three goals, yet this still **falls short of eradicating hunger globally;** prevalence of undernourishment is expected to decrease by 7.5 percentage points by 2050 under the TSS scenario
- **Fewer people would suffer from hunger** if essential parameters were changed. A fair distribution could be achieved by **minimizing food waste:** today, the amount of food wasted during production or thrown away annually equates to the amount needed to nutritionally sustain 3 billion people

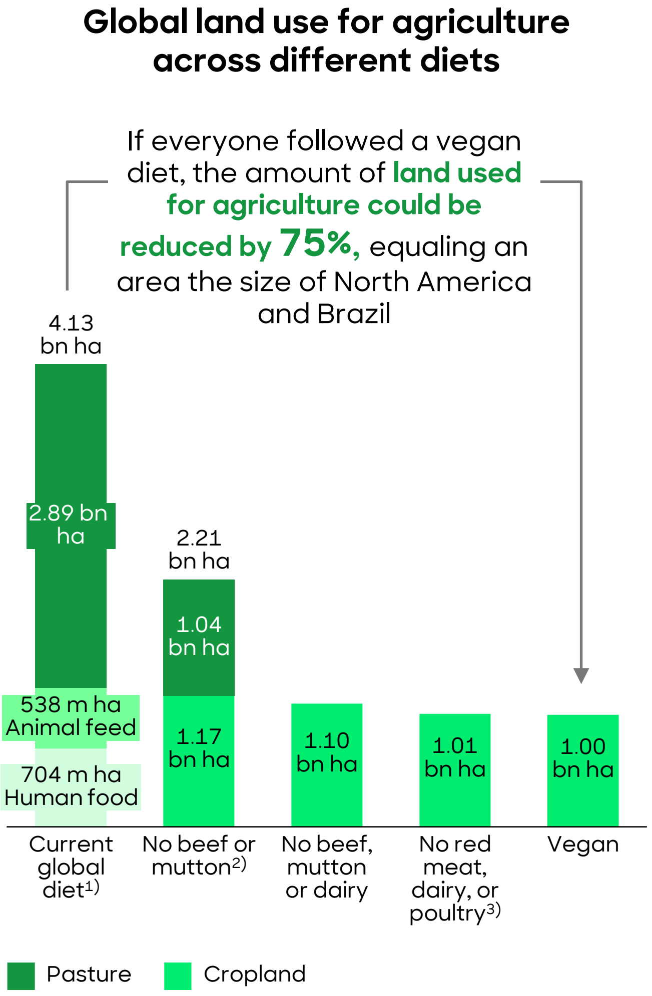
1) TSS: Towards sustainability scenario refers to meeting the climate target, a globally fairer distribution of income, and a more sustainable agriculture; 2) BAU: Business as usual scenario refers to a continuation of current policies

Source: FAO; Roland Berger

Transitioning to a global plant-based diet could potentially release up to 75% of agricultural land for other purposes

Land use of foods per 1,000 kcal [m²]



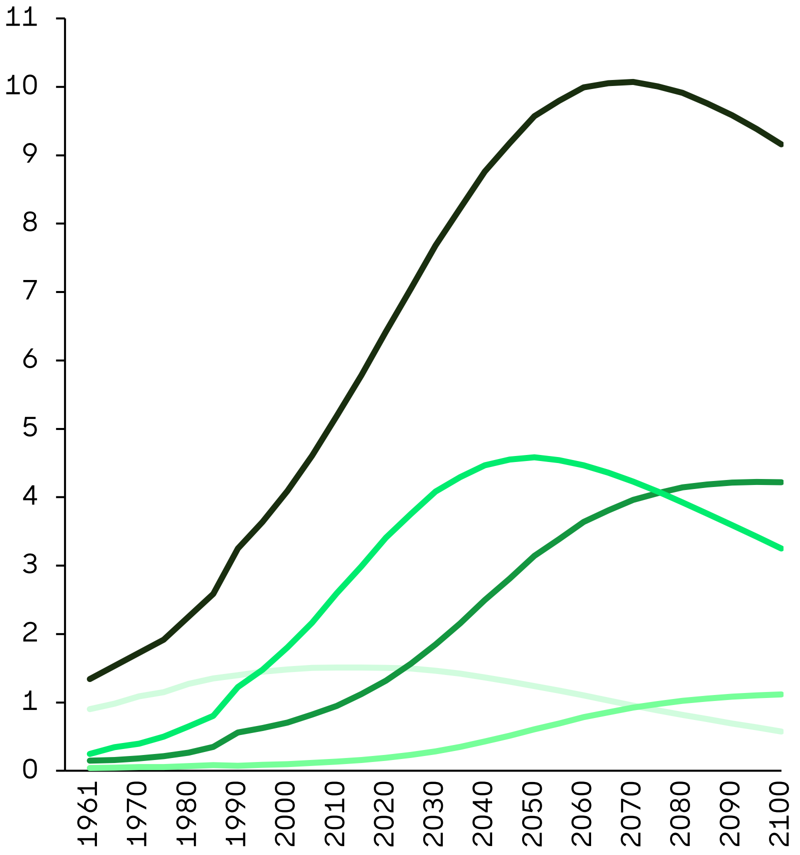


- **Nearly 50%** of the Earth's habitable land is **dedicated to agriculture, predominantly for the purpose of raising livestock** for dairy and meat production
- Livestock are **fed from two key sources – lands,** on which the animals **graze** and **cultivated lands** for producing **feed crops** such as soy and cereals
- The highest land consumption per 1,000 kcal is attributed to beef at nearly 120 m², closely followed by mutton (117 m²). Even plant-based foods like coffee (39 m²) or chocolate (13 m²) exhibit significant land use. By contrast, **staples such as rice, grains, or vegetables** have considerably lower land consumption
- One primary reason for this is **the higher energy efficiency of plant-based foods.** They directly **convert solar energy** into **calories** through photosynthesis, while animal products require the cultivation of feed crops, adding an **extra step** in the energy transfer process
- If one **combines pastures and cropland for animal feed, around 80% of all agricultural land** is used for meat and dairy production
- If the world were to **shift to a plant-based diet,** the **amount of cropland** could be **significantly decreased:** land used for animal feed could be diverted to produce more food for direct consumption

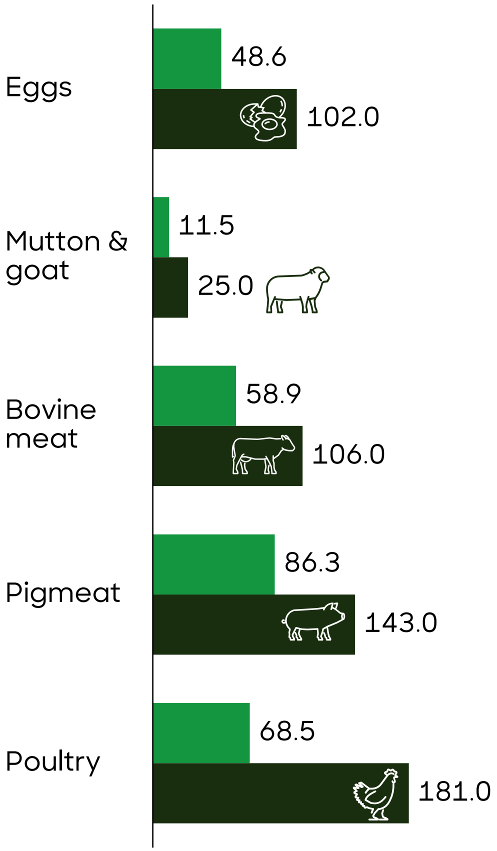
1) The global diet refers to the average global diet in 2010; 2) Beef from dairy cows still included; 3) Eggs & fish only
Source: Poore & Nemecek; Roland Berger

Global animal-based energy demand is projected to peak only in 2070 – In the interim meat consumption is projected to increase further

Total animal-based food energy demand projections per region [EJ[1]]



Projected global meat consumption [m tons]



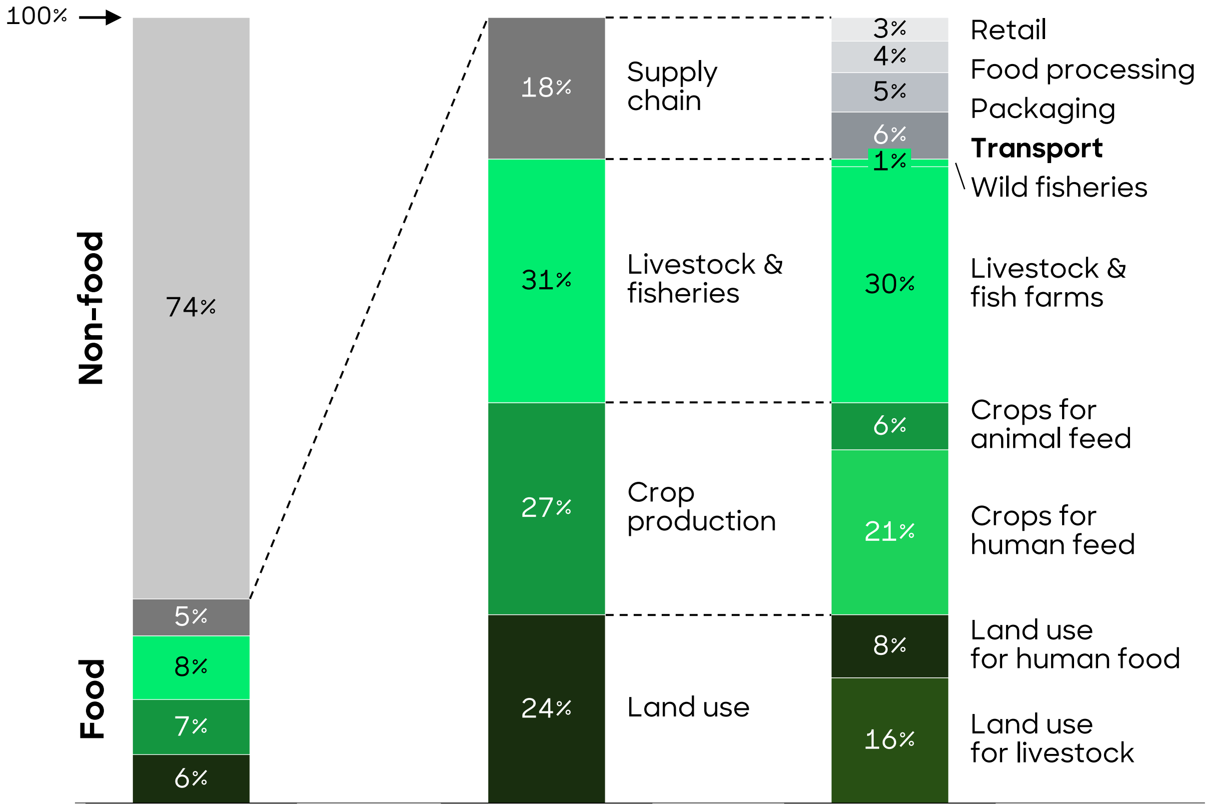
- **Global consumption of meat** is expected to **continue to increase** in the coming decades, owing to **population growth** and a **change in diets due to rising incomes** – developments taking place particularly in lower middle-income and low-income countries
- **Rising prosperity** often correlates with **increased meat protein in diets, but only to a certain point:** in high-income countries meat consumption is already on the decline and this development is expected for upper middle-income countries from 2050 onwards
- Growing meat consumption poses **sustainability challenges straining global resources** and contributes to **greenhouse gas emissions**
- Anticipating only **slow shifts in population growth and consumer preferences,** a substantial **change** in global meat consumption growth **is not projected before 2070**
- Over the long term, factors such as **demographic trends, human health, animal welfare,** and **environmental concerns** are expected to restrain meat consumption. Initiatives **to curb food loss and food waste** may further **contribute to lowering meat consumption** and production

1) EJ: Exajoule (= 10^{18} Joules)
Source: OECD; FAO; Roland Berger

The ability to reduce the impact of GHG emissions of our diet is much more determined by what we eat than by where it comes from

Greenhouse gas emissions across the food supply chain

Global emissions of CO_2 equivalents



- **Food production** contributes to about a **quarter of global greenhouse gas emissions,** emphasizing the **impact** of individual **dietary choices** on one's **carbon footprint**
- **Despite common advice to eat locally** to help reduce emissions, **for most foods, the transportation element constitutes only a small fraction** of the total GHG emissions along the supply chain
- In a meta-analysis encompassing 29 food products, ranging from beef to nuts, the study scrutinized the stages in the supply chain where GHG emissions originate, spanning from land-use change to packaging. A crucial finding emerged: there are **substantial variations in GHG emissions of different foods,** with **animal-based foods** generally exhibiting a **higher footprint** than plant-based ones
- The analysis revealed that, for most foods, especially major emitters, the **majority of GHG emissions** stem from **land-use change** and **farm-stage processes.** Farm-stage emissions, such as the application of both organic and synthetic fertilizers and enteric fermentation, contribute **over 80% to the footprint** of most foods
- By contrast, **transport plays a minor role** in GHG emissions. It accounts for less than 10% for most food products and is **significantly smaller for major emitters,** like beef from beef herds, where it constitutes only 0.5%

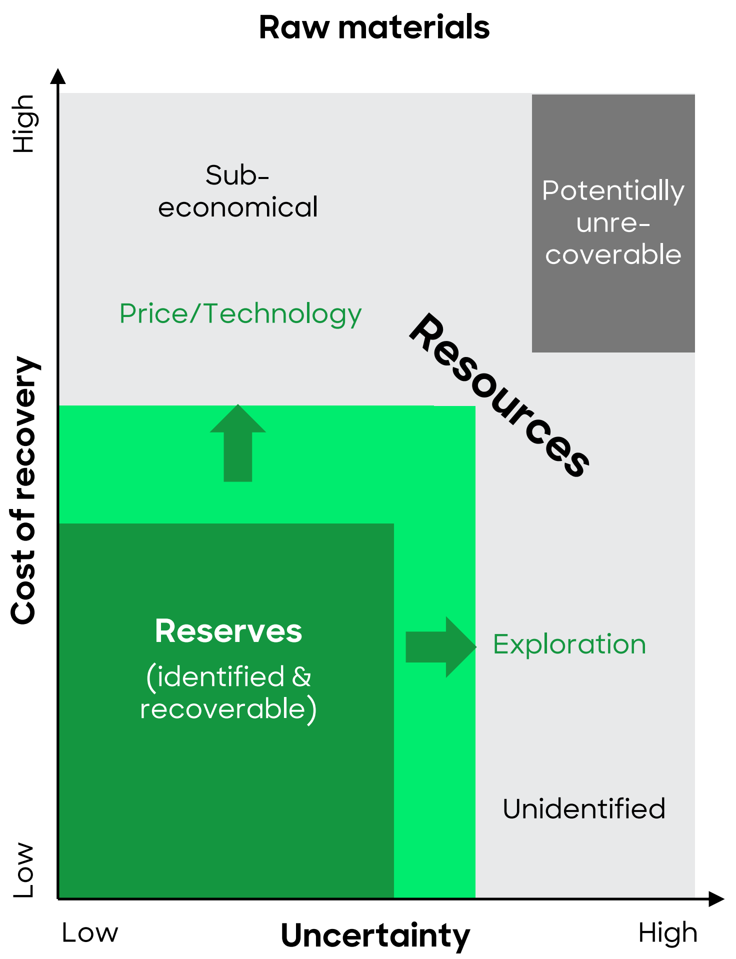
Source: Poore & Nemecek; Roland Berger

From food to non-energy raw materials: In the future, it is important to find a balance of finite resources set against abundant use

Raw materials and two approaches of classification

Raw materials

- **Energy raw materials**
  - Fossil energy raw materials: coal, oil, natural gas
  - Renewable energy raw materials: hydrogen
- **Non-energy raw materials**
  - **Metal raw materials**
    - Gold
    - Iron ore
    - Copper
  - **Industrial raw materials**
    - Oil
    - Salts
    - Limestone
  - **Construction raw materials**
    - Sand
    - Clay
    - Cement



- **Raw materials** are categorized either as **reserves** or **resources**
- For **reserves,** the following conditions apply: first, their **existence** in the respective places of extraction must be **proven** and their **quantity** must be known **exactly.** Second, their **extraction must be economically viable**
- If at least one of the two conditions is not met, raw materials are not considered as reserves, but as **resources** (their amount in mineral deposits is estimated). However, on further exploration, the level of **certainty** can be increased and thus be newly counted as reserves. The same applies to changes in the fundamentals of **recovery** (higher prices, better technology) that make it more economically viable to extract resources and therefore count them as reserves

Source: EU; Transport Geography; Roland Berger

In relation to resources, accessible reserves are quite small – Metal raw materials in particular show limited availability

Cobalt
Resources: 325 m t
Reserves: 11 m t
Mine prod. (2023): 230,000 t
Price (2024): USD 28,000-30,000/t
Substitutes: iron, barium, nickel, cerium, rhodium

Copper
Resources: 3.5 bn t
Reserves: 1.0 bn t
Mine prod. (2023): 22 m t
Price (2024): ~ USD 8,300/t
Substitutes: aluminum, titanium, optical fiber, plastics

Gold
Resources: unknown
Reserves: 59,000 t
Mine prod. (2023): 3,000 t
Price (2024): ~ USD 2,000/oz
Substitutes: palladium, platinum, silver

Iron ore
Resources: 230 bn t
Reserves: 87 bn t
Prod. (2023): 1.5 bn t
Price (2024): USD 120-130/dmt1)
Substitutes: none

Lithium
Resources: 86 m t
Reserves: 28 m t
Mine prod. (2023): 180,000 t
Price (2024): ~ USD 15,000/t
Substitutes: calcium, mercury, magnesium, aluminum soap

Magnesium
Resources: > 13 bn t
Reserves: 7.7 m t
Mine prod. (2023): 22 m t
Price (2024): ~ USD 2,700/t
Substitutes: alumina, chromite, silica

Platinum Group Metals (PGM)
Resources: 100,000 t
Reserves: 71,000 t
Mine prod. (2023): 390 t
Price (2024): multiple prices
Substitutes: PGM can substitute for another, with losses in efficiency

Rare Earths
Resources: unknown
Reserves: 120 m t REO2)
Mine prod. (2023): 350,000 t REO
Price (2024): multiple prices
Substitutes: available for many applications but less effective

Silver
Resources: unknown
Reserves: 610 m t
Mine prod. (2023): 26 m t
Price (2024): USD 20-25 oz
Substitutes: stainless steel, aluminum, rhodium

Zinc
Resources: 1.9 bn t
Reserves: 220 m t
Mine prod. (2023): 12 m t
Price (2024): USD 2,400-2,500/t
Substitutes: aluminum, cadmium, magnesium, plastics

Phosphate
Resources: 300 bn t
Reserves: 74 bn t
Mine prod. (2023): 220 m t
Price (2024): ~ USD 152/t
Substitutes: none

Cement
Resources: shortages unlikely
Clinker capacity: 3.8 bn t
Cement prod. (2023): 4.1 bn t
Price (2023): ~ USD 132/t
Substitutes: fly ash, ground granulated blast furnace slag

Coal
Resources: 19.9 trillion t
Reserves: 1.1 trillion t
Mine prod. (2022): 8.8 bn t
Price (2024): USD 100-145/t
Substitutes: oil, natural gas, renewable energy

Natural Gas
Resources: 631 trillion m^3
Reserves: 188.1 trillion m^3
Extraction (2022): 4.0 trillion m^3
Price (2024): USD 1.7-3.2/mmBtu3)
Substitutes: oil, coal, renewable energy

Oil
Resources: 502 bn t
Reserves: 244.4 bn t
Extraction (2022): 4.4 bn t
Price (2024): ~ USD 75/barrel
Substitutes: natural gas, coal, renewable energy, bio-gas

Metal raw material | Chemical raw material | Construction raw material | Energy raw material

1)dmt: dry metric tonne; 2) REO: Rare-earth oxide; 3) mmBtu: million British thermal unit (~ 28,3 m^3 natural gas at defined temperature and pressure, price for the US at Henry Hub)
Source: USGS; CapitalIQ; DERA; Energy Institute; Roland Berger

The green transition necessitates a whole range of raw materials for different purposes, with battery technologies requiring many minerals

List of selected critical raw materials for green technologies

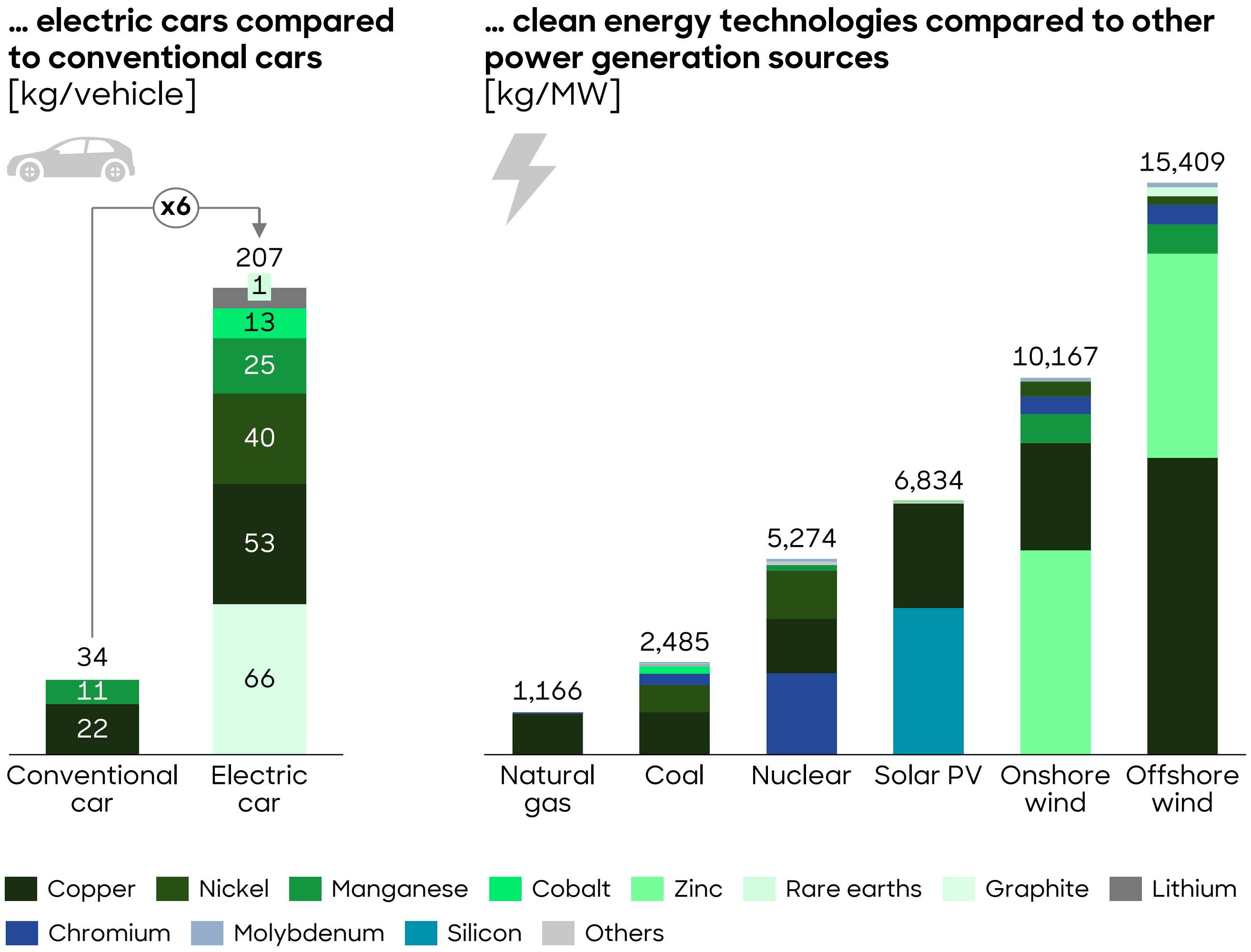
	Li-ion batteries	Fuel cells	Wind energy	Electric traction motors	Solar PV
Aluminum	✓	✓	✓	✓	✓
Copper	✓	✓	✓	✓	✓
Iron ore	✓	✓	✓	✓	✓
Cobalt	✓	✓	✓		
Rare earth elements	✓	✓	✓	✓	
Lead	✓		✓		✓
Manganese	✓	✓	✓		
Molybdenum		✓	✓		✓
Nickel	✓	✓			✓
Chromium		✓	✓		
Lithium	✓	✓			
Natural Graphite	✓	✓			
Selenium	✓	✓			
Silver		✓			✓
Tin	✓				✓
Titanium	✓	✓			
Arsenic		✓			
Cadmium					✓
Magnesium		✓			
Palladium & Platinum		✓			
Zinc					✓

- **Raw materials** play a crucial role in **transitioning** the global economy from fossil fuels to **renewable energy technologies.** These technologies typically rely more heavily on minerals than their fossil fuel counterparts
- Given the necessity to achieve net zero CO_2 emissions by 2050, there is a pressing need to significantly **scale up production and international trade** of various raw materials, bringing industrial raw materials to the forefront of policy discussions
- **Certain abundant raw materials** like aluminum, copper, and iron ore, which have traditionally supported industrial production, will continue to be **essential in green sectors** and their associated technologies
- Additionally, **rare earth minerals** such as neodymium and dysprosium, as well as lithium, cobalt, and nickel, are **vital to emerging technologies,** resulting in an anticipated surge in demand

Source: OECD; Roland Berger

The global energy transition is expected to substantially increase the demand for minerals, as green technologies heavily rely on minerals

Minerals usage in …

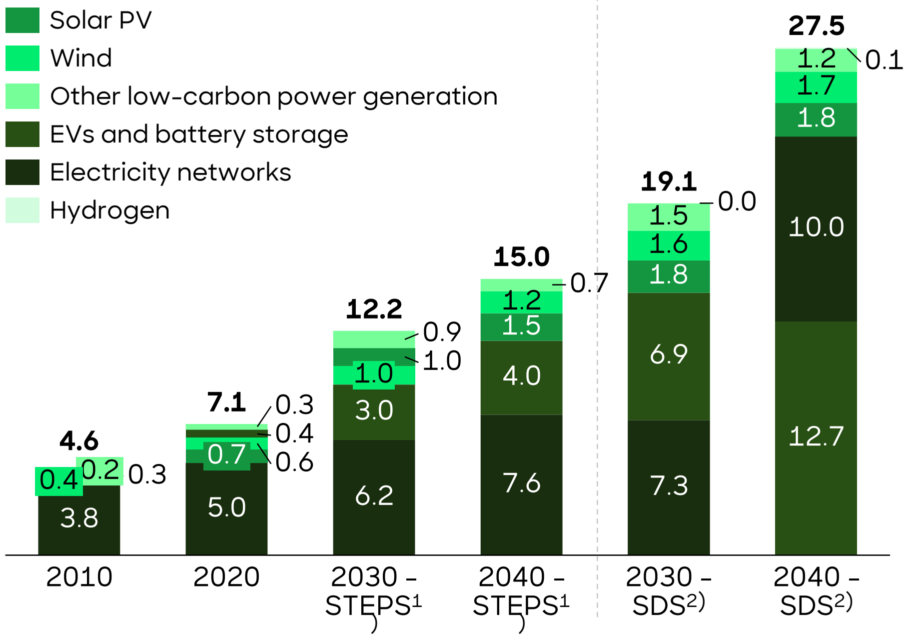


- The **energy landscape** is undergoing a **profound transformation** by transitioning from traditional hydrocarbon resources to clean energy technologies
- **Clean energy technologies,** including solar photovoltaic (PV) systems, wind farms, and electric vehicles (EVs), typically necessitate a **higher quantity of minerals** for their manufacture compared to fossil fuel-based alternatives
- For instance, the production of an **electric car requires six times more mineral** inputs than that of a conventional vehicle, while an **onshore wind farm** necessitates **nine times more mineral resources** than a gas-fired power plant
- **Various minerals play critical roles in different clean energy technologies.** Lithium, nickel, cobalt, manganese, and graphite are vital for battery performance, longevity, and energy density. Rare earth elements (REEs) are vital to produce permanent magnets required for wind turbines and EV motors. Additionally, copper and aluminum are essential for electricity networks, with copper being fundamental to all electricity-related technologies
- The **demand for minerals in new power generation** capacity has **surged by 50%** since 2010, corresponding to the increased investment in renewable energy sources

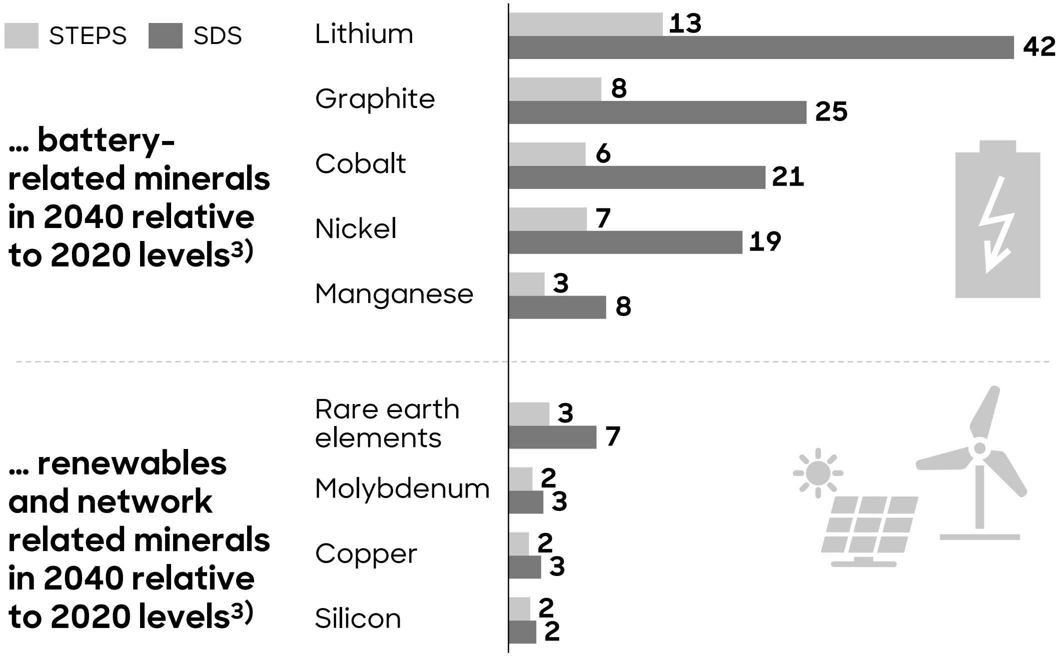
Source: IEA; Roland Berger

As clean energy technologies require a wide range of minerals and metals, their future demand is set to increase rapidly

Total mineral demand for clean energy technologies by scenario [m t]



Demand growth factor for selected ...



- The global clean energy transition will significantly impact mineral demand over the next two decades. **By 2040, the demand for minerals from clean energy technologies is expected to double in the Stated Policies Scenario (STEPS)** and **quadruple in the Sustainable Development Scenario (SDS).** Electric vehicles (EVs) and battery storage will drive about half of this demand growth, particularly due to the increasing need for battery materials. **Mineral demand from EVs and battery storage is projected to increase tenfold in the STEPS scenario** and **over 30 times in the SDS scenario by 2040**
- In terms of weight, **graphite, copper, and nickel** will **dominate** mineral demand in 2040. Lithium will experience the fastest growth rate, with demand expanding by **over 40 times** in the **SDS scenario.** The shift towards lower cobalt chemistries for batteries will limit the growth in cobalt demand, which will be offset by the growth in nickel demand

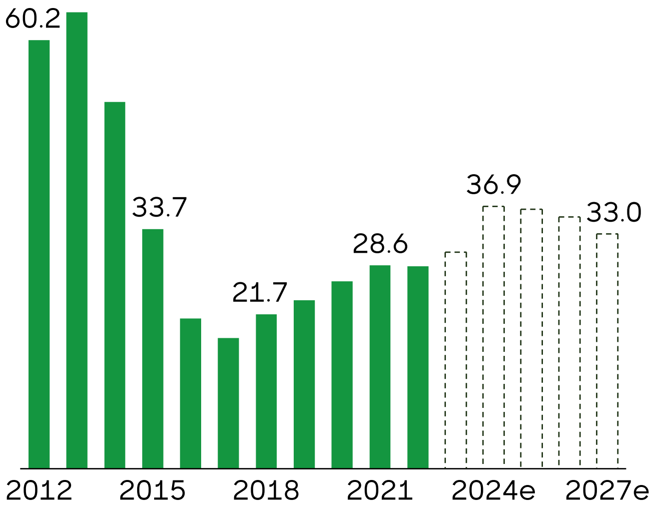
1) The STEPS scenario provides an indication of where today's policy measures and plans might lead the energy sector. These outcomes fall far short of the world's shared sustainability goals;
2) The SDS scenario charts a pathway that meets in full the world's goals to tackle climate change in line with the Paris Agreement, improve air quality and provide access to modern energy;
3) Data as of 2021, projected increase factor (1 = current demand)

Source: IEA; Roland Berger

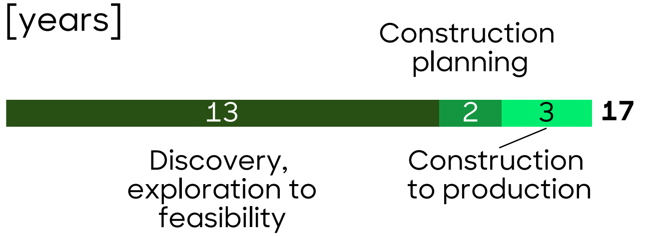
While demand is expected to surge, supply remains constraint by under-investment, long lead times, and increasing protectionism

Supply obstacles for commodities

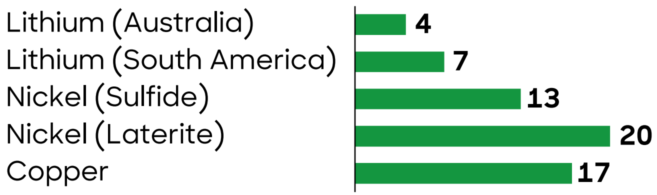
Capex estimates for the largest listed mining companies[1] [USD m]



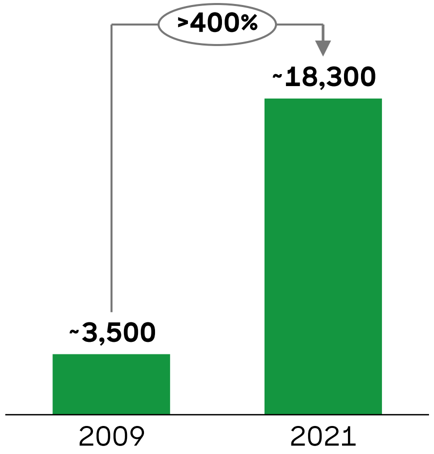
Global average lead times from discovery to extraction, 2010-2019 [years]



Average observed lead times by mineral [years]



Number of export restrictions on industrial raw materials



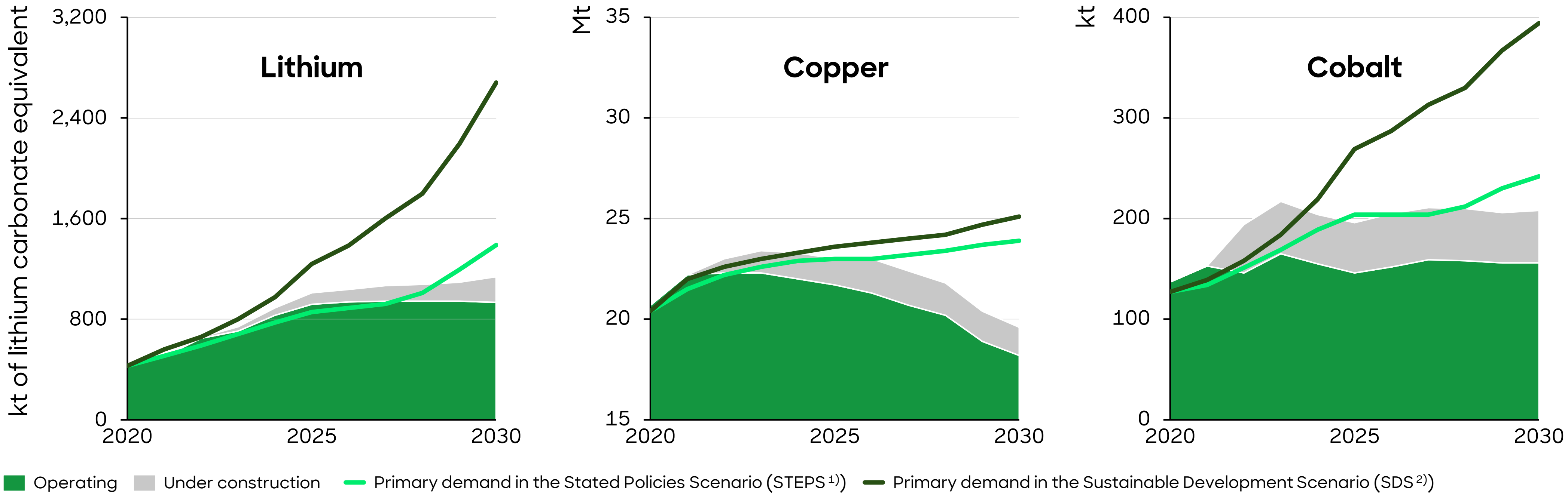
- While there is **no scarcity in reserves** for minerals crucial for the clean energy transition, **mining and refining capacities remain limited**
- Market constraints are anticipated in the near to mid-term, partly due to **insufficient investment** in upstream operations and protracted **lead times** for mining endeavors
- A significant concern lies in the rise in **resource nationalism** and **export restrictions** regarding minerals. In recent years, many governments have **increased state control** over their mineral resources to benefit more directly from extraction – or to mitigate its adverse effects
- Nevertheless, **it is unlikely that a global deficit of any single mineral will impede the clean energy transition.** Production has experienced a notable upswing for numerous transition minerals, and reserves extracted from economically viable sources have expanded. Furthermore, transformative innovations – such as efficiency gains and material substitutions – are already reshaping demand

1) Estimates cover the market analyst's Capex projections for Anglo American, BHP Group, Glencore, Rio Tinto and Vale

Source: OECD; Capital IQ; IEA; IRENA; Roland Berger

The projected primary demand of many raw materials critical to the clean energy transition is expected to outgrow future mine production

Committed mine production and primary demand for selected raw materials



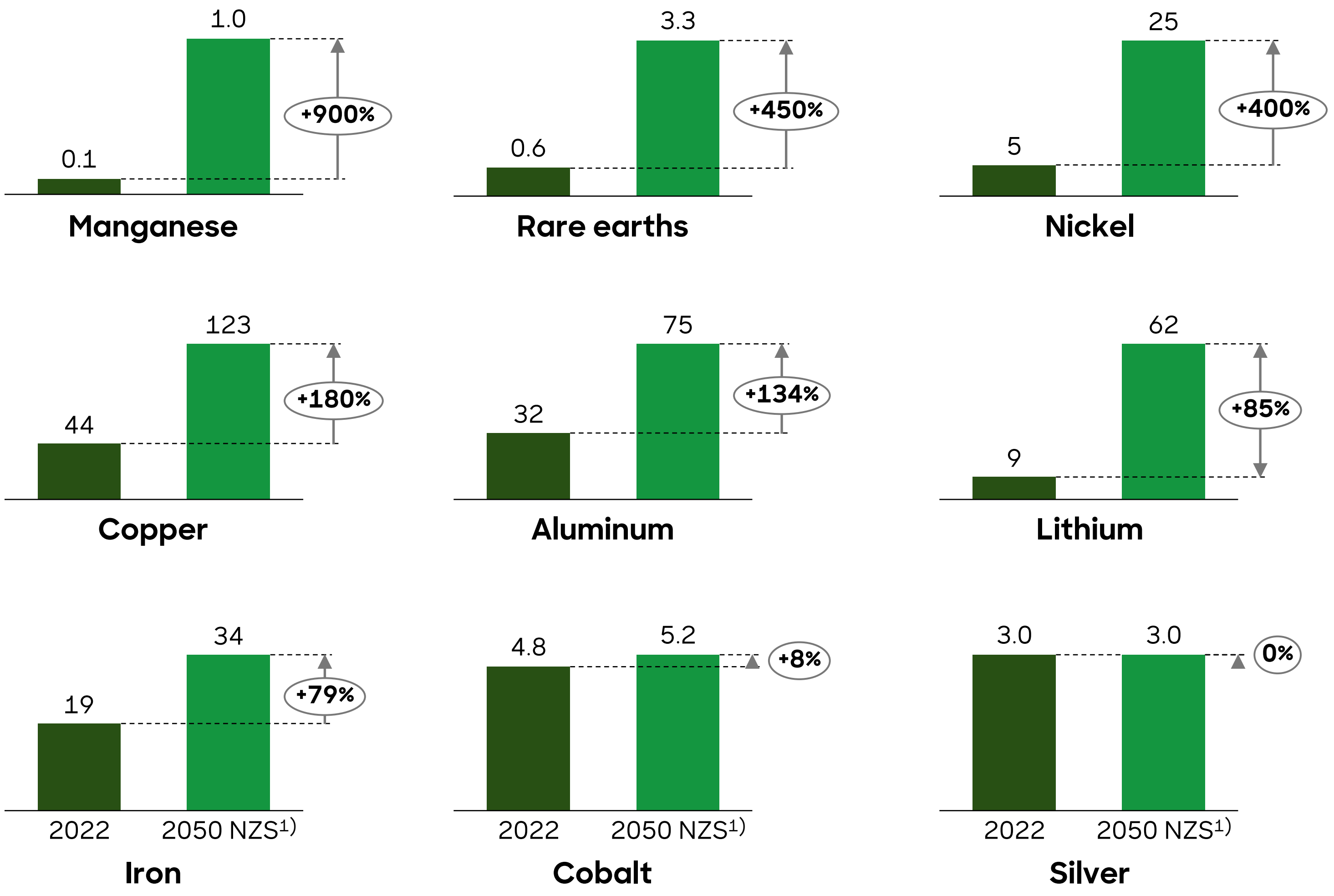
- The significant increase in demand for critical minerals raises questions regarding the **feasibility of meeting this heightened demand,** which often exceeds historical rates
- The clean energy transition requires **significant investment in raw materials extraction.** This coincides with a period of **reduced investor confidence** in mining due to various **interconnected factors,** such as recent market volatility, the complexity of developing new mines, and concerns about environmental and social impacts linked to extraction processes
- In the context of the clean energy transition, a **lack of mineral supply** could result in **higher costs, delays, and/or reduced efficiencies.** Given the urgent need to reduce emissions, this would be a most undesirable scenario

1) The STEPS scenario provides an indication of where today's policy measures and plans might lead the energy sector. These outcomes fall far short of the world's shared sustainability goals; 2) The SDS scenario charts a pathway that meets in full the world's goals to tackle climate change in line with the Paris Agreement, improve air quality and provide access to modern energy

Source: IEA; Roland Berger

With demand outgrowing supply, prices are likely to rally – The value of energy transition metals is expected to increase markedly

Annual value in energy transition, real 2022 [USD bn]



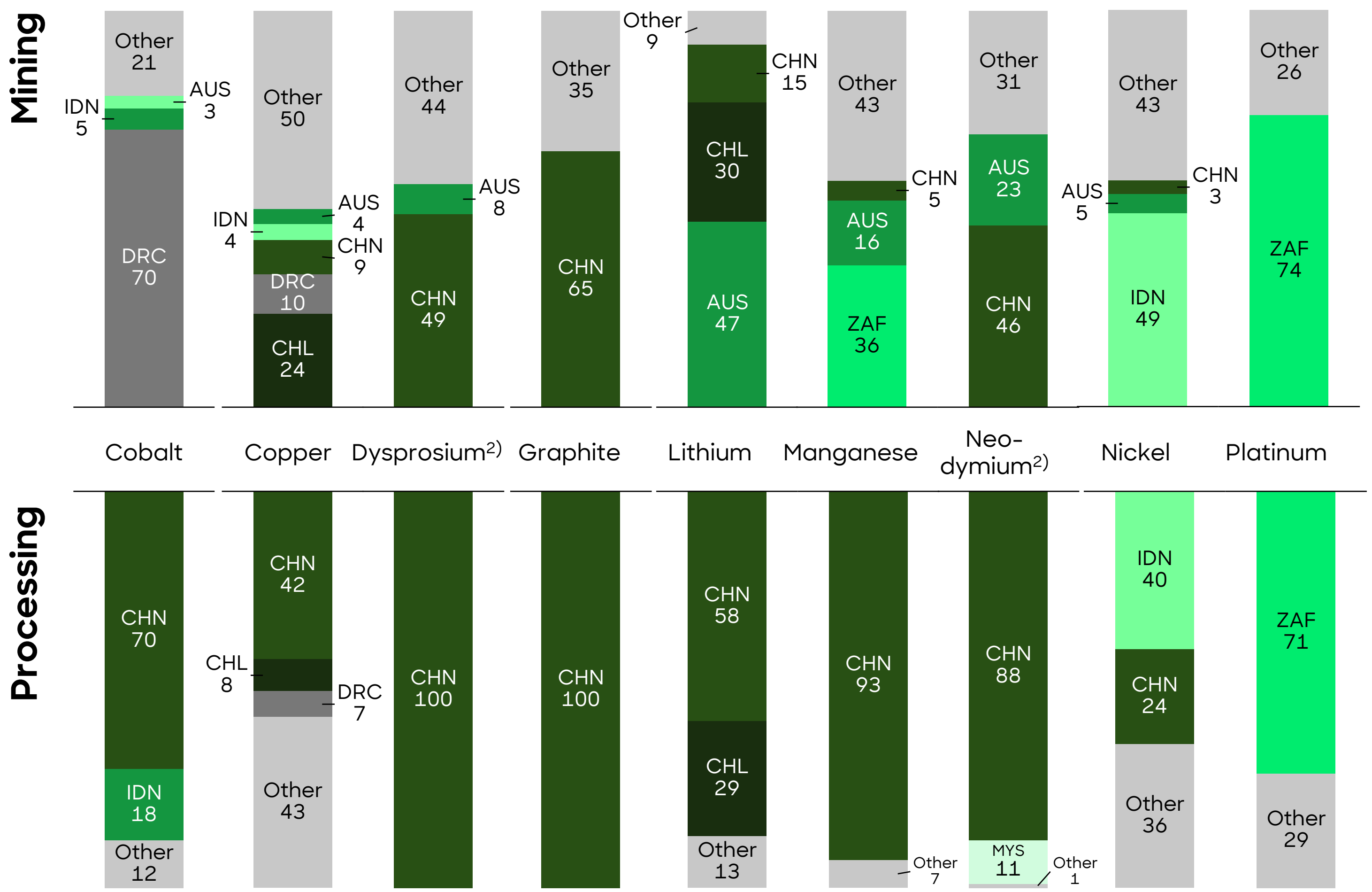
- The demand for clean energy transition metals is expected to increase significantly, while their **supply** is likely **to lag due to underinvestment, long lead times, and protectionism**
- The interplay of demand outgrowing supply is expected to **result in higher prices** for critical raw materials. According to a BNEF analysis, prices of certain commodities are projected to multiply by 2050
- Especially **prices for manganese** (used for battery technology), **nickel,** (used for batteries and solar technologies), and **rare earths** (used in nearly all green technologies) are expected to significantly increase
- By contrast, the use of **materials** required for **power generation technologies** reliant on fossil fuels is **anticipated to diminish**
- Even in **BNEFs Economic Transition scenario, metals demand** from fossil-fuel based power plants will account for **only 6% of total metals demand** from power generation **by 2050,** down from 16% in 2022, whereas metals consumption in renewables and battery storage will double over the same period

1) In the Net Zero Scenario (NZS), BNEF modeling indicates that the world can stay on track for 1.77 °C, and global net zero by 2050, with rapid deployments of clean power generation, electrification, and, to a lesser extent, carbon capture and storage and hydrogen

Source: BNEF; Roland Berger

Mine production of critical raw materials is mainly concentrated in a small number of countries – China dominates many key commodities

Mine production of critical raw materials by country, 2022[1] [%]



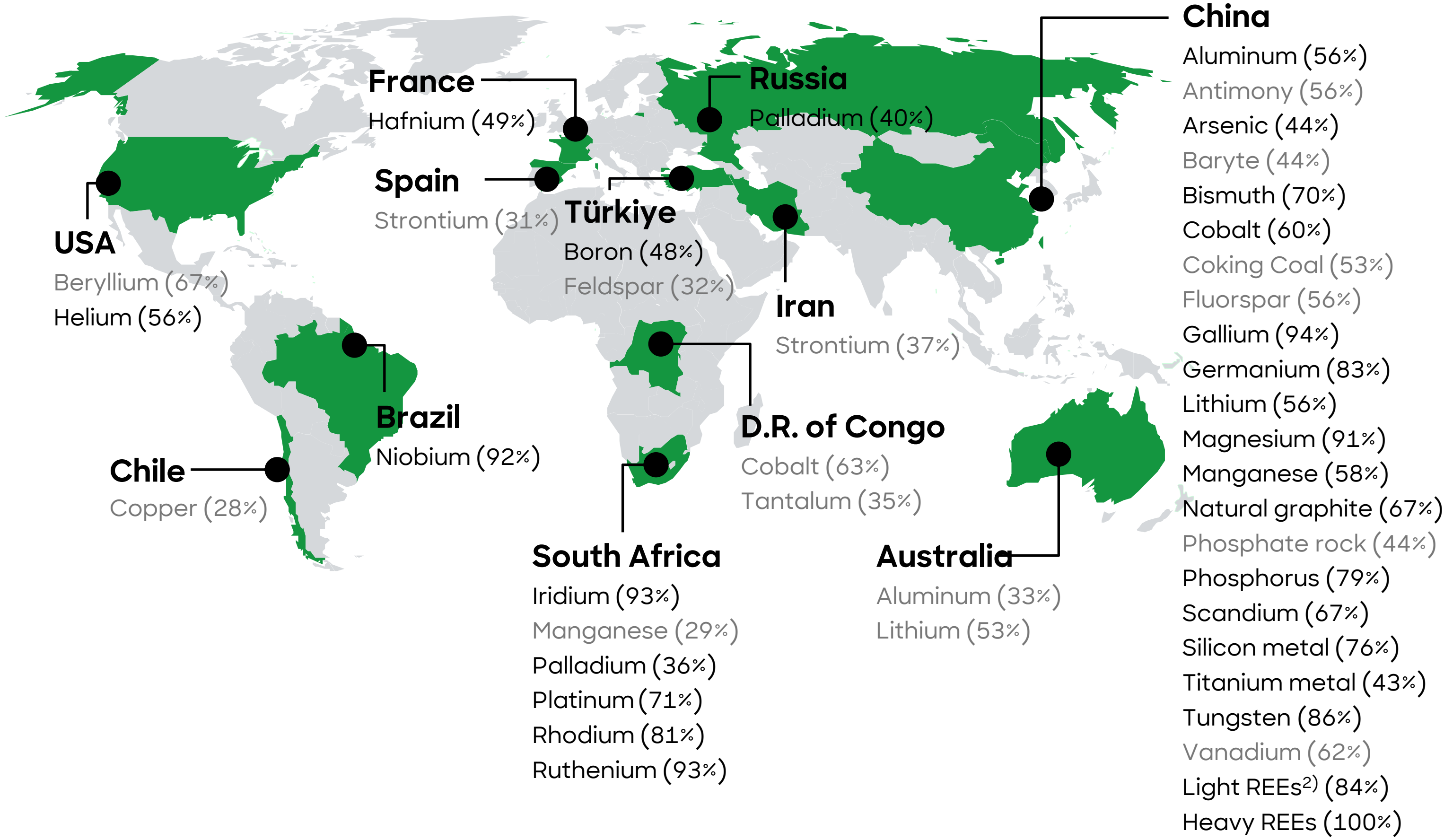
- The **transition to cleaner sources of energy requires a substantial amount of minerals and metals.** Currently, the bulk of demand for these materials is for purposes unrelated to the energy transition. However, **as the transition progresses, the demand** for many of these materials **is expected to increase**
- Mining of critical materials is heavily **concentrated in certain geographic regions.** Major players include Australia (lithium), Chile (copper, lithium), China (graphite, rare earths), the Democratic Republic of Congo (cobalt), Indonesia (nickel), and South Africa (platinum)
- **Processing is even more concentrated geographically,** with China alone responsible for over 50% of the global refined supply of (natural) graphite, dysprosium and neodymium (rare earth elements), cobalt, lithium, and manganese
- A **high concentration** of mining and processing in a specific country **increases the vulnerability of the global supply chain** to disruptions caused by factors such as natural disasters, political instability, labor strikes, regulatory changes, or trade restrictions

1) DRC: Democratic Republic of the Congo, CHL: Chile, CHN: China, AUS: Australia, ZAF: South Africa, IDN: Indonesia, MYS: Malaysia; 2) Dysprosium and Neodymium are among the 15 lanthanide elements of rare earth elements

Source: IRENA; Roland Berger

Many raw materials critical for modern economies are concentrated in a few countries – China is a dominant supplier of a wide range of CRMs

Countries accounting for largest share of global supply of selected critical raw materials (CRMs), 2023[1] [%]



xxx = Extraction stage

xxx = Processing stage

EU analysis concerning critical raw materials (CRM) and global suppliers

- Since 2011 the **EU reports on the global supply of raw materials.** The 2023 (fifth) assessment covers 87 individual raw materials of global/EU importance
- The EU defines a raw material as **critical** when its **economic importance** and its **supply risk** is **high.** For the EU, **34 raw materials** or **raw material groups** are identified as **critical**

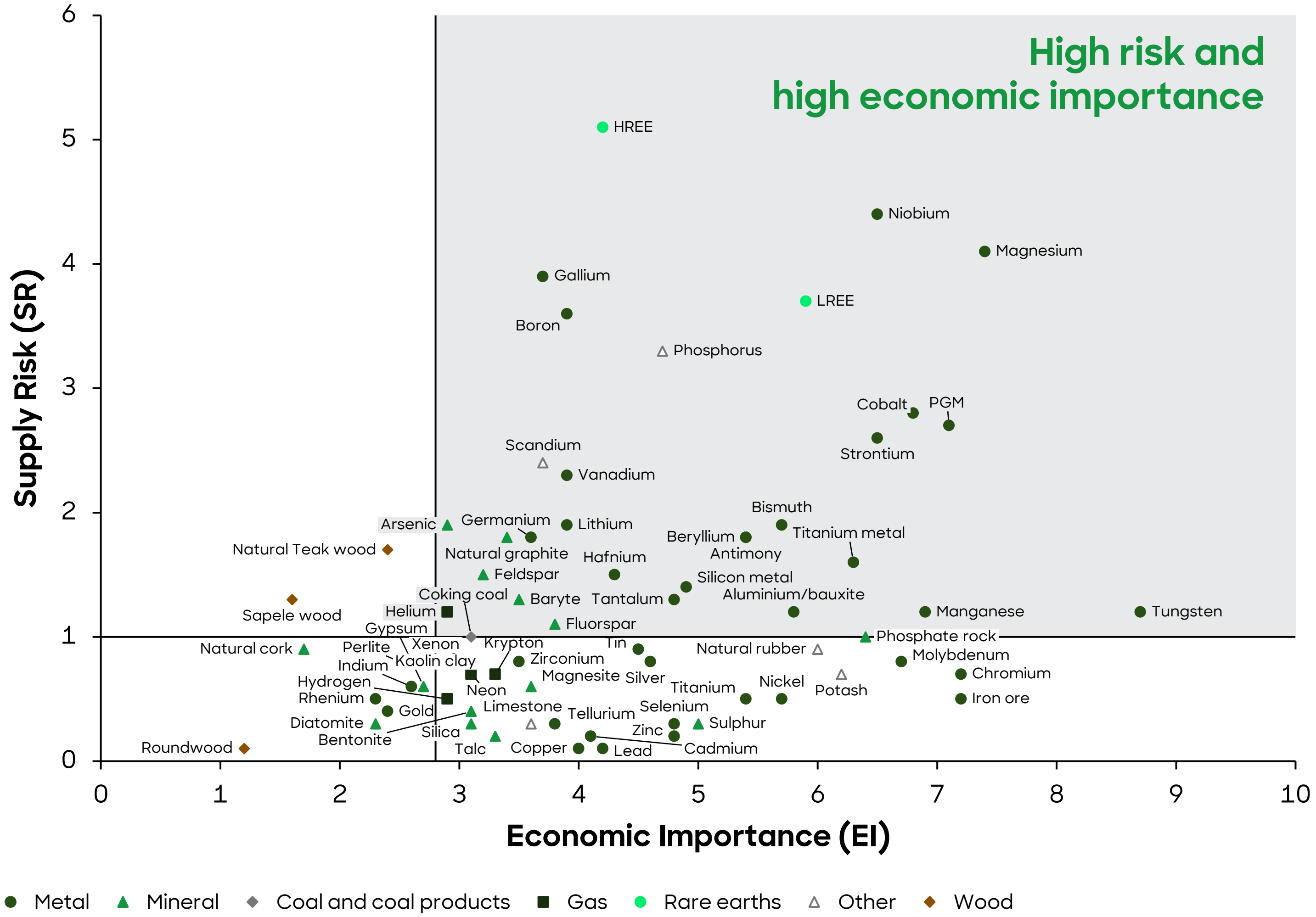
Selected CRMs and examples of end-use

- **Beryllium:** electronic and telecommunications equipment
- **Germanium:** infrared optics
- **Hafnium:** superalloys
- **Rhodium:** auto catalysts
- **Phosphate rock:** mineral fertilizer
- **Tantalum:** capacitors
- **Tungsten:** tools

1) Main global producers/processors of raw materials listed as critical for the EU in 2023; 2) REEs: Rare earth elements
Source: European Commission; Roland Berger

Many of today's raw materials with a high supply risk, such as rare earths or magnesium, are of particular economic importance

Economic importance and supply risk of selected materials for the EU

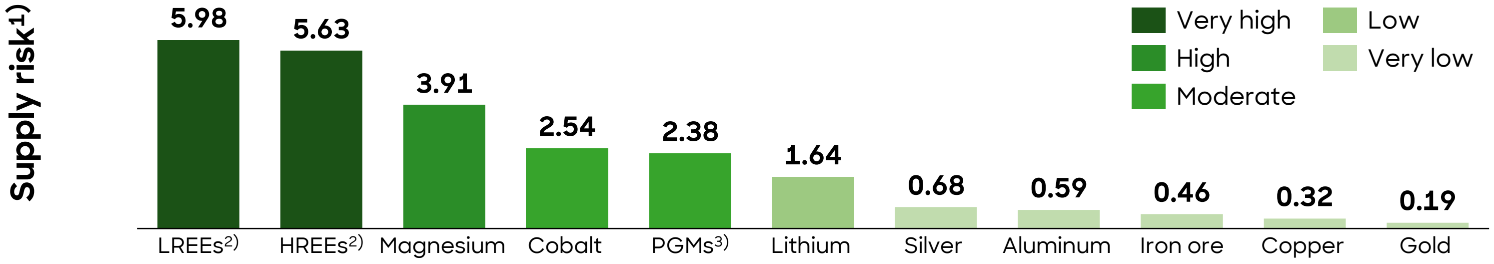


- With its Critical Raw Materials Act 2023, the EU has drawn up a **list of critical and strategic raw materials.** The assessment utilized a comprehensive methodology, considering the **factors economic importance** and **supply risk**
- Regarding the **economic importance,** various aspects such as the share of end use of a raw material in manufacturing industries, relevance of the respective sector measured with GVA in total manufacturing, and the possibility to substitute the raw material have been considered
- Regarding the **supply risk,** geopolitical risks (via WGI indicators[1]), concentration of production, substitution and recycling options, and the import reliance have been considered
- For the **EU, rare earths, magnesium, and niobium** have a particularly high supply risk and high economic importance
- However, many other commodities, especially **metals,** also have a supply risk above the thresholds for supply risk (>=1.0) and economic importance (=> 2.8)

1) WGI indicators refer to world governance indicators provided by the World Bank
Source: European Commission; Roland Berger

Rare-earth elements that are difficult to substitute due to their unique properties are particularly crucial for strategic technologies

EU supply risk index of selected metal raw materials and their use in strategic technologies



	LREEs[2]	HREEs[2]	Magnesium	Cobalt	PGMs[3]	Lithium	Silver	Aluminum	Iron ore	Copper	Gold
Batteries	□	□	□	■	□	■	□	■	■	■	□
Fuel cells	■	■	■	□	■	■	■	■	■	■	■
Motors	■	■	□	□	□	□	□	■	■	■	□
Wind	■	■	□	□	□	□	□	■	■	■	□
PV	□	□	□	□	□	□	■	■	■	■	□
Robotics	■	■	■	■	■	■	■	■	■	■	■
Drones	■	□	□	■	■	■	■	■	■	■	■
3D printing	□	□	□	□	□	□	□	■	■	■	□
ICT	■	□	■	■	■	□	■	■	■	■	■

■ Metal used for strategic technology   □ Metal not required for strategic technology

- In coming years, the EU sees **very high supply risk issues** for two types of **metals,** both are groups of **rare earth elements: LREEs** (e.g. cerium, samarium) and **HREEs** (e.g. ytterbium, thulium)
- **Demand for rare earth elements** used in permanent magnets for electric vehicles, digital technologies or wind turbines could **increase tenfold by 2050**
- By **2050,** the EU will require around **60 times more lithium,** essential for e-mobility, and **15 times more cobalt,** used in electric car batteries. However, their supply is less risky because reserves are spread across several countries, are sufficiently available or can be replaced by other sufficiently available metals, albeit with efficiency losses

1) The Supply Risk Index (0-6) considers the global supply risk, the European domestic supply, criticality factors, import reliance, substitution and recycling of the respective raw material;
2) LREE: Light rare earth elements; HREE: Heavy rare earth elements; 3) PGM: Platinum group metal

Source: European Commission; Roland Berger

The transition to cleaner energy technologies and systems alters raw material dependencies – Future CRM demand is a multiple of today's

Indicative supply chains of fossil fuels and selected clean energy technologies[1)]

Oil and gas

	Upstream			Refining/midstream			Consumption		
Oil	US	SA	RU	US	CN	RU	US	CN	IN
Natural gas	US	RU	IR	RU	QA	AU	US	RU	CN

Clean energy technologies

	Mining		Processing		Battery material			Battery cell/pack			Electric vehicle deployment		
Copper	CL	PE	CL	CN	CN	KR	JP	CN	US	KR	CN	US	EU

	Mining		Processing		Polysilicon			Solar panel			Photovoltaic system installation		
Lithium	AL	CL	CN	CL	CN	KR	DE	CN	KR	CA	CN	EU	US
Nickel	ID	PHL	CN	ID	CN	KR	DE	CN	KR	CA	CN	EU	US

	Mining	Processing	Wind turbine & components					Wind installation		
Cobalt	DRC	CN	CN	IN	US	ES	DE	CN	EU	US
Rare earths	CN	CN	CN	IN	US	ES	DE	CN	EU	US

Looking ahead

Regarding the global energy transition and its underlying clean-energy technologies, **certain CRMs[2)] will be considerably more in demand in the future:**

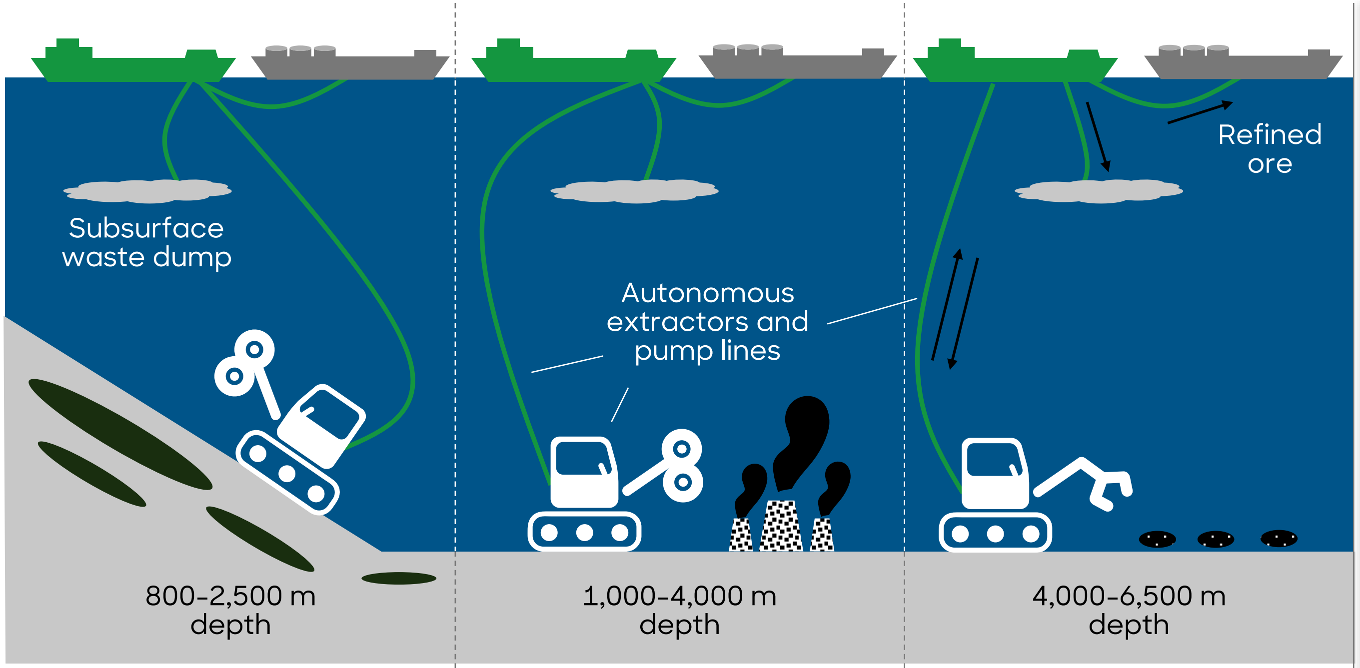
Mineral	Use in clean-energy tech	Rise in demand, 2050 relative to 2021, factor[3)]
Lithium	Electric vehicles (EVs), battery storage	**24.0**
Nickel	Geothermal, EVs, battery storage, hydrogen	**12.3**
Rare earths	Wind, EVs, battery storage	**7.2**
Cobalt	EVs, battery storage	**6.2**
Copper	Solar, wind, bio-energy, EVs, electricity networks, battery storage	**2.8**

2050

1) Largest producers and consumers are indicative only; 2) CRMs: Critical raw materials; 3) Data calculated under the IEA's Announced Pledges Scenario
Source: Leruth et al.; IEA; WEF; MSC; Roland Berger

Deep seabed mining is seen as a new way to access precious minerals and materials – The oceanic seabed contains three types of deposits

Deep seabed mining (DSM) targets three types of mineral deposits



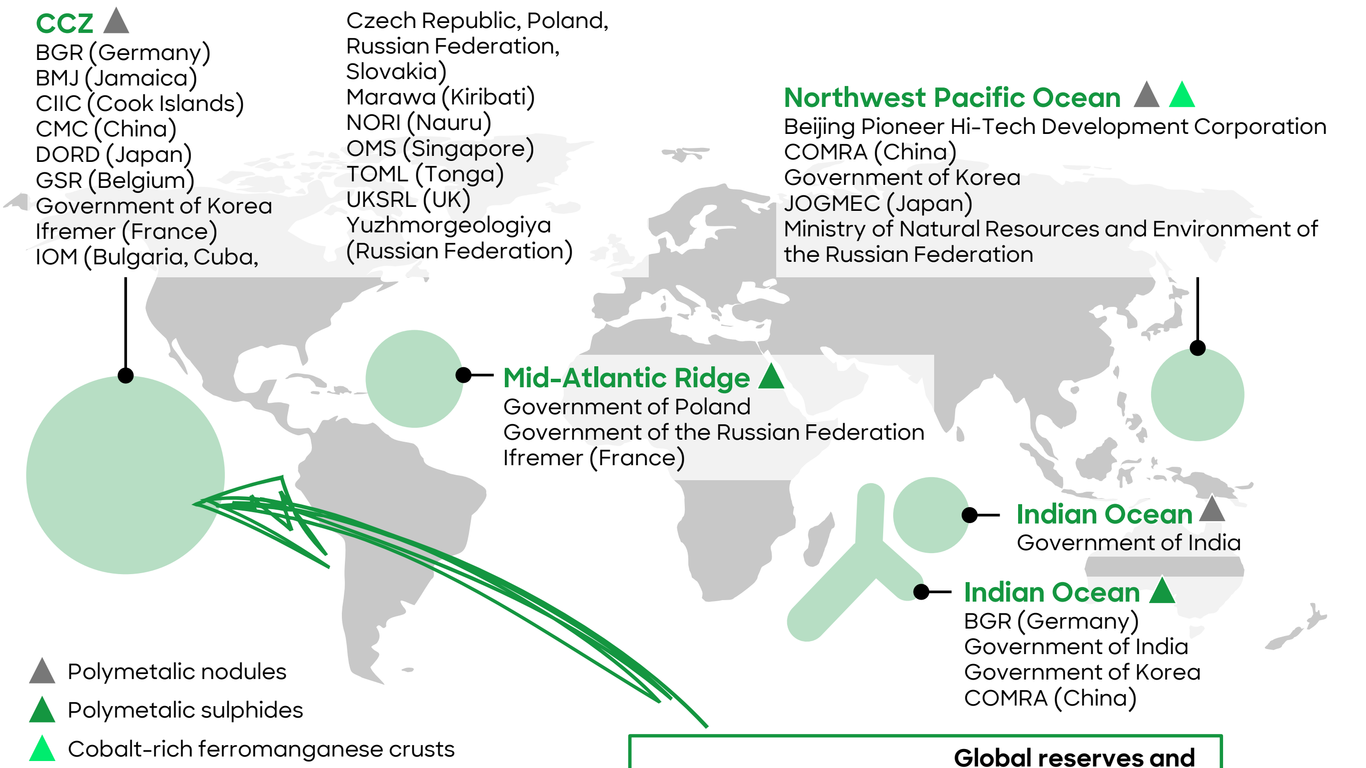
Crusts	Polymetallic sulphides	Nodules
Forming on **hard rock surfaces** of seamounts, **crust** are rich in …	**Hydrothermal vents** release **polymetallic sulfides** that harden into mineral deposits containing …	Polymetallic **nodules** are potato-shaped rocks that lie on **vast abyss plains,** containing …
Cobalt, manganese, nickel, iron, REEs, copper	**Copper, zinc, lead, barium, iron, silver, gold**	**Manganese, iron, aluminum, nickel, copper, cobalt**

- **Deep sea(bed) mining (DSM)** is a nascent industry concerned **with the process of retrieving mineral deposits from the deep seabed** – deep sea is the ocean below 200 m – an area covering around 65% of the planet
- The deep sea, the largest ecosystem on Earth, also harbors a rich **diversity of species** with an estimated **two thirds yet unknown** to science
- Proponents contend DSM is needed because of **depleting terrestrial deposits,** the **rising global demand for minerals** required for the **clean energy transition,** as well as many consumer tech, defense, and aerospace applications
- **Three types of oceanic mineral deposits are targeted: crusts, polymetallic sulphides,** and **nodules,** containing varying amounts of precious minerals; they require different mining technologies at different depths and locations
- **Nodules** are considered the most promising source of precious materials – but they are also an integral part of the **deep ocean's ecosystem**

Source: Reuters; ISA; Roland Berger

A mix of national governments and private operators are exploring the seabed in ISA regulated zones – Extraction a near-future goal

Who is exploring the ISA regulated international seabed zones?



Clarion-Clipperton Zone (CCZ): 21 bn tons of polymetallic nodules are estimated to be resting on the **CCZ ocean floor**, containing an estimated (in m t):

	CCZ	Global reserves and resources on land[1]
Manganese	5,992	5,200
Copper	226	>1,000
Cobalt	44	13
Nickel	274	150

- The high seas and the international ocean floor (beyond national territories) are governed by the **UN's Convention on the Law of the Seas (UCLOS)** and the **International Seabed Authority (ISA),** which has 169 members
- ISA's mandate – **covering more than half of the global ocean's seabed** – is to organize, regulate and control all activities related to mineral resources in international seabed **zones** (officially termed **"the Area"**)
- Currently, **31 entities can explore the Area** according to ISA contracts, which are held by **a mix of commercial companies,** or are **directly managed** by western or rapidly industrializing **state governments**, such as France, Belgium, Germany, India, Korea etc., or by **state-controlled companies** in China and Russia
- ISA has granted **19 exploration contracts for nodules, 7 for sulphides,** and **5 for crusts** across certain areas in the Indian, Pacific, and Atlantic Ocean. Within the Area, the Clarion-Clipperton Zone (**CCZ**) is considered the **most lucrative** due to its vast amount of mineral-rich **nodules**
- As of early 2024, **no commercial mining is under way in ISA mandated zones**
- So far absent from ISA's Mining Code, **regulation concerning extraction** under the 31 contracts is not expected until **mid-2025**

1) Both economically recoverable and sub-economic reserves

Source: ICUN; ISA; Roland Berger

DSM is facing increased, widespread opposition as prospects remain uncertain – Environmental mitigation is beyond current capabilities

Multiple stakeholders oppose DSM due to environmental concerns

Governments and parliamentarians

Fishing sector

Financial institutions

Scientists and civil society actors

Companies

Environmental impacts of deep-sea mining

- Widespread sediment plumes
- Biodiversity loss and habitat destruction, esp. of endemic species
- Pollution: Noise, vibration, light, processing waste (tailings)
- Increased temperatures
- Potential carbon sequestration effects and climate change implications
- Threat to fisheries and food security

But most concerning and in contrast to terrestrial mining, where mitigation and remedial measures are understood and widely implemented, there is no such possibility in the deep sea."

Environmental Justice Foundation

- **Deep seabed mining (DSM)** garners increasing criticism and outright opposition: in a **2023 petition to ISA,** more than **1,000 signatories from 34 countries and 56 indigenous groups** called for a **moratorium**, precautionary **pause**, or **ban** on deep-sea mining, either in international waters, national waters, or both
- Amongst the still growing list of **signatories** are some of the largest **global companies in their respective sectors** (automotive, software/high tech, finance) as well as a wide spectrum of scientific and civil society organizations
- Some indigenous island communities are intimately connected to the ocean for **fishing** and other cultural traditions and thus oppose DSM, setting up a conflict with **Nauru** and other Pacific island nations that support it
- Regulatory, governance, and control issues are key areas of conflict in this emerging industry. For example, there are **critical weaknesses** in the system of **self-reporting by DSM contractors.** Regarding environmental impacts, ISA also lacks the **capacity to monitor** DSM activities or **enforce compliance** with environmental protection and **mitigation** – areas yet to be fully understood

Source: DSCC; EJF; Roland Berger

However, seabed mining is fast becoming a new and unchartered vector of competition and positioning – Norway is setting a precedent

Deep seabed mining (DSM) positions and status quo in selected countries, 2024

USA

At a DSM crossroads

- As the US never ratified the deep-sea convention (UNCLOS) and only holds **ISA observer** status, **it currently plays no part in international DSM agenda setting,** nor can it **sponsor firms that apply for exploration contracts from the ISA**
- But political and economic pressure is building to ratify/join to secure access to key **energy transition metals** and to avoid **national security vulnerabilities** for **critical defense technologies** as well as deep **seabed infrastructure**
- Under the **US National Defense Authorization Act,** assessments are underway **regarding the domestic processing of seafloor polymetallic nodules;** until the US ratifies UNCLOS/joins ISA, it will be limited to processing and refining activities only
- At present (spring 2024), a draft bill supporting DSM, entitled the **Responsible Use of Seafloor Resources Act (RUSRA),** is before Congress, aimed at stepping up **national DSM** interests, pushing for financial, diplomatic, and infrastructure support for the industry. This **includes an analysis whether deep-sea mining is possible in US waters** – a further move that would help the US avoid reliance on China and other adversarial nations for precious minerals

Norway

Setting a precedent in its domestic waters

- In January 2024, **Norway**'s parliament voted to **allow the controversial practice of sea-bed mining (exploration) in its territorial waters** – going against the advice of the Norwegian Environment Agency and other marine experts. The designated area will open up over **280,000 sq km of its national waters** between Iceland and Greenland for DSM activities. However, it is estimated that commercial **mining will not begin until the early 2030s,** as extraction requires another vote in parliament
- In setting this precedent, Norway's move is at odds with EU (and UK) positions on DSM. The **European Parliament issued a resolution** raising EU **concerns** about **Norway's deep-sea mining intentions in Arctic waters**
- Despite Norway's territorial ambitions, the country has declared its **full support for a UN treaty (BBNJ)[1] to protect marine biodiversity in the high seas**

China

DSM rule maker

- **China** – which **ratified UNCLOS in 1996** (bar certain provisions) – is an important ISA member and a key DSM rule maker
- China has permitted **three state-owned companies to undertake deep-sea mineral exploration** – the most of any country

Nauru

Accelerating the Mining Code's exploitation regulation

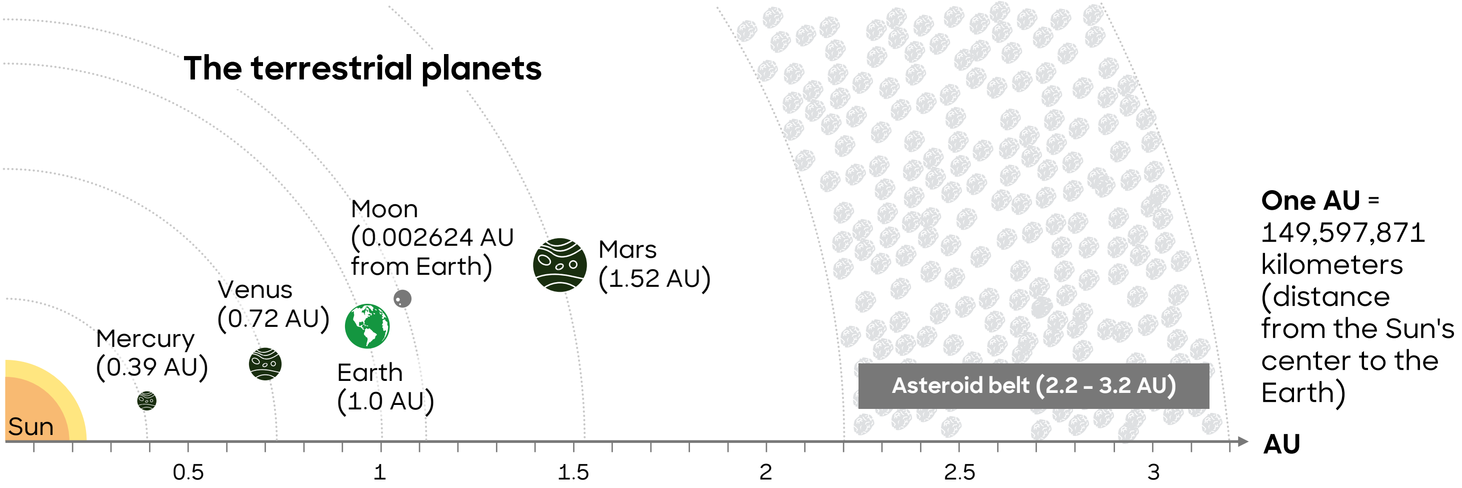
- The country is a **vocal proponent of DSM,** sponsoring a commercial company holding ISA exploration and commercial rights licenses regarding nodules in the CCZ
- Exploiting a legal loophole, **Nauru** has forced ISA to **accelerate the hitherto slow process of DSM exploitation regulation** – a process already underway for over a decade – now expected for mid-2025

1) Adopted by the Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction (BBNJ), the high seas treaty aims at taking stewardship of the ocean on behalf of present and future generations, in line with UNCLOS

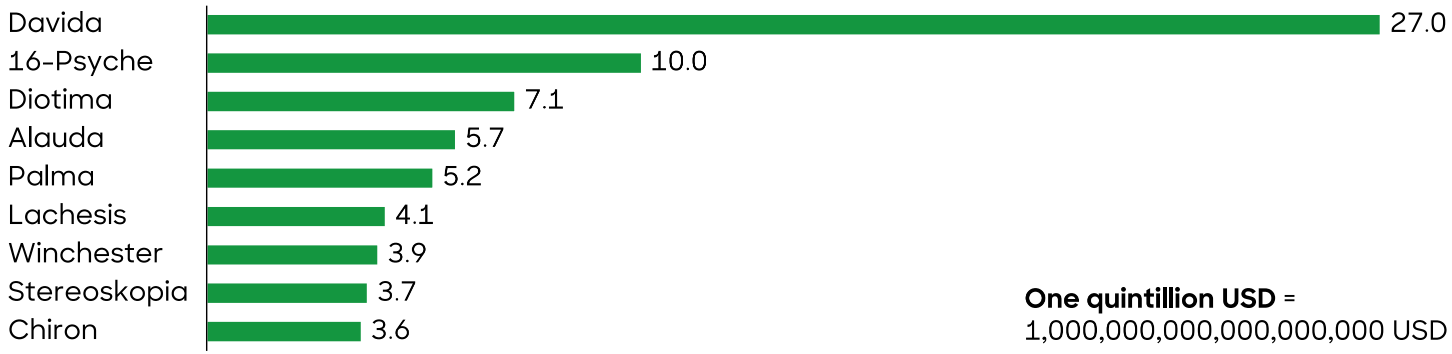
Source: Secondary research; WSJ; US Congress; TMC; European Parliament; Wilson Center; Roland Berger

Space mining: In a more distant future, metals and minerals could be mined far, far away

The terrestrial planets, the asteroids, and their distance from the sun



Estimated value of the most valuable asteroids in our solar system [in USD quintillion]



- Improved technology, lower costs, and increased competition from private companies have made **space exploration** a prominent focus. Analysts predict that the **commercial space industry** may soon embark on the biggest **resource rush** in history: mining on the Moon, Mars, and asteroids
- Claims suggest that the moon, other planets, and asteroids contain raw materials of enormous value. For example, there are headlines that mention asteroids like 16-Psyche which is estimated to have iron and nickel resources worth USD 10 quintillion based on terrestrial commodity prices. Even though, such claims about the economic value of space mining are often exaggerated; currently, **space mining is neither economically nor technologically viable**
- However, the OSIRIS-REx mission to the asteroid Bennu has returned the **largest sample of extraterrestrial material** to Earth since the Apollo Moon missions. Initial analysis of this sample has already revealed the **presence of carbon-rich materials and water-bearing clay minerals**

Source: Visual Capitalist; Wired; NASA; Milken Institute; Roland Berger

The Moon and other celestial bodies carry an abundance of minerals – Yet legal concerns remain regarding resource ownership

Types of celestial bodies targeted for mining

The Moon

- The Moon's surface contains valuable resources such as **water ice,** which could be split into **hydrogen** and **oxygen** through electrolysis, providing both breathable air and rocket propellant.
- Additionally, the Moon has **metals such as iron, aluminum, and titanium** that could be used for construction.
- Harvesting **Helium-3,** a non-radioactive isotope for energy use, is also under investigation as its value is estimated at USD 4 bn per ton

Asteroids

- Asteroids are small rocky bodies that orbit the Sun
- They are rich in a variety of resources, including **precious metals** (such as platinum, gold, and silver), **industrial metals** (like iron and nickel), and volatile materials (such as water and carbon compounds)
- Asteroids are also **intriguing for space exploration** as they contain vital resources such as **water.** If the water is **extracted and separated** into hydrogen and oxygen, it can be used to **produce fuel**

Mars and other planets

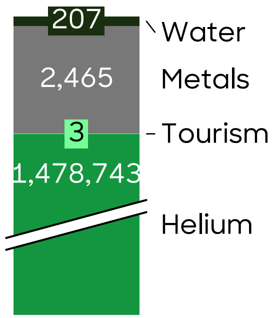
- While other planets like Mars are also expected to have resources that could be exploited, their **greater distance from Earth** makes **transportation and mining highly challenging** but their resources could still be valuable for supporting future human space efforts

Space mining – The legal question

The Outer Space Treaty of 1967 asserts that space and celestial bodies are **the common heritage of humanity,** belonging to everyone. However, the specifics remain **ambiguous.** For instance, the ownership of mineral resources discovered on celestial bodies is not clearly defined. While this wasn't a pressing issue in 1967, it has since become a significant concern.

The US and Luxembourg have emerged as pioneers in establishing legal frameworks. In 2017, **Luxembourg** became the first European country to enact legislation governing the extraction of natural resources in space, thus aiming to provide legal certainty for companies interested in mining raw materials. Similarly, the **USA** passed the SPACE Act in 2015, permitting US companies to engage in asteroid mining. However, such **unilateral national initiatives** have faced criticism on the international stage

Estimated value of lunar resources [USD bn]



Average abundance of selective minerals in metallic asteroids and on Earth [g/mt]

Mineral	Asteroid	Earth's crust
Iron	893,000	41,000
Nickel	93,000	80
Cobalt	6,000	20
Platinum	29	1

Source: Fusion Technology Institute; Media Research; PNAS; ESA; Roland Berger

Extraterrestrial mining activities would be faced with a wide range of challenges – From environmental to economic, legal, and technological

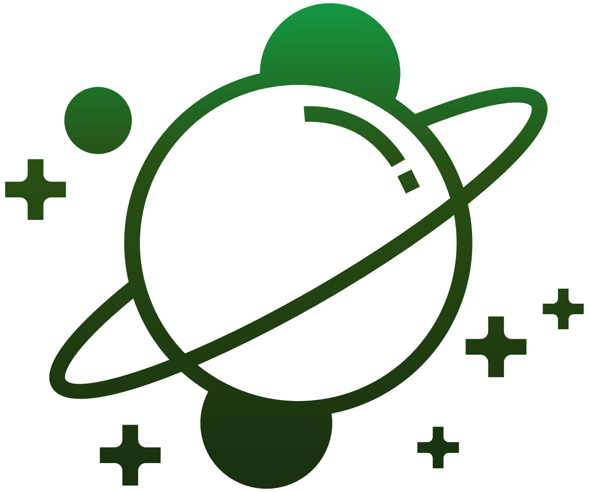
Challenges and considerations regarding space mining

Environmental impact

Space mining could potentially **alter the natural orbits of asteroids or other celestial bodies,** leading to unintended consequences for **space ecosystems.** It is important to consider the environmental impact and develop responsible mining practices

Economic viability

The **cost** of launching missions to celestial bodies and bringing **mined resources back to Earth is currently very high.** The economic feasibility of space mining largely depends on **advancements in space travel technology** and the **market demand** for the extracted resources



Legal and regulatory frameworks

The legal ownership of resources in space is a complex and evolving issue. The property rights regime in outer space is unclear, as the **Outer Space Treaty of 1967 prohibits countries from claiming sovereignty over celestial bodies, but it does not specifically address resource extraction.** International agreements are necessary to establish a framework for equitable and responsible resource use

Space debris & collision risk

Mining activities could generate **space debris, increasing the risk of collisions in Earth's orbit.** This issue requires careful management to avoid exacerbating the problem of space debris, an area currently already lacking global agreements

Technological challenges

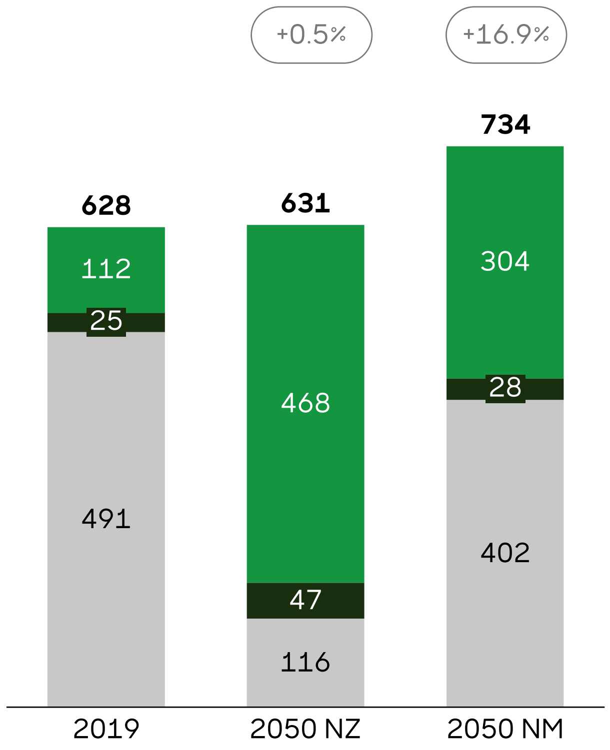
Developing the technology to **locate, mine, and transport resources from space** is a significant challenge. Space mining requires **advanced robotics, automation,** and resource extraction techniques that can operate in **microgravity** environments

Source: PNAS; Roland Berger

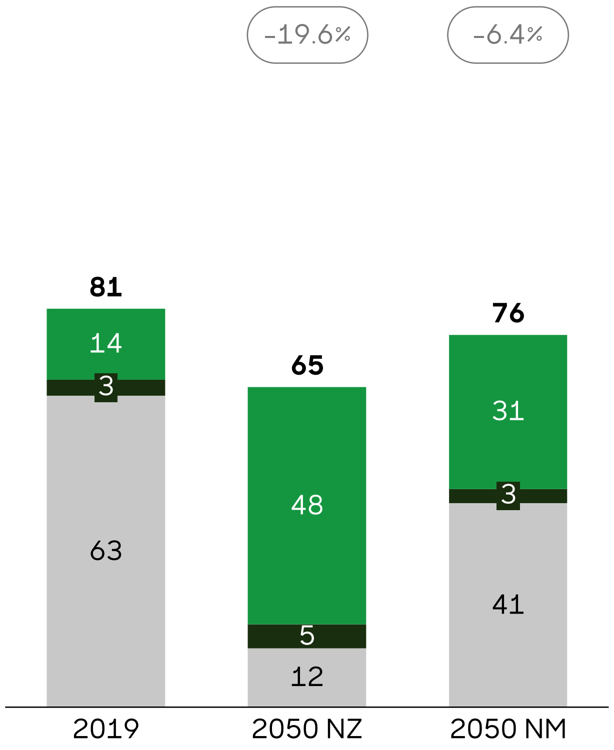
The future use of energy resources is as important as the use of non-energy resources - Global transformation is a must to comply with Paris goals

Evolution of global primary energy demand according to the Paris Agreement (2050 NZ) and to current policies (2050 NM)[1)]

Total energy consumption [EJ[2)]]



Per capita energy consumption[3)] [GJ[4)]]



Renewable energy sources[5)] Nuclear energy source Fossil energy sources

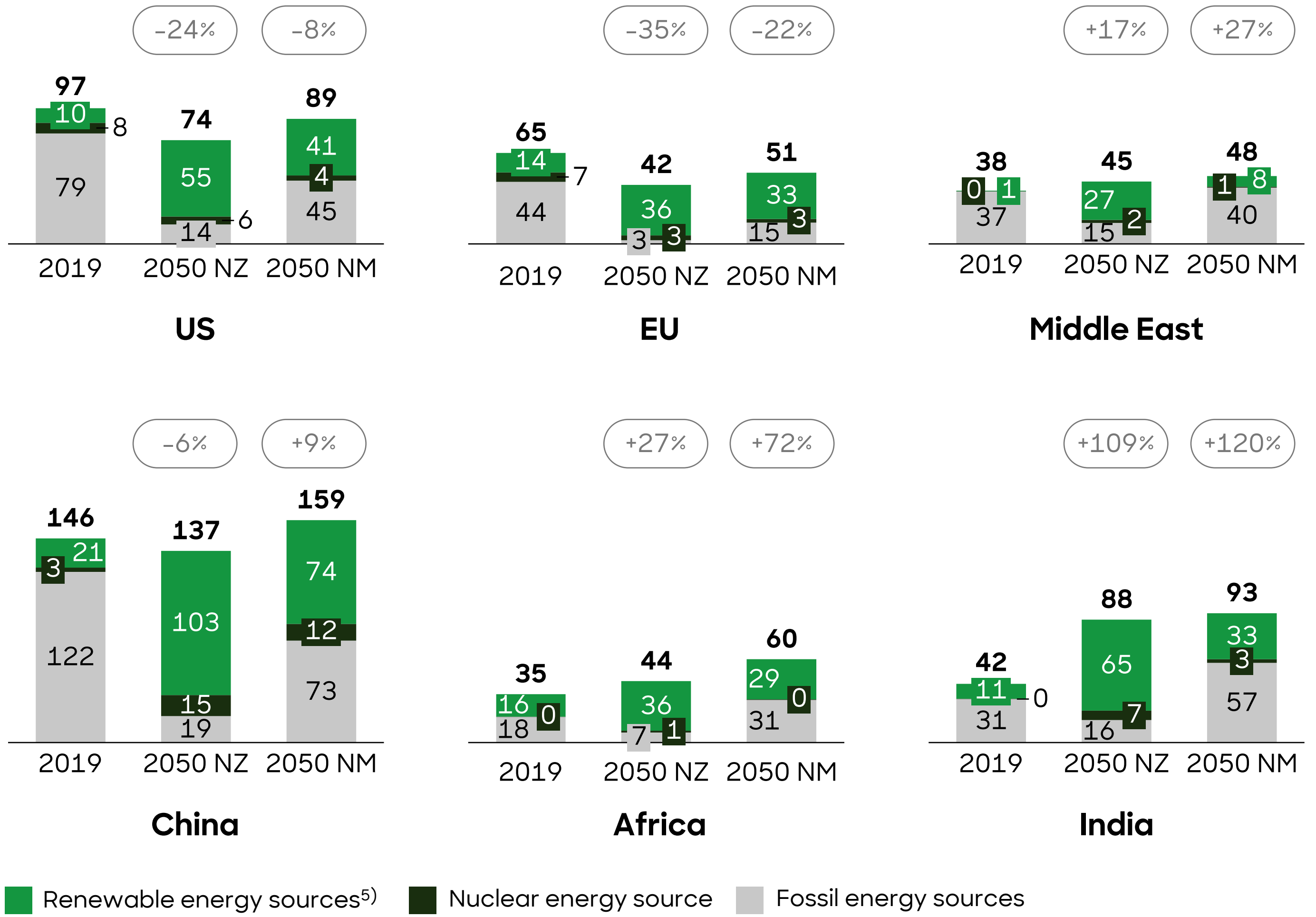
- The Paris Agreement infers a **global greenhouse gas budget** that should not be exceeded to keep global warming below 2 °C, preferably to 1.5 °C. To comply, transformation to more renewable energy sources is essential
- Presently, around 18% of global primary energy demand stems from renewables. In recent years, however, a **far-reaching transformation path** was embarked upon, with the share of renewables increasing in all scenarios
- In bp's **net zero emissions (NZ) scenario** – where global emissions amount to a net of zero by 2050 – **renewable energy sources meet nearly 75% by 2050 (468 EJ[6)]).**This development is largely driven by efficiency gains
- In the **New Momentum (NM) scenario,** only 41% of total energy demand by 2050 would be met by renewable energy sources (304 EJ). Additionally, total energy demand is expected to **increase by over 15% until 2050** compared to 2019
- In terms of **per capita energy consumption,** the energy demand is expected to **decrease** in both scenarios

1) NZ (net zero in 2050) refers to a global energy policy compliant with the terms of the Paris Agreement; NM (New Momentum) reflects the current trajectory of the global energy system; 2) EJ: Exajoule (= 10^{18} Joules); 3) Calculated with data from UN Population Division; 4) GJ: Gigajoule (= 10^{9} Joules); 5) Incl. Hydro; 6) Incl. GHG removals

Source: bp; UN Population Division; Roland Berger

All regions are mirroring the trend of increasing renewable energy – In some regions, efficiency improvements lead to lower energy demand

Evolution of primary energy demand according to the Paris Agreement (NZ 2050) and to current policies (NM 2050)[1)] [EJ][2)]



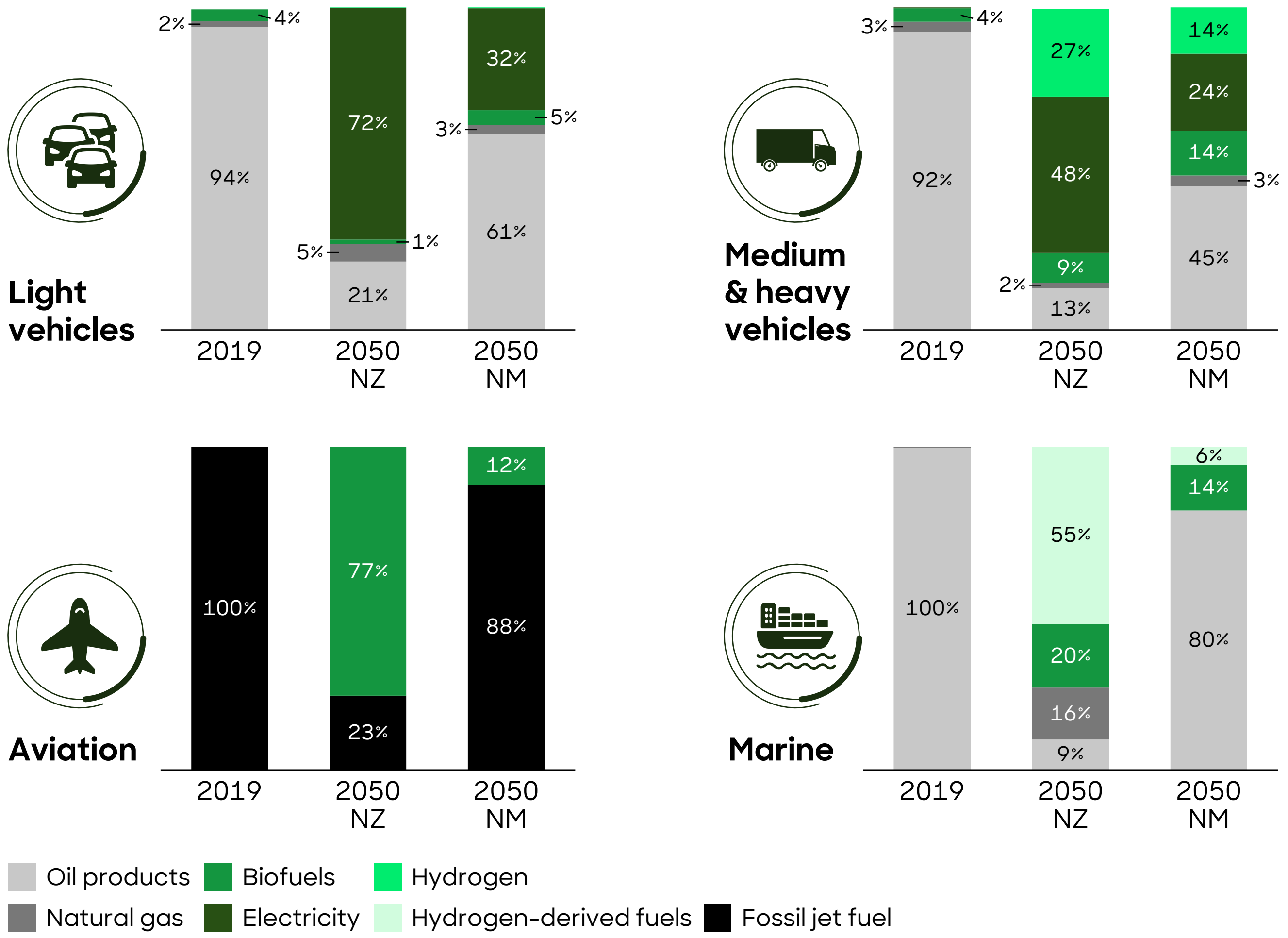
- Currently, **in all regions worldwide, fossil energy sources dominate the energy mix.** Also, economic activity correlates positively with energy demand. In the US, the average per capita demand in 2019 was around 290 GJ, whereas in China and India, demand equated to 103 GJ and 30 GJ, respectively[3)4)]
- In **the future, developed countries** with high levels of energy demand will see **demand fall due to energy efficiency increases**
- However, these developments cannot compensate for the **rise in demand stemming from fast growing economies,** such as India and parts of Africa. These countries are expected to double their energy demand under any scenario
- In **bp's net zero (NZ) scenario,** energy efficiency is set to increase more, while **renewables will play a much bigger role** in the energy mix

1) NZ (net zero in 2050) refers to a global energy policy compliant with the terms of the Paris Agreement; NM (New Momentum) reflects the current trajectory of the global energy system; 2) EJ: Exajoule (= 10^{18} Joules); 3) Calculated with data from UN Population Division; 4) GJ: Gigajoule (= 10^{9} Joules); 5) Includes hydro

Source: bp; Roland Berger

Transition to more sustainable energy consumption is achieved under two key considerations: decarbonization and ...

Fuel share for selected vehicles according to the Paris Agreement (NZ 2050) and to current policies (NM 2050)[1] [%]



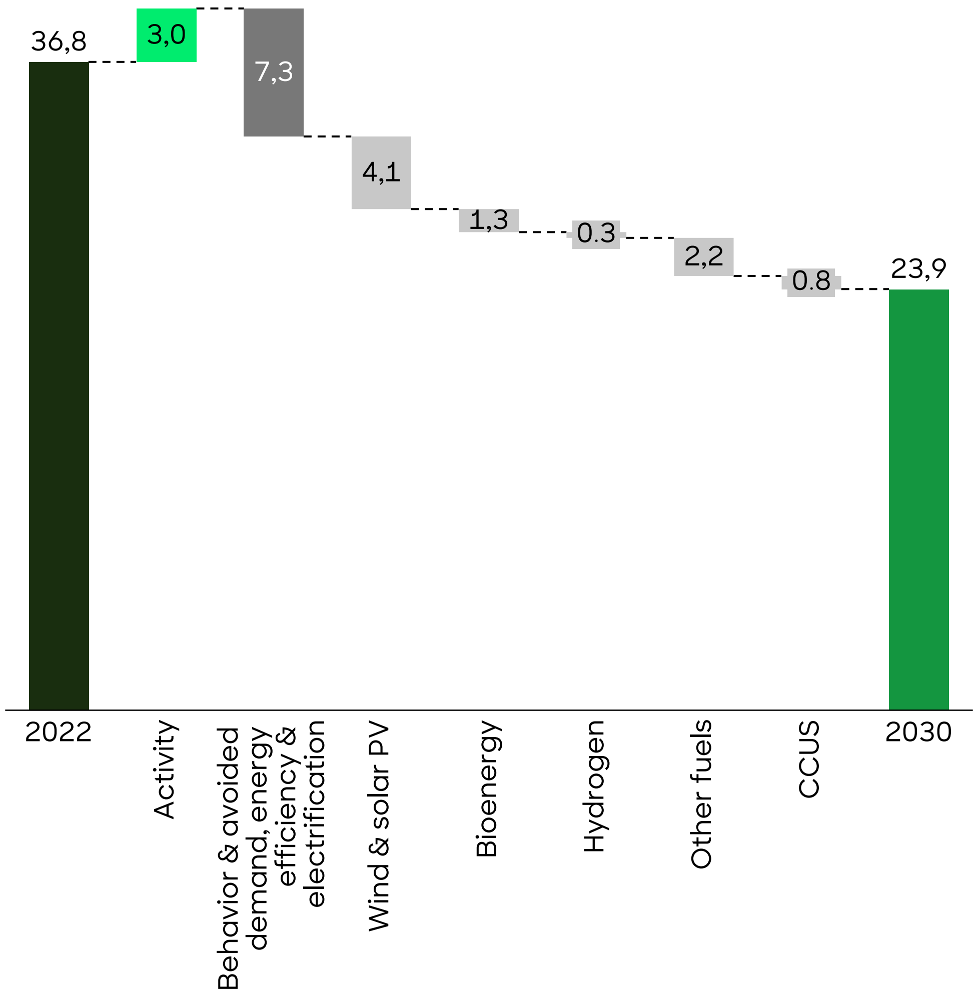
- **Decarbonization** – a key requirement of the Paris Agreement – is mostly achieved **by switching from fossil energy sources to renewables**
- In the case of bp's NZ scenario, just one quarter of energy needed in the **transport sector** will come from carbon emitting energy sources in 2050 – compared to almost 95% today
- Regulatory measures and technological advancements drive a **transition from oil-based products to electricity** as the primary energy carrier for **light vehicles.** As electrified vehicles are notably more efficient, the total energy consumption in light-duty road transportation remains stable until 2030, despite an assumed increased level of car ownership, and begins to decrease afterwards
- **Heavier vehicles** will also witness a trend towards **electrification,** supported by a growing utilization of **hydrogen**
- Decarbonization of the **marine sector** requires a **gradual transition** of the fleet to **alternative fuels,** with hydrogen-based options such as ammonia and methanol leading the way
- Also in **aviation,** the decarbonization is driven by an increasing penetration of **sustainable aviation fuels (SAFs)**

1) NZ (net zero in 2050) refers to a global energy policy compliant with the terms of the Paris Agreement. NM (New Momentum) reflects the current trajectory of the global energy system

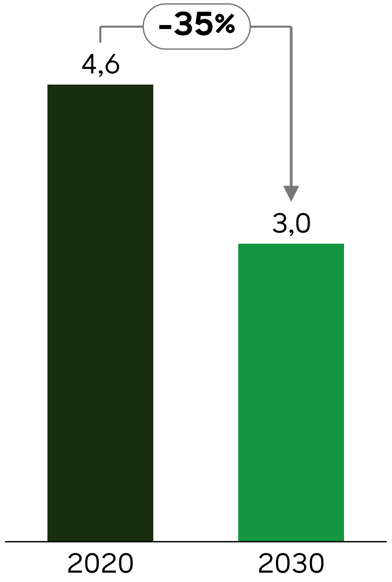
Source: bp; IEA; Roland Berger

… efficiency improvements are crucial to achieve the Paris goals – Behavioral changes and electrification provide the biggest levers

Emission changes over time by mitigation measure in the NZE Scenario, 2022-2030 [Gt CO_2]



Energy intensity of GDP in the net zero pathway [MJ per USD of GDP[1]]

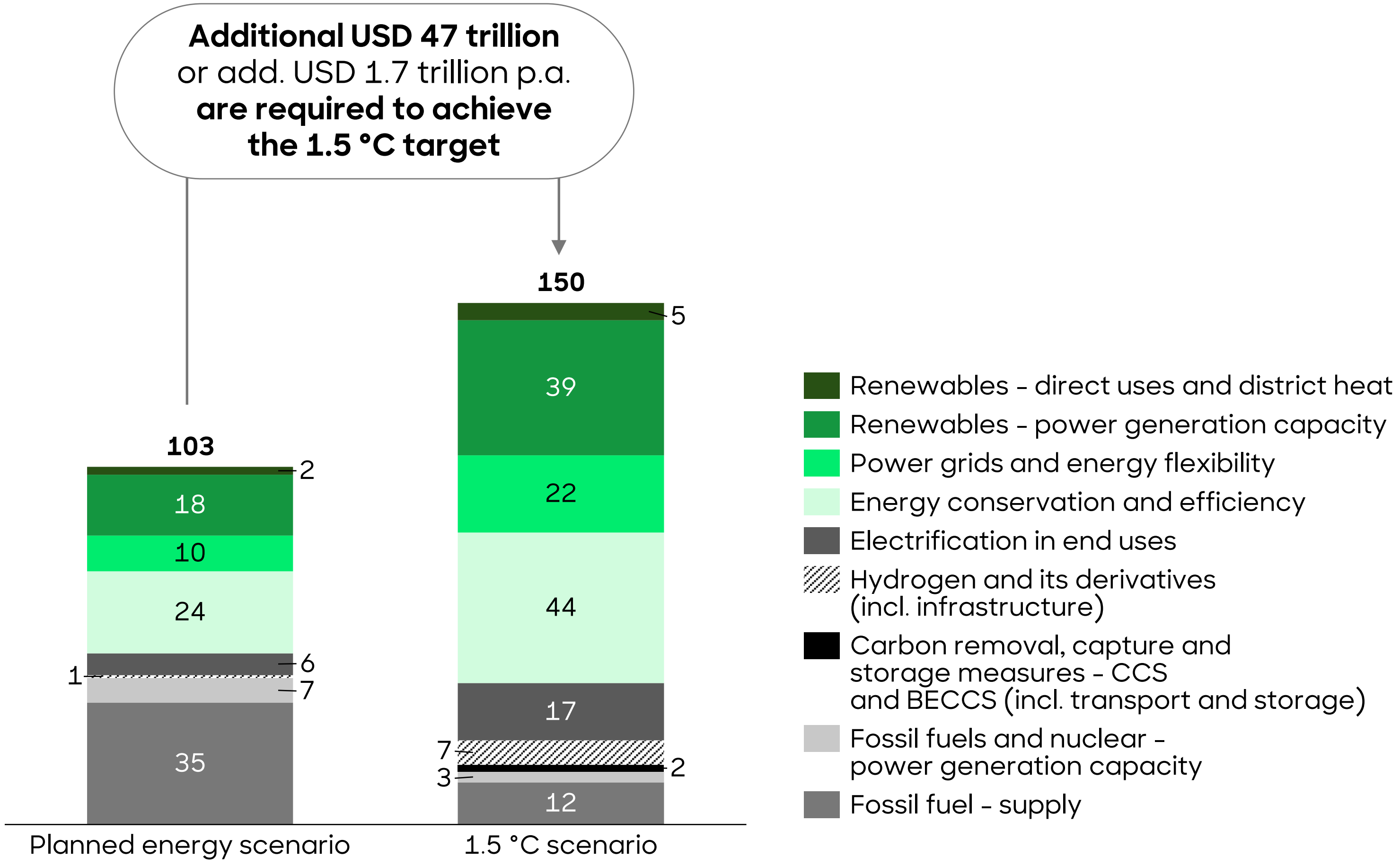


- **Efficiency improvement** will play a decisive role when it comes to meeting Paris Agreement targets
- The **largest contribution** to reach the goal of reducing carbon emissions stems from **efficiency gains**, **behavioral changes** and **avoided demand,** and **electrification**
- Without a doubt, the **energy crisis** has **accelerated the energy transition,** with **government initiatives** placing a strong **emphasis on energy efficiency policy** measures
- Since the onset of the energy crisis in early 2022, there has been a significant **surge in action,** as countries responsible for 70% of global energy demand have either **introduced** or **reinforced efficiency policy packages** to a substantial degree
- Efficiency improvements comprise **technological improvements, better thermal insulation in buildings and/or reuse of materials**

1) GDP measured in PPP USD
Source: bp; IEA; Roland Berger

To implement energy sector transformations in line with the Paris Agreement, an additional USD 47 trillion need to be invested by 2050

Cumulative global energy sector investments, 2023-2050 [USD trillion]

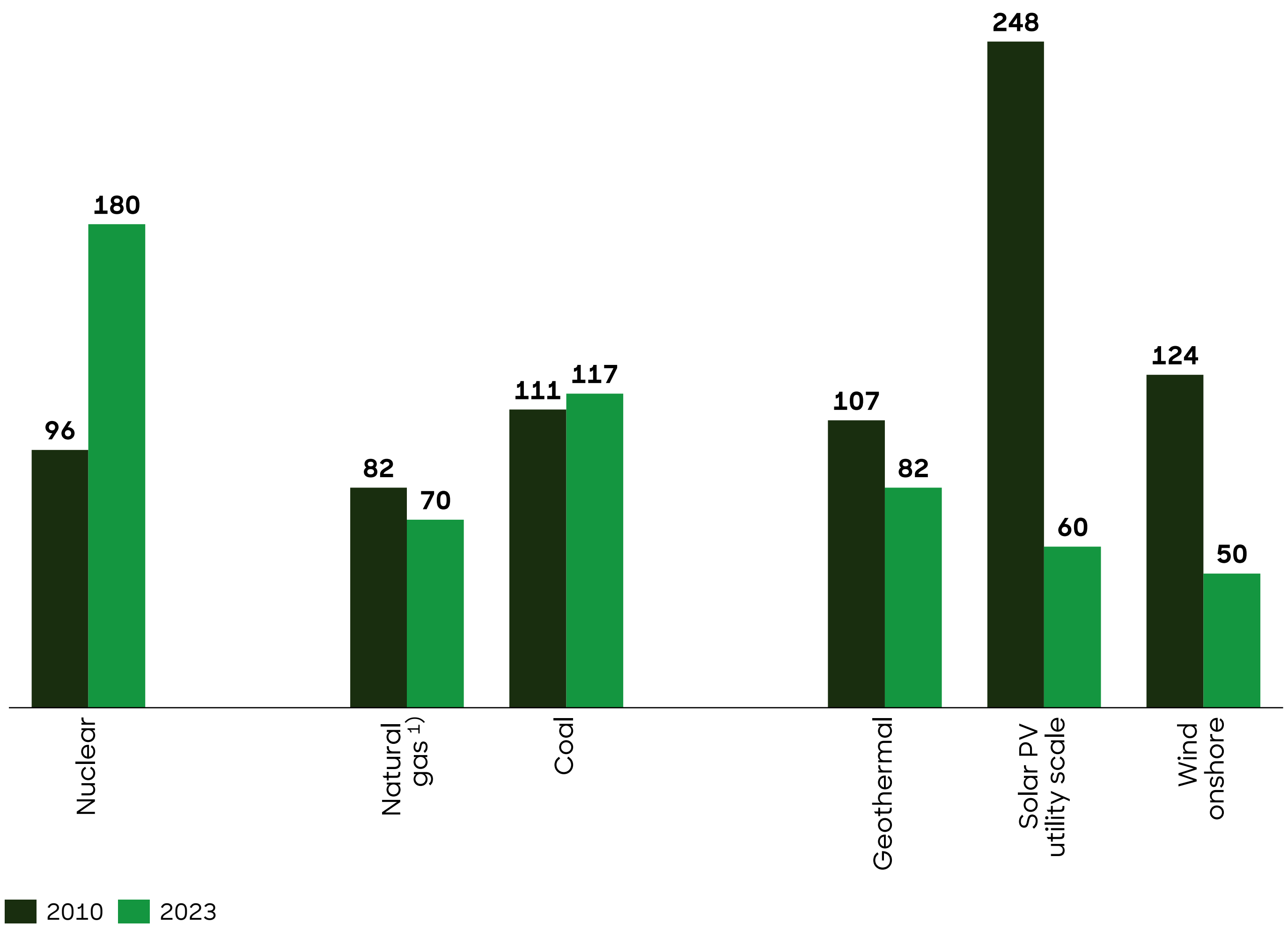


- Between 2015 and 2022, global **energy sector investments** totaled USD 6.8 trillion
- Under IRENA's planned energy scenario, **more than USD 3.8 trillion are required to be invested annually until 2050.** But, out of every ten dollars invested in the energy sector, four dollars would (still) flow into fossil energy sources – thwarting Paris Agreement efforts
- **To comply with the agreement,** the energy sector investment portfolio would require promoting increases in energy efficiency and renewable energy sources while **lowering the use of fossil energy** to achieve the 1.5 °C target
- As a result, instead of investing USD 3.8 trillion annually, **USD 5.5 trillion need to be invested annually,** bringing the **total of additional global investments by 2050 to USD 47 trillion** – an amount nearly equal to the combined GDP of the US and China (2023)

Source: IRENA; Roland Berger

Renewables are now competitive in terms of levelized costs of electricity when compared to fossil fuels

Mean unsubsidized levelized cost of energy (LCOE) by selected sources for 2010 and 2023 [USD/MWh]

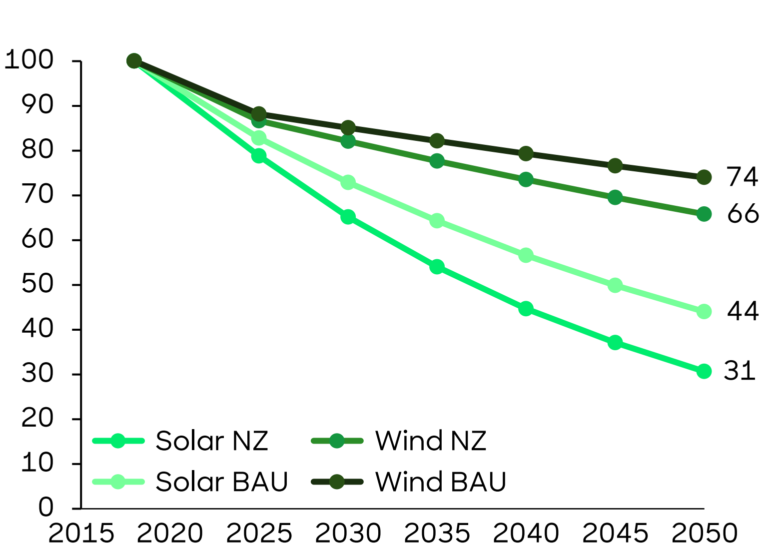


- For a transition from fossil fuels to renewable energy sources to be successful, **respective technologies must be competitive in terms of energy generation costs**
- Over the past decade, the **cost** of the two most significant renewable energy sources **- wind and solar - has dropped significantly**
- Historically, photovoltaic (PV) systems have not been remotely competitive when compared to fossil fuels – being at least twice as expensive – but this **situation has changed most notably in solar PV where a 76% cost reduction** has been observed over the past decade
- **Competitiveness heightens the attractiveness of renewable energy sources to investors,** potentially addressing several challenges simultaneously: first, dependency on finite energy sources would ultimately cease. Next, lower renewable energy costs could help tackle climate change. Lastly, with a well-developed renewable energy grid, an abundant low-cost power supply could meet increasing demand stemming from future economic growth

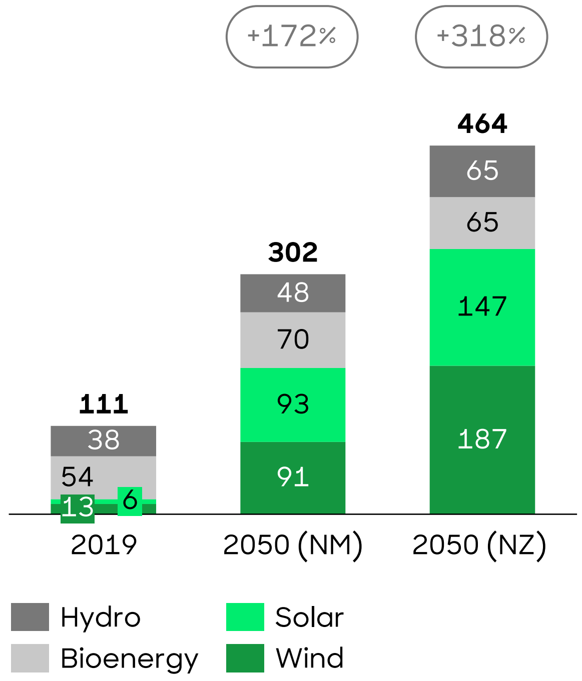
1) LCOE for a combined cycle gas plant, i.e. a gas turbine generator that generates electricity; the waste heat is used to make steam to generate additional electricity via a steam turbine
Source: Lazard; Roland Berger

In the future, renewable energy sources – driven by falling prices – will play a greater role in all cases

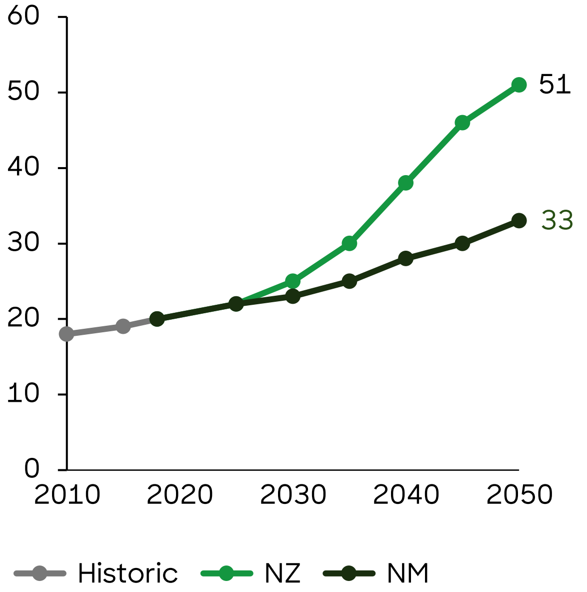
Cost of wind and solar energy by scenario[1] [Index, 2018 = 100]



Global energy consumption of renewables[1] [EJ[2]]



Share of electricity in global final energy consumption[1] [%]



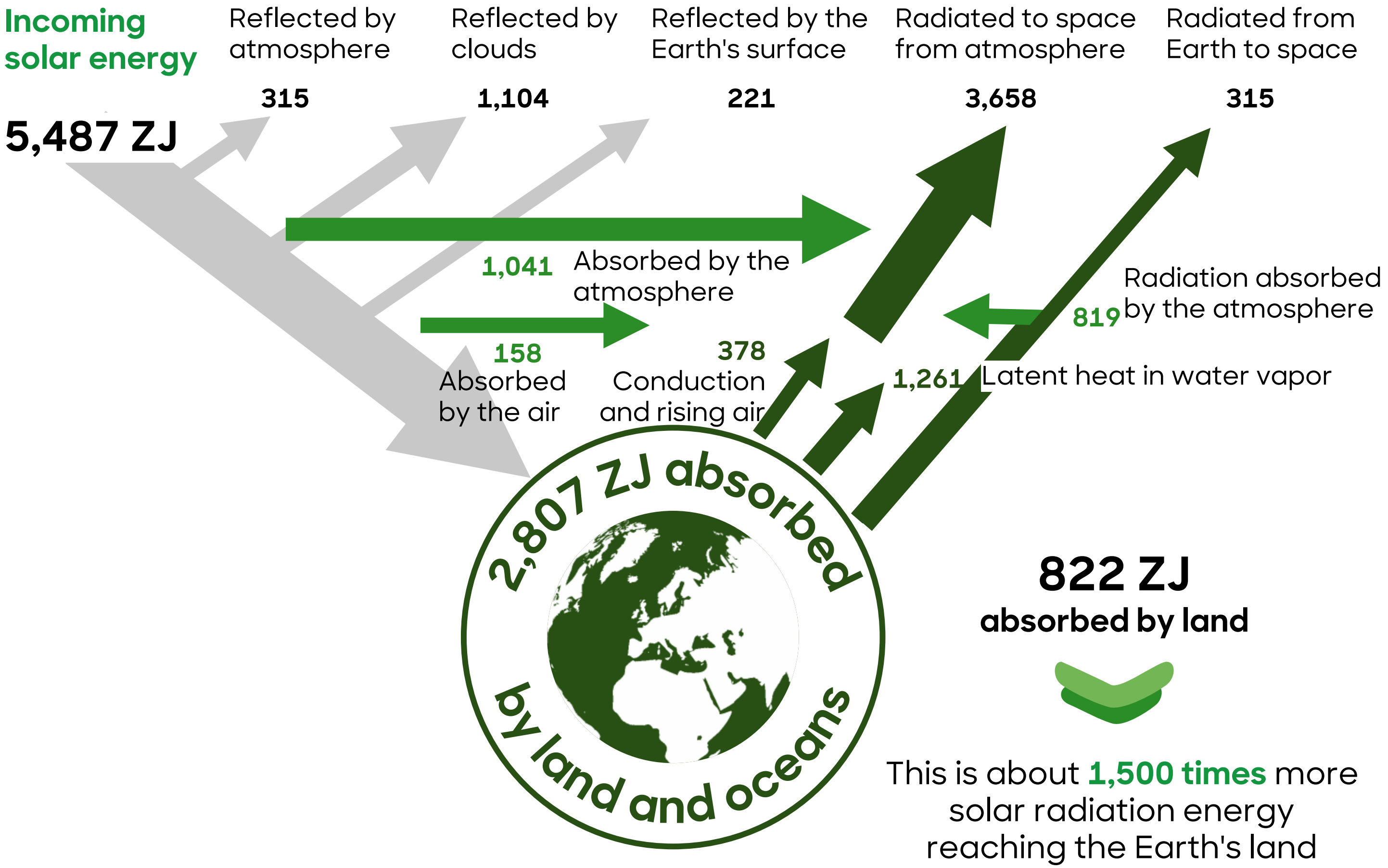
- Driven by technological progress, increased competition, promotion, and scaling, it is expected that **energy generation from renewable energy sources** will become **even cheaper in the future.** For example, solar energy – under all scenarios – will cost less than half compared to 2018
- In turn, **growth in energy consumption from renewables** appears unstoppable: under the **New Momentum scenario (NM), consumption of renewables will nearly triple,** while under the **net zero emissions scenario (NZ)** it is expected to **quadruple**
- As a result, **traditional energy sources** – such as gas – will **play a lesser role.** The economy will be decarbonized and increasingly powered by electricity from renewable energy sources

1) The Business-as-usual Scenario (BAU) assumes that government policies, technologies and social preferences continue to evolve in a manner and speed seen over the recent past. NZ (net zero in 2050) refers to a global energy policy compliant with the terms of the Paris Agreement. NM (New Momentum) reflects the current trajectory of the global energy system; 2) EJ: Exajoule (= 10^{18} Joules)

Source: bp; Roland Berger

Despite fossil fuel's dominance, the sun is our biggest energy supplier, delivering on land around 1,500 times the Earth's energy consumption

Energy input by solar radiation power per year and its distribution on Earth [ZJ]



This is about **1,500 times** more solar radiation energy reaching the Earth's land mass than our total annual energy consumption

- **Solar radiation** is the **Earth's main renewable energy source.** Incoming solar energy per year is 5,487 Zeta Joule (ZJ = 10^{21} J); energy stemming from the Earth's interior (geothermal energy) is about 3,500 times smaller, energy from gravitation of moon and sun (driving tidal power) is 35,000 times smaller
- On **Earth's land surface** (29.3% of Earth's total surface), the sun provides 822 ZJ p.a. This is nearly **1,500 times the energy we consume** per year (2020: 556 Exa Joule; EJ = 10^{18} J)
- To meet the **world's energy demand by solar power.** a solar panel spanning 335 km in length and width would be required – equivalent to **1.2% of the area of the Sahara Desert**
- **Solar radiation also drives** other renewable energy sources such as **wind and water**
- Although renewable energy seems to be available in high abundance, there are **natural limits of use:** e.g. on land there are 1,577 EJ **wind energy** p.a. usable in principle. But **only 10% can be used sustainably** – if we use more, the 'global weather machine' would falter

Source: Smil; Wengemayr (Max Planck Research); BP; Predict/Forbes; Roland Berger

Due to the rise of renewables, electricity supply will fluctuate more – New technological solutions are needed to balance the power system

Technologies that help balance the power system for different durations of energy need

	Seconds	Minutes	Hours	Days	Weeks	Seasons
Batteries	Most advantaged	Most advantaged	Most advantaged	Not applicable/expensive	Not applicable/expensive	Not applicable/expensive
Pumped hydro	Less advantaged	Most advantaged	Most advantaged	Not applicable/expensive	Not applicable/expensive	Not applicable/expensive
Demand responses and rescheduling	Less advantaged	Most advantaged	Most advantaged	Less advantaged	Not applicable/expensive	Not applicable/expensive
Hydro with high-capacity reservoirs	Less advantaged	Most advantaged	Most advantaged	Most advantaged	Most advantaged	Most advantaged
Hydrogen	Less advantaged	Less advantaged	Less advantaged	Most advantaged	Most advantaged	Most advantaged
Gas (or coal) with CCUS[1)]	Not applicable/expensive	Less advantaged	Less advantaged	Most advantaged	Most advantaged	Most advantaged
Bioenergy with or without CCUS	Not applicable/expensive	Less advantaged	Less advantaged	Most advantaged	Most advantaged	Most advantaged

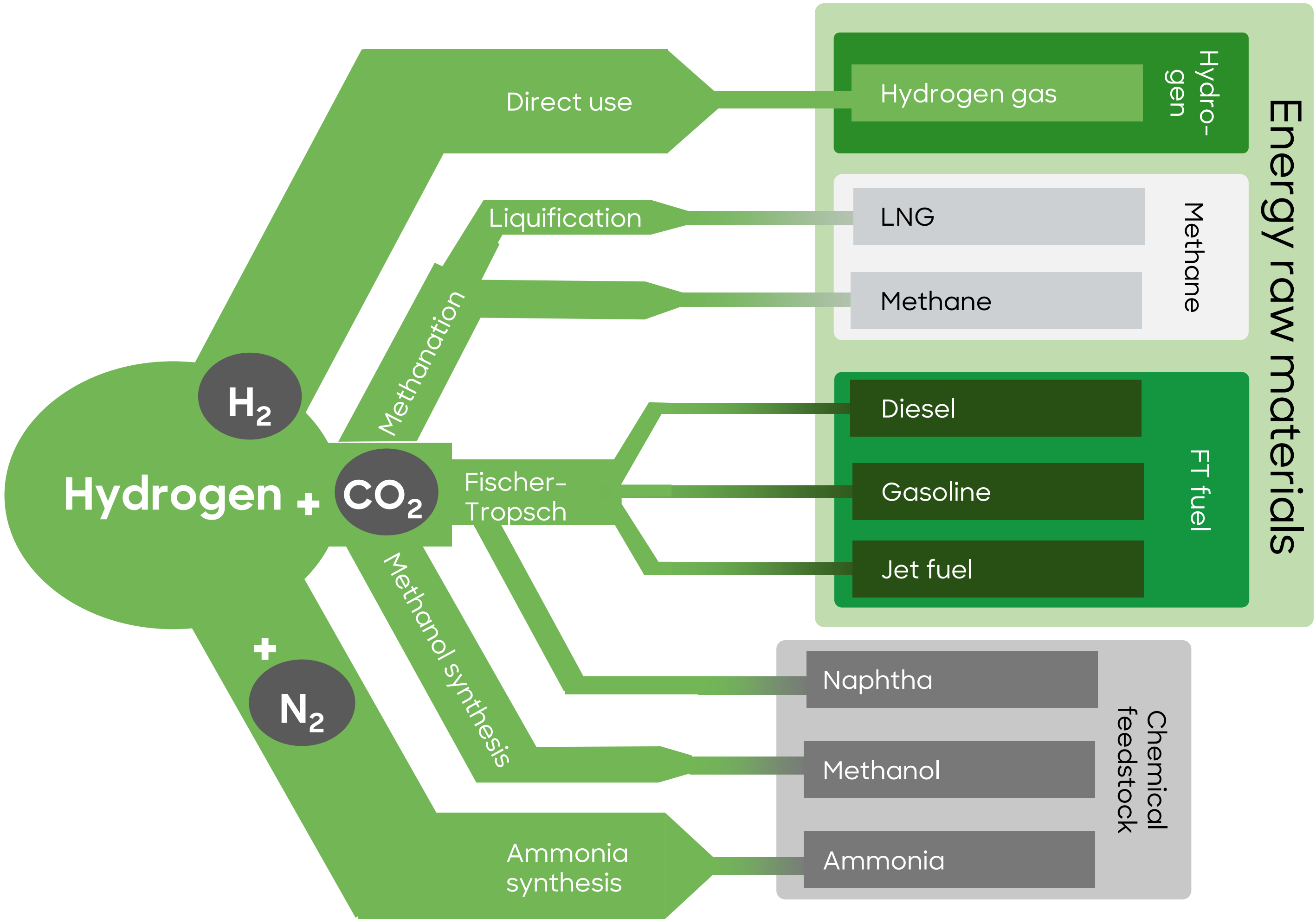
Most advantaged | Less advantaged | Not applicable/expensive

- The **quality** of a country's **power supply** is measured by **continuity of supply, voltage quality (stability of voltage level) and commercial quality** (e.g., response time, compensation in case of failures)
- **Renewable energy sources are dependent** on external circumstances, especially the **weather,** for their energy production. In the **absence of the right conditions** (windless, overcast, etc.) it is not possible to feed (enough) renewable energy into the power grid – the power supply would fail
- To **guarantee a stable energy supply** during the energy transition, the reliability of various **technological energy storage solutions is key:** in the event of overproduction, these technologies can help **balance the power system** during adverse weather conditions
- The optimal choice and use of the technology depends mostly on **economic feasibility,** but also on the technological one

1) CCUS refers to carbon capture, utilization, and storage and describes the possibility to store or further process CO_2 emitted by energy production
Source: bp; CEER; Roland Berger

Hydrogen is a particularly flexible solution for decarbonizing the economy with multiple possible options for processing and use

Possible uses of hydrogen

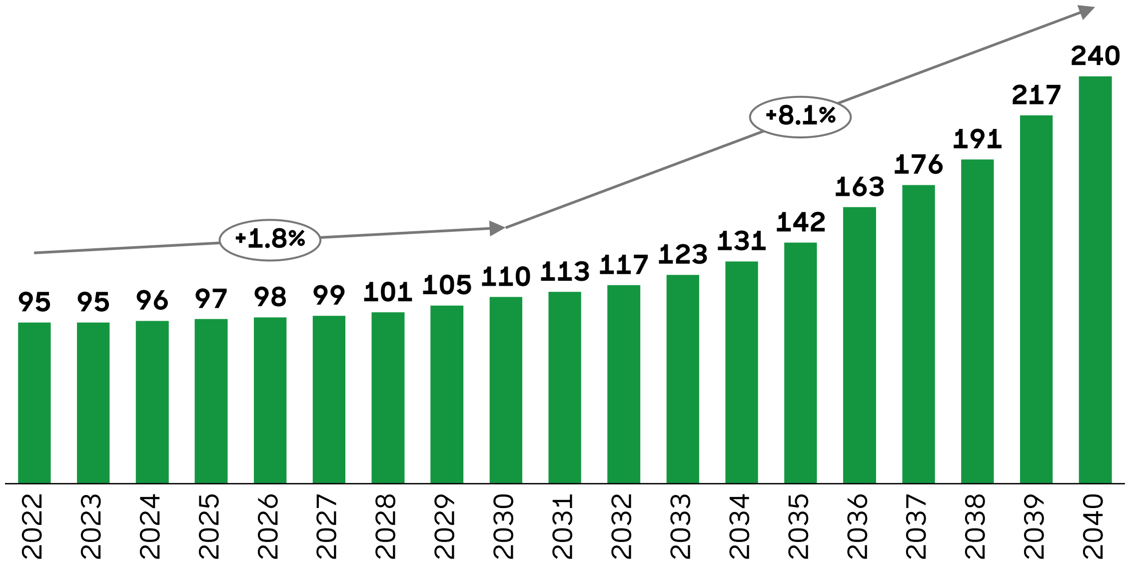


- **Hydrogen** is the simplest and **most abundant element** in existence (under standard conditions two hydrogen atoms share their electrons, thus hydrogen is H_2). The potential of hydrogen in the clean energy transition is becoming increasingly evident, buoyed by technological progress, the declining cost of renewable energy, and worldwide initiatives to curb emissions
- As hydrogen does not occur naturally as a gas on Earth, it must be **produced through manufacturing processes.** One common method involves **steam-methane reforming (SMR),** which utilizes natural gas as a feedstock. While this pathway is the most cost-effective for hydrogen production, it does generate carbon emissions
- Hydrogen that is produced by **electrolysis directly from renewables** is called **green hydrogen.** Electrolysis requires electricity to split water into its hydrogen and oxygen components
- By **utilizing various processes** and **adding other elements and compounds,** hydrogen can be used **not only as an energy carrier** but also as a **chemical feedstock**

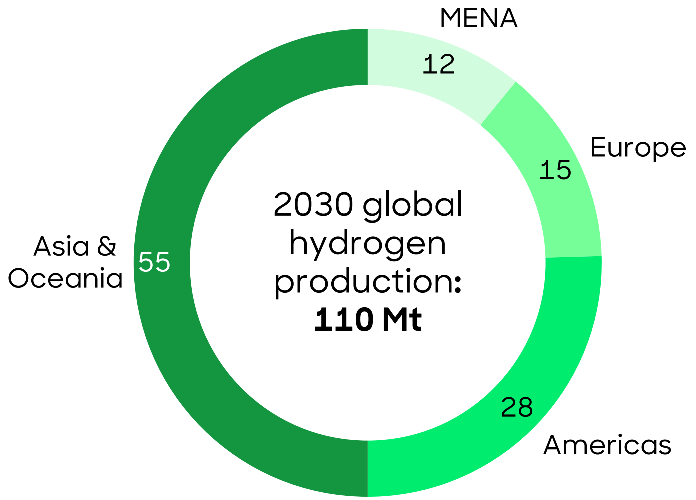
Source: LUT University/SolarPower Europe; Roland Berger

As the world endeavors to decarbonize, hydrogen is expected to play a vital role with production set to surge in the coming years

Forecast for the global production of hydrogen [Mt p.a.]



Regional split of hydrogen production in 2030 [Mt p.a.]

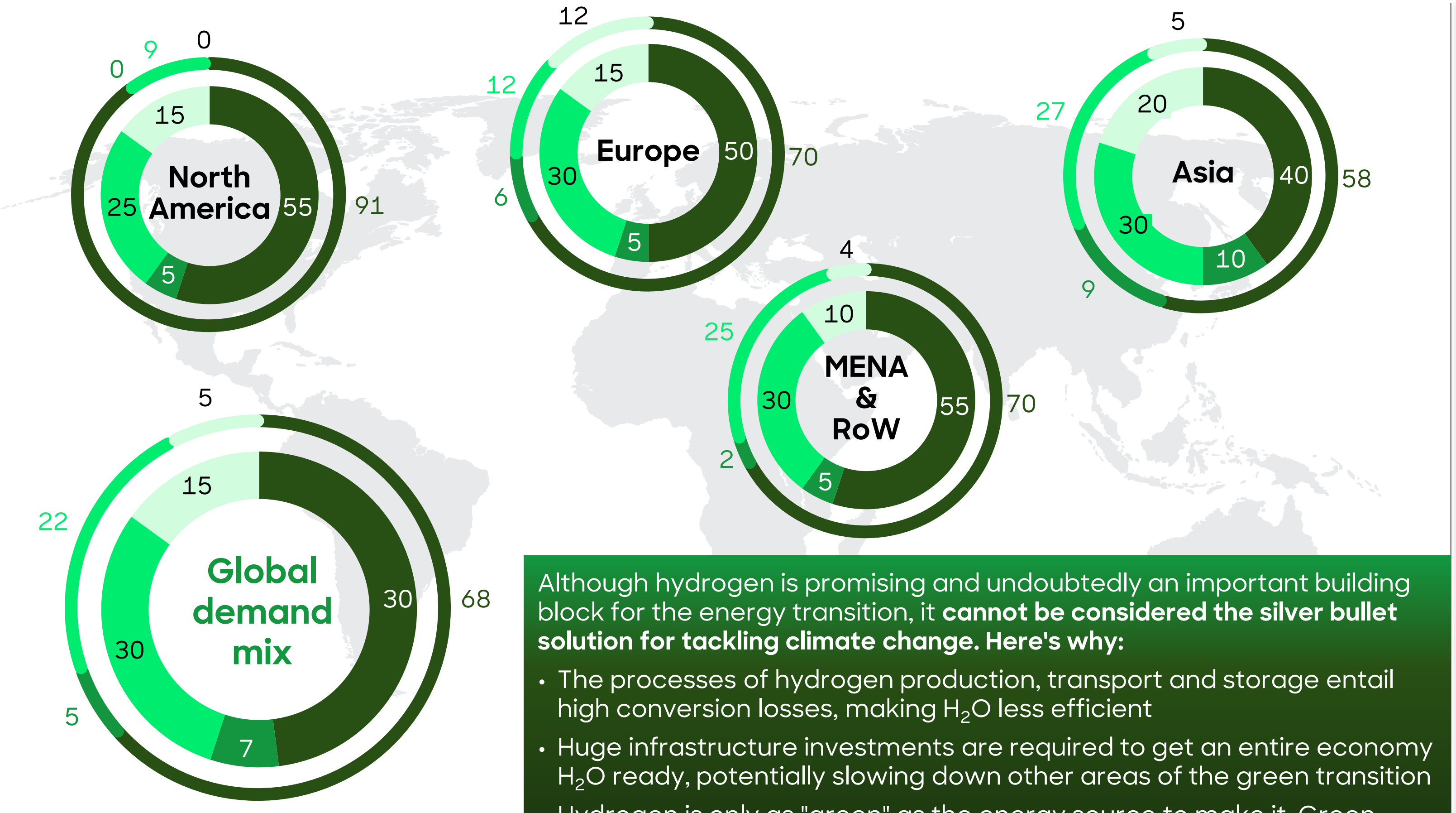


- Hydrogen is expected to emerge as a **fundamental component of global decarbonization initiatives** in the years to come. As of 2024, the **annual production of hydrogen** stands at just below 100 million tons. **By 2030,** this figure is projected to **increase** to around 110 million tons, with **green hydrogen accounting for around 12%** of the total
- A significant **surge in hydrogen production** is expected throughout the **2030s.** Assuming an installed electrolysis capacity of around one terawatt by **2040,** it is estimated that **hydrogen production** could reach around **240 million tons per year,** of which nearly **half** is anticipated to comprise **green hydrogen**
- **By 2030, the Asia & Oceania region is projected to become the leading producer of hydrogen.** In 2022, **China** was already the **largest single producer** of hydrogen by a significant margin and had an **extensive project pipeline in its final stages.** While a substantial portion of China's hydrogen production is **currently fossil fuel-based,** the government **has ambitious plans** to significantly increase green hydrogen production. Meanwhile, **Australia** currently operates **the largest number of green hydrogen production facilities** worldwide

Source: Roland Berger

The role of hydrogen is expected to shift from predominantly industrial usage to applications in mobility and power generation

Regional hydrogen demand by sector in 2040 (inner ring) and 2030 (outer ring) [%]



Industry | Energy (buildings) | Mobility | Energy (power)

Although hydrogen is promising and undoubtedly an important building block for the energy transition, it **cannot be considered the silver bullet solution for tackling climate change. Here's why:**

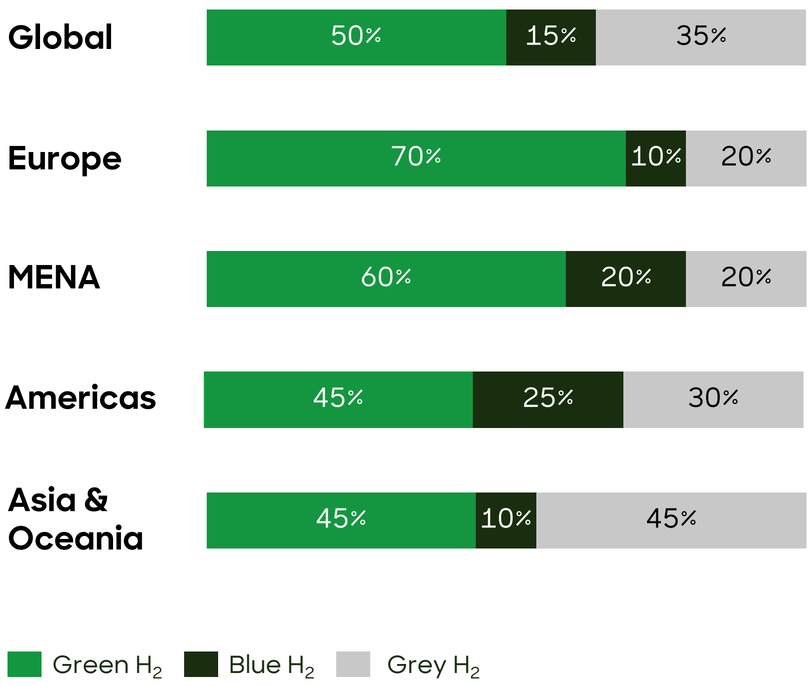
- The processes of hydrogen production, transport and storage entail high conversion losses, making H_2O less efficient
- Huge infrastructure investments are required to get an entire economy H_2O ready, potentially slowing down other areas of the green transition
- Hydrogen is only as "green" as the energy source to make it. Green hydrogen, created by renewable energy, might use up energy that could be used by other, more efficient uses

- The period between 2030 and 2040 will not only be an **acceleration phase for hydrogen** but also the period in which **industry's dominant share in demand** is beginning to **decline,** from 68% to 48% globally, while **other sectors gradually gain** in importance, creating a **more diversified** picture overall
- Notably, the **mobility and energy sectors** will require **more and more hydrogen.** The hard-to-abate aviation and maritime transportation sectors will need hydrogen to achieve a large-scale switch from traditional to clean synthetic fuels, ammonia and methanol
- In the **energy sector, hydrogen** will **gradually take over** the role of **natural gas and coal** in the context of an increasing share of intermittent renewable energy in the mix
- At the same time, the use of **hydrogen to decarbonize building heat** will be a less important but **constant** source of demand

Source: Roland Berger

In the years ahead, hydrogen production is projected to surge with the majority being green hydrogen

Regional hydrogen production mix in 2040



Definition of the different hydrogen colors

Low carbon H_2

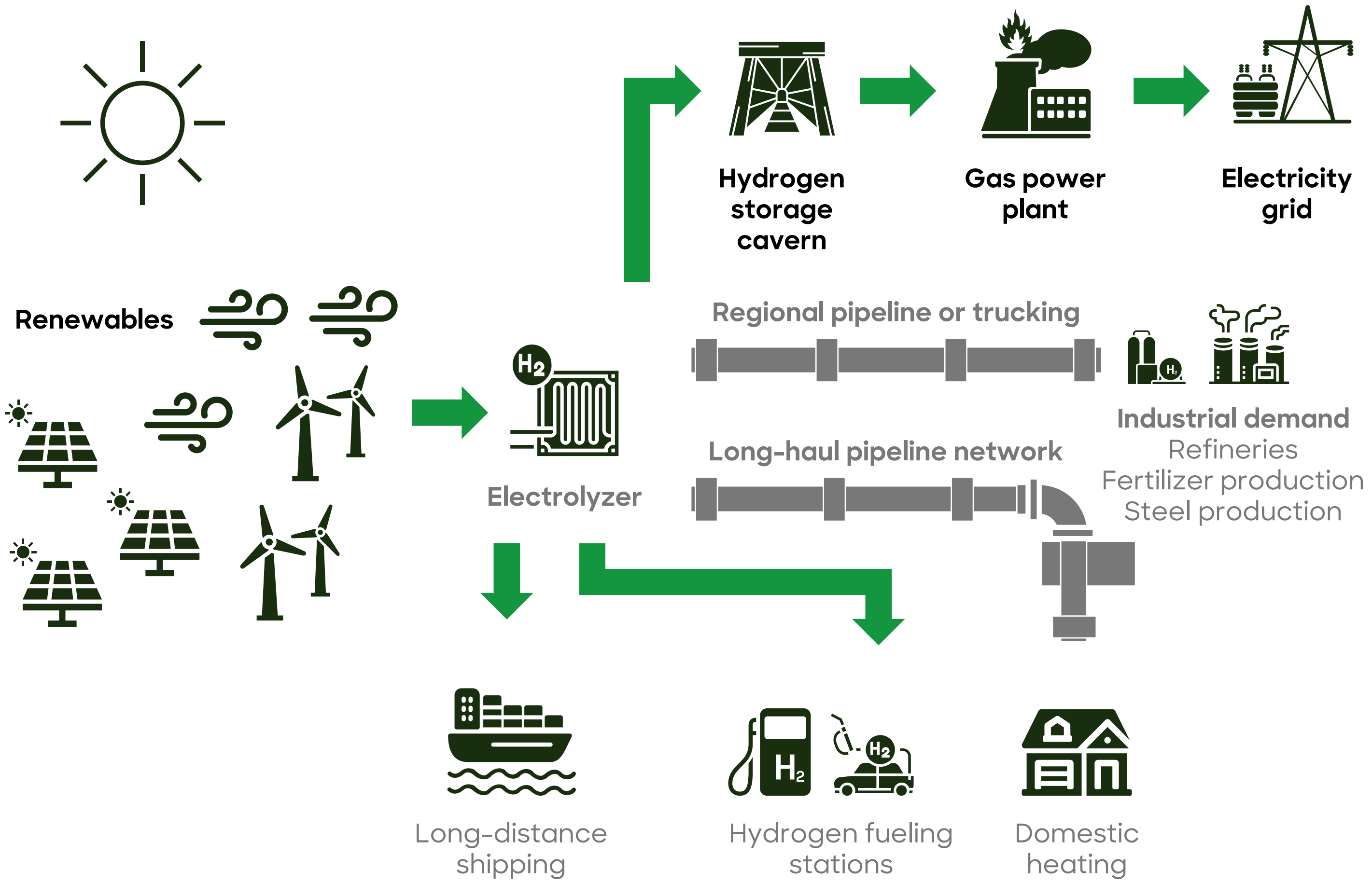
Green H_2	**Electricity from renewable energy sources** is used in a process called electrolysis (passing an electric current through water) to separate and extract hydrogen molecules from water (H_2O)
Blue H_2	Blue H_2 uses the **same production method as grey hydrogen,** with the exception that **CO_2 is captured** for storage or utilization
Grey H_2	**Steam methane reforming** uses high temperature steam to separate hydrogen from methane (CH_4), the main component of **natural gas.** The **exhaust** (which contains CO_2) is **vented to the atmosphere**

- Hydrogen (H_2) is often **described by different colors,** despite being a colorless gas. These **color labels refer to the method of production**
- **By 2030, green hydrogen is expected to account for around 12%** of the total hydrogen production and will then **increase to around half of total hydrogen production** in 2040. Although **Europe** accounts for only a small share of global hydrogen production, its share of **green hydrogen is significant.** Additionally, the **MENA region** is **poised to produce more than half of its hydrogen using renewable** sources
- Other hydrogen **color labels** refer to different production method: **red, pink, and violet hydrogen** are produced using electrolyzers powered by **nuclear energy. Yellow** hydrogen refers to hydrogen production from a **combination of renewable energies and fossil fuels,** while **white hydrogen** is a **byproduct of other chemical processes**

Source: Roland Berger; CER

Green hydrogen provides an efficient means to decarbonize various activities and could become a key pillar in future decarbonization efforts

Schematic illustration of a green hydrogen economy



- The use of **green hydrogen** offers a highly efficient way to **decarbonize various carbon-emitting activities,** as **only water is emitted** when hydrogen is burned
- Its **versatility** allows it to be **utilized across multiple sectors** including heating, transportation, industry, and electricity generation. These sectors **collectively contribute to approximately two-thirds of global carbon dioxide emissions**
- The concept involves **"storing" renewable electricity** as green hydrogen **during times when the electricity is not immediately needed,** instead of curtailing generation. The green hydrogen can **later be used as a fuel** to generate electric power through a turbine or fuel cell
- While hydrogen production and storage **offer the potential to store excess renewable electricity** for extended periods, the **process is significantly less efficient** compared to other storage technologies
- Additionally, producing (green) hydrogen is **more expensive** than the production of fossil fuels, therefore it can be expected that it will play an important role mostly in **decarbonizing particularly hard-to-abate sectors**

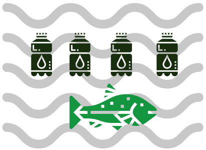
Source: S&P; CRU; Roland Berger

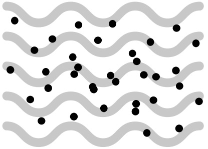
Whether it is about food, raw materials or energy resources: We need to overcome the current linear economic model and its negative effects

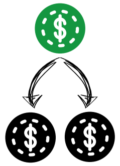
Negative impacts of the linear economic model

Highly extractive, wasteful economic models … / … result in massive economic value loss and many negative impacts

	Take Extraction of finite resources	**Make & use**	**Waste** % of materials not re-cycled in closed loop	**Annual economic loss**	**Share of annual carbon budget** by 2050[1)]	**Other negative impacts**
Plastics	359 m tons	of all plastics are single-use: 50%	98%	USD 120 bn	15%	More plastics than fish in the ocean by 2050 (by weight)
Fashion & textiles	98 m tons	of clothing is land-filled or burnt within years of being made: 60%	99%	USD 500 bn	22%	22 m tons of plastic micro-fibers entering the ocean between 2015 and 2050
Food & agriculture	82 m tons	of edible food is thrown away: 33%	98%	USD 1,300 bn	77%	For every USD 1 spent on food, society is paying USD 2 in health, environmental, and economic costs



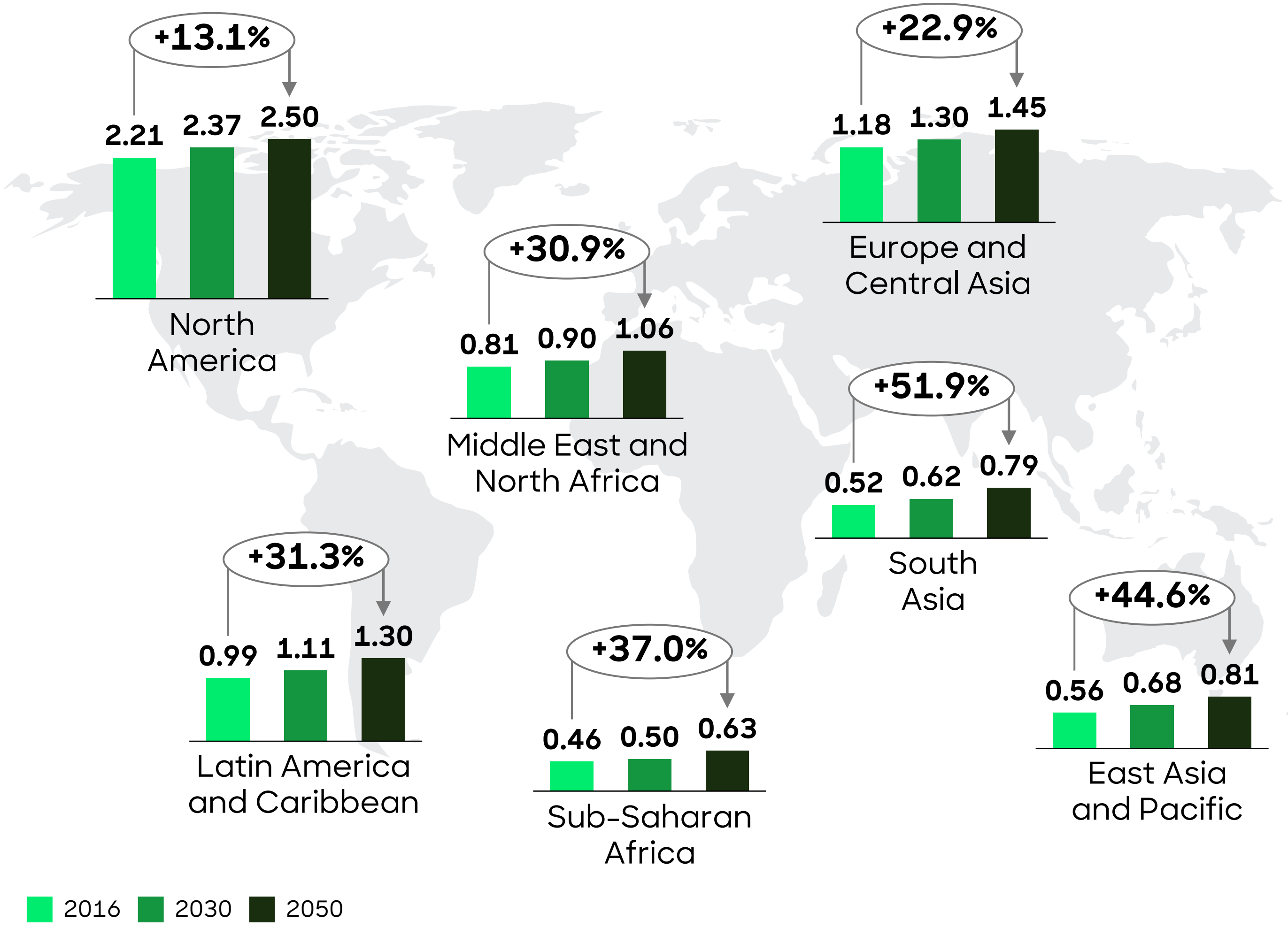




1) Share of global annual carbon budget by 2050 under business-as-usual, based on the IEA 2 °C pathway by 2050
Source: Ellen MacArthur Foundation; Roland Berger

Although we face potential raw material scarcities, persistent trends in waste generation continue due to linear economic processes

Daily waste generation 2016-2050 [kg/capita]

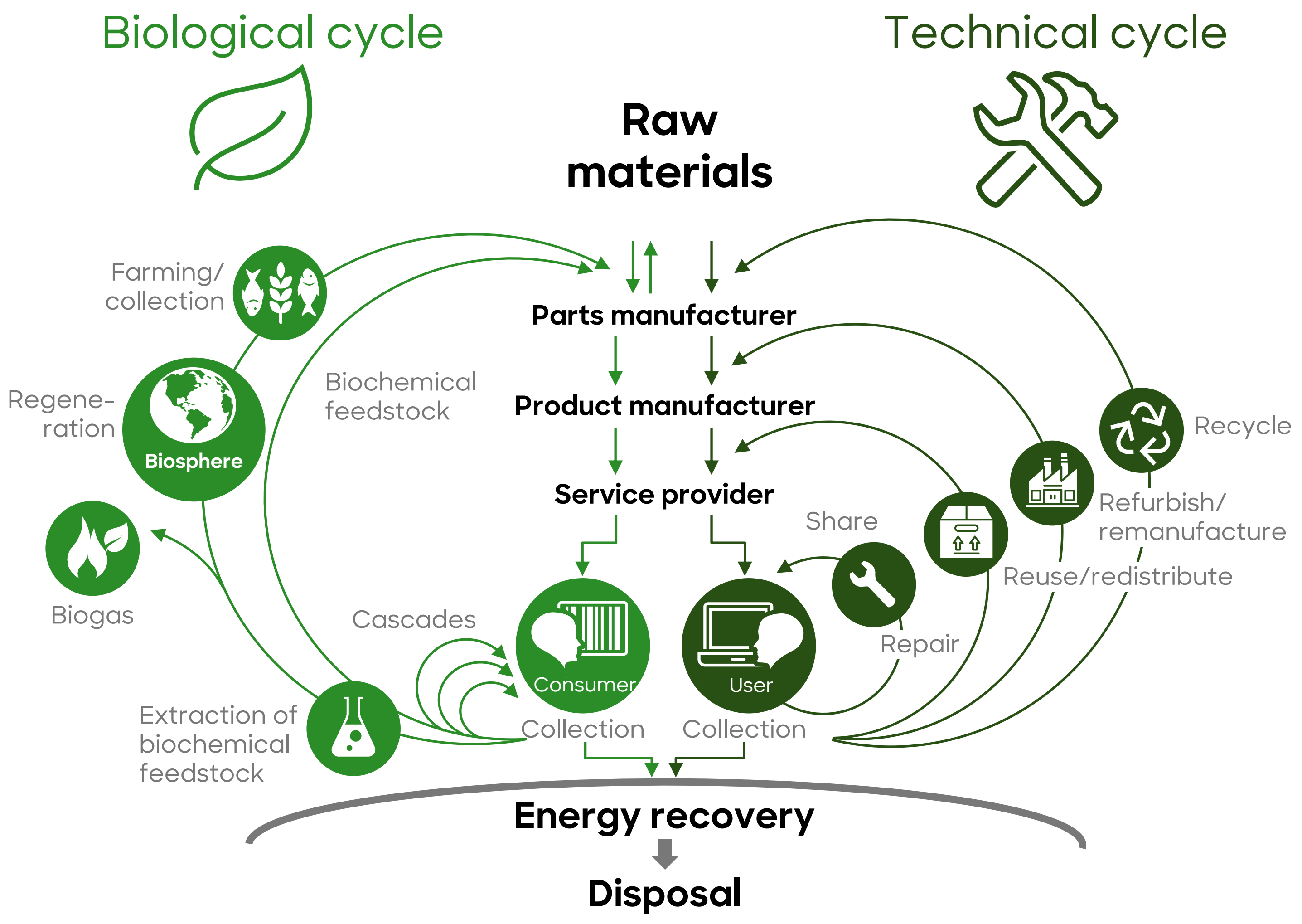


- A continuing dilemma: on the one hand, global society is faced with potential **scarcities not of several raw materials.** On the other hand, we **produce waste in abundance.** At the heart of this lies the way we have designed our production processes – these having evolved over decades if not centuries – and how we conduct our economic activities: it is a mostly **linear economy**
- In parallel with **global production** as well as **consumption patterns,** waste generation is rising; the motto is often "buy, consume, throw away"
- Expectedly, **most waste is generated in economically strong countries.** In North America, for example, more than 2.2 kg of waste are generated per person per day, while in lesser developed regions it is a fraction, for example in Sub-Saharan Africa it is around one fifth of that
- This trend appears persistent: **Waste generation is increasing worldwide,** most strongly in **those regions** of the world that can **expect the greatest economic growth** in the future, such as South Asia with an annual future growth of 1.2% in waste generation. Even so, economically strong regions will remain the number one waste producers

Source: World Bank; Roland Berger

Circular – not linear – economy concepts promise a more regenerative, less wasteful economic system, more independent of scarce resources

Circular economy concept

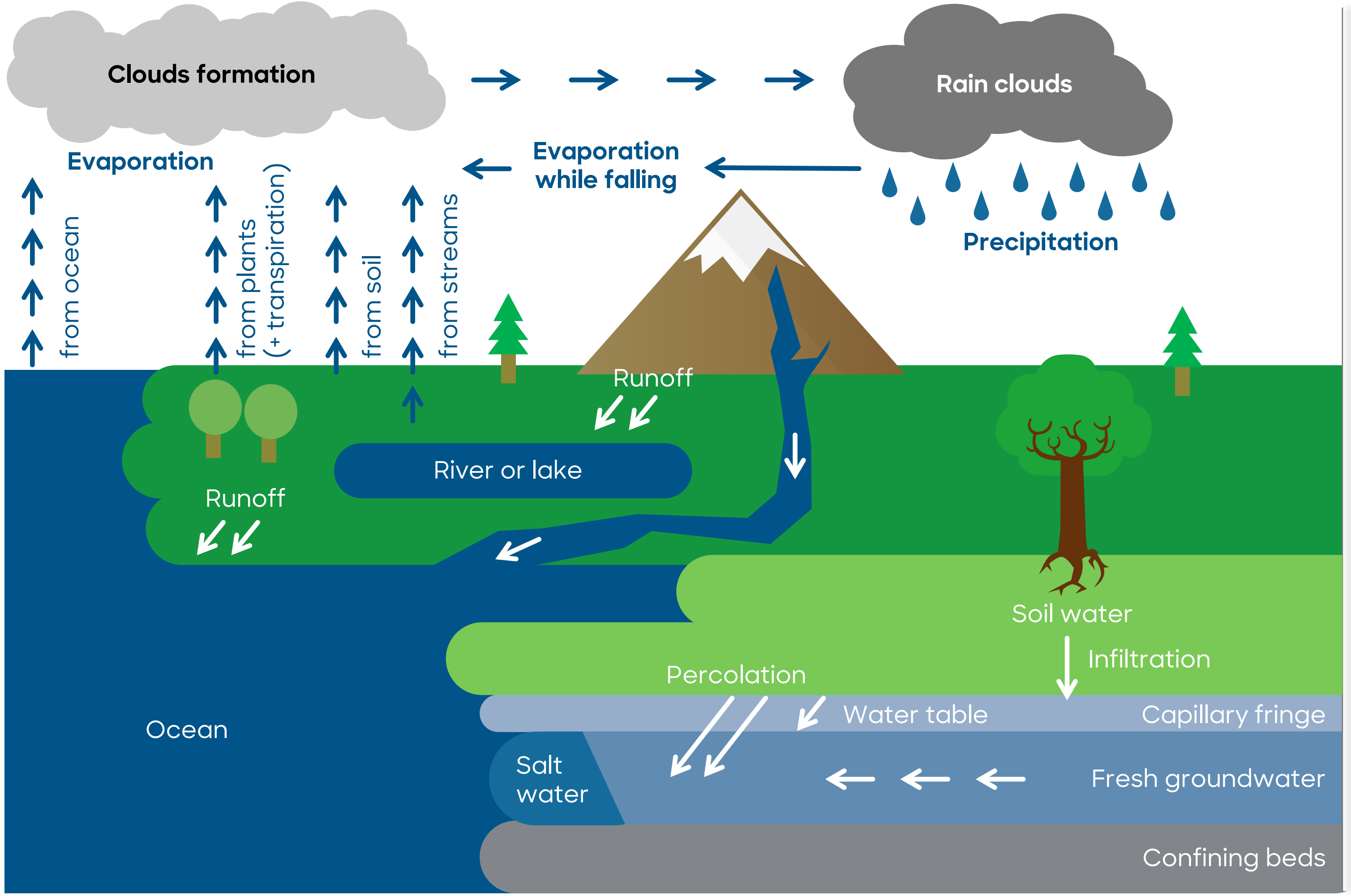


- **Circular economy** describes a regenerative economic system that aims to **minimize resource input as well as waste and emission production.** These objectives derive from the need for maximum efficiency in the use of potentially finite global resources
- The circular economy concept consists of two cycles, that, if complied with, can lead to a **sustainable economy both in terms of resources use as well as biocapacity.** However, the model represents an idealistic system that requires **profound change in production processes** and **consumer behavior**
- **Biological cycles** are solely concerned with the **management of renewable resources** and can only affect the consumer side in a circular economy. This implies that, fossil fuels no longer have a place in a circular concept
- **Technical cycles** involve the **management of finite resources** that are extracted and used in multiple economic cycles and processes. This is mainly achieved by reuse, repair, and remanufacturing, but also by recycling

Source: Ellen MacArthur Foundation; Roland Berger

The water cycle serves as a natural model akin to a circular economy – Water is collected, purified, recycled, and redistributed after use

The hydrological cycle

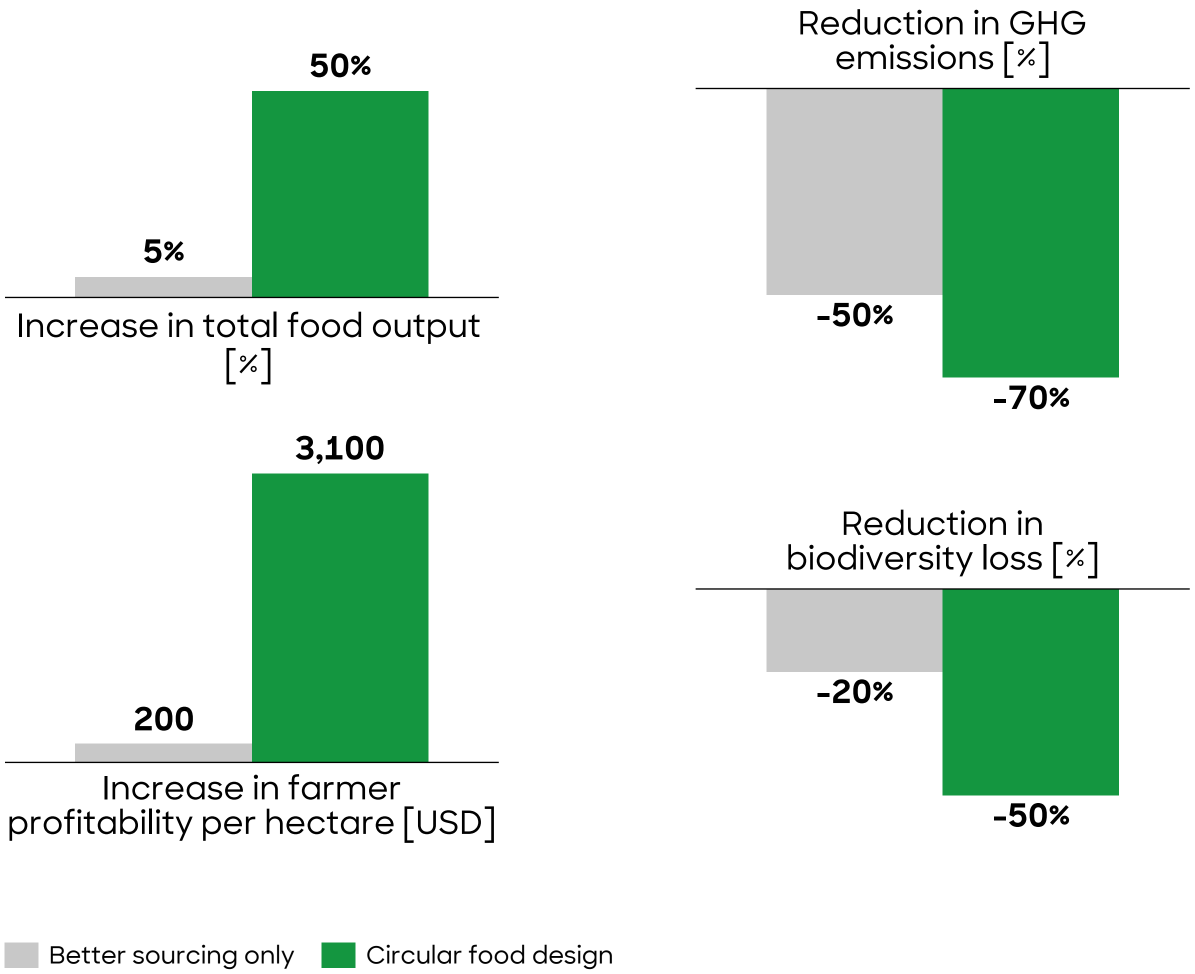


- The **hydrological cycle is the natural counterpart to the circular economy** model; it describes the various, continuous stages of the movement of water
- Water is **naturally recycled** as it evaporates from the oceans into the atmosphere and, ultimately, through precipitation, back to the oceans overland and underground
- Depending on **climate, temperature and weather conditions** as well as **human interference,** the amount of water available in individual bodies of water (rivers, lakes, water tables etc.) varies
- The water cycle can be profoundly **disrupted** by **excessive withdrawal of water** that is not returned, for example, by agriculture in arid regions; a further **disruption** stems **from sealed surfaces,** found especially in **urban areas,** where rainwater is prevented from passing through soil back into the water cycle
- Disrupting the water cycle, especially considering climate change, poses any **number of risks to humans and nature** – ranging from drought to flooding

Source: FAO; Roland Berger

Circular design principles applied to food sectors provide a way to increase output and profitability and reduce GHG emissions and biodiversity losses

Average effects of a sustainable and circular design for food[1)2)]



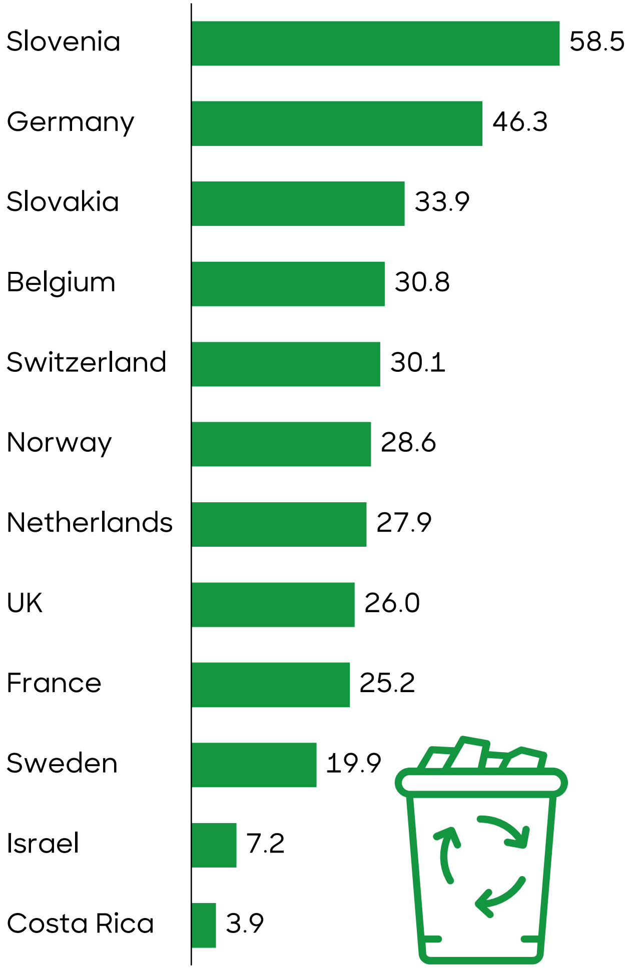
- **Sustainable** farming practices underpin multiple environmental goals. Applying **circular economy ideas** to **agricultural and food production** sectors sets free **further potential;** the extent of implementation determines not only the increase of food output and profitability, but also the reduction of GHGs and biodiversity loss
- In this way, the **circular food design concept combines different aspects of sustainability,** each of them already having a profound effect on food supply and the environment. For example, **upcycling** the global harvest of cascara (coffee cherry husk, a coffee bean byproduct) **as an ingredient** (flour) – rather than leaving it to decompose – could save GHG emissions equal to 730,000 return flights from London to New York
- Following circular food design principles brings **increased profitability** due to development in other areas and sectors, such as sustainable packaging
- To further **stabilize soils** around the world, crop farming should be **diversified further** as presently just four crops (wheat, rice, corn, potatoes) provide almost 60% of the calories consumed globally
- In this way, **circular design for food** combines a diverse, upcycled, and regenerative production of food with a **lower impact on biodiversity**

1) For three modelled ingredients (per harvest for wheat and potatoes, and per year for dairy) in the UK and EU; 2) Sustainable design for food includes, but is not limited to, healthy and stable soils, improved local biodiversity, and improved air and water quality

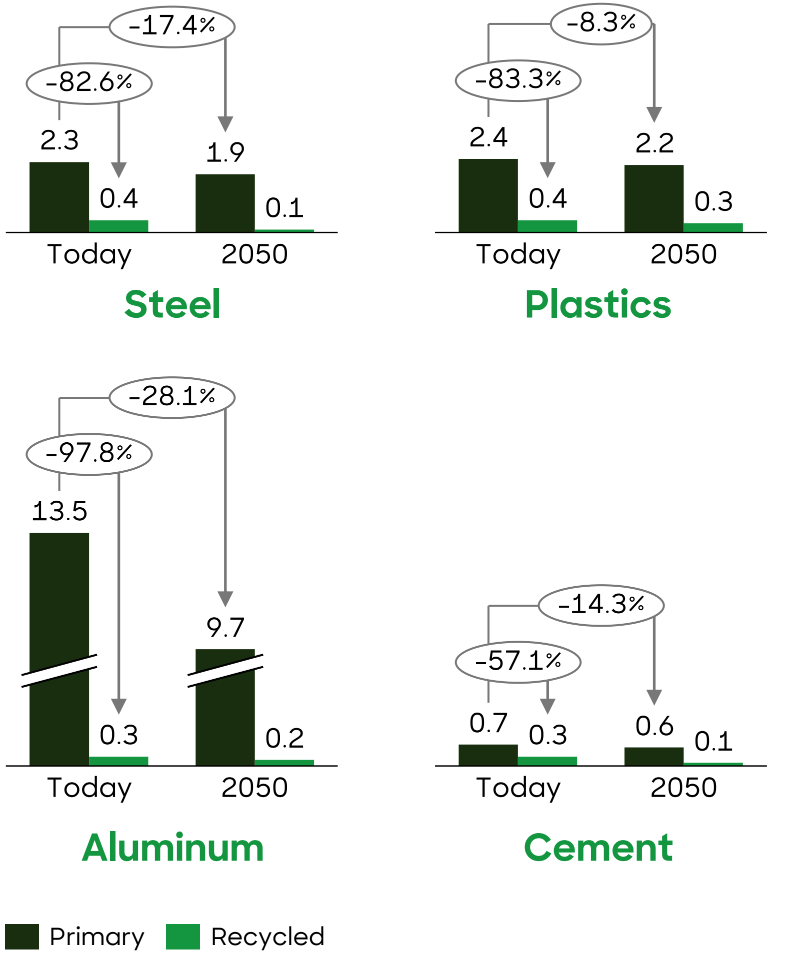
Source: Ellen MacArthur Foundation; Roland Berger

For raw materials, the use of recycled materials helps abate CO_2 emissions already today, more so than advances in production processes by 2050

Share of waste being recycled, 2021[1] [%]



CO_2 emissions during production process, primary vs recycled [t CO_2/t product]



- **Recycling** as a circular economy component generally receives the most attention, as recycled materials mostly have a clear **market value;** they can also be used for a **variety of purposes and processes,** thus closing the circular economy loop in the **most flexible** manner
- Recycling is also one of the key steps in **climate change mitigation:** use of **recycled inputs in production** processes would **save more emissions now than future advances in production** technology by 2050
- **Refurbishing, reusing,** and **repairing** would also contribute to a more sustainable economy

1) The indicator presents the tonnage recycled from municipal waste divided by the total municipal waste arisings
Source: OECD; Material Economics; Roland Berger


3.1 Climate Change & Pollution


3.2 Bio-diversity


3.3 Water


3.4 Resources & Raw Materials

In the energy and industrial sector, CO_2 collection and reuse represents one example of applied circular economy principles

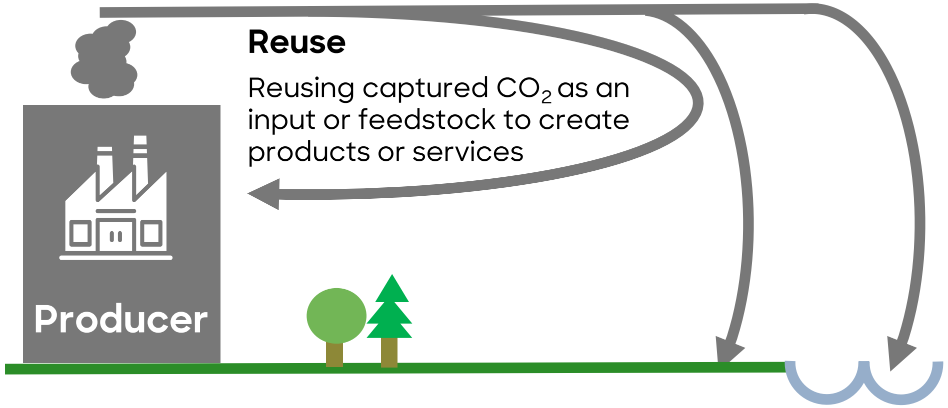
Further use of CO_2

Capture

Capturing CO_2 from fossil fuel or biomass-fueled power stations, industry facilities, or directly from the air

Transport

Moving compressed CO_2 by ship or pipeline from the point of capture to the point of use or storage



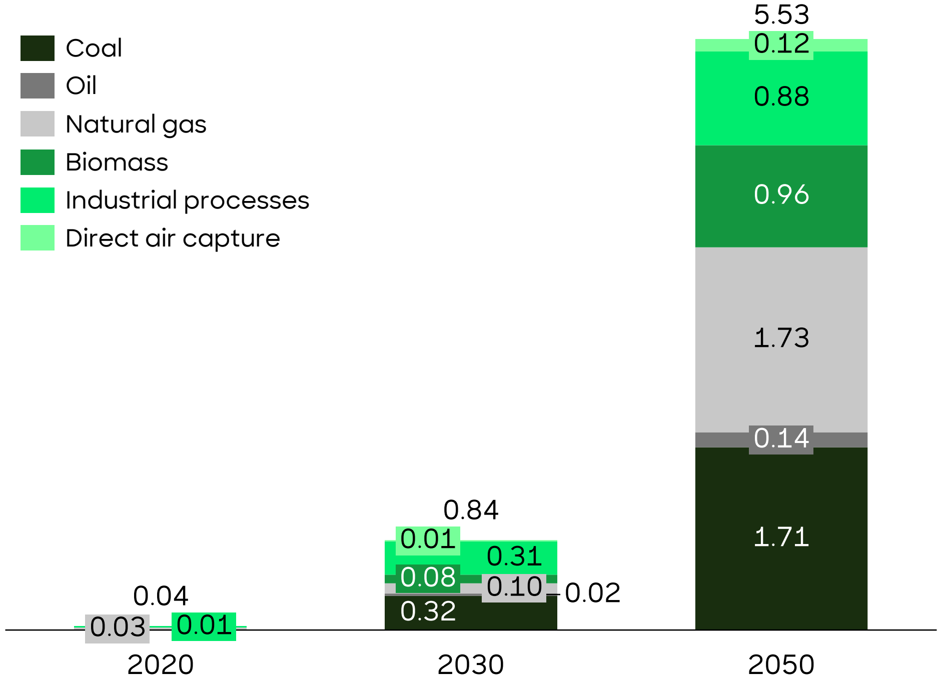
Reuse

Reusing captured CO_2 as an input or feedstock to create products or services

Storage

Permanently storing CO_2 in underground geological formations, onshore and offshore

Carbon capture by producers under IEA Sustainable Development Scenario[1)] [Gt CO_2]



- At present, most CO_2 emissions are released into the air. However, there are several ways to capture, store and/or use CO_2. By the **second half of this century, carbon capture,** for example at source in energy generation, **will play a significant role** in helping to make the global economy climate-neutral
- **Reusing captured CO_2 as a feedstock** opens many possibilities, for example in the production of **climate-neutral fuels**

1) IEA Sustainable Development Scenario assumes that global net zero emission target is met in 2070
Source: IEA; Roland Berger

Corporate actions – Let's talk about opportunities arising from megatrends regarding environment and resources (1/3)

Conclusion and corporate impacts

Impact: Climate change can affect the business model of every company. For example, CO_2 regulation may raise the cost of production, while extreme weather events can threaten manufacturing sites or supply logistics

Actions

- Companies should analyze their business model (value chain, product-market-combination, revenue model) to understand which parts are or can be susceptible to climate change effects
- They need to prioritize affected areas and develop solutions to cope with climate change impacts
- Companies should understand climate change impacts also as an opportunity to develop products that counteract climate change and/or help customers to cope with climate change impacts

Impact: Pollution can worsen the quality of important input factors of companies (e.g. water or soil pollution) as well as threaten the safety and wellbeing of employees (e.g. via air or noise pollution)

Actions

- Companies need to assess the type and the extent of pollution affecting their business model
- External support can be helpful to examine the finer details of the pollutant (e.g. type, level, cause) and to find technical/technological and other solutions
- Companies should strive for high standards to protect their employees from harmful pollution in the workplace, also in countries that may lack strict(er) regulations

Learn how Roland Berger can help you to create corporate impact

Global Carbon Restructuring Plan

Tapped out: Exploring drinking water pollution in the US

Source: Roland Berger

Corporate actions – Let's talk about opportunities arising from megatrends regarding environment and resources (2/3)

3.1 Climate Change & Pollution

3.2 Bio-diversity

3.3 Water

3.4 Resources & Raw Materials

Conclusion and corporate impacts

Impact: Biodiversity-related risks for companies can be physical (through deteriorating ecosystem services), regulatory (via new environmental rules), and reputational (if conducting business in an unsustainable way)

Actions

- Companies need to inform themselves about biodiversity-related risks concerning their industry and the area they are doing business in, e.g. with the WWF Biodiversity Risk Filter
- They should assess the specific risks of their company. And they need to respond to the risks by adapting their processes (e.g. by lowering the degree of dependency from ecosystem services under threat), and organization (e.g. by shifting the international footprint to locations with functioning ecosystem services), and by engaging in the protection and restoration of ecosystem services

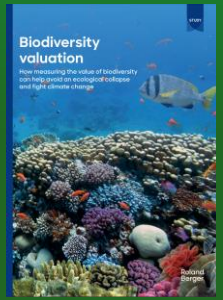
Impact: The water cycle is expected to be severely disrupted by climate change, leading to droughts, floods, and extreme weather events – all of which can harm companies' operations

Actions

- Companies should conduct detailed risk assessments to understand how droughts, floods, and extreme weather events may affect operations and identify critical vulnerabilities in supply chains, production facilities, and infrastructure
- They should establish water conservation practices to reduce overall water usage and invest in technologies that enhance water efficiency and recycling within operations
- Companies should develop and explore multi-sourcing options for key materials and components to reduce reliance on just one supplier in climate-vulnerable regions

Learn how Roland Berger can help you to create corporate impact

Biodiversity valuation



Water sobriety, alternative sources and circular models

Source: Roland Berger

Environment & Resources


3.1 Climate Change & Pollution


3.2 Bio-diversity


3.3 Water


3.4 Resources & Raw Materials

Corporate actions – Let's talk about opportunities arising from megatrends regarding environment and resources (3/3)

Conclusion and corporate impacts

Impact: The clean energy transition will cause demand for commodities to increase, while the long-standing underinvestment in supply continues

Actions

- Companies should develop relationships with multiple suppliers across different regions to mitigate the risk of supply shortages. Additionally, companies can invest in securing long-term contracts with reliable suppliers to ensure a steady flow of necessary commodities
- They should invest in R&D to find alternative materials that can replace scarce commodities without compromising product performance/quality
- Companies should explore the potential of recycling and upcycling materials to reduce dependency on virgin resources
- Companies should adjust their risk management approach, i.e. by setting up hedging units to mitigate fluctuating commodity prices

Impact: A circular economy approach can reduce waste, greenhouse gas emissions, and biodiversity losses

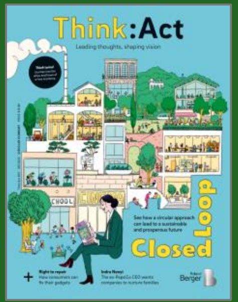
Actions

- Companies should endeavor to transform their entire business to a circular economy approach
- Product design needs to consider and include aspects of repair and remanufacture or recycling options at the end of lifetime of the product. These considerations also apply to all equipment utilized in the value chain: machines, IT infrastructure, office equipment, buildings, etc.
- To close the product loop, companies should make it easy for customers to have products repaired or returned for remanufacturing or recycling, e.g. by offering free returns
- Processes should be re-designed to enable reuse of resources, such as water, for example, and to minimize the use of inputs

Learn how Roland Berger can help you to create corporate impact

Resilient supply chains for raw materials

Think:Act Closed Loop



Source: Roland Berger

Main sources

Megatrend 3 – Environment & Resources

National Oceanic and Atmospheric Administration (NOAA): Science & information for a climate-smart nation. https://www.climate.gov/

IEA: Net Zero Roadmap, 2023 Update. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

WHO: Air pollution. https://www.who.int/health-topics/air-pollution#tab=tab_1

Dasgupta Review: The Economics of Biodiversity. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962785/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

UN Environment Program (UNEP): COP15 ends with landmark biodiversity agreement. https://www.unep.org/news-and-stories/story/cop15-ends-landmark-biodiversity-agreement

UN: Water facts. https://www.unwater.org/water-facts

WHO/UNICEF: Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP). https://washdata.org

USGS: Mineral Commodity Summaries 2024. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024.pdf

European Commission: Study on the Critical Raw Materials for the EU 2023 – Final Report. https://ec.europa.eu/docsroom/documents/54114?locale=en

International Energy Agency (IEA): The role of critical minerals in clean energy transition. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Source: Roland Berger

Authors

Dr. Christian Krys
Senior Expert
Roland Berger Institute
+49 (211) 4389-2917
christian.krys@rolandberger.com

Dr. David Born
Manager
Roland Berger Institute
+49 (69) 29924-6500
david.born@rolandberger.com

Steffen Geering
Senior Specialist
Roland Berger Institute
+49 (211) 4389-2194
steffen.geering@rolandberger.com

Photo credit

Page 1	Richard Whitcombe/Adobe Stock
Page 4	kalafoto/Adobe Stock; Wirestock/Adobe Stock; willyam/Adobe Stock; Lee Prince/Fotolia
Page 38	big to small: chokniti/Adobe Stock; Sergey Novikov/Adobe Stock; flashmovie/Adobe Stock
Page 138	vegefox.com/Adobe Stock
Page 140	vegefox.com/Adobe Stock

Roland
Berger