Enponential Roadmap

EXPONENTIAL ROADMAP

SCALING 36 SOLUTIONS TO
HALVE EMISSIONS BY 2030

2050

VERSION 1.5, 2019.

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Complete citation

J. Falk, O. Gaffney, A. K. Bhowmik, P. Bergmark, V. Galaz, N. Gaskell, S. Henningsson, M. Höjer, L. Jacobson, K. Jónás, T. Kåberger, D. Klingenfeld, J. Lenhart, B. Loken, D. Lundén, J. Malmodin, T. Malmqvist, V. Olausson, I. Otto, A. Pearce, E. Pihl, T. Shalit, Exponential Roadmap 1.5. Future Earth. Sweden. (September 2019).

Published 19 September 2019

This is a co-designed report. We have put together a multidisciplinary team representing academia, business and NGOs – from energy specialists, data modellers, ICT analysts and urban researchers to exponential strategists, journalists, editors, designers and data visualisers. The lead partners of this edition of the Exponential Roadmap are Future Earth, WWF, Ericsson, KTH Royal Institute of Technology, Potsdam Institute for Climate Impact Research, Stockholm Resilience Centre, Sitra, Mission 2020 and Internet of Planet.

Lead partners

Supporting partners


2030
LET'S HALVE
GLOBAL
EMISSIONS BY

“The next few years are probably the most important in our history.”

Debra Roberts
Co-Chair of IPCC Working Group II

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FOREWORD

We need a vision for a world free from fossil-fuels and a pathway to achieve it. As co-chair of the United Nations Climate Action Summit's ambition advisory group I welcome this report because it provides just that.

Our history is defined by momentous societal transformations: the industrial revolution, the women's vote, civil rights, the end of apartheid in South Africa and the Green Revolution. Major leaps forward are driven by disruption from a combination of social movements, government policies, market confidence, new technologies and science.

"Progress must accelerate and governments must drive it. First by declaring a goal of net zero emissions by 2050 at the latest. Then adopting a carbon law pathway to reach the goal."

These five forces are aligning once more. We are at the beginning of the mother of all transformations to stabilise Earth's temperature at 1.5°C. The Fridays For Future movement and Extinction Rebellion have exploded onto the scene in the last twelve months and are changing how we talk about climate. More countries are discussing climate emergency declarations, and goals to reach net zero by 2050 or earlier. Businesses are calling for stronger legislation and investors are demanding climate-risk disclosure. Now zero-carbon technologies outcompete fossil-fuels and this is killing old tech. And finally, science is highlighting the colossal risks of inaction, and the equally huge opportunities from a fast transformation. This will deliver energy and food security, cleaner cities, less pollution, healthier diets and economic growth.

"Meeting the 1.5°C Climate Ambition" is part of the second Exponential Roadmap. Together they articulate how far we have come and how far we need to go. Step by step, they chart how the world can move from incremental to exponential action – doubling the number of companies, cities and countries acting on climate, then doubling again and again. These are the exponential strategies now needed to cut emissions 50% by 2030 or earlier, then doing it again by 2040 and again by 2050. This is the carbon law pathway and you will be hearing a lot about it in these pages.

Along this journey we also need to store more carbon by protecting forests and peatlands and planting more trees on a truly unprecedented scale. We will need to turn agriculture from a source of carbon to a giant store, but this will enhance soils and improve crop yields. And we will need to protect Earth's remaining wildernesses – the oceans and land that safely store half of our carbon dioxide emissions and shelter our biodiversity. This report highlights how:

- About 56% of potential emissions in 2030 could be reduced relatively easily with economically attractive solutions that can scale rapidly. This jumps to 64% if we use promising technologies that are unproven at scale.

- The energy sector has recently reached a tipping point where wind and solar outcompete fossil-fuels in most regions of the world. The end may well be nigh for coal. Oil and gas will not be far behind. Expect the unexpected.
- We should not assume energy demand must keep rising. Energy demand can be reduced a phenomenal 40% while still providing the same quality of life and services as today. What's more, people in developing economies can access the same opportunities.
- And finally, nature-based climate solutions – planting trees and protecting peatlands – have the potential to become vast stores of carbon.

Solutions are scaling fast. More people are demanding healthier diets with lower carbon footprints. Major vehicle manufacturers have announced plans to phase out fossil-fuels from light vehicles and investors are gaining confidence in alternatives to fossil-fuels. But progress must accelerate and governments must drive it. First by declaring a goal of net zero emissions by 2050 at the latest. Then adopting a carbon law pathway to reach the goal.

All this points to the potential for the 2020s to see the fastest economic transition in history. This is the future we all want.

Manuel Pulgar-Vidal
Leader of WWF's global climate and energy practice

I see all evidence that social and economic tipping points are aligning. We can now say the next decade has the potential to see the fastest economic transition in history. The 2019 Exponential Roadmap is an excellent guide for the necessary journey to net zero emissions.

Christiana Figueres
Former head of the United Nations Framework Convention on Climate Change, founder of Mission 2020

The remaining carbon budget for a 1.5°C future is falling 10% each year we fail to act. We should be nervous. But the window of opportunity is still open. While this scale of transformation is unprecedented, the speed is not. We hope the 2019 Exponential Roadmap provides a useful compass.

Johan Rockström
Director of the Potsdam Institute for Climate Impact Research, Germany and co-chair of Future Earth

Every day we get reminders of the urgency of climate action. Our experiences with record temperatures, sea ice melts and widespread wildfires give us a sense of the changes underway. And the science provides an increasingly clear picture of the dangers ahead. This report shows there are solutions for businesses and governments thanks to the combination of science and ingenuity. We have the tools to drive the transformations needed to tackle the climate crisis. Let's use them.

Amy Luers
Executive Director, Future Earth

As a sustainability pioneer, we have been both an advocate of climate action and investing in research and development of climate solutions. We believe leveraging technology, such as digitalisation and 5G, will be fundamental to halve emissions every decade. Ericsson have cut our own emissions by 50% and are working to meet further reductions. We have demonstrated solutions that help make it possible. Now other companies and policy-makers must act to scale demonstrated solutions to enable exponential reduction of carbon emissions globally.

Börje Ekholm
CEO, Ericsson

Understanding where we are and how far we still need to go to tackle climate change, is the foundation for achieving our common exponential action plan. We have the vision, we know what to focus on. Now we need to accelerate the efforts of civil society, business, cities and people and make sure the transition is fair and brings us well-being and a sustainable future. This is the responsibility of us all.

Mikko Kosonen
President, Sitra

All universities have a responsibility to support exponential climate work. KTH Royal Institute of Technology do this through leadership in research, in education and in cooperation with other parts of society. Thus, we are dedicated to stimulating new ways of thinking about society and about how these can support climate targets and the SDGs.

Sigbritt Karlsson
President, KTH Royal Institute of Technology

Food and land-use account for 23% of global greenhouse gas emissions, yet these sectors are often overlooked when it comes to developing mitigation strategies. Shifting unhealthy, unsustainable diets in Western industrialised countries and preventing the transition to Western diets in low income countries is the greatest lever we have in reducing emissions from food consumption, while simultaneously reducing health-care costs and human suffering from malnutrition and diet-related diseases. In addition, agriculture has huge potential for both reducing emissions from land-use and storing carbon. Science is clear. It's now time to act.

Gunhild Stordalen
Founder and executive chair, EAT Forum

This roadmap uniquely focuses on three things. The immediate priorities – reaching peak emissions in 2020 and racing to cut emissions in half by 2030. How we scale the new low-carbon solutions exponentially and how we need to think in terms of systems transformation of the whole economy. We must now reach a critical mass of countries, cities, companies and citizens with the new compass direction to enable a virtuous circle of change. Then it is achievable.

Johan Falk
Exponential Roadmap co-lead author and programme manager, Internet of Planet, senior innovation fellow Stockholm Resilience Centre and Future Earth

The world is a long way off the pathway we need to be on. But the roadmap shows that we can achieve this goal.

Owen Gaffney
Exponential Roadmap co-lead author, Stockholm Resilience Centre and Potsdam Institute for Climate Impact Research

EXECUTIVE SUMMARY

- The 2019 Exponential Roadmap focuses on moving from incremental to exponential climate action in the next decade. It presents 36 economically-viable solutions to cut global greenhouse gas emissions 50% by 2030 and the strategies to scale this transformation.
- The roadmap is consistent with the Paris Agreement's goal to keep global average temperature "well below 2°C" and aiming for 1.5°C above pre-industrial levels.
- The 2019 roadmap is the second in the series. Each new roadmap updates solutions that have proven potential to scale and charts progress towards exponential scaling. The roadmap, based on the carbon law (see box) is a collaboration between academia, business and civil society.
- The roadmap is complemented with a high-ambition narrative, *Meeting the 1.5°C Ambition*, that presents the case why holding global average temperature increase to just 1.5°C above pre-industrial levels is important. Since the first roadmap, the Intergovernmental Panel on Climate Change (IPCC) published its special report on 1.5°C. The report concluded that the economic and humanitarian risks of a 2°C world are significantly higher than 1.5°C.
- The remaining emissions budget for 1.5°C is small, and will be exceeded within ten to fifteen years at current emission rates. The window of feasibility is closing rapidly.
- The global economic benefit of a low-carbon future is estimated at US$26 trillion by 2030 compared with staying on the current high-carbon pathway.
- The scale of transformation – halving emissions by 2030 – is unprecedented but the speed is not. Some cities and companies can transform significantly faster.
- Developed nations with significant historic emissions have a responsibility to reduce emissions faster.
- Greenhouse gas emissions, and the solutions to reduce them, are grouped by six sectors: energy, industry, transport, buildings, food consumption, nature-based solutions (sources and sinks).
- Meeting the 1.5°C goal means implementing solutions in parallel across all sectors.
- The solutions must scale exponentially. The roadmap identifies four levers required to scale the transformation as well as necessary actions for each: policy, climate leadership and movements, finance and exponential technology.
- Implementation must be fair and just or risk deep resistance.

The carbon law pathway

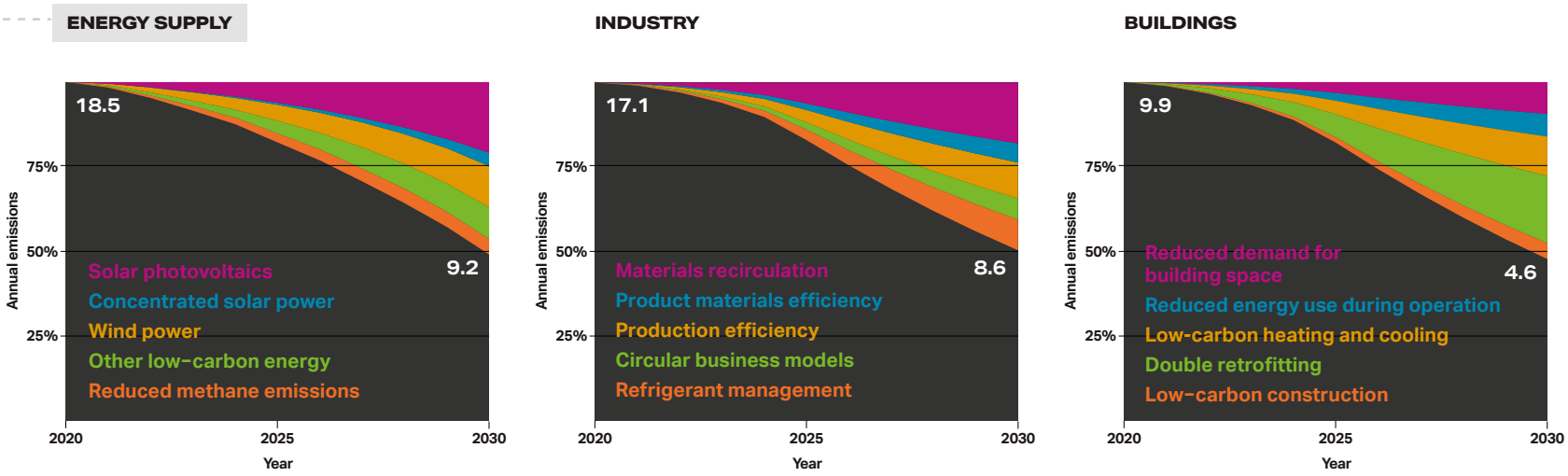
We need Moonshot Thinking and exponential strategies inspired by Moore's Law* to reach the Paris Agreement's ambitious goal. The carbon law trajectory**, first proposed in 2017, is consistent with the UN agreement and the limited remaining carbon budget:

- Emissions peak by 2020.
- Emission fall about 50% by 2030, then a further 50% by 2040, and a further 50% by 2050.
- Agriculture transforms from a carbon source to a carbon sink.
- Solutions to store carbon, for example reforestation, biochar or bioenergy with carbon capture and storage, are scaled up.
- Remaining natural carbon sinks are protected and enhanced.

*The observation that computing power doubles approximately every two years.

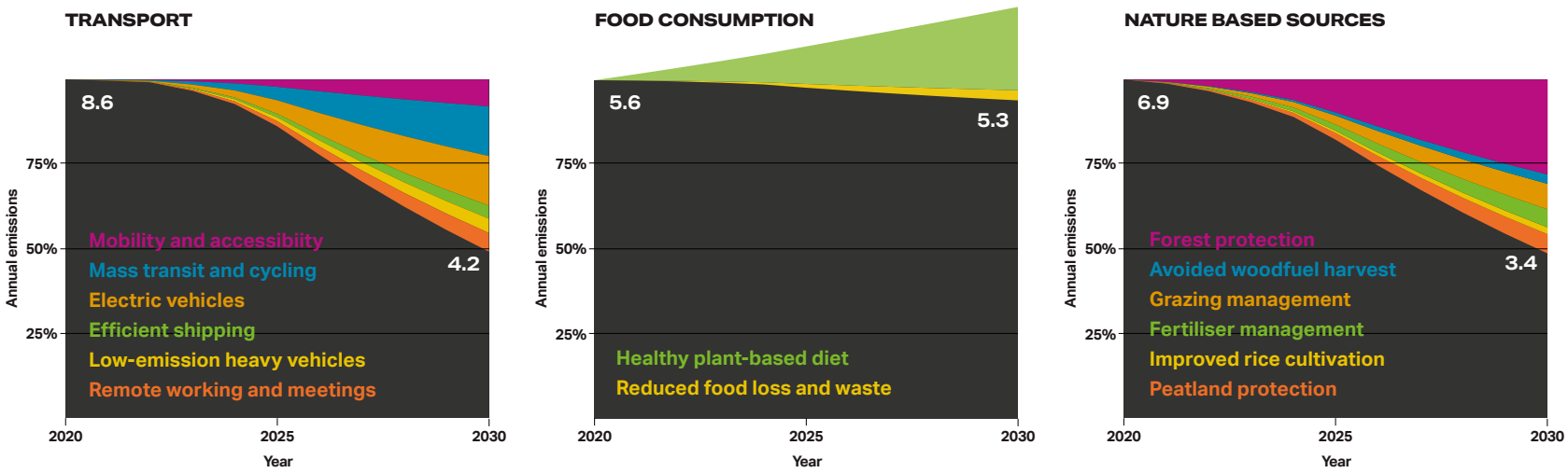
**J. Rockström et al., A roadmap for rapid decarbonization. Science 355.6331, 1269-1271 (2017).

Exponential Roadmap: 36 solutions to cut greenhouse gas emissions 50% by 2030



TOTAL EMISSIONS (Billions of tonnes of CO_2e, baseline year 2020)

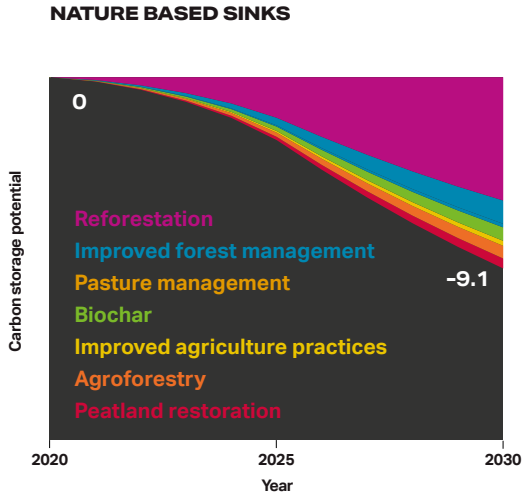
6.1	5.3	6.2	0.2	0.3	0.3
ENERGY'S OWN EMISSIONS	INDUSTRY	BUILDINGS	TRANSPORT	FOOD CONSUMPTION	NATURE-BASED SOURCES
6.1	17.1	9.9	8.6	5.6	6.9



Sectoral roadmap to halve emissions by 2030

Proposed trajectories for greenhouse gas emissions to peak in 2020 and approximately halve by 2030 (y-axis shows the sector's annual % emissions). Each trajectory shows the overall sector emissions and the relative contribution to emissions reductions from existing scalable solutions, for example, solar photovoltaics or electric vehicles, plus nature-based sinks (right) that sequester greenhouse gases. The number inset in each trajectory indicates emissions in 2020 and 2030 respectively in billions of tonnes (Gt) of CO_2e per year for each emitting sector, and the storage potential for nature-based sinks. A global shift to more healthy plant-based food can prevent the increase in emissions caused by population growth and reduce emissions from the food sector 5% by 2030. Nature-based sources can avoid emissions of 3.5 Gt CO_2e by 2030 and new nature-based sinks can store 9.1 Gt CO_2e by 2030.

The grey bar to the left shows the relative contribution of emitting sectors for the assumed 2020 baseline emissions of 54 billion tonnes of CO_2e, i.e. it is including food and nature-based emission sources but excluding nature-based sinks. The Energy supply trajectory addresses both the energy sector's own emissions (6.1 Gt) and emissions related to providing electricity and heat to other sectors (e.g. industry and buildings) with distribution visualised by the fields above the grey bar.



TRANSFORMING SECTORS

Energy transformation

- Any further investment in new carbon dioxide-emitting energy systems is not consistent with the remaining carbon budget for 1.5°C global warming.
- In 2018 renewable energy accounted for almost two thirds of new installations for electricity generation. Solar and wind energy accounted for 84% of this growth. The world has reached a tipping point in price and performance for wind and solar power. In many places wind and solar are cheaper than fossil-fuel alternatives.
- The assumption that global energy demand will keep rising should be questioned. Global energy demand has the potential to fall 40% without sacrificing services and quality of life according to new energy scenarios. These scenarios bring the ambitious goal of halving emissions by 2030 within reach.
- Not hindering the current exponential trajectories for wind, solar photovoltaics and battery storage will be enough to achieve a halving of emissions by 2030. In less-developed markets, however, support is still needed to reach a point where solar and wind energy can be supplied at lower costs than fossil-fuels.
- Policies to remove obstacles and ensure a rapid and smooth transition from fossil to renewable energy include immediate removal of subsidies from fossil-based power plants and infrastructure, introducing carbon pricing, and minimising the social and economic impact on individuals who lose out in the transition.
- With the right policies and financing, many cities could achieve an electrical grid mix of 50–70% renewables (primarily solar and wind, balanced with other zero-emission generation sources) by 2030.
- Investment and research in new zero-carbon energy storage and generation technologies, such as wave power, must be sustained to achieve the reductions necessary beyond 2030.

Transport

- Shorter trips are responsible for three quarters of transport emissions. Taking these emissions to around zero is economically viable and brings many co-benefits from healthy lifestyles to less polluted cities.
- Electrical and plug-in hybrid passenger vehicles can reach close to 100% of new sales by 2030 if they continue on high current exponential growth curves, even if growth slows from today's growth of 50% per year to 32%. This shift towards 100% of light vehicle sales to electric vehicles is the biggest immediate opportunity to dramatically reduce emissions in the transport sector. The snowball has started rolling in last few years with many major economies and cities announcing incoming bans on new fossil-fuelled light-duty vehicles as well as corporates committing to 100% electric vehicles.
- Mass transit, micromobility (cycling, scooters) and walking to avoid unnecessary car use is the other major opportunity to dramatically reduce emissions in the transport sector by 2030.
- A strong move to a usership instead of ownership model for cars can untap more value from cars, which are unused 95% of the time. Such a car fleet could be just 3% of the size of today's fleet of individually owned vehicles.
- Digital technology can cut business flights by 50% or more. Local co-working hubs can reduce commuting emissions by around 50–60% annually for many people.
- Heavy transportation can be optimised, retrofitted, electrified and use renewable fuels enabling a fast halving of emissions. Long-haul transport requires ambitious technology road maps.
- Halving emissions from shipping is technically feasible and economically viable with the right policy incentives and collaboration across the maritime industry and stakeholders.

Industry

- In most places energy and emissions efficiency standards are too weak. Stronger policies can drive dramatically higher material efficiency, particularly with steel, cement, plastics and aluminium production. Decarbonisation of high-emission materials might not add more than a few

percent in cost to end users. An increase in near-term R&D investment in those industries will be vital to enable the deep decarbonisation required for the second and third halvings.

- Develop and scale the infrastructure required for the circular economy and accelerate reuse of materials through refunding schemes, increased scrap collection and recycling rates.
- All manufacturing businesses and industries should set ambitious targets to aim to halve emissions by the latest 2030 and there is a need to develop industry roadmaps across all sectors and value chains aligned with 1.5°C, creating a race to the top between companies.
- Physical retailers and e-commerce platforms should develop strategies to incentivise low-emissions products, recycling and longer product lifetimes.
- Digitalisation is a key enabler to increase energy and material efficiencies, and enable circular economy and usership-based business models. The Internet of Things allows greater traceability of materials and products, while artificial intelligence can optimise processes for efficiency. Industrial design, engineering and architecture should increasingly adopt low-emissions options as default.

Buildings

- For countries, cities and companies, strong policies and programmes to halve carbon emissions in existing building stock are necessary. These solutions must scale rapidly.
- New procurement practices for construction and renovation are required. These should require dramatically improved energy and carbon emission standards.
- A critical mass of companies in the construction and facilities management industries must become true climate leaders, driving emissions cuts through value chains and setting an example for others to follow.
- New low-carbon business models for sharing space and smart buildings must scale globally to achieve economies of scale.
- Businesses must be open to new economic models that take advantage of the sharing of space.
- Funding should be allocated for sustainable retrofitting and construction, perhaps through the use of green bonds.
- Solutions in this sector should be standardised and scalable around the world – rather than dispersed and fragmented – to achieve results.

Food consumption

A rapid shift towards reduced meat consumption (plant-based diets) and reduced food waste are essential components of a systematic strategy to keep global warming well below 2°C. This will be accelerated through:

- Removal of subsidies promoting unsustainable and unhealthy food production and consumption and new incentives for healthy and sustainable practices and behaviour.
- Carbon pricing and supportive emission standards for the food system.
- National dietary guidelines promoting healthy and sustainable eating and policies enacted to make healthy food affordable and accessible to everyone.
- Regulatory measures in place to drastically reduce food loss and waste.

Nature-based solutions

In 2018/2019 several major academic assessments on food system transformation were published, for example the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems. These findings are now included in the roadmap. For these reasons, the 2019 roadmap expands on nature-based solutions, for example reforestation and peatland management, to create new carbon sinks.

Nature-based solutions, from forest protection, grazing management and fertiliser management, can halve emissions by 2030, while reforestation, biochar and improved agricultural practices have the potential to store up to 9.1 billion tonnes of CO_2e annually, eventually storing 225 billion tonnes by the end of the century.

SCALING THE TRANSFORMATION

Four exponential levers will scale the transformation.

Policy and political momentum

- The global economy is undergoing long-term structural changes: emissions have peaked in 49 countries. This is likely to continue and it is likely to accelerate. Emissions in 18 developed countries have been falling for over a decade, but the rate of decay is too slow.
- The political response to the IPCC 1.5°C special report has been surprisingly swift. The UK and France join a growing number of countries with laws to reach net zero by 2050 or earlier. More than 20 countries are discussing or have agreed a net zero 2050 target and climate and nature emergencies have been declared in 717 cities, municipalities and states.
- A carbon price, though often too low, now covers territories representing 20% of emissions. At the same time, large subsidies support the fossil-fuel industry.
- In the recent European Union elections, voters in several major economies decisively moved towards parties with strong climate policies.

Policies to scale a just transformation include:

- Introduce national targets to reach net zero emissions by 2050 with sub-targets to halve emissions by 2030 or earlier.
- Develop national sectoral roadmaps and supporting policies and strategies that reflect this ambition while safeguarding vulnerable groups and all planetary boundaries.
- Price carbon emissions at a sufficient level.
- Remove fossil-fuel subsidies and revolutionise agricultural subsidies.
- Strong efficiency and emissions standards and policies that drive innovation towards low-energy demand and decarbonisation.
- Climate action integrated into technology strategies and accelerate digital, circular and sharing economies.
- Incentivise behaviour towards low-carbon consumption.
- Promote nature-based solutions.

Climate leadership

- Climate leaders among cities, businesses, housing communities, and individuals should demand 100% renewable electricity and explore investing in their own renewable energy production.
- More than 200 cities have committed to 100% renewable electricity with target years between 2020 and 2050. More cities should adopt initiatives such as the WWF One Planet City Challenge to become net zero by 2050 and halve emissions by latest 2030.
- Social movements demanding large-scale action to address climate change are growing. The Fridays For Future strikes by schoolchildren are public displays of anger, frustration and disbelief among children that current political inertia will mean they inherit a dangerously destabilised climate. These movements are expanding to include people of all ages.
- More than 630 major companies are adopting Science Based Targets to reduce emissions. However, just 15% of Fortune 500 companies have targets aligned even with a 2°C world. A strategy for scaling is urgently required so, by 2020, all Fortune 500 companies adopt climate targets aligned with the carbon law and disclose carbon assets, emissions, and climate risks and opportunities.
- Media engagement in the climate crisis is changing. The media and political language is shifting from a neutral “climate change” or “global warming” to “climate emergency” and “climate crisis” in recognition of the record-breaking flooding and drought events, and scientific progress.

Finance

- Investors are recognising climate risk. Over 160 companies overseeing US$86 trillion in assets support the G20's Task Force on Climate Related Financial Disclosures (TCFD).

- 34 central banks recently joined forces to ensure a smooth transition to a low-carbon economy: the Network for Greening the Financial System (NGFS). This network, including the Bank of England and the Banque de France, represents half of global greenhouse gas emissions.

- The divestment movement continues to grow. Organisations with investments of US$10 trillion have committed to divesting from fossil-fuels.

Exponential technology

- The digital sector is responsible for just 1.4% of global emissions, but has an outsized influence on the exponential transformation to halve emissions by 2030 because digitalisation will disrupt all parts of the global economy in the next decade.

- Digital services have potential, tenfold their footprint, to reduce energy and materials across the economy and could directly enable a third of the emissions reductions needed by 2030. We urgently need to explore how the digital industry can enable societal goals beyond the industry's narrow footprint. This report explores some of these possibilities.

- Exponential technologies risk driving emissions upwards as digital platforms improve behavioural prediction to drive consumer demand of unsustainable products and services. Moreover, social media platforms can help climate advocacy and engagement. However, they are also designed to accelerate the spread of emotionally charged information including disinformation – algorithmic propaganda. This is contributing to a rise in national populist movements that are often hostile to climate policies, international cooperation, and even science. The most significant risk from the digital revolution may not be artificial intelligence or biotechnology – it might be the inability for consumers and citizens to distinguish between fact and fiction.

This summary provides a flavour of the solutions and how to accelerate them. Much analysis lies behind it. Make sure to browse the whole report to get the full picture and start implementing it. This is a race we can and must win.

ABOUT THIS REPORT

The first Exponential Climate Action Roadmap was produced for Global Climate Action Summit in September 2018 where it was presented as the opening keynote by Christiana Figueres and Johan Rockström. It was based on an analysis published in *Science*, "A roadmap for rapid decarbonisation",[1] showing that peaking emissions in 2020, and approximately halving every decade to 2050 is consistent with delivering the Paris Agreement on climate change. This was further emphasised by the IPCC 1.5°C Special Report released in November 2018.[2]

This new version of the report, Exponential Roadmap 1.5, explores further how the carbon law can be implemented across all sectors of the global economy to limit climate change to 1.5°C above pre-industrial levels. While the end goal is 2050, it focuses on the road to 2030 – the first halving – and concludes that while solutions exist, the scale of transformation requires system-wide action accelerated by climate leadership, much stronger policy, finance and exponential technologies.

The roadmap represent a continuous development effort using agile methodology. It will require ongoing and rapid iteration following feedback, new evidence and up-to-date information. For example, in this version of the report, solutions and trajectories have been refined and updated from the first version based on the recent reports from the Intergovernmental Panel on Climate Change,[2,3] the EAT-Lancet Commission,[4] and the recently published "LED scenario" (low energy demand).[5]

Values and models, including allocation between supply and demand side solutions, will be continuously updated based on new research, methods and data. We encourage any analysis to accelerate this process.

Navigating this report

The report consists of three main blocks: "Meeting the 1.5°C ambition", "Transforming sectors" and "Scaling the Transformation".

The first block summarises the climate situation and highlights the challenges and required actions ahead of us. The second presents the decarbonisation trajectories of sectors such as energy, industry and transport – and 36 solutions to halve or reduce emissions in line with the carbon law. The third block covers the key accelerators or drivers required to scale the solutions exponentially; policy, climate leadership, finance and exponential technologies.

Data, model and analysis

The report looks to approximately where the world needs to be in 2050 to limit global warming to a maximum of 1.5°C. A range of solutions are explored and their maximum potential for reducing and sequestering emissions are evaluated. Then the report works backwards to estimate the journey that could take the economy to this destination by implementing the solutions focusing particularly on the first step to 2030. It marries this with current data and trends, for example the exponential market growth of photovoltaics, wind power and healthier diets.

The solutions database is predominantly drawn from Project Drawdown[6] and research and reports from the Finnish future fund Sitra,[7] Roadmaps for Fossil Free Sweden competitiveness (Fossilfritt Sverige), the International Energy Agency (IEA) and the World Wide Fund for Nature (WWF) Climate Solver and Mission Innovation Framework.[8] Several solutions are updated based on the "LED scenario".[5] You can find a full description of the methodology and assumptions used to create the trajectories found in this report online at **www.exponentialroadmap.org**.

The “Food consumption” and “Agriculture and forestry” chapters from the first version (called “Food consumption” and “Nature-based solutions” in this version) have undergone a major update based on the recently published EAT-Lancet Commission report.

This more detailed modelling concludes that 50% reduction of the food sector´s emissions by 2030 would not be realistic given projected population growth and significant burdens of malnutrition in many countries. For this reason the report reflects a drawdown of the food sector’s emissions from 5.6 Gt to 5.3 Gt by 2030 (and to at least 5 Gt, the planetary boundary for food,[4] by 2050) through a shift in diets in mainly Western industrialised countries while preventing a nutrition transition to Western diets in many developing countries.

The nature-based solutions are drawn from many recent studies and reports outlined in the chapter. Solutions for reducing emissions and sequestering emissions are now presented separately.

Assumptions in this report

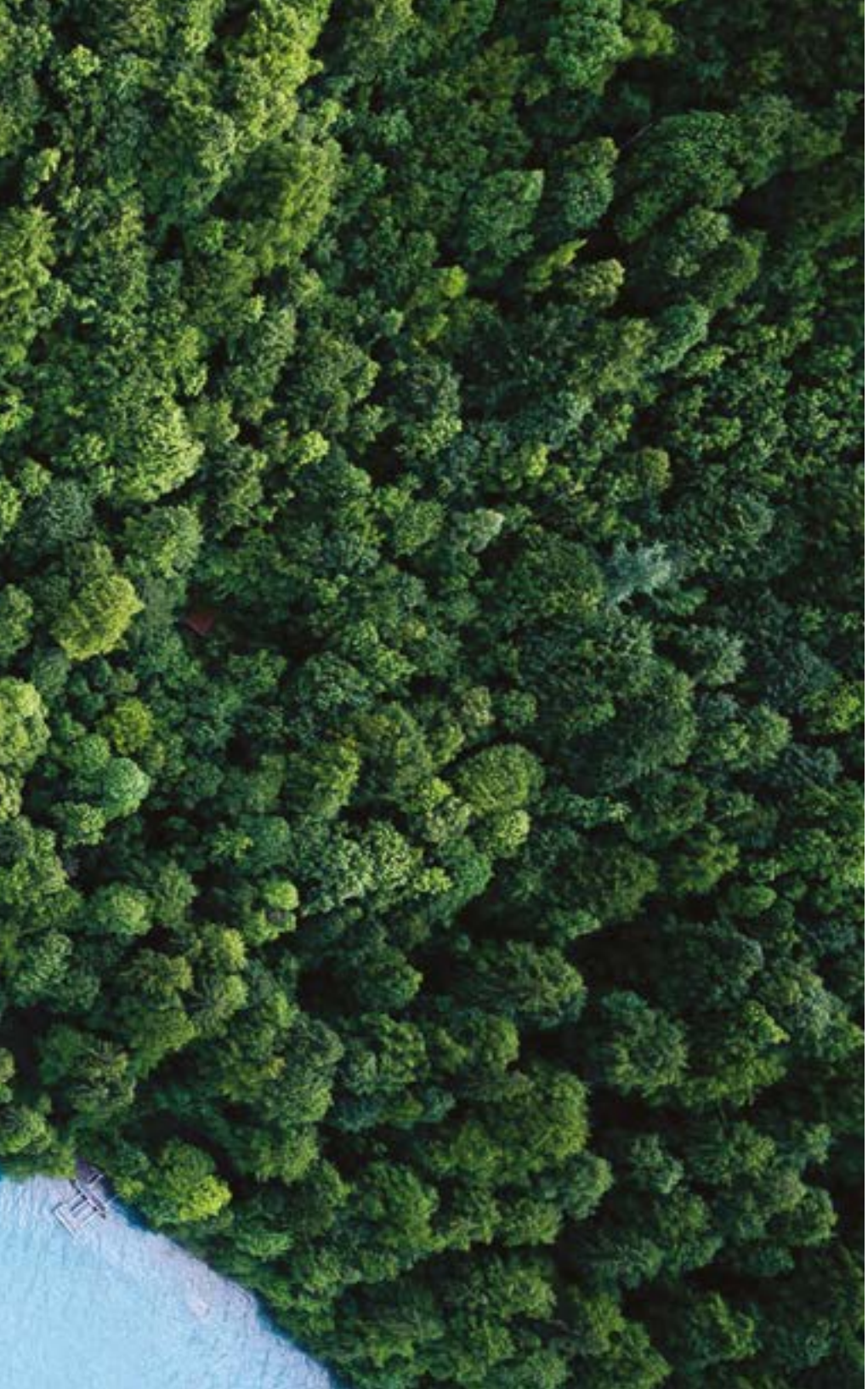
The global emissions of greenhouse gases were estimated at 54 billion tonnes (Gt) of CO_2 equivalents in 2018,[10,11,12] which is used as the baseline. These 54 Gt are distributed among six sectors addressed in the report, as described in the diagram on pages 12 and 13. The basic principle is that we allocate emissions to one sector and address it in that sector only. For instance, emissions from gasoline combustion in cars is allocated to only the transport sector. However, in the case of energy, both demand and supply solutions are very important, so emissions from electricity and heat production are addressed in both the supply sector (energy sector) and demand sectors and emissions are distributed accordingly.

In order to achieve rapid decarbonisation to 2030, global primary energy demand should be reduced, in line with the LED scenario.[5] This is achieved by efficiency gains in energy conversion, in industry, transport and buildings. In our scenario we assume electricity consumption to be flat in 2020–2030 as increasing electrification and number of end-users counteracts efficiency gains and savings elsewhere.

Digital view of the exponential roadmap

The data from this report is open, and can be combined with other roadmaps and planning tools. We use a digital tool, developed by ClimateView, to develop and visualise roadmaps – the tool is also being used by the Swedish government to map policy and action to reach a fossil-free economy by 2045. We have adapted the tool to track the carbon law trajectory of halving emissions every decade. For more information, see the “Open data” chapter of this report.

MEETING THE 1.5°C AMBITION



Climate change is now affecting people on all continents and the impacts are becoming more severe. Scientific evidence shows that humanity is taking grave risks with the stability of Earth's climate system if global average surface temperature continues rising alongside ecological destruction. Reducing this risk means societies working together to stabilise temperature rise at around 1.5°C. This translates to halving greenhouse gas emissions every decade from now on to approach net zero emissions by 2050.

Achieving a 1.5°C planet will require the fastest economic transition in history. This transformation is both necessary and achievable. The journey has already begun. Here we chart the actions needed immediately and in the next decade to accelerate the transformation towards a safe operating space for humanity.

Meeting the 1.5°C Ambition began in 2015 when 197 nations forged the Paris Agreement and the Sustainable Development Goals (SDGs). The Paris Agreement created a global consensus to limit Earth's temperature rise to "well below 2°C", and "to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels", in order to safeguard world development and human wellbeing.

In 2015, nations invited scientists to assess the impacts of 1.5°C global warming and provide pathways to achieve this goal. In 2018, after two years of intense effort, the Intergovernmental Panel on Climate Change (IPCC) concluded that a 1.5°C world would be substantially better for societies than 2°C. The assessment also concluded that stabilising temperature at around 1.5°C is feasible, the cost would be affordable and that achieving it brings many other substantial benefits for the economy, ecosystems and human wellbeing.[1]
The cost of weak action setting course for a planet over 3°C warmer – which is the current trajectory – will be catastrophic for many societies. Based on the findings of the report we conclude that we face a planetary crisis: the need to act is urgent and failure to act in time and at scale brings existential risks.

The IPCC 1.5 Special Report and other recent research firmly conclude that stabilising temperature at 1.5°C above pre-industrial levels is essential and will require an extraordinary transformation of lifestyles, behaviours, norms and values in our society.

Three levers are essential for large-scale systems change:

1. A new worldview. We face unprecedented planetary risks where exponential action is necessary to stabilise Earth's climate.

2. A global goal. We need to reach net zero greenhouse gas emissions by 2050 to stabilise global average temperature at 1.5°C above pre-industrial levels. This can and should be achieved equitably and without compromising other Sustainable Development Goals.

3. A just pathway. We must aim to cut global greenhouse gas emissions in half by 2030 – or sooner – then halve them again by 2040 and reach net zero by 2050 – a pathway called the carbon law.[2]

Countries have already committed to meeting Nationally Determined Contributions (NDCs) under the Paris Agreement, but these must be significantly enhanced to meet a 1.5°C goal. The NDCs are far too weak to meet even the 2°C target. Immediate and ambitious targets for countries, cities and companies, backed up with actions, are now essential to cut emissions 50% by 2030 or sooner.

It will take colossal efforts to redirect investment towards clean energy, shift production and consumption towards low-carbon solutions, and forge broad political support to make this transformation a reality. However, the means to achieve these goals already exist.[3] With ambitious leadership based on the best science the next decade can bring the fastest economic transformation in history.

You are here

Despite tremendous improvements in some low-energy technologies in the last decade, in 2018, global emissions grew an estimated 2.7%.[4] A major economic transformation, though, may be underway, and visible in the plateauing of emissions between 2014 and 2016 (see figure 1). In the energy sector exponential improvements in cost and performance are already disrupting old business models. Solar and wind power are now the same price or cheaper than electricity from coal in most places even without accounting for the health and environmental impacts of fossil-fuels.[5] Prices are tumbling as small-scale, distributed clean energy networks innovate and roll out faster than large-scale fossil-fuel infrastructure. Similar transformations in other sectors – transport, agriculture, buildings and industry – are visible, too.

Yet, technology alone will not solve the climate crisis. Technological innovation helped cause the problem in the first place and, undirected, it could simply drive us towards a catastrophic 3°C world. Policies to reverse this trend are needed. So too are policies to change the behaviour of markets and people. For example, fossil-fuel subsidies currently outstrip all investment in renewable energy globally. In 2018, fossil-fuel subsidies reached over US$400 billion, a level not seen since 2014, according to the International Energy Agency.

The Exponential Roadmap focuses on the actions needed to reach the short-term goal of peaking emissions as soon as possible and halving emissions by 2030. The presented solutions, which must be implemented in parallel, are based on academic research and expert assessment of their potential to scale exponentially and create virtuous cycles, like those in the technology industry, where improvements in performance and price drive higher value.

The roadmap presents one among many potential pathways. Reality will unfold with many twists and turns. Whichever path societies take will require exponential action to transform our global economy if we are to increase prosperity and well-being for the most people globally.[6,1] The roadmap necessarily focuses on mitigation. Unavoidable climate change will require adaptation and resilience building but this is not the focus of this report.

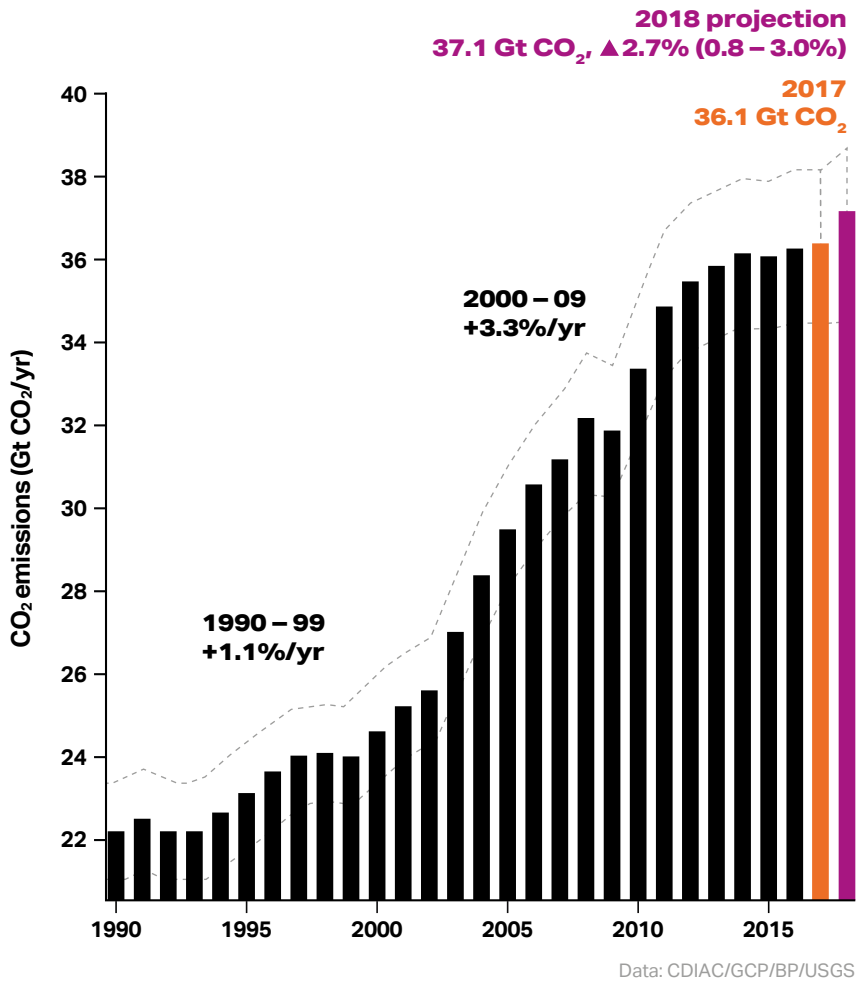


Figure 1. Global fossil-fuel and cement emissions 1960–2018

After a three-year hiatus with stable global emissions, CO_2 emissions grew by 1.6% in 2017 and were estimated by the Global Carbon Project to have grown a further 2.7% in 2018 (range: 1.8%–3.7%). Estimates for 2019 emissions remain uncertain but similar strong growth appears likely because the persistent expansion of oil and natural gas use and solid growth projected for the global economy, according to the Global Carbon Project. Data: Global Carbon Project (2018)[4]

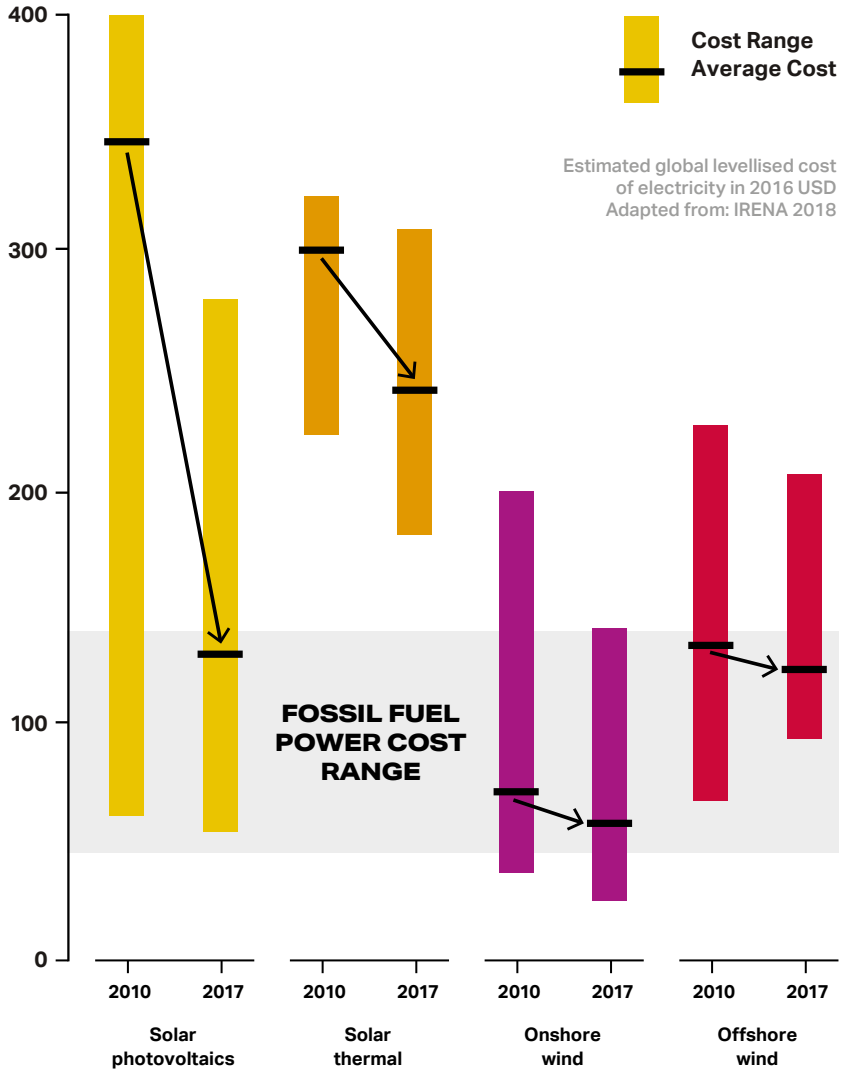


Figure 2. Price drop in solar and wind power since 2010

The dramatic fall in costs of wind and solar energy in the last decade has reached a tipping point where prices increasingly are lower than many fossil-fuel alternatives. Source: Irena Renewable Cost Database.[5]

THE SCALE OF THE CHALLENGE

IN NUMBERS

197	The number of parties that have signed the UN's Paris Agreement on climate change.
185	The number of countries that have ratified the agreement.
The probability of exceeding 2°C based on what countries have promised to do.[7]	**90%**
The probability of exceeding 2°C based on what countries are actually doing.[7]	**97%**
16	The number of countries with national laws consistent with their emissions reduction pledges.
8	The number of countries with legislation or proposed legislation to reach net zero emissions by 2050*.
The growth in carbon dioxide emissions from fossil-fuels and cement in 2018.[4]	**2.7%**
The years left until emissions need to peak for the world to stand a much better chance of reaching the 1.5°C target.	**0**

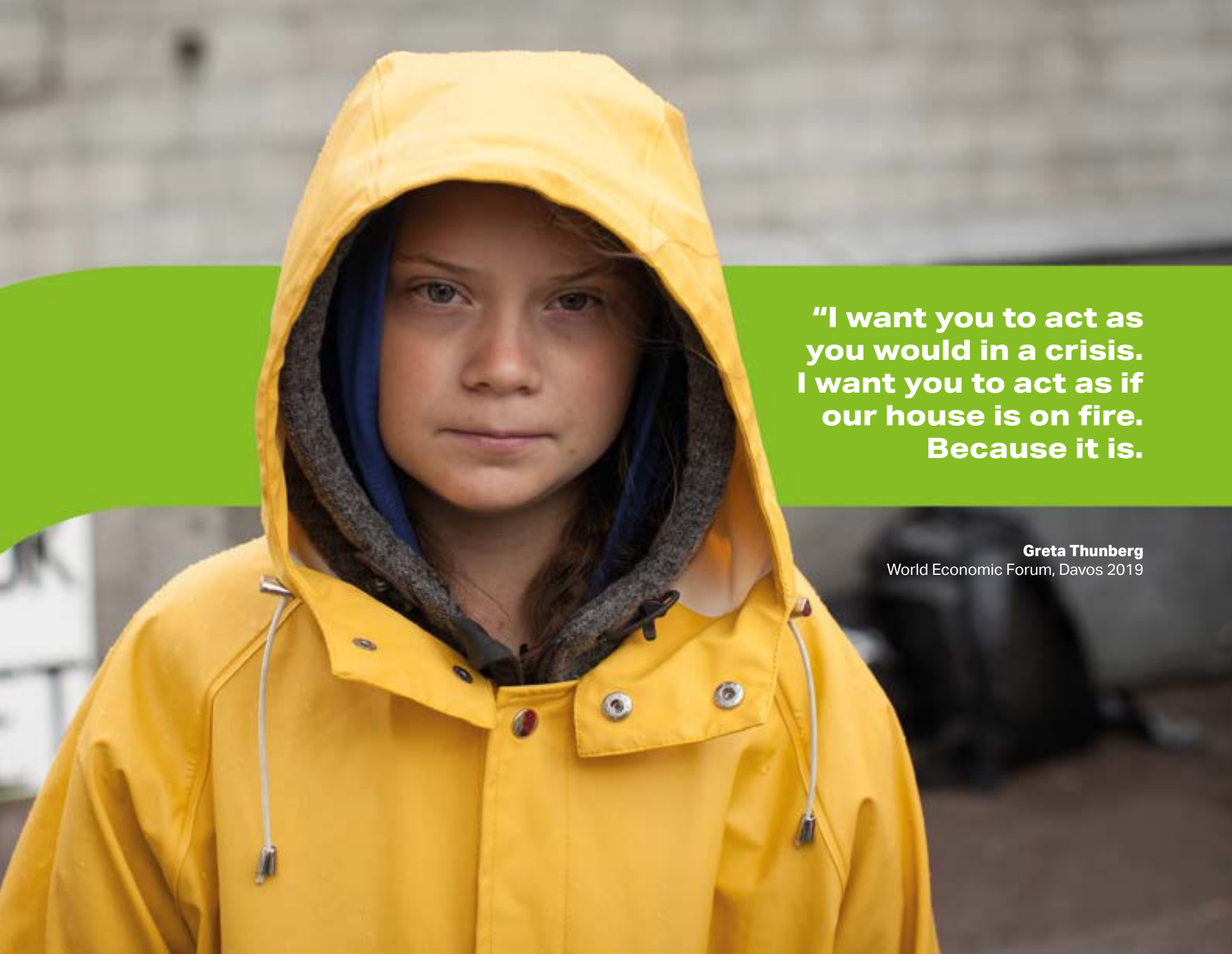
*Legislation includes options to purchase carbon credits to reach these targets.

A NEW WORLDVIEW: OUR PLANET ON THE EDGE

In January 2019, Swedish student Greta Thunberg told world leaders at the World Economic Forum "I want you to act as you would in a crisis. I want you to act as if our house is on fire. Because it is." Every child's birthright, and our common heritage is a stable, resilient planet. This birthright is now at risk.

From the unparalleled heat-waves across the northern hemisphere in 2018 and 2019 to Cape Town's "Day Zero" water crisis, to this year's hottest summer on record in Australia, to an unprecedented cyclone in Mozambique that created an "inland ocean" overnight, climate-related natural disasters are now assailing our planet.

Modern societies arose during a 10,000-year period of remarkable climatic stability on Earth, known as the Holocene. Earth has left the Holocene and entered the Anthropocene where industrialised societies are the prime driver of change to Earth's life support system. Earth's temperature has now topped 1°C above pre-industrial temperatures – an unprecedented leap in human history. The impacts are already more severe than most researchers estimated a decade ago. The temperature is rising almost 0.2°C every decade and the rate is accelerating. In October 2018, the Intergovernmental Panel on Climate Change (IPCC) concluded that the impacts of a warmer world are – and will be – significantly worse than previous estimates. In a 2°C world we can expect increased water stress, food security challenges, summer sea ice regularly disappearing in the Arctic and near-total loss of existing warm-water corals, impacting livelihoods. Limiting warming to 1.5°C rather than 2°C could result in 420 million fewer people being exposed to severe heatwaves.



“I want you to act as you would in a crisis. I want you to act as if our house is on fire. Because it is.

Greta Thunberg
World Economic Forum, Davos 2019

Hothouse Earth

In 2018, researchers warned that going beyond 2°C – which is very likely based on current emissions trajectories – could potentially trigger natural processes to drive uncontrollable warming and pushing the planet towards a "Hothouse Earth" state about 4°C above preindustrial temperatures.[8] If temperatures rise much further than today, major ice sheets are likely to destabilise (there is evidence this may be underway), causing sea levels to eventually rise 20 metres or more, bringing constant flood risks to coastal cities from Miami to Mumbai. Food security will be severely threatened and many parts of the planet will become uninhabitable due to the extreme heat. Earth has not been this warm in over three million years.

This risk arises due to tipping points in the Earth system. These relate to, for example, the dieback of boreal forests and Amazon rainforest or permafrost melting, both of which store vast quantities of carbon. If these tipping points are crossed it could lead to the release of additional carbon into the atmosphere, making climate stabilisation significantly more challenging. The problems are compounded though, because research also indicates that crossing one tipping point can create a domino effect making it more likely other tipping points are crossed. Due to these complex feedbacks, a "Hothouse Earth" scenario is plausible even if greenhouse gas emissions from human sources are reduced dramatically. There is strong evidence to suggest that these feedbacks are unlikely to be triggered if temperature rise remains below 2°C.[9]

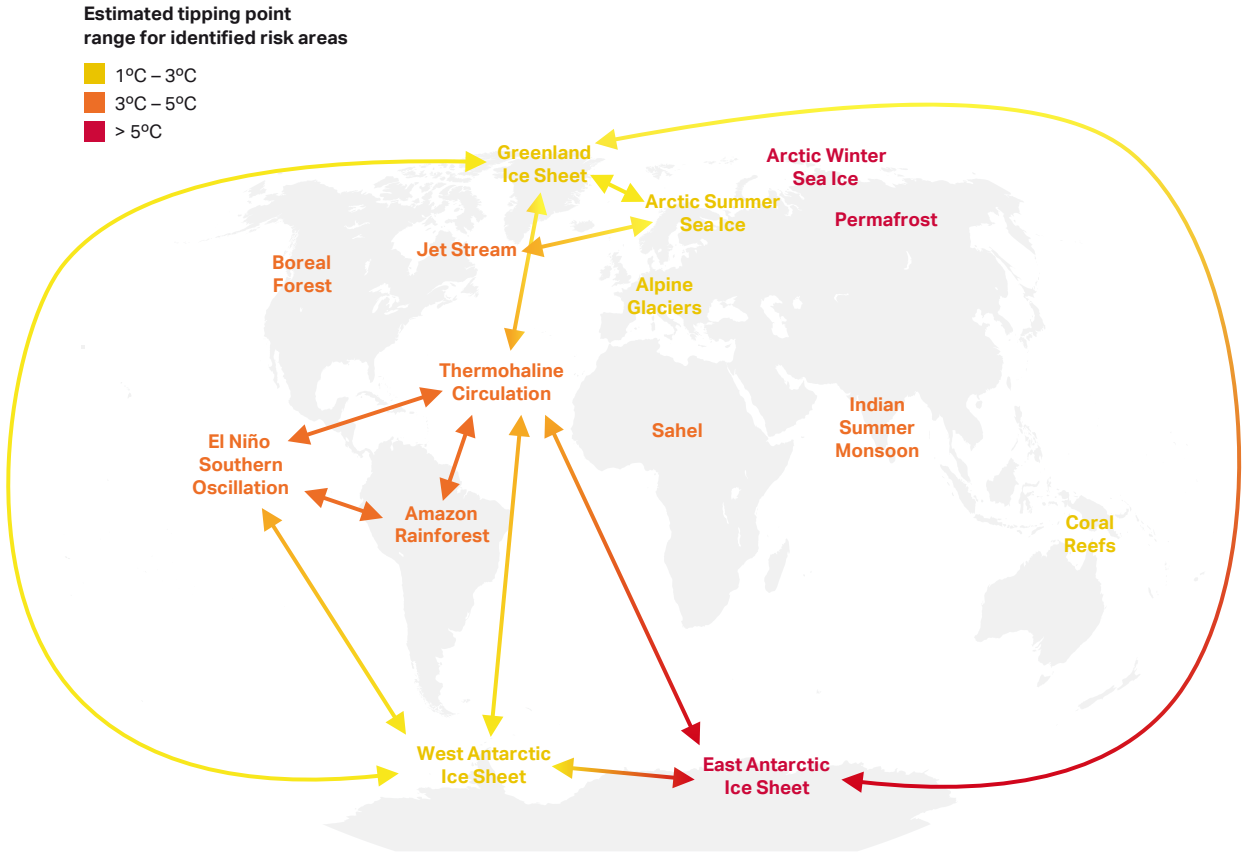


Figure 3. Earth's tipping points

Map of the locations of potential large-scale tipping points, the estimated temperature ranges of the tipping points and potential interactions between tipping points. Crossing one tipping point can increase the risk of crossing another (PNAS 2018 Steffen et al.[8])

Existential threats

Climate change threatens people's lives and livelihoods, and the most vulnerable are disproportionally affected. For communities on low-lying Pacific Islands, as well as people living in towns and cities along exposed, low-lying costs, climate change is an existential threat. Even if emissions disappeared tomorrow, sea levels will keep rising for centuries. Climate change is also an existential threat to people eking out a living on marginal lands and expanding deserts. It is an existential threat to once-fertile farmlands that feed millions of people. And it is an existential threat to stable societies the world over as droughts, floods, migration and food crises exacerbate conflicts. The IPCC's Fifth Assessment Report concludes, "From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing poverty traps and create new ones, the latter particularly in urban areas and emerging hotspots of hunger." This is supported by Philip Alston, UN special rapporteur on extreme poverty and human rights. Alston recently raised the concern that the world is at risk of "climate apartheid" where the rich pay to avoid devastating consequences of climate while the poorest suffer: "Climate change threatens to undo the last 50 years of progress in development, global health, and poverty reduction."[10]

On top of this, human activities are placing increasing strain on Earth's ecosystems, reducing their resilience to absorb shocks from human impact. About 12% of all species are now threatened with extinction.[11] This creates huge threats to fishing grounds and coral reefs, to Arctic habitats and rainforests, and to many other ecosystems which support the fabric of our economies and societies. Warmer waters led to mass bleaching events in the Great Barrier Reef in 2016 and 2017 that killed almost half of the coral across wide swaths of the reef.[12] In 2019, deforestation in the Brazilian Amazon has reached a rate of at least three football pitches a minute, weakening the role the forest plays in stabilising the climate.[13]

Above: People take refuge on the roofs of buildings following flooding caused by Cyclone Idai in Mozambique.

Changing our language to communicate the risk

More people and organisations are changing the language they use to describe climate change. Increasingly, phrases such as "climate and nature emergency", "climate crisis", "climate breakdown" or "global heating" are being used by the United Nations, the UK's Met Office, the Guardian newspaper and others. The evidence now supports this change in language.

Likewise, phrases such as "business as usual" or "current trends" should increasingly be viewed as problematic descriptions of future economic pathways because their blandness masks climate disruption. Updating the language used must reflect the need to support just and safe transformations.

THE GOAL: NET ZERO BY 2050

There may still be time to stabilise Earth's temperature at around 1.5°C without recourse to very large-scale and high-risk geoengineering deployment. But the window is closing rapidly. Limiting temperature rise to 1.5°C will require unprecedented action in four areas: Global greenhouse gas emissions must be drastically reduced, peaking now and reaching net zero by 2050 at the latest. Farming and other land use must move to become stores of carbon rather than emitting greenhouse gases. We need large-scale reforestation and forest, wetland and peatland management to protect the resilience of vital Earth systems. Finally, we must develop and scale robust solutions for storing carbon safely.

The IPCC 1.5 report concludes that this is achievable: "These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors." Wealthier nations, with large historic emissions, have a responsibility to set tougher targets. Norway has set a target of net zero by 2030. Finland has set 2035 and Sweden 2045 to reach net zero for emissions within their jurisdictions. It should be noted though that these targets often include purchase of carbon credits.

A rapid transition to 1.5°C world will bring strong co-benefits in terms of prosperity, health, security and economy. Heatwaves will be less frequent and the number of people at risk of water stress reduces by 50% compared with 2°C. The number of premature deaths is estimated to be lower by 100–200 million people in a 1.5°C world compared with 2°C.[1] The economic benefit of a low-carbon future by 2030 is US$26 trillion compared with staying on the current high-carbon pathway.[14] The UK Committee on Climate Change, for example, estimates the direct cost of achieving net zero emissions by 2050 is just 1–2% of the UK's GDP.[15] This estimate does not cover significant avoided costs and indirect benefits. On the flipside, the estimated losses due to stranded assets (worthless pipelines, coal mines and oil wells) is up to US$4 trillion if weak policies in the next decade slow down climate progress.[16]

Greenhouse gas emissions from existing and proposed energy infrastructure – coal-fired power plants under construction or commissioned, for example – represent more than the entire carbon budget remaining to limit warming to 1.5°C with a probability of at least 50%, and perhaps two thirds of the remaining carbon budget if warming is to be limited to less than 2 °C.[17]

Most computer model scenarios to achieve climate stabilisation at 1.5°C rely on so-called negative emissions technologies (NETs) to remove between 400 and 1000 billion tonnes of carbon dioxide from the atmosphere, or 20–50% of the CO_2 emitted in the last 200 years.[18] While the world will likely need to deploy a range of NET solutions, for example Bioenergy and Carbon Capture and Storage (BECCS), these technologies are controversial. They have never been attempted at large scale, they are expensive and carry the risks of serious unintended consequences. At a minimum, BECCS, for example, will require a trade off between growing energy crops and growing food. It will place huge demands on freshwater and fertilisers and conflict with biodiversity goals. Given the grave risks of over-reliance on untried technologies, these should be deployed as an insurance policy, not the primary solution. But, as the remaining carbon budget dwindles, they will become increasingly necessary.

“We will move to a low-carbon world because nature will force us, or because policy will guide us. If we wait until nature forces us, the cost will be astronomical.”

Christiana Figueres
Convener of Mission 2020. Executive secretary of the UNFCCC from 2010 – 2016 and directed the Paris Agreement of 2015

THE PATHWAY: HALVE GREENHOUSE GAS EMISSIONS EVERY DECADE

The goal of reaching net zero emissions by 2050 translates to an exponential pathway of cutting greenhouse gas emissions in half every decade: 50% by 2030, then 50% again by 2040, then 50% again by 2050. At the same time farming and land use must shift from emitting greenhouse gases to storing them and we need to scale up solutions to store carbon. We call this pathway the "carbon law".[2] The carbon law is an exponential trajectory inspired by Moore's Law in computing where computing power doubles and costs halve every few years.

Reaching net zero emissions by 2050 will not be simple. But as this roadmap shows, solutions already exist in all economic sectors to halve emissions by 2030, as a stepping stone to the ultimate goal. The solutions are described in detail in the sector specific chapters. The key strategies are to markedly improve efficiencies in energy and material usage, reduce demand for energy intensive activities, electrify as much as possible, and produce that electricity from renewable energy sources. The United Nations Environment's Emissions Gap report estimates that existing, market-ready solutions can cut greenhouse gas emissions by more than 50% by 2030.[19]

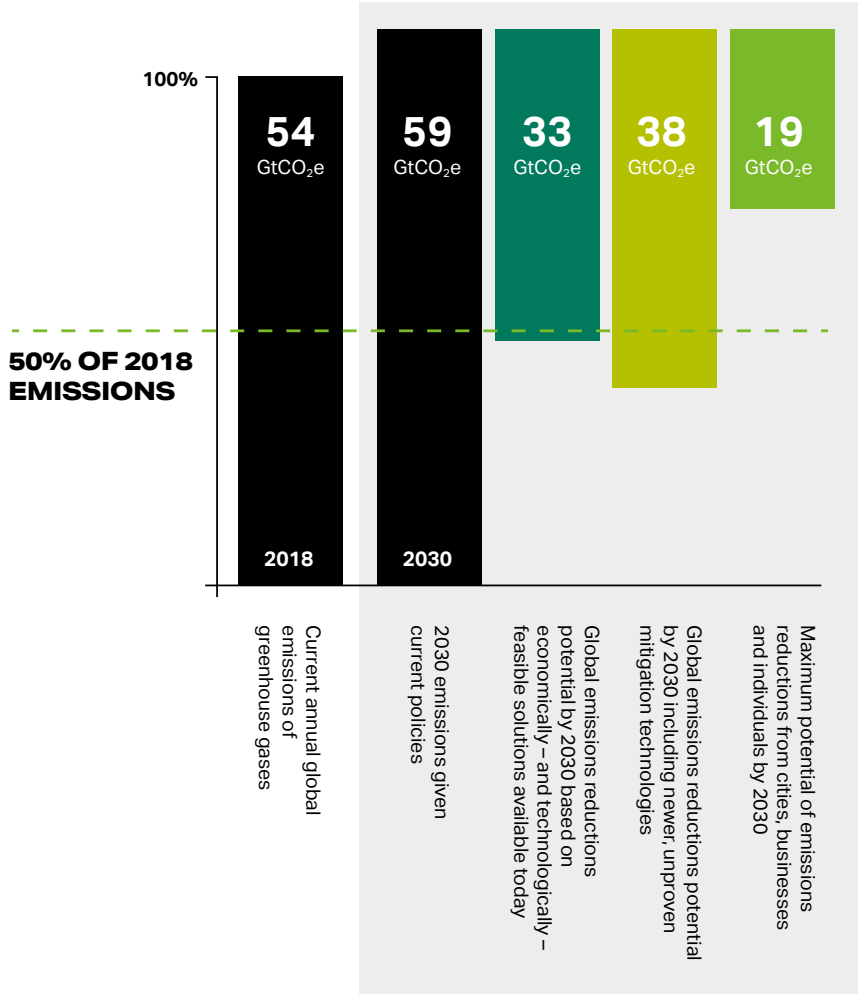


Figure 4. Emissions reduction potential

Sectoral emission reduction potentials that are technically and economically feasible in 2030 based on carbon pricing up to US$100/tCOe. The assessment shows that global emissions could be reduced by 33 $GtCO_2e$/year in 2030, compared to the current policy scenario of 59 $GtCO_2e$/year based on existing market-ready solutions and behavioural change. Data: UNEP Emissions Gap Report 2018.

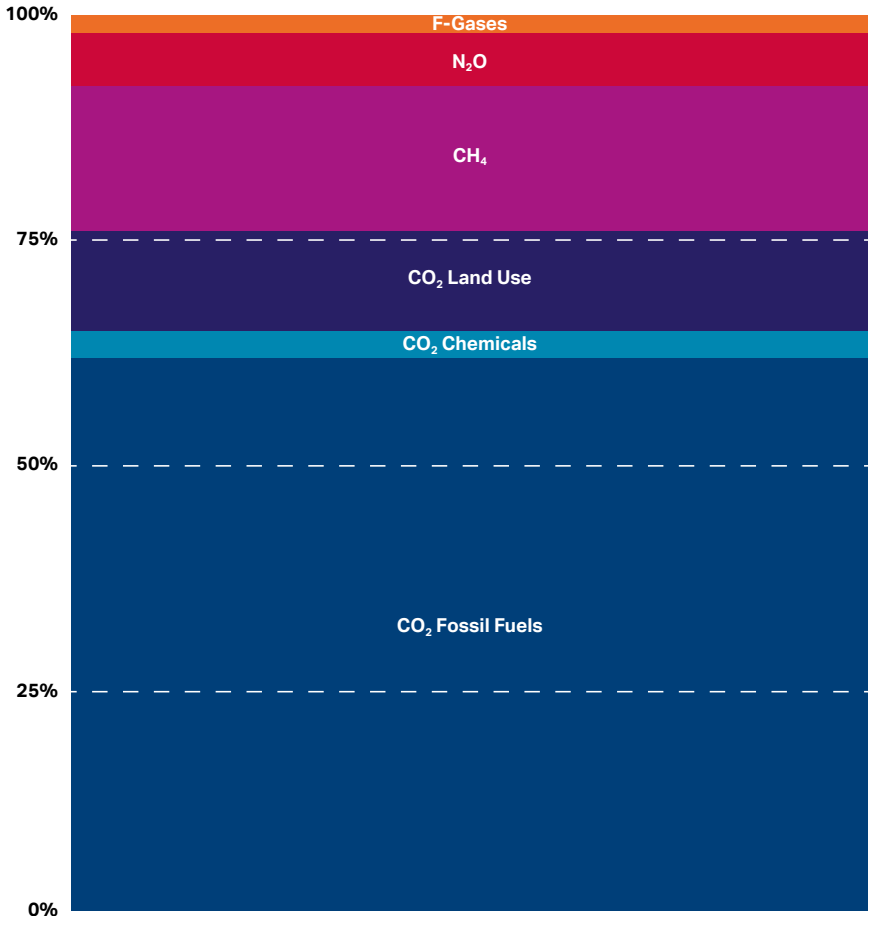


Figure 5. Greenhouse gas emissions

Carbon dioxide is the primary greenhouse gas emitted by human activities. Unlike other greenhouse gases, it affects the climate system for thousands of years. Methane (CH_4) is 28–36 times more powerful as a greenhouse gas than carbon dioxide and emissions today last about a decade in the atmosphere. Nitrous oxide (N_2O) is more powerful still (265–298 times the warming potential of CO_2) and lasts a century in the atmosphere. Fluorinated gases (F-gases) also have a greater warming potential than CO_2 and last thousands of years in the atmosphere. Data: Environmental Protection Agency and Project Drawdown.

"We are already at the start of this pathway. In the last decade, the share of wind and solar in the energy sector doubled every five years. If doubling continues at this pace fossil-fuels will exit the energy sector before 2050."

Johan Rockström
Director Potsdam Institute of Climate Impact Research

Difficult to decarbonise sectors

Some economic sectors are more difficult to decarbonise than others, including aviation, shipping, long-distance transport, cement and steel production. These account for about 27% of global CO_2 emissions from all fossil-fuel and industrial sources (~9.2 Gt CO_2).[20] Investments in R&D in the 2020s will be essential to ensure market-ready solutions exist to halve global emissions a second time from 2030. However, reducing demand for these products will also play a critical role in sustaining a carbon law pathway. (See the following pages: Seven strategies central to the 'low energy demand' scenario).

Some major companies are taking substantial strides to tackle these hard-to-reach sectors. For example, truck company Scania has published a roadmap to become net zero by 2050. The world's largest shipping company, Maersk, has committed to becoming 100% carbon neutral by 2050. And cement company Dalmia aims to be carbon negative by 2040. In Sweden, the steel industry is planning to have the first commercial scale zero-emissions steel plant, using hydrogen fuel, operational by the early 2030s. Since 2017, Oslo has required that municipal construction projects are fossil free and a commissioned study showed that almost all construction site emissions could be eliminated in the city by 2025.

The UK's Committee on Climate Change estimates that reducing greenhouse gas emissions by 96% by 2050 is feasible but reducing emissions in certain hard-to-reach sectors – from aviation and shipping to manufacturing and industrial processes – will likely require significant scaling-up of electrification, hydrogen, carbon capture and storage, and other low-carbon solutions.

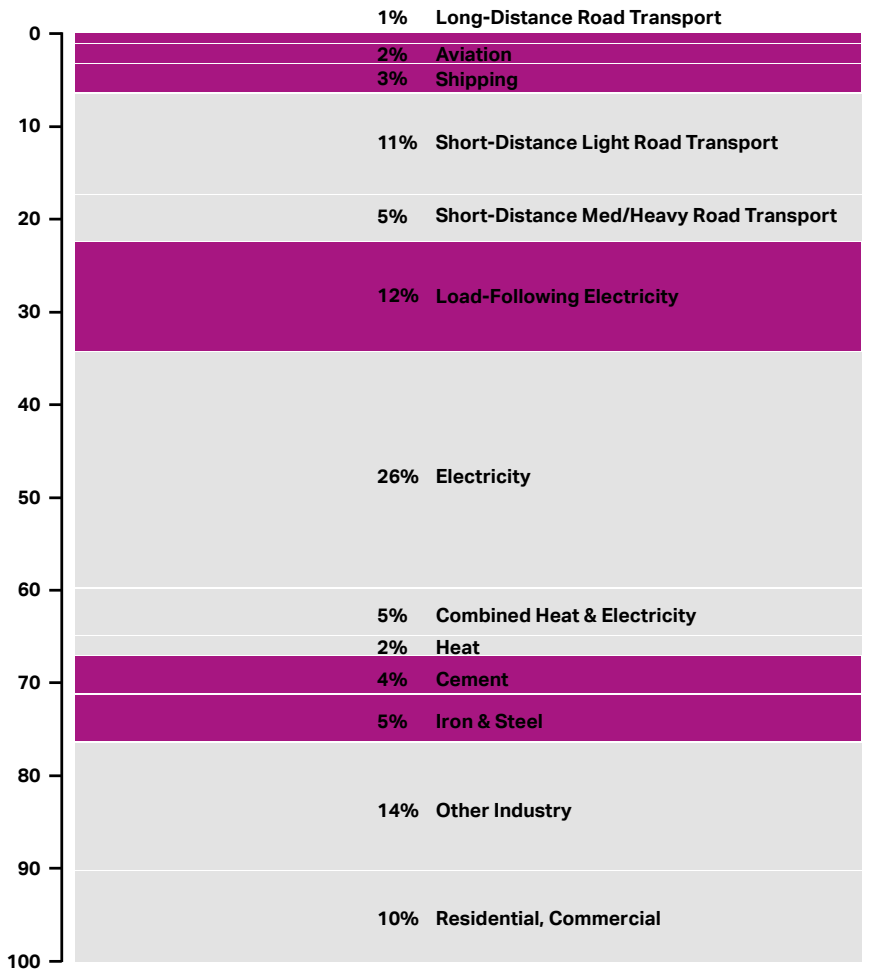


Figure 6. Hard to decarbonise sectors

Global fossil-fuel and industry emissions by sector based on 2014 data (total 33.9 GtCO_2). Industrial sectors that are hard to decarbonise are marked in purple and sectors that are easier to decarbonise in grey (graphic based on data from reference 20).*

**Percentages may not add up to 100% due to independent rounding.*

Dramatically reducing energy demand

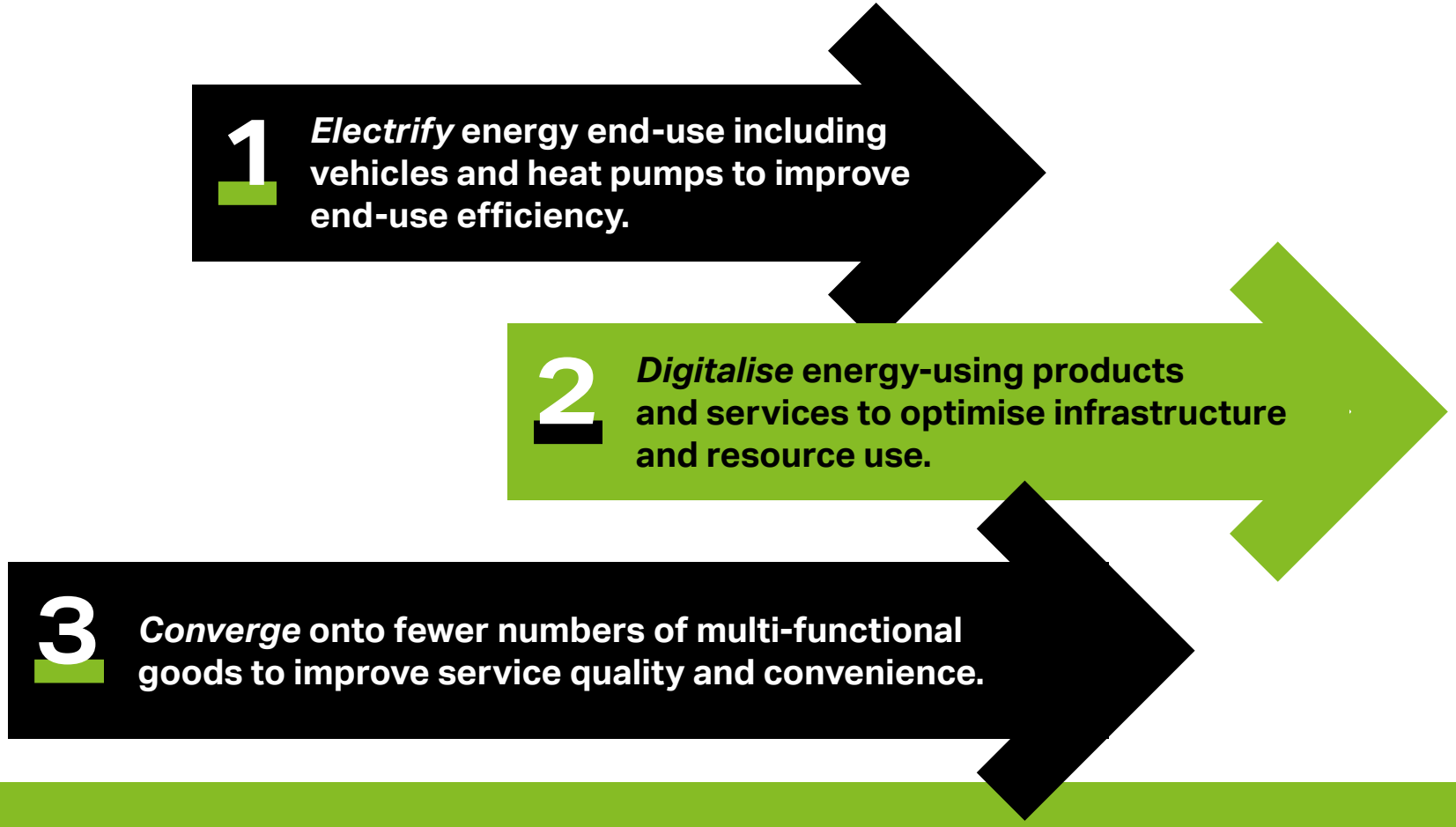
In recent years, researchers and policymakers have overwhelmingly focused on how to decarbonise the energy supply in order to meet climate goals. In contrast, the recent 'low energy demand' study showed how reducing energy demand can deliver a 1.5°C climate while supporting global health, education, poverty, employment and food security goals.[23]

In the 'low energy demand' scenario, global consumption of energy is 40% lower in 2050 than it is today. Seven strategies are at the heart of this energy demand transformation (pages 28–29). Each strategy is founded on examples of best practice from pioneering countries, cities, neighbourhoods, consumers, service providers, and research organisations around the world:

- Countries like Chile, Japan and France which have used standards and codes to continually ratchet up the energy and material efficiency of buildings and consumer goods.
- Cities like Vienna, Montreal and Sydney which have integrated shared mobility providers into their municipal transport infrastructures.
- Neighbourhoods like Pecan Street, Brooklyn and North Portland which have provided living labs for new peer-to-peer business models for electricity trading, tool sharing, and product exchange.
- Consumers who have reduced meat consumption, or who are no longer interested in car ownership or even driving.
- Service providers like Nest and Phillips which have developed smarter, lower-energy systems for heating and lighting homes.
- Research organisations like the International Transport Forum which have shown how flexible on-demand 'taxi-buses' can deliver urban mobility needs with less than half the CO_2 emissions and close to zero congestion.

Digitalisation and electrification are common themes of the 'low energy demand' scenario as they support the efficient provision of useful services like mobility and thermal comfort. They are also enablers of the emerging shift in consumer culture away from owning things and towards accessing services. This shift has already happened in how we consume media, and is now starting to reshape how we use and consume transport services, consumer goods, and building space. The ubiquitous smartphone is the multi-functional device which – if it continues to displace the need for dozens of single-purpose devices (from radios and TVs to music systems and cameras) – could deliver 100-fold reductions in power consumption when in use or 30-fold reductions when on standby.[23]

SEVEN STRATEGIES CENTRAL TO THE 'LOW ENERGY DEMAND' SCENARIO



The central insight of the low energy demand scenario is that dramatically downsizing the global energy system by scaling-up tried and tested solutions brings the decarbonisation challenge well within the reach of available low-carbon energy technologies. If renewables continue to grow at their current double-digit annual rates to 2030, and then at 5-10% per year to 2050, the low energy demand scenario removes any need to rely on carbon capture and storage as well as negative emission technologies. The energy supply diversifies rather than relentlessly expands, and fossil-fuels are phased out.

4 ***Shift*** **from ownership to usership to reduce material needs.**

5 ***Utilise*** **consumer goods, vehicles and physical infrastructures at higher rates to accelerate the introduction of improved alternatives.**

6 ***Innovate*** **business models offering low-energy services to appeal to consumers while making sense commercially.**

7 ***Tighten*** **efficiency standards continually upwards to deliver cost, performance, health and other benefits.**

SCALING THE SOLUTIONS

The next pages introduce the most important levers accelerating the transformation. All of these are presented in greater depth in the section Scaling the Transformation

"We need to step up ambition quite radically. We are not talking about a small incremental approach."

Luis Alfonso de Alba
United Nations Secretary General's envoy on climate change

More ambitious country targets and policies

The IPCC 1.5°C report has sparked a first wave of action among nations to legislate for targets to reach "net zero" as soon as possible, and at the latest by 2050. Progress is promising, but must spread to other countries rapidly.

- Eleven countries in the European Union are now discussing a 1.5°C target for their economies.
- Norway, Finland, Sweden and the UK have now agreed targets to reach net zero emissions by 2030, 2035, 2045 and 2050 respectively. Developing countries like Costa Rica and Fiji have declared they will be carbon neutral by 2050.
- In 2018, Portugal's CO_2 emissions fell 9% and Ireland's dropped 7%, while their economies grew.
- In 2019, the UK and Ireland declared climate emergencies. In 2018, Ireland announced plans to divest its national investment fund from fossil-fuels – the first nation to make this commitment.

Emissions have peaked and are now decreasing in 49 countries (accounting for 36% of global greenhouse gas emissions).[21] In 18 developed countries (representing 28% of global emissions), CO_2 emissions declined at an average rate of 2.4% per year between 2005 and 2015.[22] These sustained declines in CO_2 emissions are associated with concerted policy efforts to support renewable energy and switch away from carbon-intensive fuels, improve energy efficiency and reduce energy demand.

These positive examples do come with caveats. These modest declines occurred during the global financial crisis when economies slumped and the rise in emissions slowed globally. Most of the progress to date has been made in the energy sector. Other economic sectors – food, transport, buildings and industry – have not been sufficiently addressed, so transforming these sectors would result in significantly faster emissions declines. Moreover, country legislation to reach net zero by 2050 often allows purchase of carbon credits. Ultimately, this creative accounting must go: countries must actually reach net zero.

This is a critical moment in international policy. In 2020, nations are required to raise their climate ambition and declare this through enhanced Nationally Determined Contributions (NDCs) under the Paris Agreement. Such pledges must aim for net zero by 2050 and pathways in line with carbon law. This greater ambition must be combined with coherent policy to accelerate the pace of change to ignite and accelerate rapid system transformation. Policies should support low-carbon solutions while discouraging carbon-intensive processes and lifestyles.

Policies that support a rapid transition to a 1.5°C world include:

- Remove fossil-fuel subsidies and revise agricultural subsidies.
- Establish a price for carbon at a sufficient price level, and apply it globally.
- Ensure that national decision-making, budgets, tax systems and technology strategies are aligned with a 1.5°C world.
- Develop sector-wide roadmaps in energy, transport, buildings, food, agriculture and industry to halve carbon emissions by 2030 and reach net zero by 2050.
- Legislate for higher standards on emissions, efficiency and performance across all industries and accelerate the next generation zero/low-carbon solutions.
- Set stop dates for fossil-fuel extraction and use.
- Connect technology strategies to climate strategies, allowing for mutual reinforcement.
- Adopt and accelerate circular, digital and sharing economies, directed towards decarbonisation.
- Incentivise a shift in behaviour towards healthy diets, cycling and public transport.
- Promote nature-based solutions including the creation of carbon sinks and enhance biodiversity.
- Ensure climate policies are fair – protecting vulnerable communities without violating planetary boundaries.

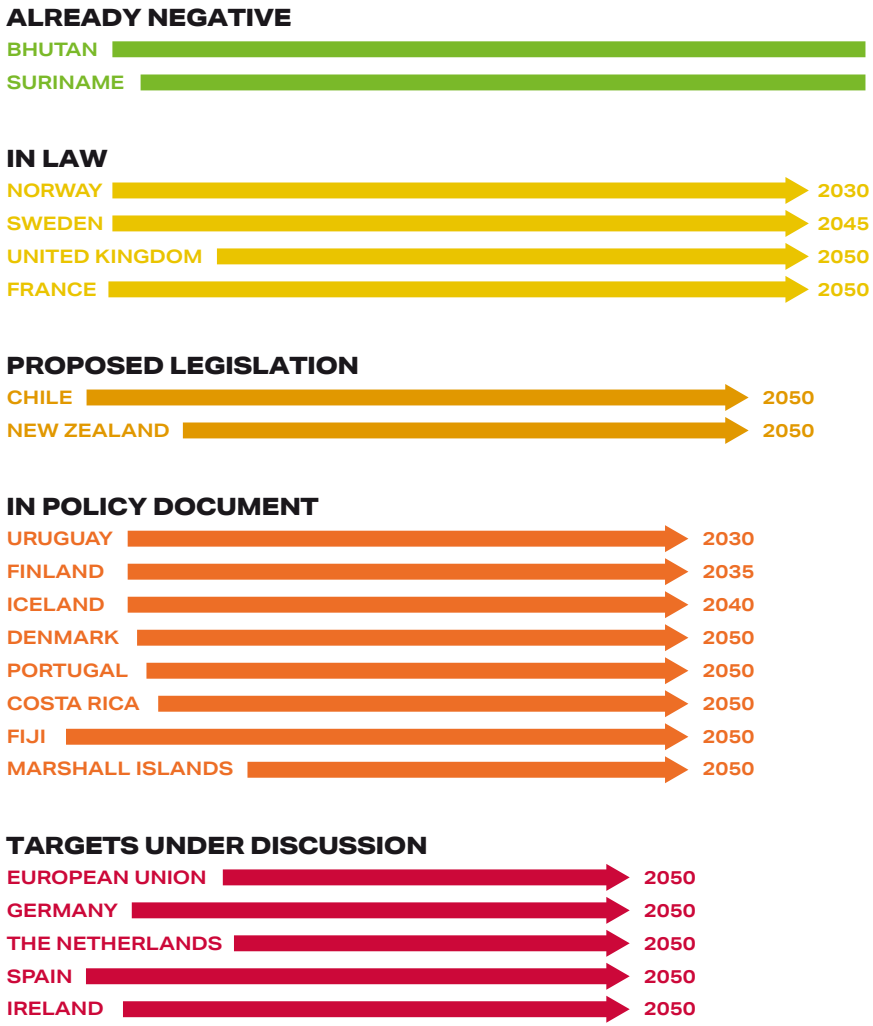


Figure 7. Momentum towards net zero by 2050

More countries are discussing high-ambition policies to reach net zero emissions by 2050 or earlier. While this is a positive step, many rely on purchase of carbon credits. In addition to the countries listed, other countries are discussing "Green New Deals" for example the United States, though cross-party political acceptance is likely to prove challenging. Data: adapted from the Energy and Climate Information Unit.

Leadership and movements

Cities, companies and citizens have a critical role to drive momentum to accelerate the solutions required to follow the carbon law pathway. Cities and companies have direct control over about 35% of greenhouse gas emissions. Policymakers can work with these groups to nurture engagement with climate action. In the last 12 months there has been a step-change in public action on climate, as well as city, company and investor momentum. But this needs to expand further and faster to reach the critical mass with the high climate ambition required.

"The youth are sending a clear and unmistakable message: This is an emergency."

Patricia Espinosa
Executive Secretary, United Nations Framework Convention on Climate Change

Citizen movements

In early 2019, fuelled by growing anger and frustration at those in power reneging on their promises and responsibilities to tackle climate disruption, schoolchildren walked out of school to strike in cities around the world. The students describe climate change as an emergency and have demanded policymakers set stronger targets. The root cause of the school strikes is intergenerational inequity – the costs of stabilising Earth's climate will be borne by the next generation if deep cuts are not made immediately. For the first time, we now have a voice for future generations.

The movement is having a noticeable impact and has the potential to be a significant tipping point in social attitudes to climate action. The secretary general of OPEC, Mohammed Barkindo, has said that the growing mass mobilisation against oil is beginning to "dictate policies and corporate decisions, including investment in the industry".[24]

Research shows schoolchildren strongly influence parental attitudes[25] indicating that the new movement may begin to challenge existing societal norms. Moreover, the school strikes reflect a perceptible shift in worldviews. According to a recent 26-nation survey by the Pew Research Centre, people around the world agree that climate change poses a severe risk to their countries. In 13 of those countries, people listed climate change as the top international threat, above Islamic terrorism, cyberattacks and Russia.[26]

Cities

Cities are concentrations of human ingenuity, and for the 1.5°C revolution they must be engaged. 70 cities now receive over 90% of their energy from renewable sources.[27] Indeed, on their own, cities and other subnational entities have the power to reduce greenhouse gas emissions by about one third by 2030, according to one scenario.[19]

Many cities are using their political might to work together to drive up ambition.

- 9,138 cities (representing 10% of the global population) have made climate commitments to the Global Covenant of Mayors.
- 23 cities, including nine African cities, have already set net zero targets for 2050 or sooner.


BE A PART OF THE
SOLUTION
NOT A PART OF THE
POLLUTION
WARUM FÜR EINE
ZERSTÖRTE
ZUKUNFT
LERNEN?
STOP
WASTING
OUR FUTURE
SAFE
SAVE OUR
WORLD


141
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- At least 230 cities have set a 100% renewable goal in at least one sector.[27]
- More than 200 cities representing 62 million people in Europe have demanded the European Union adopts a net zero by 2050 policy.
- 221 cities have accepted WWF's One Planet City Challenge in 2019 signalling their commitment to being assessed against a 1.5°C target.
- 19 major cities including London, New York, Tokyo and Stockholm have committed to make new buildings net zero carbon by 2030 (C40).

Companies

Businesses are also beginning to act. Over 600 major companies have committed to science-based targets aligned with the Paris Agreement. At least 27 large companies (with revenues in excess of US$1 billion) have committed to net zero emissions by 2050 at the latest. Ikea, Unilever and Telia Company plan to reach net zero emissions by 2030 and Verizon by 2035.

However, only 15% of the Fortune 500 companies have set targets aligned with the Paris Agreement, and far fewer have set targets aligned with a 1.5°C world. Initiatives to halve emissions through the value chain, in line with the carbon law – must scale rapidly and encourage companies of all sizes to reach their full potential, not the bare minimum.

But the role of the business sector goes much further than reducing the direct emissions. The business proposition as such has an even stronger impact and businesses must make sure they align with a 1.5°C world. This goes hand in hand with new, exponential business opportunities as markets shift. Already many start-ups have positive climate impact at their core and front-running companies has started to change their offerings and actively influence industries, customers and policy makers.

Finance

The G20's Task Force on Climate Related Financial Disclosures (TCFD) has asked companies to disclose their exposure to climate risk. 160 companies overseeing US$86 trillion in assets support the initiative and another initiative, Climate Action 100+, includes 360 investors with more than US$34 trillion in assets under management and aims to ensure the world's largest corporate greenhouse gas emitters take necessary action on climate change. Since the fossil-fuel divestment movement began in 2013, over 900 organisations with assets worth about US$10 trillion have committed to divest from fossil-fuels.

More significantly, 34 central banks have joined forces to ensure a smooth transition to a low-carbon economy through the Network for Greening the Financial System (NGFS). This network, including the Bank of England and the Banque de France, represents half of global greenhouse gas emissions. In 2019, it provided a series of recommendations for all central banks to avoid a climate-driven "Minsky moment" – the term for an abrupt collapse in asset prices.

Exponential Technologies

From digitalisation to robotics and synthetic biology, a technological revolution is underway and artificial intelligence, cloud computing, 5G and the Internet of Things (IoT) are poised to create further disruption in the next decade.

The digital revolution may be the biggest wildcard in the economic transformation. It can influence whether we end up on a 1.5°C planet or a world 3-4°C warmer – Hothouse Earth. Reaching net zero emissions by 2050 will require rapid transitions across all economic sectors and a shift towards sustainable consumption, increasingly mediated by technology. This means the digital revolution is an essential tool to support societal goals.[28, 29]

Exponential technological development can considerably reduce energy consumption and material waste in all sectors, while supporting global health, sustainability and economic goals. It can also enable rapid transformation through new disruptive business models.

When it comes to applying the carbon law, the digital sector has the potential to directly reduce fossil-fuel emissions 15% by 2030[30] and indirectly support a further reduction of 35% through influence of consumer and business decisions and systems transformation.

For example:

- Solar, wind, storage and smart grid technology supported by digital solutions, will enable electrification, decentralisation and greening of the energy system.
- Energy usage in buildings can be brought down by increased space utilisation through new digitally enabled sharing models.
- Mobility as a service, electrification, and autonomous vehicles connected to one another can tap the value of unused vehicles.
- Digitalisation can improve delivery by optimising shipments, routes and traffic systems.
- Artificial Intelligence can be applied to design products for re-purpose, sharing, re-use and recycling as the new default.
- Deforestation can now be predicted and detected through digital solutions which helps take proactive action, and to monitor and improve agriculture, reforestation and peatland restoration.
- Through the use of Internet of Things, AI, 5G and digital-twin technology, the need for more roads and physical infrastructure can be dramatically reduced through optimising existing infrastructure.

Supporting societal goals

While digitalisation and emerging technologies can contribute to reducing greenhouse gas emissions, many online platforms could be better utilised for the benefits of society. Platforms such as social media, search and eCommerce now influence the behaviour of about four billion consumers and producers every day – over half the population of the planet.

As well as influencing consumer behaviour – advertising revenue is now predominantly about online presence – these platforms now increasingly influence the flow of information in the world. This is influencing democratic processes by enabling disinformation campaigns and algorithmic propaganda – but also offers opportunities to accelerate the climate movement.

While some of the leading technology companies have ambitious internal sustainability targets, the conversation about how they use their influence to support the rest of society is less well developed. Given the power of digital platforms, it is time for a new social contract between them and society. Specifically for these companies, this means starting with a strong commitment to using technology for the good of society, promising to make low-carbon solutions the default, enabling shifts to low-carbon consumption, and promoting fact-based worldviews.

To avoid unintended consequences from technology, the potential impacts of early-stage innovations should be assessed and learnt from. Innovations with high positive climate-impact potential must be strongly supported in the coming decade.[31]

“Preventing irreversible climate disruption is the race of our lives, and for our lives. It is a race that we can and must win.”

António Guterres
UN Secretary-General

TRANSFORMING SECTORS

ENERGY SUPPLY

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS IN THIS SECTOR GLOBALLY?

Yes, as the cost of solar and wind electricity has fallen in the last few years and storage is following a similar trajectory, it is possible for this sector to halve emissions at a low or no cost.

CAN THIS BE ACHIEVED BY 2030?

Yes. If the growth of wind and solar photovoltaics continues at earlier best rates, the world's energy emissions are on track to halve by 2030.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Institutional constraints, current energy systems design, market control by incumbents, and policies that favour conventional fossil-fuel technologies and business models.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

Removing fossil-fuel subsidies, access to institutional capital for clean energy investments, modernised grid infrastructure, and decentralisation of power production. Fair pricing of carbon emissions will also accelerate the transition.

CURRENT SITUATION

Energy use is responsible for about two thirds of global greenhouse gas emissions, which is made up of 32 Gt of annual CO_2 emissions, plus 3.3 Gt of CO_2 equivalent emissions (CO_2e) from other greenhouse gases.[1] This chapter addresses the 18.46 Gt CO_2e per year that the sector can directly influence, which is 34% of total global emissions. This comprises 12.4 Gt of direct emissions from electricity and heat production for other sectors, and 6.1 Gt of the sector's own emissions associated mainly with extraction, refineries and distribution of fossil-fuels. The remaining 17 Gt of emissions from fuel use in other sectors, such as gasoline use in cars or coal in industry, are not included here but covered in other sectors. In 2017, energy sector emissions grew 1.6%, with an average growth of 1.1% per year in the last decade.[2]

After being relatively constant for decades, the market share of fossil-fuels (and therefore the CO_2 intensity of electricity generation) has decreased over the last few years due to growth of renewable energy.

TRAJECTORY

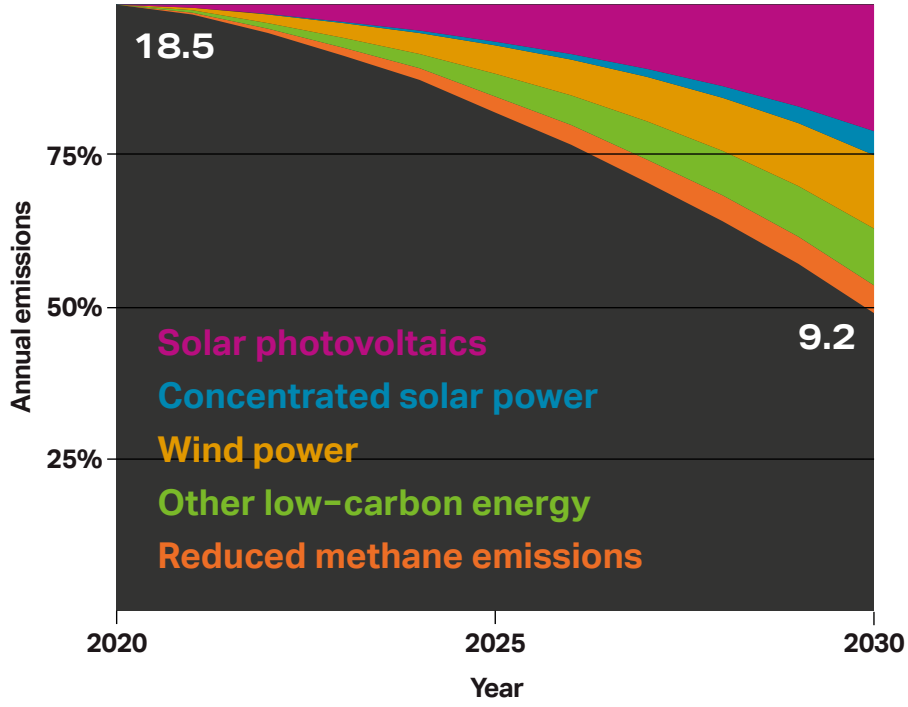


Figure 8. Energy Supply

Estimated 50% reduction of annual emission proposed for energy supply sector by 2030. The diagram includes both the sectors' own baseline emissions of 6.1 Gt CO_2e and the additional 12.4 Gt emissions from electricity and heat production for other sectors.

SOLUTIONS FOR FIRST HALVING

For the energy sector, the solutions to halve emissions by 2030 are available and a transition has begun. Improved energy efficiency in all sectors (covered in more detail in subsequent chapters), is by itself economically important, but the halving in this chapter refers to emissions generated directly by the supply of energy. That consists of emissions from extraction, refineries and distribution of fossil-fuels (6.06 Gt) and the generation of electricity and heat (12.46 Gt). In order to achieve rapid decarbonisation to 2030, global primary energy demand should be reduced, in line with the low energy demand (LED) scenario.[3] This is achieved by efficiency gains in energy conversion, in industry, transport and buildings. In our scenario we assume electricity consumption to be flat in 2020–2030 as increasing electrification and number of end users make up for efficiency gains and savings elsewhere.

Today, almost a billion people lack access to electricity[4] while 3.3 million people die prematurely each year from outdoor air pollution – mainly as a result of the burning of fuels.[5,6] The climate solutions presented here contribute to achieving UN Sustainable Development Goal 7 on affordable and clean energy, as well as other goals.

There are five key solutions that can play major roles and scale sufficiently fast – solar photovoltaics, concentrated solar power, wind power, reduced methane leakage, and grid flexibility and storage. We'll look at each in turn.

Solar photovoltaics (PV)

Solar PV uses the physical properties of materials to convert sunlight into electricity. PV panels can supply local systems or regional grids. They can be put on buildings or on the ground. It is possible that solar electricity one day will provide more than all current energy use globally – sunlight is capable of providing about 1,000,000 TWh annually, which is 6,000 times our current total energy use.[7]

Photovoltaics is capable of both exponential cost reductions and exponential capacity growth. That growth is not currently limited by the construction of power plants, but by the construction of factories producing solar cells and panels. Global installed solar PV capacity has expanded from 0.8 GW in 2000 to 500 GW by the end of 2018, with the highest relative growth – almost 80% in a year – in 2011.[8] Since then, global growth has slowed slightly to 20–25% per year in the last two years. China surpassed Germany in 2014 as leader in installed capacity, with Japan, the US and Germany now competing for second place.

To contribute to the 2030 goals for the energy supply sector, we estimate that solar should continue growing exponentially at a pace of 20-25% per year, reaching ~6,000 TWh/yr and reducing emissions in the sector by 4 Gt/yr in 2030. This rate represents less than half of the highest historical growth rates, meaning that solar energy could potentially drive emissions down even faster.

Solar photovoltaics in India

India plans to build 100 GW of solar capacity by 2022 to meet its Paris Agreement commitments.

50% of all new energy capacity in India came from solar in 2018.

Massive Chinese solar capacity

In the last two years alone, 98 GW of solar PV have been added to China's electrical grid.

The installed capacity of grid-connected solar PV in China has more than 1,000-doubled in a decade.

Concentrated solar power (CSP)

Concentrated solar power works in a different way to solar photovoltaics. Sunlight from a large area is focused on a small receiver using mirrors or lenses. The heat generated is then used to drive a turbine or Stirling engine. Unlike photovoltaics it needs direct sunlight to collect energy, and so is mainly used in arid regions. On the other hand, the energy collected can be stored as heat and used to produce power at night. These plants are therefore able to balance daily fluctuations in the energy system and complement solar PV.

CSP grew on average ~60% per year between 2009 and 2014,[9] mainly due to incentive schemes in Spain, the US and Italy. The withdrawal of some of these schemes, together with competition from solar PV (which now has a lower cost per installed capacity and electricity produced),[10] has driven investors away and caused a slowing of growth in cumulative CSP capacity.

CSP can still contribute a significant portion of renewable energy when solar PV has satisfied daytime demand, and its relatively low-cost storage capability provides a competitive advantage. The analysis in this report assumes a scenario where new policies allow for exponential growth of 40% per year until 2030. This contributes to a reduction of CO_2e in the sector by 0.4 Gt/yr in 2030. CSP can also provide industrial heat, in place of fossil gas, oil or electricity.

The Gemasolar tower

The Gemasolar plant in Spain concentrates sunlight onto a tower, producing 80 GWh of power per year.

Using molten salt heat storage, the tower can produce power for 15 hours without sunlight.

Wind power

Wind power is a larger source of electric power than solar PV and one of the least costly generation technologies per unit of energy. Wind can be deployed on land (onshore) or at sea (offshore), and when connected to the grid, wind power can be produced without subsidies.

Wind power growth in Portugal

Between 2001 and 2018, Portugal rapidly increased national capacity for wind power. 24.3% of its electricity is now provided by wind.

Portugal produces 55% of its yearly electricity from renewables.

Several countries have successfully reduced their carbon emissions by transitioning to wind power. Wind power sustained exponential growth at rates above 20% annually between 2000 and 2013, increasing electricity generation from 31.5 TWh/yr to 640 TWh/yr. By the end of 2018 there was almost 0.6 TW of installed wind power capacity that today is capable of generating 5% of global electricity – around 1300 TWh/year. Future technical potential for wind energy, like solar, may be greater than current global energy use.

To cut energy supply emissions in half by 2030, wind power generation should continue growing at a pace of just above 10% per year, reaching above 4000 TWh/yr and reducing emissions in the sector by 2.0 Gt. As with solar PV, this is slower than past growth rates, meaning that the technology could potentially drive down emissions even faster.

Other low-carbon energy

New nuclear, hydro, wave-power, geothermal, and biomass-fuelled heat/power cogeneration capacity will also contribute to emissions reductions in energy supply. Scaling these to 2030, it is estimated that their combined contribution will be 0.92 Gt per year, with none of them contributing more than 0.22 Gt each.

Grid flexibility and storage

The energy sector has not yet been disrupted by digital technology in the same way as other sectors. Often energy systems are operated as politically backed monopolies. Such institutional settings tend to operate conservatively, rather than being open to innovation.

However, there is great potential to cut emissions through the use of new technologies. Power electronics and batteries can provide stability. Real-time pricing and web-controlled appliances give customers opportunities to reduce cost by being more flexible in their demand, which will help efficiently stabilise the grid. Distributed electricity generation may benefit from trading mechanisms based on blockchain. With abundant use of low cost renewables, power transmission will also become more important to supply areas of high power demand, such as large cities and industrial regions, from areas with abundant renewable energy resources.

As renewable electricity is becoming available in parts of the world at a lower cost than the price of fossil-fuels, electricity may be used to produce so-called "electrofuels". These are a type of energy storage or flexible demand that by 2030 may have started to have an impact, but the scale of that impact is still difficult to quantify.[11,12]

With increasing production from intermittent power sources and a need to substitute gas turbines and other fossil-fuel power for balancing the grid, batteries are a key component of a decarbonised energy system. Batteries are already today balancing grids at low cost, while also making the growth of decentralised power and even 24/7 off-grid solar electricity possible.

A key issue is cost, but batteries are becoming cheaper to produce as demand from the automotive industry has increased the scale of production. Bloomberg New Energy Finance estimates that global battery capacity will grow exponentially, doubling every 28 months from 2016 to 2030.[13] This would mean a capacity in 2030 of 125 GW/305 GWh. Acknowledging uncertainty, we assume that storage together with technologies for more flexible and optimised grids will decrease the use of fossil-based electricity by 10% by 2030. This reduces emissions by 1.6 Gt per year by 2030.

Germany's flexible grid

The German network operator 50Hertz has shown that it's possible to run a grid with a renewables share of 56.5%.

Germany has set a goal of 63% renewable power by 2030.

Wind power in Denmark

Strong national policies have allowed Denmark to generate 44% of its grid power from wind – the highest proportion in the world.

Denmark aims to have 100% renewable energy for heat and power by 2035.

Solar power law

California has approved a law requiring homes built after 2020 to use solar power.

It is estimated that installations will grow 80% in new homes compared to the current rate.

Reduced methane leakage

Methane is a strong greenhouse gas – about 30 times more potent than CO_2– which leaks out when fossil-fuels are extracted and during transport of fossil methane gas in pipes or as liquified natural gas on ships. Conservative estimates of methane emissions from oil, gas and coal extraction and distribution run to about 2.7Gt CO_2e.

Solutions to reduce a significant portion of this leakage are generally available, and many are profitable, but aren't applied at a large scale because return on investment is considered too low. Stronger policy, and better monitoring techniques can help close the gap.

Available technologies to accomplish this include optical or portable measurement tools, and drones to detect and monitor leaks. Machine learning can help make sense of the large amounts of data already available. Reducing leaks is often both profitable and environmentally beneficial.

With appropriate policy, industry cooperation and application of the latest technology, emissions of methane from oil and gas could be reduced by 0.45 Gt CO_2e by 2030, which would also come with a net economic gain.[14] The full technical potential is almost three times as high. Reduction of methane leakage should be seen as a complementary, short-term solution that can be applied to rapidly cut emissions related to fossil energy while the main strategy is to replace all fossil energy.

Methane leaks from byproducts in agriculture and waste in landfills can also be collected and used to replace fossil gas. Such opportunities may be significant globally, but are not quantified here.

South Australia battery

South Australia's Tesla battery has paid back a third of its cost in the first year through services provided to the local grid.

The 100 MW/129 MWh battery was the biggest in the world.

Crowdfunding solar power

Trine connects small-scale investors with solar power entrepreneurs in East Africa. To date €25,647,968 have been invested in solar energy.

544,077 people have been provided with renewable electricity through the scheme.

ACCELERATORS

Climate leadership

Demanding 100% renewable electricity, both through on-site generation and direct purchase from the market, is an important step that cities, businesses and individuals can take to transition the energy system towards cleaner sources of power. 40 cities around the globe, as well as 182 large companies, have signed up for 100% renewable energy targets in the RE100 initiative, and these numbers are growing.[15] Access to renewable energy is also becoming an important decision criterion for progressive businesses.

But that's not all – cities, businesses and pension funds can divest from fossil-fuels and move assets in order to close the investment gap in new renewable energy instead. Corporations, individuals and organisations can also accelerate the transition by investing in local renewable energy solutions such as rooftop solar heating and PV, and through peer-to-peer lending. Bundling of projects to meet risk criteria may help financial institutions to participate.

Policy

Energy supply and distribution is often a politicised sector because of its role as a strategic resource for national security, societal stability and industrial competitiveness. Today, the low-carbon options described above can serve all these purposes as well as, if not better than, conventional energy systems.

Policymakers can speed up the energy transition while caring for people whose livelihoods are disrupted in the process. Ways to do so include removing fossil-fuel subsidies, with compensation for lowest income households, and withdrawing support for infrastructure investments like pipelines and fossil-fuel power plants. Taxing fossil-fuels based on their external environmental costs will also accelerate the transition. As new renewable energy is already competitive or close to competitive, this will not significantly increase energy costs. Carbon pricing schemes, however, must be designed in a way that they are considered fair.[16]

Policymakers must also facilitate system changes. Regulations designed for an inflexible one-directional power supply system should be replaced by flexible solutions where people and companies can contribute to decentralised energy supply and grid balancing.

Finally, coordination of research and innovation processes can accelerate the development of competitive renewable energy technology.

Exponential technology

Renewable technologies like wind, solar PV and CSP, and battery storage become substantially cheaper over time as industrial experience accumulates. Solar PV has dropped in price by an order of magnitude in the last ten years and the cost of lithium-ion batteries have fallen by almost 80% in seven years.[17] This trend will continue. The exponential nature of these technologies has tended to be underestimated in the past and should not be in the future.[18]

Operating power grids with a high level of predictable but not controllable solar and wind power is often said to be difficult. However, the experience of grid systems operators in Germany and Denmark, where around half of the energy is supplied by such sources, is that they can work well even without significant storage.

There is evidence suggesting that energy systems could go to an 80% share of variable renewables at low cost with current technologies, enough to halve emissions by 2030.[19] An energy system that is 100% powered by variable renewables would require a host of solutions such as flexible power consumption by heating, automotive batteries and fuel production to balance surplus low-cost electricity.

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	Investments in fossil-fuel infrastructure and technology should drop rapidly. Investments are moved to renewables, with companies, cities, regions and individuals driving demand. Access to clean energy becomes a key competitive factor for regions attracting businesses.	Investments in fossil-fuel infrastructure restricted. Global renewable energy finance redirected to underserved locations with high gains from rapid energy transition.	Strong emphasis on phasing out fossil technologies.
Policy	Fossil-fuel subsidies eliminated. Carbon pricing in most markets. Supportive emission standards established. All public financing of fossil-fuel energy through, for example, development banks or export credits, has been phased out. Stricter regulation of oil and gas supply to decrease methane leakage. Policy packages to accelerate innovation and market share of renewables. De-risking policies to improve access to finance for renewables, particularly decentralised and in developing countries. Begin construction of sustainable strategic long-range transmission infrastructure as well as low-voltage network expansion for decentralised renewable electricity generation. Measures to address social and economic impacts, as well as distribution opportunities.	Carbon pricing and supportive emission standards are universal. Fossil-fuel bans begin to be implemented by cities and nations. Restrictive policies introduced for new fossil-fuel infrastructure. Measures to address social and economic impacts, as well as energy poverty. New transmission infrastructure roll-out and legal frameworks in place for grid integration of decentralised renewable energy. R&D efforts in new renewables, battery technologies, power-to-gas, and biomass with carbon capture.	Support for novel renewable technologies like wave power and power-to-gas. If necessary, support for biomass with carbon capture and storage technology and new nuclear fission or fusion.
Exponential technology	PV, wind and CSP continue to grow at least half as fast as historic rates. Battery technologies continue scaling up rapidly. Accelerated innovation in renewable energy and grid balancing. Exponential growth of distributed renewable energy production/storage in buildings and industries	Breakthrough of distributed, renewable and more resilient energy systems. Creative solutions emerge to handle price variations caused by the transition from traditional centralised systems to renewable-based distributed systems.	Technologies for advanced grid balancing maturing and widely adopted.

THE WAY FORWARD

In many places, not hindering the exponential trajectories for wind, solar photovoltaics and battery storage will be enough to achieve a halving of emissions by 2030. In less experienced markets, however, support is still needed to reach a point where solar and wind energy can be supplied at lower costs than fossil-fuels.

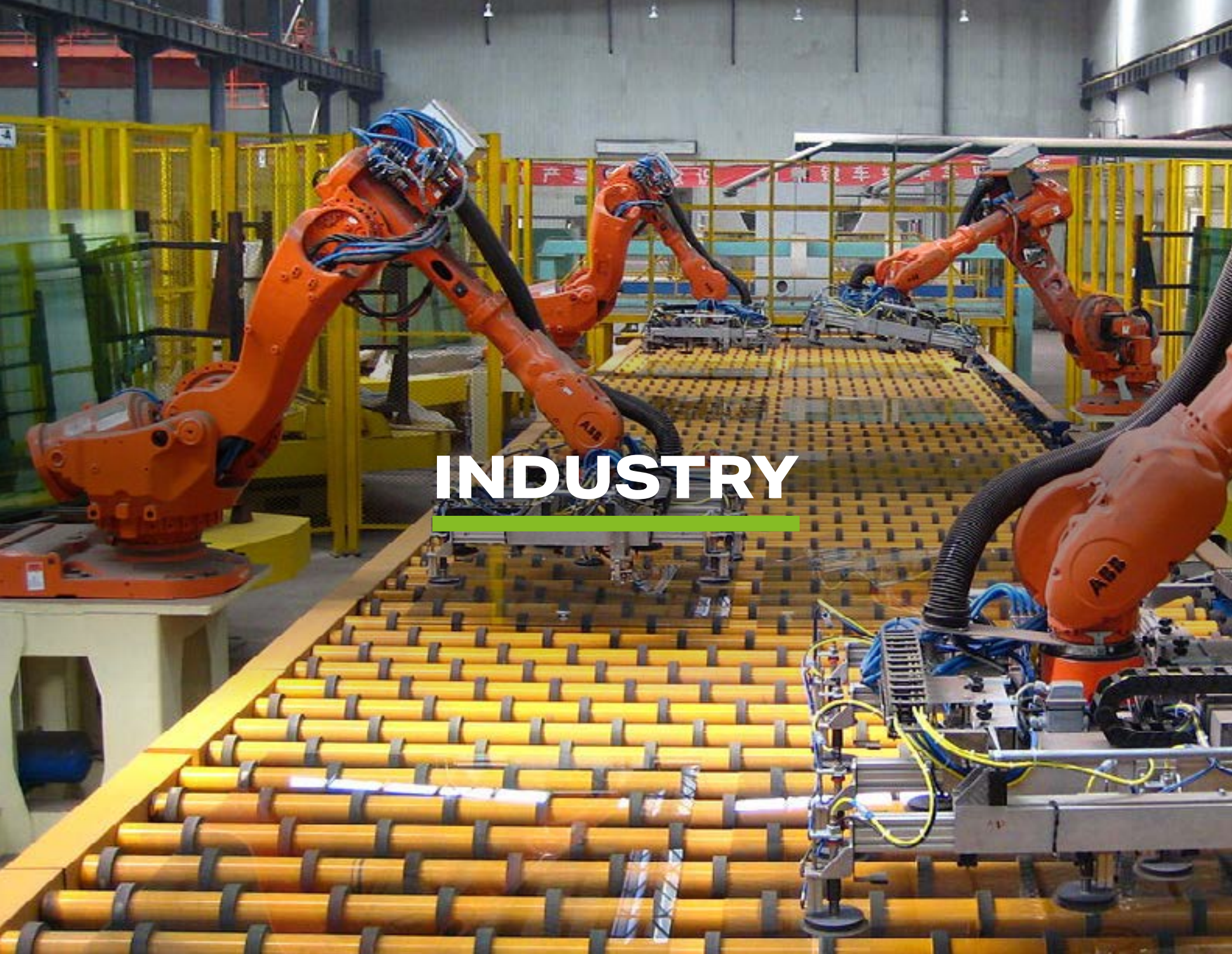
Where conditions are suitable, solar CSP can return to the growth figures it saw in 2009–2014, providing grid-balancing services as a complement to solar PV and wind.

Grid infrastructure should be regulated to allow for decentralised power production, and new interconnections between regions should be added to utilise potential cost reductions in generation. Fair grid access and transparent competitive markets for balancing power are important for renewable energy developers.

Fundamental policies for a rapid and smooth transition from fossil to renewable energy will include removing subsidies from fossil-based power plants and infrastructure, introducing CO_2 taxation and minimising the social and economic impact on individuals who lose out in the transition.

Investment and research in new zero-carbon energy storage and generation technologies, such as wave power, must be sustained to achieve the reductions necessary beyond 2030.

Climate leaders among cities, businesses, housing communities and individuals should demand 100% renewable electricity and consider investing in their own renewable energy production.


INDUSTRY

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS IN THIS SECTOR GLOBALLY?

Yes. By improving materials recirculation and production efficiency, cutting waste, adopting renewable energy and rapid scaling up of circular design and business models.

CAN THIS BE ACHIEVED BY 2030?

Yes. Halving emissions is feasible by 2030 as current practices are highly wasteful and the emissions savings from renewable energy and circular economies are largely untapped.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Lack of strong policy, weak investment, insufficient demand from customers, inertia and slow rates of innovation are the major obstacles.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

Incentives for industry to shift to low-carbon solutions and design for circular economies. A critical mass of climate leadership, innovation and strong customer demand. Access to renewable energy and circular economy infrastructure.

CURRENT SITUATION

The industrial sector is responsible for 17 Gt CO_2e annually, which represents 32% of the global total. This figure can be split into two parts. First, energy-intensive heavy industries which include materials manufacturing that represent substantial emissions: steel, cement, plastics, aluminium and chemicals. Second, less energy-intensive light industry, such as fashion, furniture and home appliances.

Heavy industry has grown exponentially in emissions for several decades. Industrial emissions reached a new all-time high in 2018, and are anticipated to grow further unless measures to reverse the trend are applied rapidly across sectors and regions. In a business-as-usual scenario, demand for industrial goods is expected to rise as the global middle class swells from 3.2 billion in 2016 to a projected 5.2 billion by 2030.[1]

With 60% of the global population expected to live in urban areas by 2030, growing cities will fuel demand for building materials.[2] Without rapid transformation of the sector, concrete, steel and plastics alone will easily eat up the 1.5°C carbon budget.[3] As an example, in 2019, the production and incineration of plastic will produce more than 850 Mt of greenhouse gases – equal to the emissions from 189 large coal power plants.[4]

However, a number of large industrial companies are setting climate targets and implementing circular business models, and low-carbon materials are becoming common in all types of products. Companies are realising that new strategies aligned with the Paris Agreement can deliver a competitive advantage.

TRAJECTORY

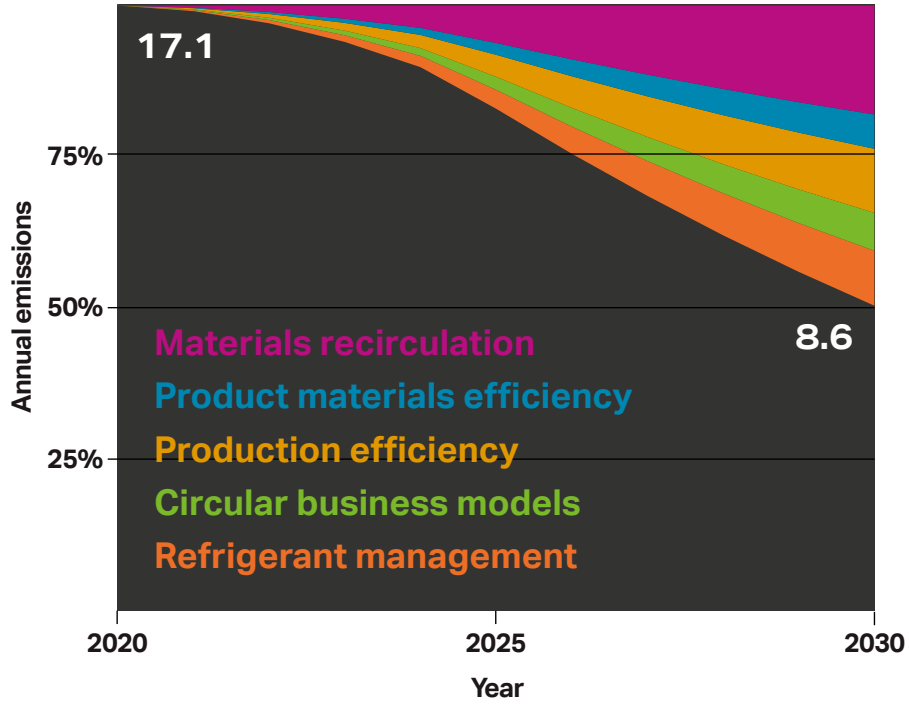


Figure 9. Industry

49.5% reduction of the annual emissions of the industry sector by 2030, which includes reduction of 2.6 Gt (31%) electricity and heat-related emissions.

SOLUTIONS FOR FIRST HALVING

The key solutions to reduce supply-side emissions in industry revolve around a few key principles. Making products with less materials, recirculating materials, replacing high-carbon materials with low-carbon ones, optimising production processes and enabling a circular economy. Cutting emissions associated with refrigerants is also an important factor.

This chapter will explore these solutions and how they can be accelerated through policy, exponential technology and climate leadership. It will not discuss innovations required for the second and third halvings, like using hydrogen in steel and cement production. Nor will it address consumer demand, which is covered in the climate leadership chapter.

Material recirculation, efficiency and substitution

Wealthy nations frequently use more materials than necessary – for example, EU countries use an average of 800 kg of steel, concrete, aluminium and chemicals per person per year.[5,6,7] By reducing the amount of materials used, or increasing their usable lifetime, costs can be lowered at the same time as emissions are reduced.

Additionally, reusing material which already has been produced is a key opportunity to reduce emissions. The amount of reclaimable material in the world is steadily growing, and energy savings range from 60–75% for using recycled, rather than new steel. The savings for steel are up to 90%.[7] Achieving these savings requires that products be designed specifically for disassembly and recycling, that material contamination is avoided and that material collection rates and processes are improved.

Material recirculation

Neste offers a 100% renewable alternative to crude oil in plastics and chemicals production.

By using renewable raw materials the plastics and chemicals producers are able to decrease the carbon footprint of their products.

Fossil-free food packaging

The food retail sector's goal in Sweden is for all plastic packaging to be recyclable by 2022, and to be produced from renewable or recycled raw materials by 2030.

Plastics will add 0.85 Gt greenhouse gases to the atmosphere in 2019.

Materials substitution

Betolar turns different side streams from energy, mining, steel and forestry sectors into geopolymer-based construction materials.

These materials substitute concrete with up to 90% lower carbon footprint.

Action on plastic

Movements are growing to reduce plastic use. France has pledged to use only recycled plastic by 2025.

Unilever has committed to 100% reusable, recyclable or compostable plastic packaging by 2025.

Construction projects often use 30-50% more steel and cement than necessary,[6, 7] and increasing material efficiency across all industries is a clear opportunity to reduce both emissions and costs. Large emission reductions can also be achieved by substituting low-emission materials which perform equally well or better than the high-emission materials they replace. New directives and requirements, backed by improved design tools and technology, will be necessary to turn these possibilities into reality.

Production processes

While major efforts to reduce demand for steel, cement, plastics, aluminium and other materials are essential, so too are emissions reductions from improving the efficiency of production. The energy intensity of this sector could be reduced by up to 25% by 2030 by upgrading or replacing existing equipment with the best available on the market. The adoption of renewable electricity and heating/cooling will provide further cuts. Additional reductions of up to 20% of annual energy intensity are possible by measuring processes and energy use in real time and using artificial intelligence techniques to continually optimise them.[3]

Mining and minerals going fossil-free

The Swedish mining and minerals industry is aiming to make its mining operations completely fossil-free by 2035.

The sector currently accounts for 8% of Sweden's total CO_2 emissions.

Sustainable fashion

By July 2019, 90 companies, representing 12.5% of the global fashion market had signed the 2020 Circular Fashion System Commitment to reduce waste.

Textile production causes 1.2 billion tonnes of CO_2e emissions annually.

Electric site

Volvo and Skanska's Electric Site research project is a test bed for switching to electric autonomous haulers in the quarrying industry.

The project has shown a 98% reduction in CO_2 emissions, 70% in energy cost and 40% in operator cost.

Circular economy and closed-loop business models

More companies are adopting a circular economy model in their business operations and supply chains. The Finnish innovation fund Sitra defines a circular economy as maximising the circulation of products, components and materials and the value bound to them as much as possible in the economy. This goes beyond environmental benefits and creates real economic and social benefits too.

A more circular economy could cut cumulative emissions from heavy industry by 56% by 2050 in the EU, and 45% of cumulative emissions from the steel, cement, plastic and aluminium products globally.[5] Additionally, service-based business models, where buildings, tools and vehicles which sit idle for 90% of the time are unlocked for others to use, are another huge opportunity to boost profits and reduce emissions simultaneously. These are addressed in the building and transport chapters.

Circular strategy

IKEA has announced that all products will be developed to be repurposed, repaired, reused, resold, and recycled and will only use renewable and recyclable materials by 2030.

IKEAs goal is to be climate neutral by 2030.

Circular business models

Apple has promised to adopt a 100% circular business model, including sourcing of zero-carbon aluminium for its products, by 2024.

Daisy, Apple's disassembly robot, can rip apart 200 phones an hour.

Refrigerants

In the wake of the discovery of the hole in the ozone layer in 1984, UN member states agreed to phase out the chlorofluorocarbon (CFC) refrigerants that were causing the problem. In their place, many industries shifted to hydrofluorocarbon (HFC) refrigerants, which cause less damage to the ozone layer. However, HFCs happen to be powerful greenhouse gases, with a global warming potential thousands of times higher than carbon dioxide and a long lifespan in the atmosphere.

In Kigali, Rwanda in 2016, nations agreed to phase out these HFCs with some countries starting in 2019. Doing so has the potential to reduce cumulative emissions by the equivalent of 90 billion tonnes of carbon dioxide by 2050[8] making a significant contribution to meeting the Paris Agreement. More than 90% of the climate change impacts of HFCs can be avoided if emissions stop by 2030.[9] The treaty, ratified by 65 countries, entered into force on 1 January 2019, and is projected to reduce global warming by 0.4°C this century. Europe and the US have committed to acting first – rapidly cutting HFC emissions 10% by 2019, while middle-income countries such as China and Brazil plan to cap emissions in 2024.

However, the demand for cooling equipment is rising, not at least in developing countries. Global warming is creating a vicious circle where warmer air temperatures drive demand for more cooling. Low levels of efficiency and high leakage rates of refrigerant gases with high global warming potential will increase these emissions drastically.

Apart from tougher policy, a strong green cooling movement among both suppliers and customers can rapidly reduce emissions by applying new types of refrigerants and increase efficiencies.

Work clothing as service

Textile service company Lindström offers work clothing as service. This way the customer companies can pay a fixed fee and receive clean, repaired, safe and quality-requirements compliant clothing.

RFID tags are used to collect data to enable optimal usage.

ACCELERATORS

Climate leadership

Climate leadership in this sector means companies and coalitions acting as champions to drive a rapid halving of emissions throughout their value chains, creating a race to the top.

Companies can also set strong requirements on regions to provide renewable energy, and invest in production of clean electricity and heating. An example of this is the RE100 initiative, which represents 190 companies with a combined US$4 trillion in revenue who are committed to implementing 100% renewable energy.[10]

Industry-wide roadmaps aligned with the carbon law, developed in collaboration between suppliers, customers and governments, are crucial. Examples include the UNFCCC textiles charter[11] and Fossil Free Sweden's 13 industrial roadmaps.[12] These roadmaps help identify key barriers to be overcome to reach emission targets, and can accelerate decarbonisation across sectors.

Early adopters of circular economy business models will be essential. This will drive more efficient use of materials, more high-quality material recirculation, new production processes and service-based business models.

Policy

Most countries have very weak emissions standards, and policies largely focus on information. This is not a successful strategy, and will not reduce emissions fast enough. Strong economic incentives are required in order to reward low-emissions approaches and encourage high-emissions firms to put in place strong investment plans to dramatically cut carbon dioxide.

One effective way to do this is through pricing of emissions and credible national long-term emission reduction targets which signal the long-term direction. Strong investment programmes in low-carbon materials and processes are required to speed up the transition, and sectoral roadmaps can help to pinpoint key barriers that need to be addressed with policy measures or in public-private collaboration.

Other strategies for policymakers include requirements that products are designed for circularity, extended producer responsibility, making sure that infrastructure is in place for recycling, regulating what happens at the end of a product's life, mandating material reuse, adapting public procurement policies and more stringent waste regulation. The tax systems also need to be adapted to support circular solutions. Finally, bans on materials driving emissions and pollution, such as single-use plastic items (banned in the EU from 2021), can be implemented.[13]

Exponential technology

Digital technologies will be an essential driver of decarbonisation and cost savings across industries, enabling great gains in material, energy, process and logistical efficiency.

Zero-carbon design is vital – creating products optimised for re-purpose, sharing, re-use and recycling. Using 5G and other network technologies for increased precision in manufacturing can save materials and energy.

Reverse logistics and real time tracing of material, components and products will make it possible to increase utilisation rates of consumer goods, vehicles and physical infrastructure. This will allow the adoption of a sharing economy and circular business models, which will in turn cut huge amounts of material waste. Finally, artificial intelligence techniques can be applied to rapidly develop a new generation of ultra-low carbon materials.[14]

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	Cities and nations adopt stringent emissions and efficiency standards to encourage rapid reductions in emissions from steel, cement, plastics and aluminium. Development of industry roadmaps across all sectors aligned with 1.5°C, creating a race to the top between companies.	All companies have set targets to halve their annual emissions by 2030 or earlier. Significant shift from ownership of products to "usership" for transport, consumer goods and commercial space, reducing material consumption.	Strict emissions regulations in place, which also reduces air pollution and promotes greater efficiencies. All construction is carbon neutral or even stores carbon. All leading companies have adopted circular business models.
Policy	Policies and economic incentives put in place to reward low-emissions strategies. Low-carbon public procurement standards become established and scale globally. Companies are required to publish carbon footprint information on their products and services. Companies take responsibility for the entire product life-cycle.	All public procurement committed to low-carbon and a circular economy. Stringent emissions standards now universal. Strong public-private investment initiatives in place with the goal of 100% fossil-free materials.	Requirements on low-carbon/ fossil-free materials, production and circular material handling applied globally in policies.
Exponential technology	Digitalisation transforms all industries, increasing energy and material efficiencies, and reducing carbon emissions. Technology enables circular economies and usership-based business models. The Internet of Things allows greater traceability of materials and products, while artificial intelligence optimises processes for efficiency. E-commerce platforms and product search engines prioritise low-emissions products. Industrial design, engineering and architecture increasingly adopt low-emissions options as default.	Purchasing recommendations and decisions become more automated and factor in planetary boundaries and national emissions reduction pledges. Alternative aluminium and cement production systems reach market and scale rapidly.	New innovations to remove remaining carbon in heavy industries such as steel and aluminium reach the market and scale rapidly.

THE WAY FORWARD

There is an urgent need for stronger policy and industry action to drive dramatically higher material efficiency through circular business models. Decarbonisation of high-emission materials might not add more than a few percent in cost, compared to end-user/consumer level price.[6] It is however important to note that an increase in near-term R&D investment in those industries will be vital to enable the deep decarbonisation required for the second and third halvings.[6]

In the meantime, policymakers must focus on incentivising energy and material efficiency through stringent standards and support for best available technologies, for example through public procurement standards for construction projects, which can spread globally.

An immediate priority is to build out the infrastructure required for the circular economy and accelerate reuse of materials through refunding schemes, increased scrap collection and recycling rates.

Physical retailers and e-commerce platforms should develop strategies to incentivise low-emissions products, recycling and longer product lifetimes. All manufacturing businesses and industries should set ambitious targets to aim to halve emissions by latest 2030.


DIGITAL INDUSTRY

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS IN THIS SECTOR GLOBALLY?

Yes, solutions exist and are being implemented by many companies in the industry.

CAN THIS BE ACHIEVED BY 2030?

Yes. Emissions can be halved through investment in renewable energy alone, and can be cut even further through improved energy efficiency and bundling devices with renewable energy.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

The main barrier is the low availability of renewable energy in some countries, the geographical spread of infrastructure and achieving a critical mass of digital companies.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

Policies to incentivise renewables. Global initiatives to ensure that a broad majority of digital companies implement a carbon law climate strategy.

CURRENT SITUATION

In the last version of this report, the life cycle carbon footprint of the information and communications technology (ICT) sector was estimated to be 730 Mt of CO_2e (1.4% of the global total while using 3.6% of global electricity for its operations), based on 2015 data. The entertainment and media (E&M) sector's electronic footprint was estimated at 420 Mt (0.8%) and the footprint of traditional paper media 220 Mt (0.4%).[1] In this report, the ICT and E&M sectors will collectively be referred to as the "digital industry" – which is a subsection of the "industry" sector previously described.

Between 2010 and 2015, data traffic quadrupled and the number of mobile subscribers increased by 30%. However, at the same time, their combined emissions and the electricity used for operation both declined about 15%, while ICT emissions remained roughly constant.[2] The main reason for this development has been massive gains in energy efficiency and a shift in computing from desktop and laptop to handheld devices. Similarly, the steady shift of entertainment experiences online means that the entertainment and media industry's ongoing emissions are also in decline. Ongoing research based on more recent market statistics from industry analysts and ICT companies suggests that these trends will continue.

Carbon emissions in the digital industry are expected to continue to drop up to 2020, while total data traffic is forecast to increase. Beyond 2020, discussions are ongoing between the International Telecommunication Union, GSM Association, Global e-Sustainability Initiative and the Science-Based Targets Initiative to establish a decarbonisation pathway that supports a 1.5°C trajectory for the ICT sector.

TRAJECTORY

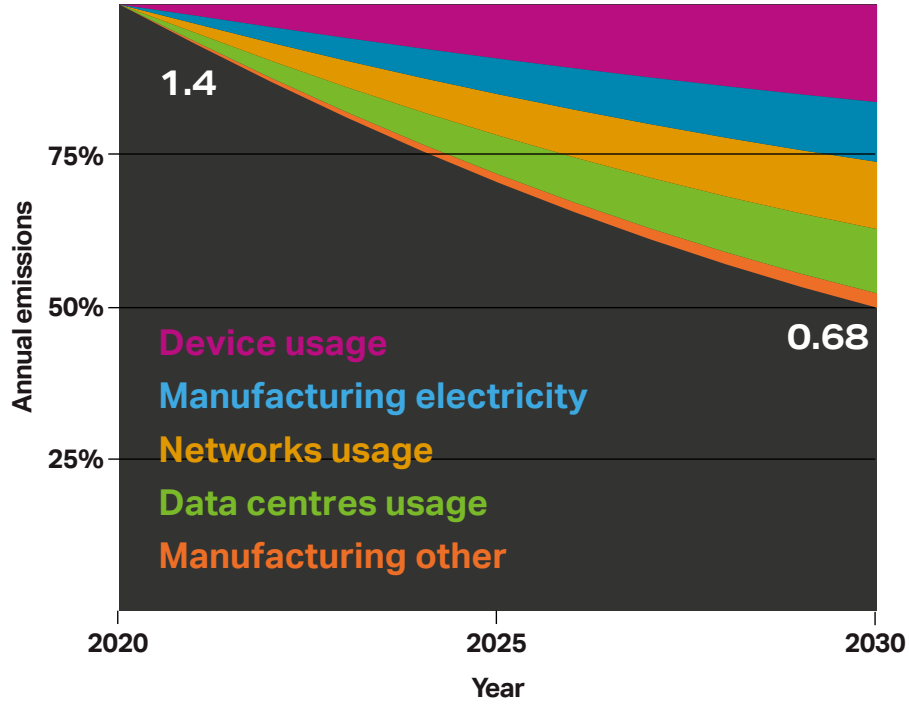


Figure 10. Digital Industry
Estimated 50% reduction of annual emissions for the digital industry sector (including ICT and E&M) by 2030.

SOLUTIONS FOR FIRST HALVING

The digital industry has continually reduced its emissions for almost a decade,[3] and both its strategies and its success in technological innovation may be instructive in other industries. Nonetheless, its remaining emissions must halve by 2030, and this chapter presents the most likely ways for the industry to achieve this.

The most important solution is to use renewable electricity to power data centres and networks. Already, the ICT industry is by far the largest purchaser of renewable energy.[3] However, the industry must also continue to improve its energy performance and has the opportunity to further invest in its own energy production, especially in regions where clean energy is not widely available. Increased collaboration with other sectors can accelerate the renewable transition.

To date, many ICT companies have set carbon reduction targets that have resulted in large emissions reductions. Additionally, the digital industry can be seen as a catalyst for transformative emissions reductions in other sectors, due to already-existing technological low-carbon solutions for industry, consumers and cities.

Renewable electricity

Electricity is a key part of the emissions of many industries, but perhaps none to such a great an extent as in the digital industry. Ensuring that its electricity comes from renewable sources is the most effective strategy to reduce those emissions fast and will have an impact across all parts of the industry.

Transitioning to renewable energy

Apple has achieved 100% renewable electricity for its operations worldwide.

23 suppliers committed to clean energy.

Many of the largest technology companies, such as Google, Apple and Microsoft, have already achieved or are close to 100% renewable electricity.[1] However, outside of parts of the United States and the Nordic countries, the picture is more diverse. Many regions still lack renewable production capability, and network infrastructure – in contrast to data centres – needs a local presence to ensure universal access to telecommunications and the internet. Still, based on extrapolation of current trends [1], we estimate that about 100 TWh of the 600 TWh of electricity used by the digital industry will come from certified renewable sources by 2020.

Data centres and networks

As well as powering data centres and networks with renewable electricity – either generated on-site or purchased from the grid – network operators can do even more. The most forward-thinking networks are aiming for net zero emissions from their operations – Verizon is aiming for net zero for its own emissions by 2035, while Telia has set out to reach net zero emissions by 2030, including in its value chain.

Mobile network efficiency

The energy performance of networks improves continuously through modernisation programmes and the integration of antennas and base stations.

Ericsson and Nokia have seen around 40% energy savings.

A zero-carbon data centre

Google's data centre in Hamina, Finland is built in an old paper mill and uses water from the Baltic Sea to cool servers.

The data centre uses 100% wind power.

Data centres and similar technical network sites benefit from efficiencies of scale. Many smaller and older sites can be replaced by fewer centralised facilities with optimised operations. Cooling is a major component of data centre electricity use, so locating data centres in regions with a colder climate and with access to clean energy will lead to reduced emissions. The Nordic countries are already attracting increased investments in large data centres for these, and other, reasons. Another opportunity is the potential for reuse of excess heat from data centres, which could be used in district heating systems or similar.

In many areas there is potential to replace multiple parallel legacy networks (e.g., older telephony and cable TV networks) with new, efficient fibre-optic or cellular networks which reduce maintenance needs and energy use. Many network sites and their back-up power solutions could play an important role in smart electrical grids, allowing for energy storage, backup and stabilisation.

Beyond measures to optimise the electricity usage of data centres and networks, operators can also help to measure and reduce energy consumption and emissions in other sectors, such as buildings, transport strategies and fleet management.

Devices

The introduction of the smartphone has had a profound impact on the digital industry's total environmental footprint. Functionalities which previously required separate hardware, such as media players, clocks, calculators and satellite navigation systems, have been replaced by one single material- and energy-efficient device, which can be augmented and updated over time with new features.

On the other hand, the electricity consumption of devices such as smartphones, tablets and computers still remains a large part of the total electricity consumption of the digital industry, and the decentralised nature of the power use of these devices means that shifting to 100% renewables is a greater challenge. Until renewable electricity reaches most buildings on the planet, it is important to develop new business models where devices are purchased with renewable energy credits, which cover charging throughout the life cycle of the device.

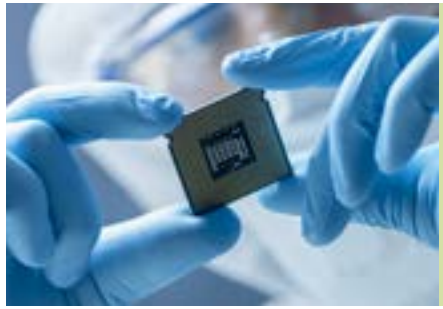
Manufacturing

The final key component of emissions in this industry is manufacturing. For networks and data centres this is a minor part of the overall footprint, but it is significant for devices. About two thirds of manufacturing-related emissions can be eliminated with a switch to 100% renewable electricity .[1] The remaining third is more difficult to address, as it is split between materials, industrial processes, non-electrical energy and transportation. Possible strategies here include accelerating the development of alternatives to industrial gases with high global warming potential, rethinking materials life cycle (including packaging), and a reduction in the use of air freight to transport goods.

Daring goals of a network operator

Telia has committed to zero waste and net-zero emissions by 2030 across its entire value chain.

It is using >90% renewable electricity on core markets.



Halving chip manufacturing emissions

Intel has quickly and drastically reduced the fluorinated gas emissions from its chip manufacturing plants.

The firm will reduce emissions from 2010 levels by 10% by 2020.

ACCELERATORS

Climate leadership

The digital industry is well-positioned to decarbonise fast, due to its focus on innovation and the fact that its footprint is fairly small and mainly associated with the use of electricity. With the right climate leadership, the digital industry can halve emissions rapidly and efficiently by 2030, and likely go beyond this target.

Globally, a critical mass of the digital industry companies and their supply chains must align their climate strategies and develop roadmaps to drive down emissions. The digital industry can accelerate this transformation by mandating renewable energy when investing and expanding global operations, and building up its own renewable electricity production capability.

Finally, this industry's role as an enabler, as an innovator and as a provider of services and solutions to other sectors is important and must not be neglected. Many of the solutions and platforms that allow other sectors to halve emissions will originate from the digital industry, which must therefore put its best minds towards solving the climate crisis.

Policy

Digital companies are continuously seeking to address energy efficiency due to competition and price pressure. What will accelerate this transition further, however, is strong policy in the energy sector – to expand the availability of renewable electricity supply and achieve the emissions reductions needed for the next halving in the 2030s.

Increased transparency of the carbon footprint and decarbonisation measures of digital products and services should be implemented in order to foster positive competition. But of greater importance for emission reductions overall is probably how policymakers can ensure access to digital infrastructure in other sectors, and leverage the use of digital technology to help these sectors reduce emissions.

Exponential technology

The digital industry is expected to continue to accelerate efficiency in data centres, networks and manufacturing based on system optimisations and hardware development. It can, if optimised for climate and resource efficiency, take an even larger role in accelerating the halving of global emissions by developing new performance and energy-efficient technology for other sectors. You can find more details on this in the "Exponential technologies and solutions".

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	All digital companies set strong emissions reduction targets and increase investments in renewable electricity production. Digital industry companies stimulate innovation and creativity, especially related to decarbonisation. Carbon footprint information for digital products and services is made available for businesses and consumers. Business models to decarbonise end-user device electricity consumption are established.	Rapid increase in on-site renewable energy production and grid purchase globally. Non-renewable energy used in production/ manufacturing drastically reduced.	Digital companies become net producers of renewable electricity.
Policy	Policy accelerates the use of renewable electricity in all markets and for all categories of users globally.	Renewable electricity made available for all production/manufacturing activities worldwide.	Renewable electricity made available throughout value chains globally.
Exponential technology	Next-generation hyperscale data centres, 5G networks and energy efficiency techniques and management drive up efficiency further. Active dismantling of obsolete legacy networks. Circular business models taking off. Innovation and development of technologies and platforms based on connectivity that support drastic carbon reduction across sectors.	A majority of digital products are designed with circular economy in mind. Establishment of standardised platforms for communication, automation and artificial intelligence that other industries can use to reduce their emissions.	All technology products designed with circular economy in mind. Full connectivity is implemented in all industries and seen as default requirement in products with a climate impact potential.

THE WAY FORWARD

The digital industry has a strong head start on emissions reductions, but this is not a reason for complacency.

The most effective solution to reducing emissions in the digital industry is a rapid shift to 100% renewable electricity.

The digital industry should set requirements on suppliers and put positive pressure on regions to halve emissions before 2030. As the largest buyers of renewable energy, digital companies can take the lead in accelerating the renewables revolution globally.

Other solutions include replacing and dismantling legacy networks with more efficient digital networks, rebuilding and/or moving data centres to regions with a larger share of renewable electricity production, and rethinking packaging and transport.

However, the biggest role that the digital industry can play is in contributing to more effective and transformative solutions to other sectors, influencing consumer and producer behaviour and leading the transformation of our energy systems.

BUILDINGS

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS IN THIS SECTOR GLOBALLY?

Yes, solutions exist to halve emissions for existing buildings, and to ensure halved emissions in new buildings.

CAN THIS BE ACHIEVED BY 2030?

Yes, the technology and knowledge exist to rapidly reduce carbon footprints for buildings by more than 50%.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Key issues include outdated regulations, lack of firm requirements from customers and cities, the need for investment capital for retrofitting and a projected need for a large number of new buildings in the coming decades.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

With strong requirements for energy efficiency. By driving down carbon footprints in existing buildings. With clear incentives for using building space more efficiently and by incentivising and enforcing low-carbon construction and strong energy and greenhouse gas requirements in procurement.

CURRENT SITUATION

Annual emissions related to existing buildings were about 9.9 Gt CO_2e in 2016, and have decreased slightly since, with about 60% coming from residential and 40% from non-residential buildings. Annual emissions related to building construction, on the other hand, are increasing steadily and reached 3.7 Gt CO_2e in 2016.[1]

As of 2016, there were 235 billion square metres of building space globally, which is more or less expected to double by 2050 in a business-as-usual scenario. Energy use per square metre is reducing by about 1.5% each year, but this is offset by an increase in floor area of 2.3% per year.

This growth is mostly expected to come from China and India in the coming decade, and Africa from 2040.

TRAJECTORY

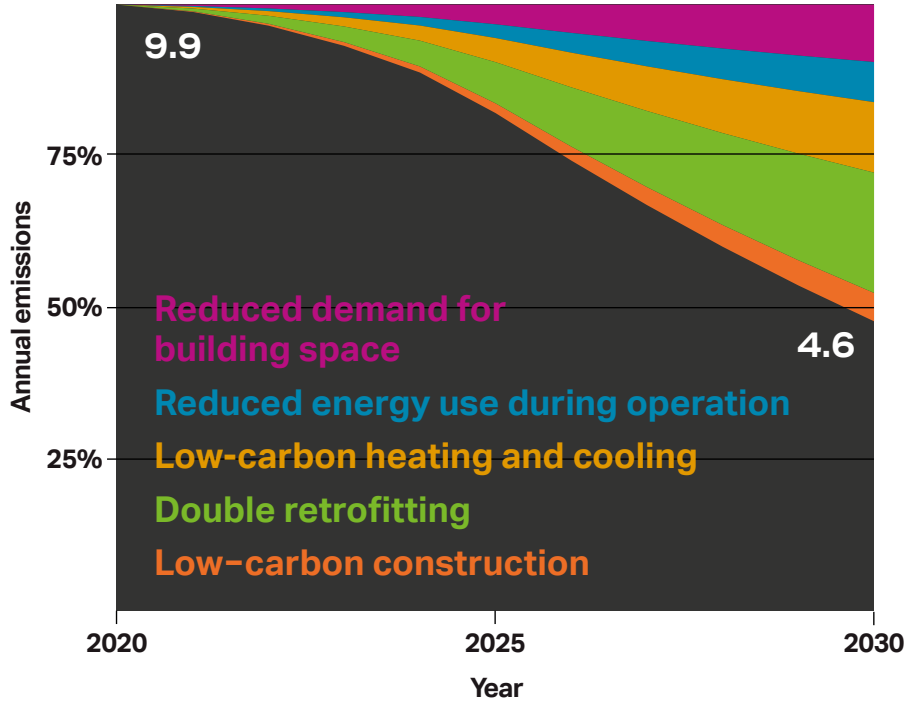


Figure 11. Buildings
53% reduction of the annual emissions of the buildings sector by 2030, which includes reduction of 3.3 Gt (63%) electricity and heat-related emissions.

SOLUTIONS FOR FIRST HALVING

We spend most of our lives inside buildings, but their impact on the climate is not sufficiently considered. This must change if emissions in this sector are to halve by 2030, but we'll also need to get comfortable with using buildings in new ways.

The sector is changing, in ways that are both positive and negative for a halving of emissions. On the one hand, new technology is helping to lower energy use through better materials and digital control systems. But on the other hand, the total area of buildings worldwide is growing rapidly – resulting in emissions from both construction and use. The projected increase is on the scale of 200 billion square metres by 2050.

The most common way of measuring energy use in buildings is kilowatt hours per square metre (kWh/sqm). But the total energy use of construction (divided by the expected lifetime of the building) should be added to the measurement. Moreover, kWh/sqm does not account for the benefit given by the building. Therefore, it should be complemented with a measurement of energy use divided by intensity of use, e.g. energy use per resident or energy use per client, depending on the purpose of the building.

The main ways of reducing energy demand and greenhouse gas emissions for buildings are a reduction in demand for building space, a reduction of energy use during operation, roll-out of low-carbon heating and cooling, retrofitting to minimise energy use and carbon footprint and a reduction of energy use and carbon footprint during construction and refurbishment.

Reduced demand for building space

Some sectors have dramatically reduced their need for building space in recent years – most notably banks and post offices, where so many of the activities that used to be performed there have moved online. Other possible future candidates for a change in that same direction would be education (with increasing opportunities for online education) and retail stores of different kinds as internet shopping changes the conditions for those businesses.

Demand for building space can also be reduced by more efficient use of space. This can be achieved either through more intense use per square metre or per day. For example, implementing flexible seating ("hot desking") in offices can increase space utilisation, while using a school building for non-school activities in the evenings would increase the level of use per day.

Residential buildings can be used more efficiently in similar ways by increasing the number of residents per floor area or by an increase in the use of home offices or short-term letting. Shared workspace solutions can provide more than double the space efficiency compared to traditional office solutions.[2]

Reduced energy use during operation

The amount of operational energy used by a building can be reduced by automatically adjusting temperature, ventilation and lighting in accordance with how a building is used. On the basic level this could be as simple as movement sensors, but newer network-connected sensors and artificial intelligence systems can "learn" the use patterns of a building and anticipate change in advance. In this way, a building can be divided up into zones which

Optimising space utilisation

Innovation companies Flowscape and Yanzi use digital technology to optimise office space use, while increasing the quality of workplaces.

Space management solutions can reduce the need to construct new buildings.

Retrofitting the Empire State Building

A recent retrofit of New York's Empire State Building included new windows and smart lighting systems throughout the building.

The retrofit cut energy use by 40%.

Smart thermostats

Smart thermostats, like those made by Nest, automatically adjust to people's habits, saving energy on heating and cooling in residential homes.

They could contribute to 2.6 Gt of emissions cuts up to 2050.

are only lit, heated, cooled and ventilated when they're used – thus reducing energy consumption and cost while improving comfort.

What's more, such a system could interface with a smart grid – knowing to heat a building, for example, when energy supply is high but demand is low. This would allow building stock to balance out supply variations in an energy system with a high percentage of renewables.

Low-carbon heating and cooling

The temperature regulation systems in buildings contribute a substantial portion of greenhouse gas emissions. This can be reduced substantially through investments in low-carbon technologies such as heat pumps, solar cells, heat storage technology and district heating systems based on renewable resources. Rapid investment in renewable energy production and storage on a building and block level offers a key opportunity to scale renewables exponentially.

Doubled retrofitting

Among the world's existing buildings, doubling the pace of retrofitting holds great potential for reducing emissions – LED lighting, improved insulation, energy-efficient ventilation and smart windows will have the most impact. It is also important to consider that emissions related to the production of new insulation, ventilation and windows must be minimised, otherwise planned emissions savings can be lost.[3]

Low-carbon construction

The emissions from the production of materials such as cement, concrete and steel, as well as the construction process itself, are substantial and therefore need to be specifically addressed. To date, the potential of lowering construction emissions has rarely been prioritised and so is to a large extent unexplored.

The reuse of old building structures is the best first option to avoid emissions. But when this isn't possible and entirely new buildings must be constructed, low-carbon materials and products should be chosen. In addition, it is important to optimise through material, space and energy-efficient designs, as well as taking advantage of low-carbon transport, and materials used in large volumes ought to be locally sourced.

Shared knowledge and the development of digital tools for the whole construction process, combined with stricter demands in procurement, will allow emissions from construction and refurbishment to be strongly reduced. Emissions from construction, most notably from concrete, cement and steel, are described in greater detail in the "Industry" chapter of this report.[4]

Wooden buildings

Mjøsa Tower, the world's tallest wooden building, proves that tall structures can be built using wood.

Using timber for buildings can reduce emissions from material production by up to 85%.

Heat pumps

Danfoss's heat pumps use energy in a building's environment to heat and cool with a low carbon footprint.

Heat pumps reduce energy use by 50–75% .

ACCELERATORS

Climate leadership

Cities, in partnership with regulators, can implement strong requirements to halve carbon footprints in existing building stock. They can require that new buildings are constructed with the lowest possible footprint and by companies that are aligned with the 1.5°C target, and that new/refurbished buildings include photovoltaics and/or energy storage capabilities by default.

Also, there is a real opportunity for companies within the building sector to show climate leadership by setting bold decarbonisation targets and push reductions in demand for building space. Not only would this reduce emissions, but it would make these low-carbon buildings attractive from an economic viewpoint. Some companies are already doing this: the Global Real Estate Sustainability Benchmark recognises building owners internationally with high sustainability performance.

Homeowners and landlords can also play a role in driving down emissions. Energy costs are a large part of household bills, so many energy-efficient technologies are available that cost more at the time of installation, but less over their lifespan. By taking rapid, decisive action to decarbonise their homes, owners can both save money and exhibit climate leadership.

Policy

Halving emissions by 2030 within the buildings sector will require a collection of related, targeted policy initiatives. Introducing a four-step principle[2] for buildings is one such initiative. First, one should try to reduce the total need for building space, then improve the way space is used, then reconstruct a building to better adapt it to new needs, and only as a fourth and last resort construct a new building.

Successful strategies here will both reduce the total amount of building space, thus reducing operational energy consumption, and reduce the need for new construction and thus energy and emissions in that phase. Technology can support more efficient use of offices, shops and educational buildings, but economic incentives can speed this up.

Emissions standards for new buildings and retrofitting existing ones must be sharpened from a life cycle perspective. The high initial costs of energy-efficient solutions can be offset by their lower lifetime costs, but this will require investment support. Finally, policy can help direct technology development towards emissions-cutting technologies in the building sector.

Exponential technology

Technologies such as big data, artificial intelligence and the internet of things – if applied successfully and at scale – have an opportunity to deliver large improvements in space utilisation and reduce building energy use. This goes hand-in-hand with new business models which increase the utilisation factor of shared space, and improve their comfort at the same time.

Other technology opportunities include the balancing of energy demand with local energy production and storage, which will become useful as more new buildings include the installation of small-scale renewable energy systems, and the tracking of a building's life cycle from construction to usage to repurposing. Both of these possibilities will drive further efficiencies in terms of cost, energy use, materials, time and – of course – emissions.

Finally, technology permits better materials management, the sharing of materials during construction, and the re-use of materials from retrofitted buildings, all of which dramatically cut the carbon costs of construction.

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	Leading cities put strong requirements on construction companies and processes to halve their emissions. Business and house owners request climate-friendly buildings to show climate leadership. Leading construction companies take the lead in low-carbon construction and materials. Private home owners and property managers take the lead in implementing low-carbon solutions in combination with automated management.	Reduction in demand for new buildings in some countries, despite growing population, through more efficient use of building space. Industry movement to implement carbon-free materials and construction methods. Companies generally require rental contracts with zero-carbon emissions.	Buildings with zero-carbon footprint become mainstream.
Policy	Policies implemented to drive retrofitting of buildings. Investment support for low-carbon refurbishment and solar energy for new or renovated buildings. Building standards set life cycle demands on new construction and refurbishment, and require transparent carbon footprint information.	Policies implemented to support efficient space use and punish inefficient use of space.	Zero emissions construction and usage for new buildings.
Exponential technology	Digitalisation, artificial intelligence and the internet of things enable strong energy and space efficiency gains in existing and new buildings. New sharing models enable efficient space use, matching demand and supply. Solar and energy storage takes off in new and renovated buildings. New low-carbon construction materials developed	Full-scale implementation of building automation for reduced energy use. New low-carbon construction materials become successfully scaled globally.	Most commercial and multifamily residential buildings produce their own energy.

THE WAY FORWARD

TRANSPORT

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS IN THIS SECTOR GLOBALLY?

With ambitious coordinated measures, it is possible for this sector to halve emissions by 2030

CAN THIS BE ACHIEVED BY 2030?

Yes, these solutions are available and economically viable with strong partnerships between industry, public sector and academia.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Strong policy packages are a requirement. Lock-in of existing vehicle stock. Aviation remains problematic in the short-to-medium term, mass transit systems are expensive, capital costs are high and it may be difficult to change behaviour. Measures to optimise transport as a system are currently inadequate.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

Carbon pricing and strict emissions standards can lower demand for high-emissions transportation, while technology and business models can make sustainable solutions cheaper and more attractive. Policies to ban emitting light duty vehicles, as a first step for new vehicles, can also help to close the gap between existing and zero-emitting vehicles.

CURRENT SITUATION

Transport-related emissions total 8.6 Gt CO_2e per year, which represents 16% of the global total. Most (73%) of these emissions come from short journeys, mainly in and around cities, in cars, motorbikes, buses and trucks. Economically-viable technologies exist that can entirely replace these with new services for accessibility and mobility, clean mass transit systems and zero-emissions vehicles.[1] However, an appropriate incentive structure for their swift implementation is missing.

The rest (27%) of the total is accounted for by long-haul transport, which includes shipping, aviation and heavy vehicles. While solutions exist to halve fossil-fuel use in these sectors by 2030, doing so will require significant policy initiatives. Eliminating them completely is technically difficult.

TRAJECTORY

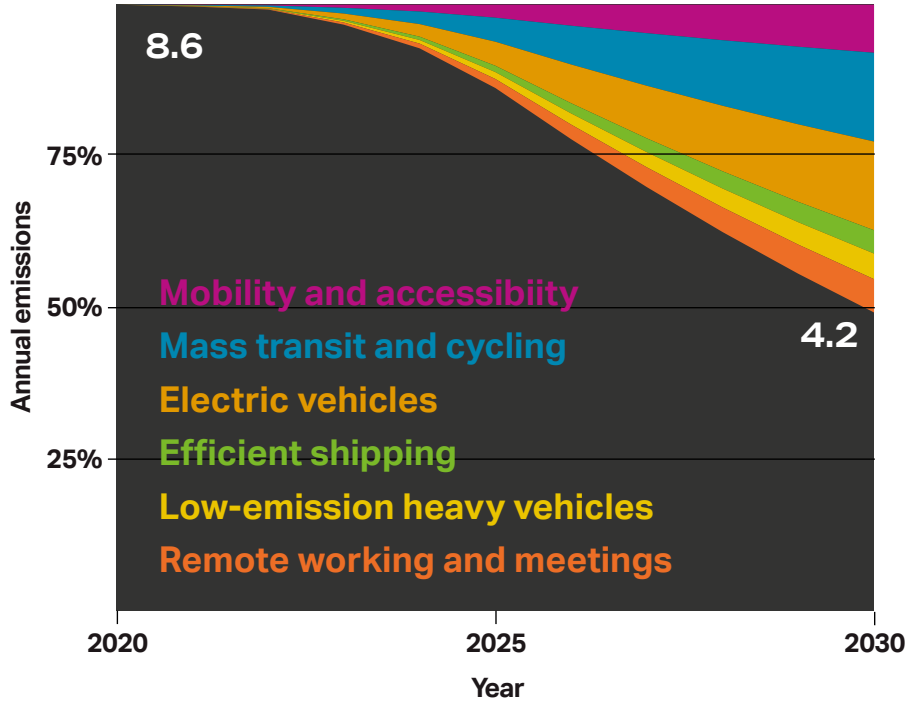


Figure 12. Transport
Estimated 51% reduction of the annual emissions of the transport sector by 2030, which includes reduction of 0.08 Gt (2%) electricity and heat-related emissions.

SOLUTIONS FOR FIRST HALVING

The way we travel has an enormous impact on the world around us. Without strong efficiency measures and major changes in the way we transport goods and people around the world, humankind is on course for a difficult future.

But it is certainly possible to halve global emissions from transport by 2030, and change has already begun. By adopting an "**Avoid-Shift-Improve**" approach to policy measures, we can significantly reduce the environmental impact of transport. This means **avoiding** inefficient or unnecessary travel with improved urban planning, management of transport demand, and digital communication technology; **shifting** to more efficient or environmentally-friendly modes of transportation and/or to off-peak travel, and **improving** the energy efficiency and carbon intensity of vehicles through technological, operational, regulatory or pricing strategies.[2]

Transport is more than cars, of course. Mass transit, walking and cycling, micromobility and accelerating the introduction of a sharing economy will be major contributors to rapidly reducing emissions. The current growth in accessibility, mobility (such as car- and ride-sharing) and micromobility (such as electric scooters and cycle hire) services is promising. The growth of electric vehicles, which beat traditional vehicles on performance and are better for the health of cities, is likely to accelerate at a time when they are increasingly competitive in terms of purchasing price. The total cost of ownership is already better for electric cars in some countries and contexts. However, the limited resources for battery production, hydrogen and biofuels may limit growth of zero-emissions vehicles. Development of infrastructure, such as charging stations and hydrogen fuelling stations is also required.

Aviation, shipping and heavy vehicles are more complex. This chapter will address all major forms of transport, proposing real solutions to halve emissions by 2030. It will focus on mature technologies, not those – like Hyperloop – which are untested and still in a very early stage of development.

Mobility and accessibility

Individual ownership of transportation is far from the most efficient way to distribute resources. The average car is parked 95% of the time.[3] A lower-emissions alternative is to replace car trips with clean "mobility-as-a-service" offerings, provided through fleets of shared zero-emissions vehicles. Such a car fleet could be just 3% of the size of today's fleet of individually owned vehicles. Although each car would be travelling a far greater distance than it does currently, total travel distance across all vehicles would fall by a third – even during peak hours.[4] Longer distances per car means that life cycles would be shorter, allowing for faster adoption of newer, cleaner technologies and more rapid CO_2 reductions.

However, it is worth noting that cities where mobility-as-a-service solutions like Uber are growing are seeing a simultaneous fall in public transport use. Without these services recommending mass transit where appropriate, and using 100% zero-emissions vehicles where not, the potential for emissions cuts will be limited. More effective would be a single interface for all mobility solutions in the area, combining public transport, car-sharing, ride-sharing, bike-sharing, micro-mobility, rental cars and more. Many of the providers of "micromobility" systems are now widening their services by adding multiple types of e-mobility.[5,6] These solutions are developing fast – in some cases so fast that the legacy systems are struggling with adaptation and integration.

Mass transit and cycling

Mass transit – buses, trains and light rail, complemented by cycling and walking – is generally the lowest-emissions solution for large numbers of people. Compared to private vehicles, mass transit saves energy, reduces greenhouse gas emissions, improves health and lowers pollution.[7] However, mass transit is

Intelligent electric bike trailers

Nüwiel's electric bicycle trailer automatically follows the movement of the bicycle so that the cyclist does not have to pull it.

Transporting small cargo by bike rather than car can avoid 64 Mt CO_2e of emissions annually by 2030.

being challenged by cheap private ride-hailing services, which risk an increase in congestion.

Traditional and electric bikes are among the most low-emissions modes of transport, manual or motorised, that exist today – and come with hefty co-benefits in terms of health and reduced traffic congestion. If the share of cycling in all annual urban trips worldwide rises from 7% to 23%, then by 2050 the sector could avoid cumulative emissions of 2.1 Gt CO_2. Meanwhile, it could cumulatively save cities around the world 25 trillion US$.[8]

Digital solutions can nudge and support the transition from infrastructure dominated by cars to those based on varied modes of transport. If 5% of the annual trips currently made by car move to foot travel, about 3 Gt of cumulative CO_2 emissions can be avoided.

Electric vehicles

In 2018, the global electric car fleet exceeded 5.1 million, an increase of two million from the previous year. Electric cars are still a very minor fraction (<1%) of all cars in circulation,[9] though a dedicated policy package (see box in Policy chapter) means that Norway is an outlier with around every second new car sold being electric in 2018.[10] If the global sales of EVs follow Norway's trajectory and grow by 33% each year, 50% market saturation will be reached by 2028 and close to 100% will be reached by 2031. If the global rate of EV sales increase in 2018 (64%) instead would be repeated each year over the coming decade, then market saturation would reach 50% by 2024 and would reach close to 100% in 2026 . This exponential transition to electric vehicles can be accelerated by cities and countries announcing bans on emitting light duty vehicles**.

Renting electric vehicles

EkoRent is a 100% electric car rental and sharing service, and therefore zero-emissions when the electricity comes from renewable sources.

With a 30% market share, about 11 Mt of emissions would be avoided annually.

Sharing fitness app data

The Strava fitness app shares anonymised local data with city officials, offering crucial insights into cyclist and runner behaviour.

Users upload more than 15.3 million activities every week.

Bans on emitting light duty vehicles

Between 2017 and 2019, eleven economies announced bans on new fossil-fuelled vehicle sales, or the intention to introduce future bans, including France, UK, China, India, the Netherlands and Ireland.[11]

27 cities have signed the Fossil Fuel Free Streets Declaration, committing to ban emitting light duty vehicles by 2030.[12]

Since September 2017, more than 35 major firms have pledged to make their vehicle fleets 100% electric by joining EV100.[13]

In December 2018 the Driving Change Together Electromobility Declaration was launched, and has already been joined by 38 countries, international organisations representing over 1,500 cities and regions, and 1,200 individual companies.[14]

*Assuming car sales will stabilise and stay flat after 2020. Data source: **carsalesbase.com** for total cars sold by year and **ev-volumes.com** for electric vehicle sales.
**An "emitting vehicle" emits more than 50g/km and is thereby not a ZLEV. A ZLEV (Zero- and Low-Emission Vehicle) is defined in the European Regulation as a passenger car or a van with CO_2 emissions between 0 and 50 g/km. For heavier vehicles these levels will be different.

Electric scooters and motorcycles are uncommon compared to those powered by fossil-fuels. However, electric versions of all these vehicles are on a strong exponential trajectory fuelled by increasing consumer demand based on cost, performance and high desirability.

A key factor in the transition to electric vehicles is where the electricity comes from. To deliver the greatest emissions cuts, it can only come from 100% renewable sources, and the supply chain should also be considered – as mineral sourcing and battery production can involve substantial emissions.

Nonetheless, a shift to 100% of light vehicle sales to electric vehicles by 2030 is one of the biggest opportunities to dramatically reduce emissions in the transport sector. Furthermore, smart charging or vehicle-to-grid technologies can improve the utilisation of the power grid and enable higher renewable energy integration.

The combined effect of electrification, sharing and autonomous vehicles will be an immense reduction of travel costs. This may generate increased transport volumes and demand for new business models in infrastructure provision and public transport.[15] It will be necessary for policymakers to steer these developments to create a transportation system that society wants and that can ensure affordable low-carbon mobility to citizens.[16]

Remote working

The nature of working life is changing rapidly. Employees are demanding more flexibility to successfully balance family and work commitments, as well as to reduce long commutes. In response, businesses are developing policies and structures in order to meet these demands and become, or remain, an attractive employer. Co-working hubs are becoming more common, but unfortunately they are often located in city centres, rather than in suburbs close to where people live. Such practices could reduce individual commuting emissions by around 50–60% annually and at the same time reduce pressure on infrastructure. High-quality telepresence also has the potential to replace many business trips, saving cost, time and carbon emissions.

Less business travel

Telia has implemented measures to reduce business travel in favour of more video conferencing and online meetings.

Air travel at Telia has fallen by almost 69%.

Reducing demand for air travel

Lighter materials and more efficient propulsion systems mean emissions from modern planes are less intensive than previous generations, but the growth in the sector is dwarfing all improvements – and aircraft emissions high in the atmosphere have a disproportionately large impact on the climate. As such, emissions cuts in aviation are more difficult than in other parts of the transport sector.

Part of the solution is to reduce demand. Rail, shipping and road transport typically emit at least six times less greenhouse gas emissions than any aviation option for each tonne transported.[17] Adopting the least-carbon intensive of these transport modes in a given region or circumstance will dent emissions – this is an opportunity for digitally enhanced optimisation. High-speed rail and long-haul road are already competitive with aviation where routes exist, and these can be fully electrified. Where routes do not exist, however, construction will come with significant emissions.

A rising anti-flight movement has been spearheaded by climate activist Greta Thunberg and the “Stay on the Ground” campaign in Sweden, urging people to take a flight-free year. This, and a recently-introduced flight tax, may already have had some impact. In the first quarter of 2019 Swedish airports saw a 4.5% decline in passenger numbers compared to the first quarter of 2018,[18] and demand for international train travel is growing simultaneously. The campaign has spread to e.g. Great Britain, Denmark, Belgium, France, Germany, Canada, Norway, Slovenia and Austria.

Efficient shipping

If the shipping industry were a country, its greenhouse gas emissions would be the sixth largest emitter. Unfortunately, emissions from international shipping are not regulated under the Paris Agreement. In 2018 nations agreed through the IMO to at least halve emissions from shipping by 2050 and some major sector companies are already aiming to reach zero emissions by this date.

This is a good first start, but more needs to happen and faster. Zero-emissions shipping is feasible, but may not be commercially competitive until at least 2030 without policy intervention. In the meantime, the industry must switch to lower carbon fuels, reduce speeds, optimise routes with digital technology, retrofit efficiency upgrades, and employ greater energy storage capabilities. Halving emissions from shipping is technically feasible and economically viable. However, to achieve this by 2030 the right policy incentives, coupled with collaboration across the maritime industry, governments, academia, international organisations, NGOs and others is required to join the dots, align and act together.

Low-emission trucks

Commercial road transport can be fossil-free by 2050,[19] but it will be necessary to transition the industry to low-carbon modes of operation to halve emissions by 2030. Improved routing and better load management can cut annual emissions by 20%, while new fuel and power-train technologies can provide additional reductions. Biofuels are seen as a promising first step, but ultimately this part of the transport sector must also electrify. Long-haul electric trucks running on electric roads or equipped with large batteries could reach cost parity with diesel engines in about 10 years.

Delivering flowers by sea

The GreenCHAINge value chain consortium transports cut flowers by air-conditioned containers at sea rather than by air.

Delivering roses by boat rather than plane cuts CO_2 emissions by 87%.

Reducing truck emissions

Scania's Transport Lab is reducing truck emissions through driver behaviour, smart maintenance, aerodynamics and alternative fuels.

Scania halved CO_2 per tonne-kilometre between 2008 and 2012.

ACCELERATORS

Climate leadership

Rapid shifts in manufacturer portfolios towards zero-emissions vehicles will drive up market share much faster than industry predictions, assuming demand continues to increase exponentially. More companies are announcing a phaseout of fossil-fuelled vehicles and the ramping up of zero-emissions vehicles. Corporations that rely on transport services must set ambitious targets for their emissions and hit them by increasing their use of battery and plug-in electric vehicles even further.

Transport is a real opportunity for individuals to step up as climate leaders, reducing the amount they travel and choosing low-carbon modes of transportation over those associated with high emissions. Already, young people are displaying less interest in car ownership than previous generations, but this is balanced out by rapidly increasing demand for air travel.

Reducing air travel might seem like a backwards step in a globalising world, but there is room for a substantial cutback while still retaining some travel. Unnecessary journeys can be minimised without anyone missing them, and many goods can be transported by sea or rail.

Policy

Enabling policy packages and frameworks to effectively employ "Avoid-Shift-Improve" approach including longer term full decarbonisation roadmaps to also improve the harder to abate transport sectors. A large range of digital solutions to mobility are available to assist mature zero-emitting vehicles in avoiding and shifting demand to achieve the first halving of emissions from the sector by 2030.

Many cities and countries have announced policies to ban sales of emitting light duty vehicles, but more must do so. This one step will drive major changes in the transport industry, and must be ambitious. Major manufacturers are ready, and it is technically and economically feasible to set a start date of 2025 or 2030.

Investment in mass transit systems is essential to encourage a transition away from individual vehicles. Policies to encourage new mobility solutions and systems will also be crucial to accelerate this shift.

Key policy measures will also include reducing the barriers for new technologies and business models that can replace their fossil-intensive equivalents. One example is subsidising the introduction of electric cars, making the technology cost-comparative at an earlier stage.

Exponential technology

Technology and transport have a lot in common. Both are seen as fundamental to meeting the needs of people in their personal and economic lives. In the transport sector, digital technology can help decrease demand and shift it to more efficient modes of travel, such as walking, cycling and public transport. It can also be used to optimise the use of existing infrastructure and vehicles.

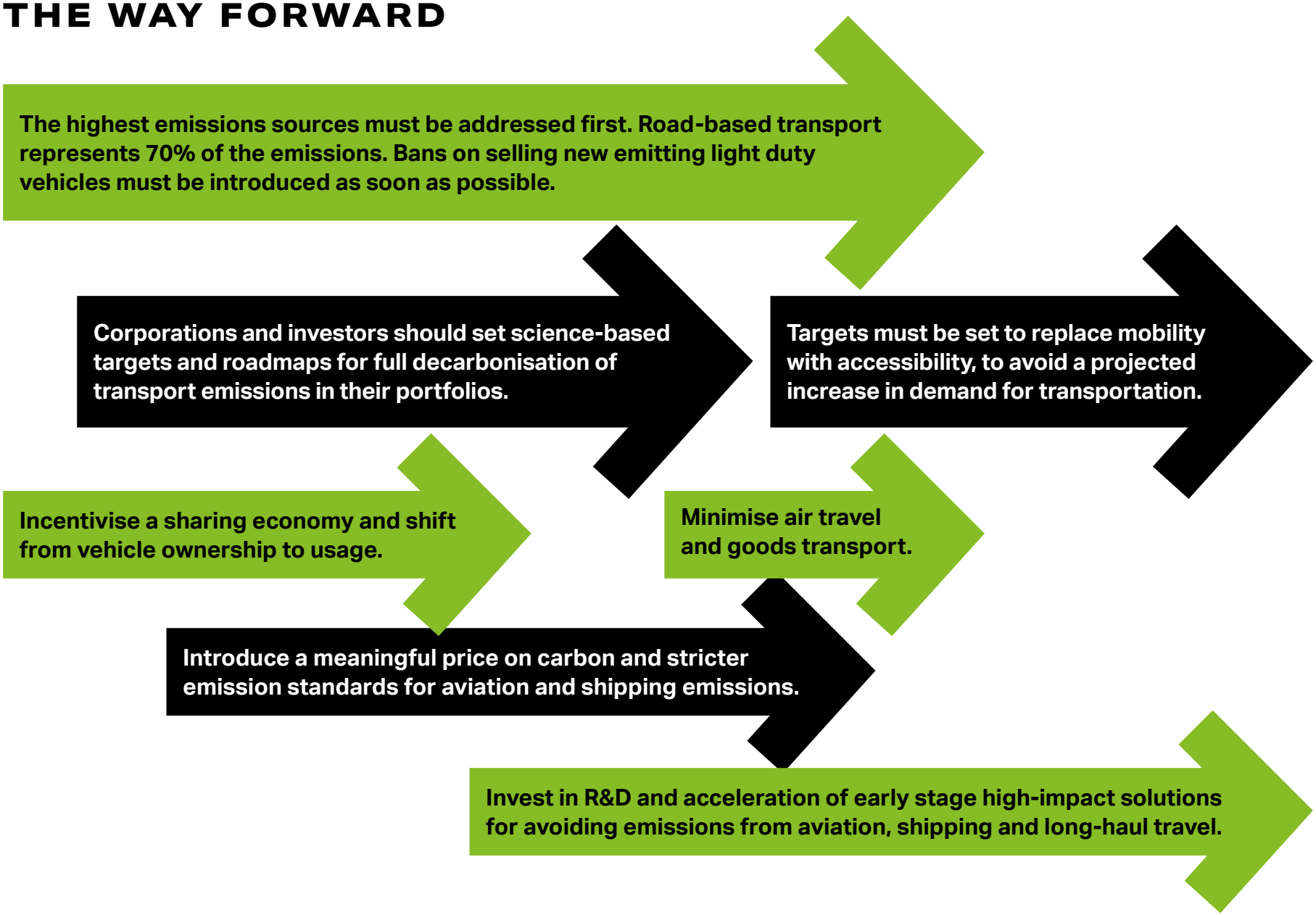
In the coming years, however, we must move away from a vision of mobility based on individual motorised transport, towards access to transport, prioritising people and their quality of life, with strong attention to safety and social equity. This will increase resource efficiency and reduce costs.

Real transformational change in the transport sector will require annual investments of around US$2 trillion. That sounds like a lot, but business as usual has a much higher cost and investments will lead to fuel savings and lower operational costs, decreased congestion and reduced air pollution. These and other benefits of sustainable transport can deliver savings of up to US$70 trillion by 2050.[20]

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	All major car companies have announced dates for when 100% of their sales will be zero-emissions vehicles. Strong climate movements among individuals, cities and companies tip the market towards zero-emissions vehicles and mass transit. Cycling in cities continues rapid growth. A sway in public opinion towards zero emission, autonomous and shared vehicles.	Fossil-fuel use in aviation begins to decline as alternative fuels are used. Renewable energy increases in the shipping sector. Zero-emissions technology economically viable in some heavy commercial vehicle markets Strong climate movements result in a shift away from high-emission transportation companies and the growth of next-generation zero-emissions transport companies.	Zero-emissions transportation is the preferred and default choice for businesses and individuals.
Policy	All major markets have announced intentions to ban emitting light duty vehicles. Major infrastructure investment in cycle routes and mass transit in cities. Barriers to technological shift are reduced with policy incentives for early-stage innovation.	Bans come into force for emitting light duty vehicles, accelerating a transition to zero-carbon transportation. Stronger policies on aviation and shipping introduced as technologies reach maturity.	First major economies announce incoming bans on emitting aviation and shipping.
Exponential technology	Light zero-emissions vehicles expand market share exponentially and zero-emissions heavy vehicles begin to reach the market. Digital tools integrate transportation options for commuters and travellers reducing time and adding value. Next-generation telepresence enables rapid growth of travel-free meetings.	Zero emissions vehicles dominate new light vehicle sales globally and investment in fossil-fuelled vehicles is phased out. Business models are developed for shared, licenced autonomous zero-emissions vehicles.	Zero-emissions aircraft begin short haul routes. Zero-emissions ships reach the market. Zero-emissions vehicles dominate new sales in heavy transport globally and investment in fossil-fuelled heavy vehicles is phased out.

THE WAY FORWARD



FOOD CONSUMPTION

DO SOLUTIONS EXIST TO HALVE EMISSIONS GLOBALLY?

Solutions exist but given local and regional realities and the need to feed a growing population, halving current emissions from food consumption by 2030 seems not possible.

CAN THIS BE ACHIEVED BY 2030?

A shift to plant-based diets in mainly Western industrialised countries and preventing a nutrition transition to Western diets in developing countries can happen quite rapidly. However, given expected population growth and dietary needs in many countries, halving food consumption emissions globally does not seem feasible.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Cultural and societal norms about food, lack of healthy food alternatives, promotion of animal source foods, and a strong resistance from the meat and dairy lobby could slow progress.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

A global movement towards healthy and sustainable diets, policies that include economic incentives and regulatory measures and behavioural change and education can help rapidly scale healthy plant-based diets.

CURRENT SITUATION

Global food production is the single largest human pressure on Earth, threatening local ecosystems, driving a sixth mass extinction of species, and impacting the stability of the entire Earth system.[1,2,3] Feeding and producing food for our current population of 7.6 billion people accounts for approximately 12.5 Gt CO_2e or 23% of annual GHG emissions, of which 5.6 Gt CO_2e (mainly from livestock production and rotting food waste) are directly related to the food choices that we make.[1] Although global food production of calories has kept pace with population growth, nearly 820 million people still lack sufficient food and many more consume an unhealthy diet that contributes to premature death and morbidity.[4,5]

Meanwhile, rising incomes and urbanisation are driving a global dietary transition in which traditional diets are being replaced by diets higher in animal source foods.[6] If this trend is not broken and reversed, emissions from food consumption and production will nearly double by 2050.[2] Livestock production is responsible for around 66% of food's annual emissions yet provides only 18% of calories.[1,7] In addition, overconsumption of red and processed meat, unsaturated fats and dairy products are linked to increased risk for certain types of preventable diseases (e.g. cancers and heart disease).[2] Given this, a significant reduction of animal source foods and increase in healthy plant-based foods in our diets will both reduce global food-related greenhouse gas emissions and improve health.[8]

TRAJECTORY

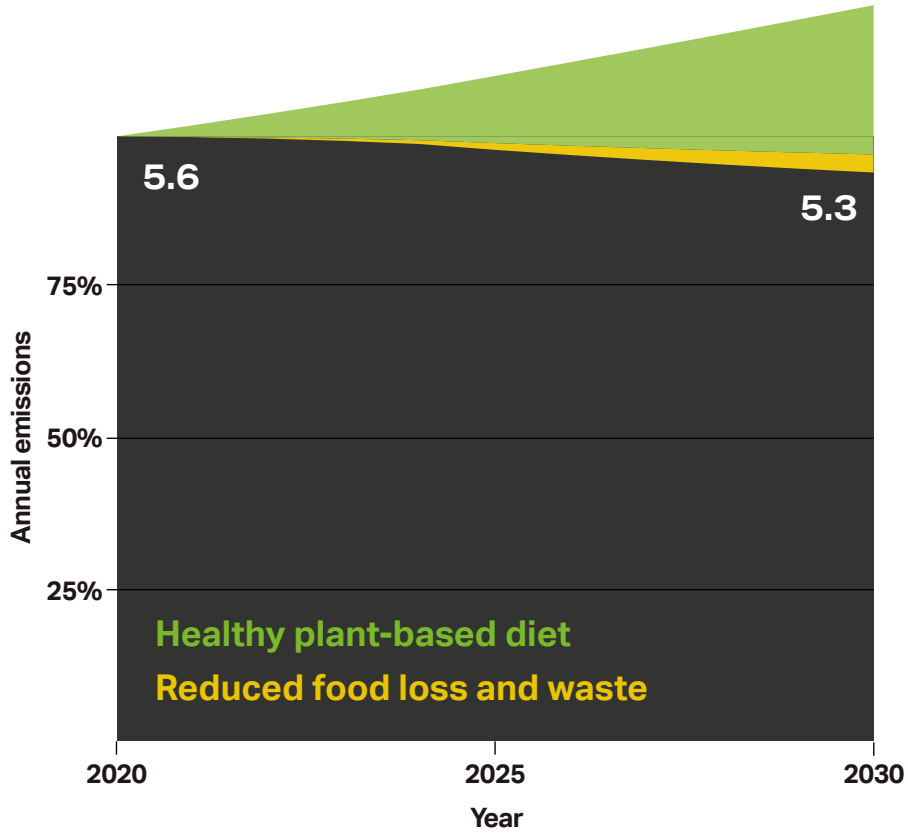


Figure 13. Food Consumption

If current trends are followed, greenhouse gas emissions from food consumption will increase from 5.6 to 6.8 Gt CO_2e by 2030 and nearly double to 9.8 Gt CO_2e by 2050. We can prevent this increase in emissions and reduce current food-related emissions to near the planetary boundary for food (5 Gt CO_2e)[2] with a 40% global shift to healthy plant-based diets by 2030 (75% by 2050) and reducing food loss and waste by 25% by 2030 (50% by 2050). Reduced food loss and waste also avoids emissions from food production and land conversion, which are addressed in the next chapter.

SOLUTIONS FOR FIRST HALVING BY 2030

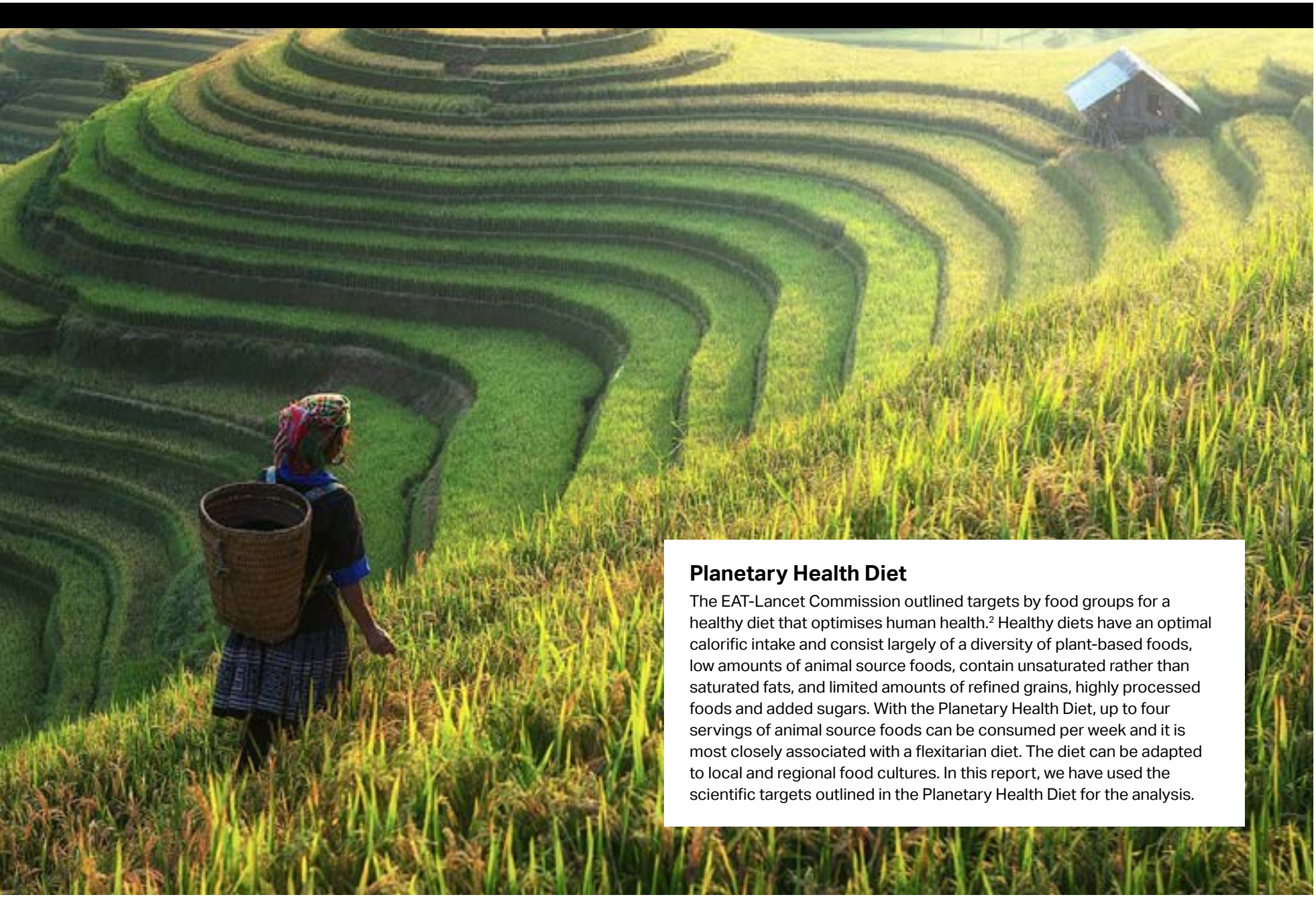
In the 2018 version of this report, we outlined a pathway to halve current emissions in the food consumption sector. In 2019, the EAT-Lancet Commission on healthy diets from sustainable food systems assessed scenarios for feeding a growing population a healthy diet within planetary boundaries and concluded that some emissions from the food sector may be unavoidable with current technologies, local and regional realities, and population growth trajectories. Here, we have adjusted our conclusions accordingly.

The objective should be to prevent emissions from rising further and slightly reduce emissions from 5.6 to 5.3 Gt CO_2e by 2030 and within 5.0 Gt CO_2e by 2050. Emissions could be lowered below 5.0 Gt CO_2e if an even greater percentage of the global population shifted to healthy plant-based diets or cut animal source foods completely from their diets and adopted either vegetarian or vegan diets. For this report, however, we have adopted the ambitious goal of a 40% global shift to the Planetary Health Diet (see definition in box below) by 2030 and a 75% shift by 2050.

The shift to a healthy plant-based diet, however, will be unequally distributed. Countries that currently have higher consumption of animal source foods (mainly Western industrialised countries) will need deeper transformations. The biggest impacts on reducing emissions in these countries will come from a transition towards healthy plant-based diets and reduction in food loss and waste. Luckily, both of these actions are now moving from the far periphery of climate policy and towards the centre of debates on climate and health.

Countries with low food-related emissions, on the other hand, often face large burdens of malnutrition or have large agro-pastoral communities that rely on protein from livestock. Given these considerations, the role of animal source foods in people's diets must be carefully considered within local and regional realities.

Either way, global net emissions from food consumption must decrease and shifting to healthy plant-based diets is the most important solution for accomplishing this.[1,2] This chapter will focus on the demand side of the food system (e.g. consumers, supermarkets and restaurants). Information about food production emissions can be found in the "Nature-based solutions" chapter that immediately follows.



Planetary Health Diet

The EAT-Lancet Commission outlined targets by food groups for a healthy diet that optimises human health.[2] Healthy diets have an optimal calorific intake and consist largely of a diversity of plant-based foods, low amounts of animal source foods, contain unsaturated rather than saturated fats, and limited amounts of refined grains, highly processed foods and added sugars. With the Planetary Health Diet, up to four servings of animal source foods can be consumed per week and it is most closely associated with a flexitarian diet. The diet can be adapted to local and regional food cultures. In this report, we have used the scientific targets outlined in the Planetary Health Diet for the analysis.

Healthy and sustainable diets

Shifting away from current global food trends may seem like an impossible task, but major dietary changes are a surprisingly common occurrence. Over the last half century, many high-income countries have undergone a nutrition transition from plant-based diets to what is known as the Western diet – rich in animal source foods, refined grains, saturated fats and sugar, and low in healthy plant-based foods.[9,10]

To cut emissions in the food sector and improve health, we must swing the pendulum back in the other direction – reversing the shift towards diets high in animal source foods in higher-income countries and slowing or stopping its progression in lower-income countries while improving access to and affordability of nutritious foods for all, especially the most vulnerable.[10,11] A shift of 40% of the global population to healthy and sustainable diets by 2030 and 75% by 2050 can keep total food-related greenhouse emissions in line with a +1.5°C world. Now is a critical moment to avoid a nutrition transition in developing countries.

There are some early signs a transition on this scale is possible. Around 60% of Americans report they are cutting back on meat-based products and of these 77% hope this to be a permanent shift in diet.[12] A recent report found that US beef consumption fell by 19% between 2005 and 2014.[13] In the UK, a recent survey shows that over a quarter (28%) of meat eaters have reduced meat consumption and a further one in seven (14%) adults aim to do so in the future.[14] Meanwhile, Sweden may have reached "peak meat" with consumption falling rapidly.[15] But to reach such ambitious targets, these trends should accelerate and scale globally.

Supermarkets

Swedish supermarket ICA has committed to help reduce household food-related CO_2 emissions.

ICA has also pledged to reduce its emissions by 55,000 tonnes of CO_2 annually from 2020.

Better burgers for the climate

The emissions from all food sold in Swedish hamburger chain Max are now offset.

By 2022, the company aims for every second meal sold to be plant-based.

Growth in healthy plant-based diets

Interest in vegan and vegetarian recipes has risen significantly on the popular German recipe website, **chefkoch.de**.

Vegan recipe popularity rose from 1.2% to 13.5% between 2005 and 2018.

Halving meat consumption in China

China has set a target of halving meat consumption by 50% by 2030. This could reduce global agricultural emissions by 12%.

China currently consumes 28% of the world's meat.

Reduced food loss and waste

About one third of the 1.3 billion tonnes of food produced each year is lost or wasted.[16] Loss refers to food that spills, spoils or is bruised or wilted before it reaches the consumer, while waste refers to food that is good quality but is discarded rather than consumed. These inefficiencies are unevenly distributed, with higher-income countries wasting almost as much food annually as the entire net food production of sub-Saharan Africa. On the other hand, relatively little food on the consumer end is wasted in low-income countries but more loss occurs during production.[2]

In addition to adopting a healthy plant-based diet, reducing food loss and waste is an important strategy for cutting emissions associated with food consumption and production. These emissions come from methane released from food waste decomposing in landfills and carbon dioxide from food production and land conversation.

Reducing food loss and waste by 50% can be achieved through increased investment in collective storage facilities, food processing, technologies and cold storage chains.[17,18] Growers can also be encouraged to adopt strategies for reducing food loss and waste. In high-income countries, awareness campaigns can be used to educate consumers to plan their purchases and meal preparations to reduce food waste. Policies that support drastic reductions in food loss and waste should be incorporated into city- and national-level public policy.[2]

Low-fossil burgers

Beyond Meat creates plant-based meat substitutes that are better for animal welfare and the climate.

Beyond Meat's burgers generate 90% less greenhouse gas emissions than a beef burger.

Rescuing food

Too Good to Go is an app that lets people rescue unsold food from shops and restaurants.

The company aims to save 100 million meals from being wasted by end of 2020.

Canada's dietary guidelines

Canada's 2019 dietary guidelines emphasize a shift toward plant-based foods and drinking more water.

A global shift in similar diets could save up to 11 million lives and reduce global emissions up to 96% by 2050.

Outlawing food waste in the EU

In 2016, France outlawed food waste from supermarkets. The policy is contagious: Italy and Germany have since implemented similar bans.

Food waste is linked to 8% of global greenhouse gas emissions.

Expiration dates

WhyWaste simplifies expiration date management for food retailers, eliminating food waste and cutting both costs and complaints.

Using WhyWaste's systems, food waste can be reduced by up to 40%.

ACCELERATORS

Climate leadership

Major businesses are already beginning to act to reduce the environmental impact of food consumption. Kellogg's, PepsiCo, Bayer, DuPont, Danone, Mars, Nestlé, Unilever and more have pledged to accelerate necessary changes in global food systems and a new generation of food companies and retail chains that focus on healthy and sustainable food have entered the market. In 2016, a coalition of 30 leaders from business, governments and NGOs announced an initiative to halve the amount of food wasted globally by 2030.[19]

Cities around the world are also working to reduce the negative health and climate impacts of food consumption. This is being done through a wide range of measures that include overhauling public procurement, improving the food environment around schools, regulating advertising and boosting local production of healthy foods.[20]

Among consumers, the popularity of flexitarian, vegetarian and vegan diets is growing along with the increasing availability of animal source food alternatives. With increasing awareness of the role that food plays in climate change and human health, a long-term and rapid shift is possible.

Policy

There are few examples of policy interventions to reduce consumption of high-emissions and unhealthy foods,[21] however there are examples of interventions to reduce sugar consumption – mostly in the form of taxes – which could prove instructive.[22] In addition to taxation, policymakers can encourage healthier and climate-friendly diets with clearer labelling on goods, certification schemes and public health campaigns.[2] Requirements for supply-chain transparency, policies to outlaw food waste and research into food system transformation can also play a useful role.

A complementary approach involves encouraging new financing models within food systems, the creation of food tech hubs, and the development of new businesses. This approach will also mean supporting the transformation of industries, companies and individuals who lose out in the transition to a more climate-friendly and healthy food system.

Exponential technology

Several food technologies, like plant-based or lab-grown meat, may have potential in reducing emissions from food consumption, however the health impacts of these foods needs to be investigated. A system-wide rethinking of the grocery store and supermarket industry also offers huge potential in the near term to reduce waste and drive a rapid dietary transition to healthy and sustainable diets.

Since 2013 there has been strong growth in food technology and it is now one of the four largest cleantech venture areas. Mobile applications, such as Too Good to Go where consumers can connect directly with stores and restaurants to purchase food that would have otherwise gone to waste, have the potential to rapidly reduce emissions from food loss and waste.

ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	Global transition towards healthy diets underway in all nations. Food companies have established emissions targets and climate strategies aligned with a +1.5°C world. Supermarkets, restaurant chains and food companies promote healthy plant-based diets and develop policies to scale these products.	Broad global acceptance of healthy and sustainable diets. Major economies halve meat-based emissions. Substantial reductions in food loss and waste.	Food system operating within planetary boundaries. Plant-based diets adopted by a majority of people.
Policy	Removal of subsidies for unsustainable and unhealthy food production and consumption and new incentives for healthy and sustainable practices and behaviour. Carbon pricing and supportive emission standards for the food system. National dietary guidelines promote healthy and sustainable eating and policies enacted to make healthy food affordable and accessible to everyone. Regulatory measures in place to drastically reduce food loss and waste.	Nutrition improves in developing countries in line with the UN's Sustainable Development Goals (SDGs).	Developing countries reach SDG targets of ending hunger and improving health. Dramatic reduction in number of people undernourished, overweight and obese.
Exponential technology	A system-wide revolution in grocery stores and supermarkets. Full digital transparency of the supply chain for food, from the producer to the consumer. Consumers' goals to eat healthier and more sustainably are supported by technology platforms and applications. Innovation and exponential scaling of plant-based food products and alternative proteins. Apps that help consumers to purchase leftover food at a reduced price become commonplace.	New technologies drive down food loss and waste. Alternative proteins are now mainstream.	Digitalisation of the food supply chain allows companies to easily target remaining emissions and develop strategies to deal with them.

THE WAY FORWARD

Food is the dark horse in our fight against climate change. What we eat and how much is lost and wasted is the final battleground in determining whether or not we will achieve the Paris Agreement. An unprecedented opportunity exists, however, to develop food as a common thread between policy frameworks aiming for improved human health and environmental sustainability.

Past experience shows that large-scale systemic change is possible and three overarching lessons from these transformations can guide the way forward in providing healthy and sustainable diets to everyone on the planet. First, systems change requires collaboration across sectors at all levels, working towards a shared set of ambitions. No single actor or breakthrough will be able to achieve this by themselves.

Second, scientific evidence is key to guiding action. While long-term research is important, rapid research is also needed to help policymakers make quick decisions with full information.

Third, the full spectrum of policy levers is necessary for transformation. This includes both "soft" measures such as food labelling and consumer information and "hard" approaches such as laws and fiscal measures; soft measures alone will not get us there.[2]


NATURE-BASED
SOLUTIONS

DO SOLUTIONS EXIST TO HALVE ANNUAL EMISSIONS GLOBALLY?

Yes. A number of nature-based solutions can be implemented today to halve emissions in the agriculture, forestry, and land-use sector, and sequester carbon at very large scales.

CAN THIS BE ACHIEVED BY 2030?

Yes. But the scale of the transformation cannot be underestimated. This may be the hardest sector to rapidly halve emissions.

WHAT ARE THE BARRIERS TO ACHIEVING IT?

Poor land-use planning, contradictory subsidies, focus on quick profits, regulatory barriers, insufficient funding, lack of knowledge, and vested interests could slow progress.

HOW CAN THOSE BARRIERS BE REDUCED OR ELIMINATED?

Policymakers and corporations can scale new land-use programmes regionally, with the help of technology and investments. Innovative funding programmes are required to scale them globally.

CURRENT SITUATION

Agriculture, forestry and land-use mainly associated with food production are responsible for approximately 12.5 Gt CO_2e or 23% of annual anthropogenic global emissions.[1,2] These emissions include 5.6 Gt CO_2e mainly from livestock production and rotting food waste, and 6.9 Gt CO_2e from rice production, agriculture practices, fertiliser use, land conversion and deforestation mainly for agriculture.[1,2]

Agriculture, forestry and land-use, however, have the potential to go from being a large part of the climate change problem to being one of the most important solutions.[3,4] This is possible because these natural systems are both sources and very large sinks for carbon. With changes in how we produce food and what we eat (see Food Consumption chapter) we can both reduce greenhouse gas emissions and use forests, croplands, pastures and peatlands to sequester carbon.[1,4]

To reach a 1.5°C world, we need to rapidly reduce global emissions and store massive amounts of carbon in plant biomass and in the ground, going from net positive to net negative emissions.[5,6,7] This may be achieved without relying upon untested technologies (such as Bioenergy with Carbon Capture and Storage) through lifestyle changes such as a shift to healthy plant-based diets.[8] Forests, grasslands and wetlands are already storing incredible amounts of carbon, but these sinks are currently being removed to grow food and emitting huge amounts of greenhouse gases in the process.[9] Halting the destruction of these ecosystems and using nature to absorb and store carbon from the atmosphere is a vital solution for reaching a 1.5°C world.[1,3]

Negative emissions

In the Paris Agreement nearly all scenarios investigated by the Intergovernmental Panel on Climate Change require using "negative emissions" to remove massive amounts of CO_2 from the atmosphere and store it on land, underground or in the oceans.[5,7] Nature-based solutions can play a significant role in meeting the negative emissions required by the end of century in line with a +1.5°C world.

TRAJECTORIES

NATURE-BASED SOURCES

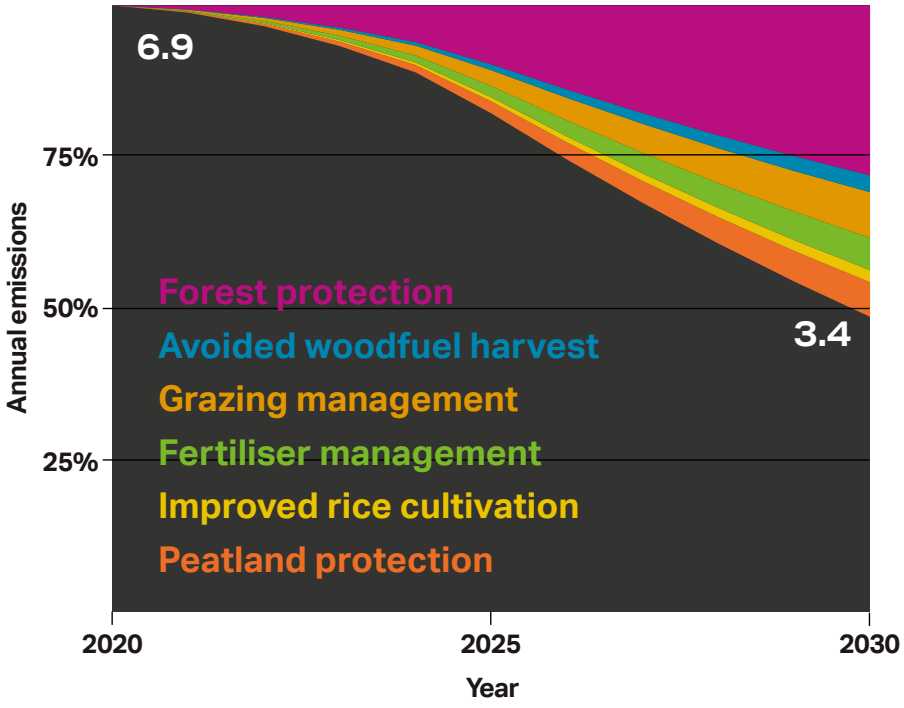


Figure 14.
Nature-based solutions can avoid 3.5 Gt CO_2e emissions by 2030 from agriculture, forestry, and land-use sectors, which are currently emitting 6.9 Gt CO_2e.

NATURE-BASED SINKS

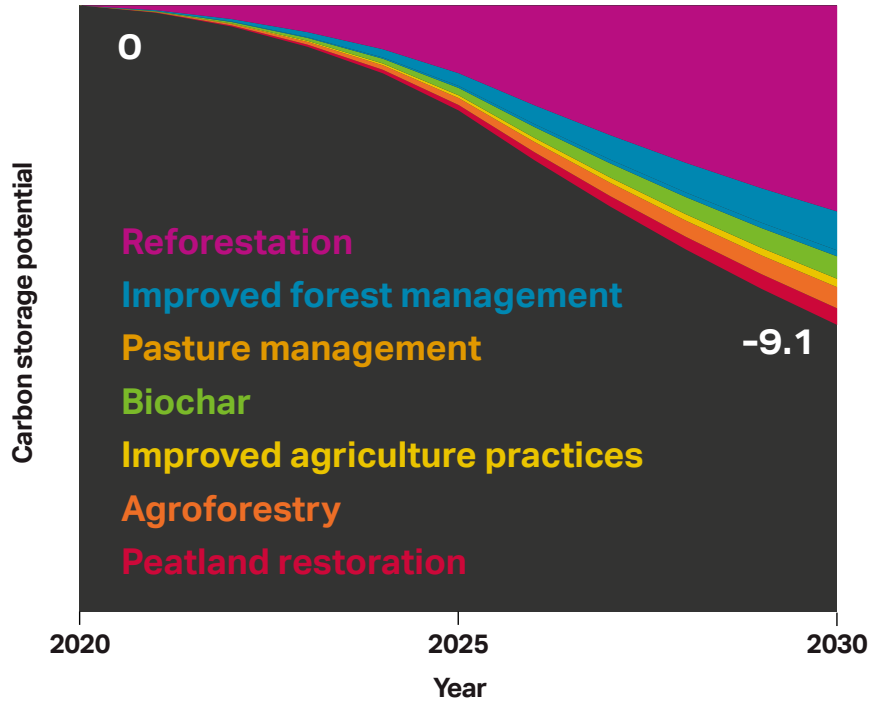


Figure 15.
Nature-based solutions from agriculture, forestry, and land-use can sequester approximately 9.1 Gt CO_2e per year by 2030.

SOLUTIONS FOR FIRST HALVING

Achieving the Paris Agreement will not only require a global shift towards healthy diets, it also requires a radical shift in how we produce food and use land – an agricultural, forestry and land-use revolution. Nature-based solutions can halve emissions from 6.9 to 3.4 Gt CO_2e by 2030 and absorb and store up to 9.1 Gt of annual CO_2e by 2030 and roughly 225 Gt by the end of the century.[3,10] The solutions presented in this chapter are grouped into three categories – forests, sustainable agriculture, and peatlands – with each solution labelled as either a source (i.e. can reduce emissions) or sink (i.e. can increase storage).

FOREST

Forest protection (source)

Halting the destruction of the world's remaining forests is the most important action that can be taken to reduce emissions from agriculture, forestry, and land-use – accounting for approximately half of the emissions reductions from the sector needed by 2030. Deforestation rates in the tropics had begun to slow globally, however in 2018 rates increased again with 12 million hectares lost,[11] the fourth-highest total since 2001. Average annual emissions in the past three years from deforestation have been 63% higher than in the preceding 14 years.[12] Wildfires are another major source of forest destruction, making up 5 to 10% of annual global CO_2 emissions each year. Improved management of existing forests and wildfires has the potential for a cumulative reduction of between 7.0 and 10.2 Gt CO_2e with a best estimate of 8.8 CO_2e by 2030.[3]

One trillion trees

The Trillion Tree Campaign connects funders with forest conservation ventures, to restore and protect one trillion trees by 2050.

A trillion trees planted could potentially capture 25% of all human-made CO2 emissions.

350 million trees in one day

Ethiopia has set a new world record by planting over 350 million trees in a day.

An acre of mature trees absorbs as much CO_2 in a year as is produced by a car driven 26,000 miles.

Reforestation in China

About 646,000 hectares of land has been rehabilitated in the Kubuqi Desert.

This restored land is capable of sequestering 15.4 million tonnes of carbon.

Avoided woodfuel harvest (source)

About three billion people cook on open fires. Fuel for these fires, often wood, accounts for over 2% of annual global emissions. Accelerating a transition away from burning wood for fuel has the potential for a cumulative reduction of between 0.7 and 1.0 Gt CO_2e with a best estimate of 0.9 Gt CO_2e by 2030.[3] This could be achieved by a global transition to cleaner cookstoves.[13]

Reforestation (sink)

Reforestation is the single greatest solution for absorbing carbon from the atmosphere. The majority of this potential (70%) lies in the tropics, particularly in grazing lands and degraded croplands[3,14] Depending on how many hectares are reforested, the cumulative sequestration potential is in the range of 6.0 to 43.0 Gt CO_2e with a best estimate of 24.0 Gt CO_2e by 2030.[3]

Drones planting trees

Drones can sense crop health, moisture and nutrients and even plant seeds. BioCarbon Engineering says its drones can plant 100,000 trees a day.

Drones may reduce planting costs by 85%.

Improved forest management (sink)

Reduced-impact logging, extended harvest rotations, and liana (woody vine) cutting can improve forest management in timber production areas, sequestering carbon in the process. When combined with extending harvest rotation in intensively managed production forests (i.e. plantations), improved management of natural forests can cumulatively store between 2.1 and 19.0 Gt CO_2e, with a best estimate of 3.5 Gt CO_2e, while improved management on plantations can cumulatively store between 0.5 and 2.6 Gt CO_2e, with a best estimate of 1.1 Gt CO_2e by 2030.[3]

SUSTAINABLE AGRICULTURE

Fertiliser management (source)

Overuse and mismanagement of fertiliser and manure on croplands results in approximately 2.0 Gt CO_2e of emissions per year. Increasing efficiency by applying the right amount at the right time to the right crops has the potential for a cumulative reduction of between 1.0 and 2.4 Gt CO_2e with a best estimate of 1.7 Gt CO_2e by 2030.[3] As the world grapples with feeding more people, it will be necessary to use fertiliser more efficiently as well as redistribute its use from areas of over-application to areas of under-application.[4]

Grazing management (source)

Over-grazing on pastures and rangelands can release significant amounts of stored carbon in soils into the atmosphere.[9] As such, decreasing the amount of livestock in areas that are over-grazed and increasing it in areas that are under-grazed can reduce emissions and improve production. Additionally, improved animal feed and the use of more efficient breeds could reduce the number of animals needed to supply the same amount of meat and dairy. These have the potential for a cumulative reduction of between 1.5 and 22.5 Gt CO_2e with a best estimate of 2.1 Gt CO_2e by 2030.[3]

Pasture management (sink)

Managing pastures and rangelands by optimising grazing can increase carbon sequestration in both biomass and soils. In addition, sowing legumes in planted pastures can increase the amount of carbon sequestered on grazing lands, even when taking into account increased emissions associated with planted legumes. Optimising grazing can cumulatively store between 0.4 and 1.6 Gt CO_2e, with a best estimate of 0.4 Gt CO_2e, while planting legumes in pastures can cumulatively store between 0.04 and 3.5 Gt CO_2e, with a best estimate of 0.4 Gt CO_2e by 2030.[3]

Improved rice cultivation (source)

Much of the world's rice is typically grown in standing water, which can become depleted in oxygen and cause bacteria to break down plant matter to produce methane. Currently, rice emissions account for about 24% of agricultural methane emissions with 89% coming from Asia[1]. Limiting the amount of time rice paddies are underwater would cut emissions substantially, save water, and not significantly reduce production. This has the potential for an annual reduction of between 0.2 and 0.3 Gt CO_2e, with a best estimate of 0.27 Gt CO_2e per year by 2030.[3]

Data-driven farming

Microsoft FarmBeats gives farmers real-time data and actionable insights to increase production, drive sustainability and lower costs.

Global food demand is projected to double by 2050.

Agroforestry

Agroforestry in Niger has resulted in the planting of 200 million trees, improving the soil and storing carbon.

Agroforestry could store 2.5 Gt of carbon dioxide by 2030 and 52 Gt by 2100.

Biochar (sink)

Biochar is a charcoal-like substance, typically made from crop residue and other organic matter in a process called pyrolysis. It can simultaneously improve soil quality while sequestering carbon and could stay in soils up to 100 years. The amount of crop residue available for pyrolysis should permit the cumulative storage of approximately between 1.5 and 3.9 Gt CO_2e, with a best estimate of 2.6 Gt CO_2e by 2030.[3]

Improved agriculture practices (sink)

There are a range of agricultural practices that can sequester carbon in the soil. These range from crop rotation and leaving unused parts of the crops on the fields to prevent soil erosion, to planting cover crops, to low- or no-tilling systems. Combinations of these techniques are usually needed, and the results are site-specific, but they can add up to substantial emissions reductions with cumulative estimates ranging from between 0.7 and 1.2 Gt CO_2e, with a best estimate of 1.0 Gt CO_2e by 2030.[3]

Agroforestry (sink)

In addition to techniques to sequester carbon in the soil, agroforestry, or trees in croplands, is another solution for carbon storage.[10] Some food crops are well-suited to growing alongside, beneath and above other species (e.g. macadamia, black pepper, coffee, cacao). Trees used as windbreaks can help reduce soil erosion, reduce evaporation, and increase yields, while storing carbon. As a result, adding scattered trees to croplands – particularly in rows with crops – can increase productivity and soil quality while reducing erosion. These solutions have the potential to cumulatively store between 1.2 and 4.7 Gt CO_2e, with a best estimate of 2.5 Gt CO_2e by 2030.[3]

PEATLANDS

Peatland protection (source)

Globally, peatlands cover up to 440 million hectares, or about 3% of global land area,[15,16] and happen to be one of the most important carbon sinks on the planet – storing an estimated 500–600 Gt CO_2e[17,18] Currently, however, only about 1% of the world's peatlands are protected. Draining peatlands for agriculture releases carbon dioxide and creates fire risks. Increasing the area of protected peatlands from 3 million hectares to over 120 million by 2030 has the potential for a cumulative reduction of between 0.4 and 2.7 Gt CO_2e with a best estimate of 1.8 Gt CO_2e by 2030.[3]

Peatland restoration (sink)

Peatlands are considered degraded when they've been drained or altered but have not been completely converted for other land uses. They can be restored, however, to prevent the further breakdown of stored plant material and to capture new plant debris and store carbon. The primary challenge to peatland restoration is economic – the technical capacity to do this already exists.[14] Restoration of peatlands have the potential to store between 0.7 and 2.5 Gt CO_2e annually, with a best estimate of 0.8 Gt CO_2e by 2030.[3]

Protecting peatland

The Katingan Mentaya Project protects vital peatland habitats in Central Kalimantan, Indonesia.

The project has prevented the release of greenhouse gases equivalent to over 30 Mt CO_2.

ACCELERATORS

Climate leadership

For governments and agriculture and forestry businesses, there are many opportunities to display leadership by establishing climate strategies and setting clear science-based targets to decrease current emissions and rapidly increase negative emissions from agriculture, forestry and land-use. Three important strategies include committing to zero expansion of new agricultural land at the expense of natural ecosystems, integrating 10% biodiversity conservation into existing croplands and adopting a Half-Earth strategy (i.e. protecting half the Earth) for biodiversity conservation.[4]

The New York Declaration on Forests, launched in 2014, is a coalition that aims to end deforestation by 2030. The declaration's 10 targets have the potential to reduce annual emissions from 4.5 to 8.8 Gt of CO_2. The declaration has been endorsed by more than 50 governments, more than 50 of the world's biggest companies, and more than 50 civil society and indigenous peoples' organisations.[19]

Large investors are also challenging agribusinesses to change their game. In 2015, Norway's pension fund, the world's largest sovereign wealth fund, divested from 11 companies – including six palm oil companies – due to their connections to deforestation.

Policy

The economic incentives driving unsustainable agricultural practices and deforestation are huge. Private investment has contributed US$414 billion to farming, forestry and fisheries operations in countries suffering from high rates of deforestation in recent years. Since 2010, out of US$167 billion given by developed countries and major donors for mitigation-related development finance, just US$3.6 billion has gone to forestry. Meanwhile, the same countries received US$87 billion in development finance for agriculture, the sector most responsible for tropical forest loss.[20]

These policy contradictions need to be fixed, combining sustainable agriculture with forest management to increase crop yields, reduce emissions and drive growth. This is a win-win-win situation for everyone. Consistency, however, is a vital component of policy interventions in this sector. A stable, consistent approach on a timescale of decades is necessary for farmers to make the long-term investments necessary to halve emissions while increasing carbon sequestration.[21]

Exponential technology

The spread of the internet to all corners of the globe provides a unique opportunity to equip farmers and those in the agriculture sector with the tools, information and education to transform the way they do business. Many of the solutions necessary to deliver a halving of emissions rely on behavioural change – more efficient farming, adopting new techniques and in some cases reverting to old techniques. Technology firms need to focus heavily on reducing friction in these areas, making it easy for farmers to access information and act on that information.

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ROADMAP 2019–2030

	2019–2025	2025–2030	2030+
Climate leadership	Agro-businesses, farms and civil society develop a worldwide strategy for sustainable food systems to drive healthier, plant-based diets. Governments and businesses commit to zero expansion of new agricultural land at the expense of natural ecosystems, integrating 10% biodiversity conservation into existing croplands, and adopting a Half-Earth strategy for biodiversity conservation. Fund put in place to finance global reforestation efforts.	Deforestation halted globally. Unprecedented global reforestation efforts underway to support mitigation efforts. All major agribusinesses on track to halve emissions. Beef production scaled back and production of healthy foods is sustainably intensified.	Agriculture sector globally on track to store more carbon than it emits.
Policy	Reform of agricultural subsidies worldwide. Stronger policies and financial instruments expand to cover all greenhouse gases. Technology transfer: ambitious policies and investment lead to adoption of sustainable agriculture among farmers everywhere. Countries have published maps of areas with potential for carbon storage. Half-Earth is adopted as a global strategy.	Price on carbon increases annually, accelerating reforestation efforts and business models for carbon storage on land. Trials of sustainable sequestration strategies are well underway. All agricultural policies support sustainable agriculture and forestry and opposing subsidies are eliminated.	Reforestation and other nature-based solutions are economically and socially viable and scaling rapidly.
Exponential technology	Internet coverage reaches all farming areas, accelerating the adoption of digital solutions and precision agriculture. Seed-planting via drones, industries and communities accelerates massive reforestation efforts. Monitoring from space provides real time deforestation, reforestation, land restoration and sustainable agriculture data.	Precision agriculture becomes a dominant technique, reducing global cropland, fertiliser and water use and increasing yields.	Technology allows complete visibility of global land use and is linked to incentives for nature-based solutions.

THE WAY FORWARD

This may be the hardest sector in which to halve emissions rapidly. It can be done, however, by implementing a small number of nature-based solutions to reduce emissions and store carbon from the atmosphere. Some of these solutions are resolutely low tech – planting trees, crop rotation – but can be accelerated by technology and with substantial funding.

Other, more high-tech solutions could be enabled by big data, the Internet of Things and, simply, internet access. Technology is on the cusp of providing complete real time visibility of land and oceans, analysing problems and opportunities at a farm scale and allowing policy incentives to be implemented within days or weeks. Within decades, the internet will reach all but the most remote places on Earth, allowing farmers access to the world's knowledge and local data on crop yields and greenhouse gas emissions.

To achieve this, the world needs an unprecedented public-private partnership of technology companies with agribusinesses, farmers and satellite data providers, along with governments, to build toolkits for nature-based solutions at all scales. The defaults for such toolkits must include reducing emissions and maximising carbon storage.

SCALING THE TRANSFORMATION


CITIES

Cities are interlinked systems of buildings, people and industries, and networks of transport, energy, water, waste, food, information and goods. People use these systems and networks to meet their everyday needs, including services like health, education and culture. They are governed and influenced by local and national policies. This chapter addresses cities in their current state and analyses their potential to support the exponential change necessary to halve emissions by 2030.

Cities occupy only 3% of the world's landmass,[1] but are dense hotspots of activity: they are home to over half the world's population and consume over two thirds of global energy – accounting for 70% of global CO_2 emissions.[2] These emissions are not evenly distributed – 18% of all global emissions come from just 100 cities – each with emission levels larger than many countries.[3,4]

Cities are also where risks associated with climate change coalesce[5] and they are often the first level of government to deal with the consequences. However, this also means they are uniquely placed to realise the economic and health benefits of climate action, as well as the avoided costs[6].

Many cities are already tackling climate change: in 2017, 7,378 cities from 133 countries pledged action on climate change, representing 16.9% of the global population.[7] Also, 27 cities, representing 54 million people, saw emissions fall by at least 10% over a five-year period to 2018, while experiencing an average economic growth of 3%.[8] However, while many cities around the globe have made specific commitments that are compatible with the Paris Agreement, most lack action plans to achieve them.

Halving emissions by 2030

Many cities could halve their emissions relatively easily by strengthening policies that aim to change the behaviour of businesses and citizens, and investing in appropriate infrastructure. The technology to halve emissions is mature and ready to be deployed at scale to reach this target by 2030.

Key barriers include the time required to change and convert infrastructure for fossil-based transport, buildings, and energy systems, difficulty raising the funds to do so, opposition from vested interests, and inertia and lack of capacity among organisations and citizens. A combination of strong climate leadership at several political levels, intelligent policy choices, adoption of the best available technologies, and citizen engagement can overcome these obstacles.

The importance of swiftly putting climate change at the core of urban policy-making cannot be overstated. The number of people living in cities grows by 1.4 million each week. This rapid pace can drive positive change if decision-makers take the opportunity to adopt the right technologies and systems and avoid locking in obsolete ones.

Copenhagen

Copenhagen has set a goal for carbon neutrality, with programs for cycling, public transport, recycling and green space access.

Approximately 62% of Copenhagen's population cycles to work or school.

Delivering the necessary emissions reductions will be demanding. But cities have historically proved that they can develop, implement and dramatically scale major change over short periods of time. City mayors can be more effective than regional or national officials, empowered to take decisive action with immediate and impactful results. What cities do to address climate change can set the agenda for the rest of the world.

Table 1: Notable climate action initiatives among cities

Initiative	Number (at 10 June 2019)*	Nature of the commitment
C40's Deadline 2020[9]	83. Of these, nine have Paris Agreement-compatible action plans	Pursuing climate action compatible with the Paris Agreement
Carbon Neutral Cities Alliance[10]	21	Cutting greenhouse gas emissions by 80-100% by 2050 or sooner
Carbon Disclosure Project A-list[11]	43	Judged by the Carbon Disclosure Project to be leading the low-carbon transition
Climate Emergency Declaration[12]	Over 594 local and regional governments (25 May 2019)	Binding resolutions committing governments to develop an action plan
Viable Cities	Nine Swedish municipalities are collaborating to become climate neutral by 2030	Designing and implementing action plans to become climate neutral and inclusive cities by 2030 through co-creation between municipalities, citizens, academia and industry

*These lists are not mutually exclusive

Key strategies

Cities are in a unique position. They have the power to improve quality of life for all citizens by dramatically reducing emissions and building climate resilience. They can simultaneously address air pollution, energy access, job creation and health concerns.[13] Halving emissions by 2030 is possible in all sectors, but it must be carefully coordinated across all policy fronts to avoid negative social and economic impacts, and to maximise synergistic benefits. All parts of the community must be on board, because citizens will be key to embedding significant technological change.[14]

Uppsala

Uppsala has agreed a city climate protocol, involving industry, academia, public authorities and environmental organisations.

The city's target is to become fossil-fuel free by 2030 and climate positive from 2050.

Job losses in obsolete industries and other equity issues such as price increases and economic segregation must be addressed. If these are not handled well, they will drive resistance to further change and undermine long- term decarbonisation plans.

The emissions profiles of different cities vary, but studies show the most effective ways to halve emissions generally are: the expansion of renewable energy in a city's electricity mix, adoption of low-carbon policies for buildings (including the retrofitting of existing buildings and strong low-energy standards in new buildings), prioritising sustainable transport and waste management solutions, and supporting citizens who adopt more sustainable lifestyles.[15]

With the right policies, support, and financing, many cities could achieve an electrical grid mix of 50–70% renewables (primarily solar and wind, balanced with other zero-emission generation sources) by 2030. By 2017, 123 cities reported that they had already reached this level,[16] and by the end of 2018, more than 200 cities worldwide had committed to 100% renewable electricity with target years between 2020 and 2050.[17] Shifting to a grid mix of 50-70% renewables would achieve 25–45% of the total emission reductions needed in that time frame.[18] More details on accelerating the renewable energy rollout can be found in the Energy Systems chapter.

Energy- and space-efficient buildings, along with low-carbon construction, can close 20–55% of the gap between current emissions trends and 2030 targets, depending on a city's climate and population growth. This strategy is crucial, as emissions from construction alone could exhaust the global carbon budget for well below 2°C if strict regulations for low-carbon construction and infrastructure are not in place.[15] Near-zero carbon construction is at an early stage of development, but feasible within a decade. In addition, city governments must ensure that public procurement processes select the most sustainable options[19] and plan to incorporate nature-based solutions. These can reduce cooling needs in addition to providing a range of other resilience, social, health and food benefits.[20]

Infrastructure built before 2030 will determine whether humanity achieves the commitments made in the Paris Agreement or not. More detail on reducing the carbon cost of buildings and construction can be found in the Buildings chapter.

Low-carbon mobility, such as public transport, cycling, electric vehicles, car-sharing and pooling, and mobility-as-a-service systems, can contribute emissions reductions equal to 20–45% of the 2030 targets, depending on urban income levels and population density.[15]

More detail on halving emissions in the travel sector can be found in the Transport chapter.

Improved waste management can deliver up to 10% of the emissions reductions needed by 2030,[15] depending on existing waste management services and the composition of waste. Improved waste management as a strategy for reducing emissions is covered in the Industry chapter (page 58).

Ambitious cities should also aim to cut carbon beyond their boundaries by addressing emissions from imported goods and services. These emissions can be up to 60% larger than those from within city boundaries.[21] Working with citizens to reduce their personal carbon footprints is a new frontier for climate action in cities, linking carbon budgets to consumer responsibility and urban planning. It has great potential to deliver significant emission reductions, and is a fairer way of sharing carbon budgets between cities globally.

In 2014, Gothenburg in Sweden was one of the first cities to set a consumption-based emissions target. The city began outreach efforts to reduce the climate impact of air travel, food and goods consumption of its citizens. However, its target of 3.5 tCO_2e consumption-based emissions per capita by 2035 is looking like it will be difficult to achieve without additional momentum, demonstrating again the need for effective public engagement strategies.[22]

Showing leadership

Individual cities, with strong, ambitious leadership, and the right resources and support, can cut emissions even faster than a halving by 2030. Cities are an ideal space for climate change leadership to emerge, given the confluence of high concentration of GDP and global carbon footprints, as well as being the place where new innovations and technologies are developed.

Shenzhen

Shenzhen has 16,000 electric buses in operation and is targeting an electric taxi fleet by 2020.

Shenzhen Bus Group estimates that 440,000 tonnes of CO_2 emissions are avoided yearly.

Cape Town

Cape Town's WhereIsMyTransport app makes public transport appealing and accessible, especially for those who depended on private vehicles.

The app tracks 1,000+ formal and informal bus and taxi routes.

Carbon budgets and emissions targets based on the Paris Agreement would allow cities to develop strategies that shift global emissions closer towards +1.5°C or +2°C scenarios. Furthermore, increasing the adaptive capacities of cities will make them more resilient, as climate change and extreme weather impose high costs for societies.

As carbon footprints are highly concentrated in relatively few affluent cities, targeted measures in a few places can have a huge effect.

Intelligent policies

City governments are key players in the transition towards a low-carbon, sustainable future. City leaders have the power to influence and surpass national targets, delivering ambitious climate plans that not only contribute to reduced emissions, but also improved quality of life for their citizens.

Many cities are already showing leadership in the development and dissemination of low-carbon solutions through progressive policies and actions. But to fully unleash their potential, cities need to do more. They can exercise massive leverage by introducing alternatives for energy, transportation and building standards, for example – all of which affect huge numbers of people.

Eliminating fossil-fuel subsidies would accelerate renewable energy deployment and free up financial resources for national governments to invest in sustainability and social measures.[23] City mayors are directly accountable to their constituents for their decisions, and often more agile than state and national elected officials. They can have the power to take decisive action – often with immediate and impactful results. In partnerships with other cities and levels of government, as well as with private businesses, investors and civil society, the potential for effective action increases.

New York City

New York City requires buildings over 25,000 square feet to reduce their emissions by 40% by 2030 and 80% by 2050.

This will reduce annual CO_2e emissions by 3.9 million tonnes by 2020.

Vancouver

Vancouver will require that all new buildings are carbon neutral from 2020.

Emissions per square metre in new buildings fell by 43% between 2007 and 2017.

Smart cities

The scale, structure, and organisational and social dynamics of cities offer great potential to scale up transformative digital solutions. However, this requires mobilisation of resources and investments towards low-carbon technologies and strategies. Bearing in mind the need to ensure that infrastructure is resilient to future climate change, "smart city" technologies can enable next-generation mobility and electric vehicle breakthroughs, improvements in energy and space efficiency for buildings, and electricity generation and storage. Meanwhile, real time systems using 5G networks, Internet of Things and artificial intelligence technologies can optimise transport and allow citizens to transform their cities. Digital twinning brings these together to enable planners and city managers to maximise the efficiency of local processes.

Furthermore, electrifying cities and preventing fossil-fuel infrastructure lock-in by creating green bonds for solar photovoltaics could contribute to scaling up the number of cities that commit to a halving of emissions by 2030.

CALL TO ACTION

- Citizens must be empowered to become part of the low-carbon transformation of cities, delivering a fast reduction of emissions, as well as health and economic benefits.
- Cities should urgently push for the transformation of finance, so they can access bonds and debt financing, land value capture, and international and national financing to enable a low-carbon transition.
- Cities should ensure that investments rapidly shift to low-carbon, climate-resilient and socially responsible infrastructure and technology, as well as employing strict sustainability reporting, standards and tools. With low-emissions solutions now often at cost parity with other solutions, cities should set tough procurement policies.
- Cities should aim to halve emissions from existing and new buildings before 2030, by placing positive pressure on landlords and companies, requiring emissions reduction targets, climate declarations for new construction and adoption of best practice standards.
- Cities should set consumption emissions targets and support citizens to adopt more sustainable everyday life practices.
- City action plans and carbon budgets should engage all sections of the community to make the most of synergies and avoid negative impacts.
- National governments and international organisations should recognise the powerful role of cities in achieving the necessary transitions and work to empower them.

Oslo

Oslo has introduced an internal carbon budget, which aims to halve emissions by 2020.

By 2030, emissions will be reduced 95% from 1990 levels.


CLIMATE LEADERSHIP

If the Paris Agreement shows a clear vision of where we need to be, the carbon law of halving emissions every decade sets the direction. Rather than putting a goal over the horizon, this places the immediate focus squarely on the next decade – where solutions to halve emissions already exist. Cities, companies and citizens have a critical role to drive momentum to accelerate those solutions.

In the last 12 months there has been a step-change in public action on climate, as well as city, company and investor momentum. Still, existing commitments are not sufficient to deliver the first halving of emissions. If the number of countries, cities, businesses and citizens pledging sufficient cuts reach a critical mass, then we can reach a tipping point to bend the curve towards a 1.5°C degree world.

This chapter will explain how climate leaders who are willing to step up, go in the frontline, share their results, and inspire others can enable a global movement and a virtuous circle of change. These climate leaders will show that a rapid halving is not only achievable, but can be done while boosting prosperity and improving economy and health.

Country climate leadership

Nations must now step up significantly to deliver on the Paris Agreement, also described in the "Meeting the 1.5°C climate ambition" and "Policies and targets". The emissions targets set by countries are not sufficient to keep the world well below 2°C of warming, let alone aiming for 1.5°C. Current emissions pledges commit the world to 3°C warming or higher.[1]

But some countries have displayed greater commitments than others. Bhutan achieved carbon neutrality in 2009. Norway, Finland, Sweden and the UK have now agreed targets to reach net zero emissions by 2030, 2035, 2045 and 2050 respectively. Developing countries like Costa Rica and Fiji have declared they will be carbon neutral by 2050.

Even when national commitments are lacking, regional governments can make meaningful carbon reduction commitments. For example, even while the United States federal government makes plans to withdraw from the Paris Agreement, the state of California passed a regional law requiring emissions to be 40% below 1990 levels by the year 2030.[2] After that point, four additional states – Washington, Hawaii, New Mexico and Puerto Rico have committed to 100% clean electricity, and at least six other states are considering similar legislation.[3]

To meet the goal of limiting warming to about 1.5°C, it's essential that all countries follow the leading nations and raise their pledges, with commitments to significant reductions by 2030 and net zero emissions by 2050 at the latest. In particular, high-income countries, with greater historic emissions, have a responsibility to adopt more ambitious trajectories.[4] Developing countries can get an advantage though by taking advantage of low-carbon technology, avoiding fossil-fuel dependence of older, high-carbon technology.

But country leadership is not only about commitments. They must also prove their leadership by setting strong policies and share their policy successes with others. As further detailed in the policy chapter, countries have a wide range of policies at hand and need to address a broad range of areas to make sure that their decarbonisation commitments do not stay as such.

This ranges from removing subsidies and pricing carbon; over curbing diffusion of old technologies, accelerating new technology development and diffusion; via incentivizing behavioural changes and system transitions to reduce demand and increase efficiency; to supporting nature-based solutions.

With no easy solution at hand, and with the need to safeguard a just transition to all planetary boundaries, countries are up for a challenging task. Even for policies, countries could accelerate transformation by learning from each other to a much larger extent. Leaders should make sure to share their success stories – and failures – and push others to follow.

Country action consistent with the carbon law

- Set targets in line with 1.5°C trajectories by 2020.
- Implement the broad policy approach described in this report.
- Closely monitor emissions, and take action to make sure they comply with targets while actively sharing their successes and failures with others to accelerate the broader transformation.
- Build coalitions with other front-running countries to push the international processes.
- Build alliances for climate action where corporates, cities, investors, academia, civil society and citizens come together to share the same mission and influence policy towards raised ambition.
- Accelerate high-impact zero-/low-carbon solutions and enable their scaling to other countries.
- Share results of climate action to help spread effective methods across the world and partner with other countries on climate action campaigns.

Green to scale labs

The five Nordic countries have declared a commitment to carbon neutrality and intend to work in support of 1.5°C trajectories.

The countries have been reducing emissions from different sectors while growing their economies.

Cities climate leadership

Cities and urban areas are home to about 55% of the global population, but account for more than 70% of global emissions.[6,7] Despite this, due to infrastructure of scale and spaces of innovation, cities and city leaders have a real opportunity to leverage the climate movement among their citizens to deliver major emissions cuts above and beyond what is being pledged at a national level. Crucially, they should not just promote climate actions, but the great opportunities in terms of health and economy that such actions hold for cities and urban dwellers.

Over the past two decades, cities have been steadily making public commitments to reduce emissions. Consortiums such as C40, the Carbon Neutral Cities Alliance, ICLEI – Local Governments for Sustainability, WWF's One Planet City Challenge, CDP and the Global Covenant of Mayors, are working to build movements and track cities' carbon reduction commitments (see Cities chapter). 78 cities have declared they will be emissions neutral by 2050. [8,9,10,11]

6,800 cities have committed to reducing the levels of CO_2 emissions in their territories by at least 20% by 2020 or by at least 40% by 2030. This approaches the level of commitment required by the carbon law.[12] More, of course, needs to be done in terms of sharpening existing targets and growing the number of cities who make new ones. In particular more needs to be done in terms of implementation.

But there's a real opportunity to deliver health, clean air, transport, efficiency and economic benefits on top of the direct benefits of emissions reductions. Climate action is highly popular with city dwellers, so city officials willing to display real leadership in this area have much to gain and little to lose.

City action consistent with the carbon law

- Set targets to halve emissions before 2030 (in 5–10 years) including emissions from imported goods and services.
- Set targets of net zero emissions before 2050.
- Monitor emissions and act to ensure they comply with targets.
- Build alliances for climate action where corporates, investors, academia, civil society and citizens come together sharing the same mission and influence policy towards raised ambition.
- Accelerate high-impact zero-carbon solutions and strategies and ensure they scale to other cities.
- Partner with other cities on climate strategy and action.
- Share solutions and the results of climate action to help spread effective methods across the world.
- Intervene with national policymakers to enable a shift towards full decarbonisation of their territories and join alliances for climate action.

Frontrunner coalitions, cities

Deadline 2020 is an initiative by C40, that sets the level of ambition needed to ensure cities meet the targets of the Paris Agreement.

103 leading cities committed to urgently pursue high ambition climate action.

Company climate leadership

Many industries, for example fashion, construction, materials and consumer goods, must evolve rapidly to thrive and stay profitable over time in a carbon-constrained world. Business models will need to change from ownership towards sharing, from product to service and from linear to circular models enabled by digital technologies. This may create the foundation for disruption and transformation of all industries in the next few years, and has been described as "the largest business opportunity on the planet".[13] Companies will need to be at the forefront to gain a competitive advantage and shift to zero- and low-carbon solutions such as exemplified in the Mission Innovation solutions framework.[14]

A growing number of companies are proving that reducing emissions does not need to harm the bottom line but can drive competitive advantage. Major firms like Stanley Black & Decker, Unilever, Dell Technologies, IKEA, Apple, Google, BT, Ericsson, Danfoss and Intel are systematically and quickly shrinking their carbon footprint, setting strong targets for future cuts, and expanding target setting and achievement to their suppliers.

Companies which build climate leadership into their core strategies seem to be outperforming those that fail to show leadership.[15,16] A study of 300 companies in Sweden found an overwhelming consensus that climate action strengthens a brand, improves customer loyalty, and boosts recruitment – on top of the direct benefits that reducing emissions brings.[17] Research shows that CEOs are aware of the importance of building a social enterprise and in 2019 they cited "their impact on society including the environment" as their most important measure of success.[18]

Several initiatives are tracking the pace of corporate decarbonisation pledges. Momentum is growing, but the number of companies setting targets in line with 1.5°C needs to grow rapidly. To date, few companies have made commitments to halve emissions in 10 years or less.

Corporate initiatives

- The We Mean Business Coalition tracks 1,560 commitments from 997 companies with a combined market cap of US$19.3 trillion.[19]
- In the Science Based Targets initiative (SBTi), more than 634 corporations are taking action to set climate targets in line with the Paris Agreement.[20]
- 175 companies have committed to switching to 100% renewable energy as part of the RE100 initiative.[21]

It will be increasingly important that key industries develop roadmaps to shift business propositions towards zero-carbon solutions. Fossil Free Sweden, a government initiative, is coordinating the development of a series of roadmaps, divided by industry sector, that set out essential steps to phase out the use of fossil-fuels by 2045. So far, roadmaps have been published for 13 industries including cement, construction, aviation, minerals, retail, forestry, transport, sea transport, and steel.[22]

Finally, the technology and finance sectors have a particularly strong opportunity to influence the future due to their disruptive power. This is further described in the exponential technology and finance chapters. As an example, the step-up declaration, launched at the Global Climate Action Summit in September 2018 includes commitments consistent with the carbon law from several hundred companies predominantly from the information and communications (ICT) industry.[23]

Company action consistent with the carbon law

- Commit to contribute to the Paris Agreement and a 1.5°C planet. Global leaders now call for business leaders to commit to 1.5°C targets.[24]
- Set targets to halve emissions faster than every decade (e.g. every 5 years) and target net zero. Closely monitor emissions, and take action to make sure they comply with targets.
- Set targets to halve emissions across the whole value chain including requirements on suppliers within a decade and offset unavoidable emissions.
- Align portfolio and value proposition with a 1.5°C planet, accelerate high positive climate impact solutions in the market and ensure they scale exponentially.
- Communicate emissions, targets and results in decarbonisation, and scaling of climate-positive business transparently and regularly according to standards.
- Enable and participate in common industry-sector initiatives and share results of climate action to help spread effective methods across all industry sectors.
- Advocate to promote a shift towards full decarbonisation of their operations and join alliances for climate action.

Citizen climate leadership

Climate change has become a top concern to people across the world.[25] Since the release of the IPCC 1.5°C special report[26] people are increasingly voicing concern and willingness to act. In places this is translating to influence in democratic elections, behavioural change, and greater awareness of the role of consumption in driving emissions. But exponential change can only be achieved if we recognize that only a minority has climate change mitigation as a key priority and guiding star. Other groups have social status, and social norm compliance at the core. So to accelerate behavioural change, this must be taken into account.

While this text focuses on the wealthy, which have the highest responsibility for the emissions, the leadership of people in all parts of the world is of utmost importance – this is not the least proven by the indigenous people of the rain forests or the taiga, committed to saving the forests and to holding their governments accountable.

A movement on the rise

People can be effective drivers of change. Citizen movements have reshaped society during the 20th century. From civil rights and gay rights to the environmental movement, the achievements have been enormous. In 2018, new movements for climate action, for example Fridays for Future and the Extinction Rebellion, swept the world.

Young movements

- **Fridays for Future** with Greta Thunberg and her followers have striked in over 2,000 locations with millions of people on the streets. Strikes have grown from 80 cities in 20 countries in January 2019 to around 400 cities in over 60 countries.[27] In the May 2019 EU elections, political parties with strong climate agendas polled well. Some of this impact was attributed to the "Greta Effect".[28]
- **Extinction Rebellion** (abbreviated as **XR**) is a socio-political movement originating from London with the stated aim of using civil disobedience and nonviolent resistance to protest against climate breakdown, biodiversity loss, and the risk of social and ecological collapse. It may have influenced the attitude shift where 76% of Britons shortly after the protests agreed that the planet is in a climate emergency. Thereafter, the UK passed the motion to declare a climate emergency, and the Labour party pledged to put climate at the heart of their agenda.[29, 30]
- Both **XR** and **Fridays for Future** make the case to declare a Climate and Nature Emergency. Climate emergencies have been declared by 975 jurisdictions and local governments, which cover 212 million citizens. Cities include Vancouver, Milano, Paris, Napoli, Edinburgh, Oxford, Leeds, Cambridge, Ottawa, Geneva, Basel, Berkeley, San Francisco.[31, 32]

Fridays for Future

The Fridays For Future movement organizes climate strikes around the world.

7,427 strikes have taken place in more than 100 countries worldwide.

Citizens driving sustainable consumption

According to Oxfam analysis, the richest 10% of the world's population are responsible for about 50% of lifestyle consumption emissions. More than half the world's population is now considered middle or upper class, with five people joining these ranks every second.[33] People with more money generally consume more, though after a certain level of income happiness seems to level off.[34] As the middle class grows it's vital that people aspire to lifestyles that combine high quality of life with low emissions.

According to one survey, two thirds of consumers are willing to change their consumption patterns to reduce their environmental impact.[35] But the challenge for consumers is to go from single ethical purchases to halving their emissions.

This requires a radical shift in the type of food, housing and travelling being consumed.[36]

However, recent data show that individuals with high-carbon lifestyles can already today halve their emissions in less than a single year with maintained or enhanced quality of life.[37]

There are also growing movements in regards to sustainable food, travelling and consumption and these are essential in order to accelerate the shift of focus by the business sector towards solutions which are aligned with a 1.5°C planet.

"Every time you spend money, you're casting a vote for the kind of world you want."

Anna Lappé
American author and educator

Examples of sustainable consumption shift

Early signs can be seen in trend shifts towards sustainable consumption.

- The US resale market has grown 21 times faster than the overall retail market over the past three years. It is projected to grow to nearly 1.5 times the size of fast fashion. Resale can be key to a circular fashion industry.[38, 39]
- Growth in meat consumption is showing signs of slowing in some OECD countries such as Sweden where meat consumption is falling.[40] The global vegan food market size is expected to reach US$24.06 billion by 2025 with a yearly growth rate of nearly 10%.[41]
- A Swedish-born anti-flying movement is spreading to other European countries. A new Swedish word "flygskam, which translates as "flight shame", is taking off and passenger numbers decreased in 2018.[42]

Finally, the wealthiest 0.5% of the global population are responsible for more emissions than 10% of the poorest.[43] The emissions of the wealthy are primarily driven by their extreme mobility, conspicuous consumption patterns, and the maintenance of spacious residences in multiple locations. There is a largely untapped potential in reducing their emissions and their contribution to the climate crisis. The world's billionaires have driven most of the main breakthrough innovations in the last 40 years.[44] And their leadership in adopting renewable energy technologies could generate new knowledge, decrease prices and lead to technology diffusion. They can shift investments from high-carbon towards cleantech and engage in forest and land protection.

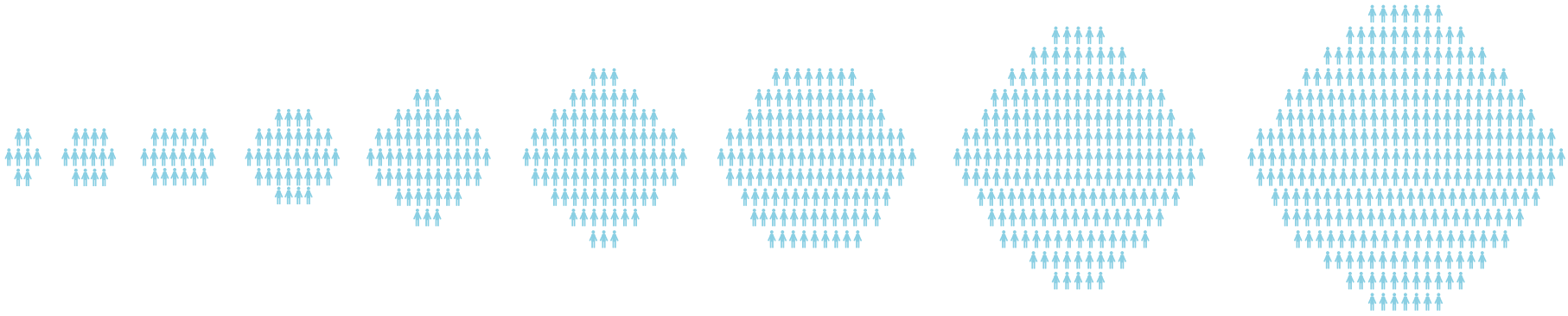
Citizens at work

Employees can wield significant influence in the workplace, particularly as companies compete to attract top talent. The idea that companies should serve the greater societal good is gaining traction, and the social enterprise is now becoming mainstream. About half of millennials (55%) believe business has a positive impact on society, according to a 2019 survey, down from 61% in the previous year.

Four out of ten millennials reported that that they have chosen to deepen relationships with companies they believe have a positive impact, and nearly as many have said they have lessened relationships with companies having a negative environmental impact.[45]

Individual action consistent with the carbon law

- Engage with politicians, companies and cities, demanding solutions that make it possible to choose climate-friendly lifestyles, and support those who deliver those solutions.
- Make climate change a factor in decisions around diet, travel, shopping, living and financial savings and home energy, shifting consumption towards low-carbon and healthy alternatives and share experiences.
- Use your role as employees to push, support and accelerate climate mitigation efforts of their companies.
- Join global and local climate movements to influence policymakers.



POLICIES AND TARGETS

This roadmap clearly demonstrates that the technology and solutions already exist to halve emissions by 2030 in line with the carbon law. But scaling them swiftly and exponentially around the world requires an extensive range of strong and coordinated policies. This chapter covers broad policy perspectives, while the sector-specific chapters cover specific policy suggestions in those areas.

Since the first edition of this roadmap, the IPCC's special report on 1.5°C [1] has been published, 20 countries have enacted in law or are discussing net zero targets by 2050 or sooner, several countries have declared a climate emergency,[2] some US politicians have advocated a Green New Deal, and Canada has established a climate fee and dividend system. Are we approaching a climate policy action tipping point?

On the flip side, global emissions are still increasing rapidly, renewables investments falling and fossil-fuel subsidies increased in 2018. To date, while our political systems have in some cases successfully delivered emissions reductions of a couple of percent per year, the world has never been close to the speed and scale of transition required to halve emissions by 2030.[3]

This must change. History shows that rapid transitions of the economy are possible in times of crisis, and all economies can learn from those that are transitioning rapidly. For the first halving, we need efficient and effective policy frameworks for rapid technology diffusion and behavioural changes, making it easy for people and companies to do the right thing – and we need them now. Ultimately, such radical shifts demand leadership, so the starting point of transformative policies will boil down to the interaction between bold political leaders and pressure from citizens and businesses.

Setting targets

It is important to draw a distinction between goals and targets that set the direction and ambition, and the policy instruments which drive actual emissions reductions.

Setting science-based emissions reduction targets is an important part of the policy landscape. While carbon neutrality commitments have been made by Bhutan (2009), Tuvalu (2020), Costa Rica (2021), Norway (2030), Finland (2035), Iceland (2040), Sweden (2045) and the UK (2050), among others, the bulk of the world's countries are yet to display the level of ambition necessary to keep the world within 1.5°C of warming.[4] The scope of existing commitments may also differ considerably. At current pledge levels, the world is still on track for at least 3°C of warming.[5]

International agreements have an important role to play in the setting of these targets, but politics at a global level is slow and the window of opportunity is closing. Climate leadership from frontrunning coalitions[6,7] and policymakers at smaller scales such as New York's commitment to carbon neutrality by 2050,[8,9,10] are critical to drive international processes to success, while inspiring others through the real economic and societal benefits that decarbonisation brings.

Achieving targets

In this report, we advocate for halving global emissions every decade until 2050, with richer countries moving even faster. To achieve this, it is vital to set corresponding interim goals, representing two to five year intervals, and to realise that halving at a global scale means that wealthy countries with high emissions per person have a responsibility to act faster.

Countries have already promised to meet Nationally Determined Contributions (NDCs) under the Paris Agreement[11], but these must be enhanced to align with 1.5°C trajectories by 2020, and given the same weight and attention as GDP. This demands the governance and administrative capacity for close monitoring of emissions reductions, yearly or even quarterly, and to create concrete roadmaps, tools, and feedback loops that allow for the regular correction of insufficient progress.

As well as halving emissions every decade, this roadmap also stresses the importance of reaching global carbon neutrality by 2050. To accomplish this,

it is vital to make sure that policies driving the first halving do not delay the final 2050 achievements.

An important role for policymakers would therefore be to address conflicts between short and long-term goals. This includes, for example, policies that coordinate electrification of road transport and the use of biofuels, policies to coordinate supply and demand, and coordination between different administrative levels. Similarly, decarbonisation goals should be aligned with biodiversity goals and the Sustainable Development Goals (SDGs).

Removal of fossil-fuel subsidies

Fossil-fuel subsidies contribute to climate change by keeping the price of fossil-fuels artificially low, encouraging greater emissions by increasing unsustainable consumption and production.[12] Without these subsidies, which equal 85% of all subsidies, total carbon emissions in 2015 would have been 28% lower, and there would have been 46% fewer air pollution deaths, while additional government revenues would contribute an additional 3.8% of GDP.[13] Globally, direct subsidies to the fossil-fuel industry total an astonishing US$300–680 billion per year.

When including indirect subsidies, the amount grows to US$5.2 trillion,[13] which represents 6.5% of global GDP (2017 estimate). This is greater than the GDP of all states except the US, European Union and China. The biggest subsidisers are China, United States, Russia, the European Union and India, and while these measures are often claimed to support underprivileged groups, just 8% of the money trickles down to the poorest 20% of the population.

A global movement to phase out fossil-fuel subsidies may be one of the most effective ways of reducing emissions and encouraging the development and acceleration of renewable energy and energy efficiency technologies. Several governments are moving in this direction, although their efforts and speed must increase. The G20 has committed to phase out fossil fuel subsidies over the medium term, while the G7 intends to eliminate fossil fuel subsidies by 2025.[14,15] Though such promises are welcome,[16] they need to be delivered. They are also far from sufficient – all subsidies must be phased out without delay and not in an unspecified future.

A price on carbon

The price we pay for goods and services rarely reflects their damage to the environment. Putting a price on carbon, by making producers and consumers pay more for products with high emissions under the "polluter pays principle" would be fairer and boost sustainable alternatives. Different implementations exist. First, there is a choice between emissions trading and taxes. Second, a system may be revenue-neutral or revenues could be used to fund investments. The revenue-neutral option might be more acceptable to business and the public, while the latter may cut emissions faster.

A total of 96 nations, representing 55% of emissions, are planning or considering carbon pricing in their NDCs.[17] Currently 57 carbon pricing initiatives are implemented or scheduled at national and sub-national levels, covering around 20% of global emissions.[18] Overall, carbon pricing in 2018 accounted for approximately US$44 billion in carbon revenues, up US$11 billion since 2017. In addition, over 1,300 companies are using or planning internal carbon pricing within two years.

But the existence of a carbon pricing scheme alone is not sufficient. Two key variables impact how carbon price trajectories deliver on the Paris Agreement. The first is the level – it must be at a magnitude that delivers decarbonisation and provide incentives for sustainable alternatives, meaning not so low that it has no effect, but also not so high that it is rejected by industry and the public. According to the World Bank, less than 1% of emissions are covered by a carbon price that is consistent with the Paris Agreement.[19, 17] It is evident that current pledges need to ramp up without further delay.

The IPCC's special report on 1.5°C suggests an appropriate carbon price in 2030 would be between US$135–6050/t$CO_2$e.[20] Numbers suggested by the High-Level Commission on Carbon Prices are somewhat lower, but emphasise the need for complementary policies.[17] In any case, regional conditions and price sensitivity variations must be considered when setting a price – past experience shows that industries adapt quickly, and that high carbon prices are needed to reduce car travel.

Gaining and maintaining public and business support for carbon pricing, a key importance, is challenging.[21] The World Bank recommends a comprehensive approach with careful planning, design and implementation,

the inclusion of stakeholders, a focus on local co-benefits, acceptable revenue usage strategies and protection of vulnerable groups.

Carbon pricing at a level acceptable to the public has so far not been enough to drive a full decarbonisation of society, it merelys play a supporting role by levelling the playing field.[22] Additional policy packages are necessary to drive the decarbonisation of different sectors, as well as to drive innovation and the scaling of technology and best practice around the world.

Progressive carbon pricing

Sweden has the highest carbon price in the world at US$139 per tonne of carbon dioxide.

Since its introduction in 1991, the Swedish economy has grown by 60% and territory carbon emissions have decreased by 25%.

Pricing carbon through trade

Though carbon pricing is often associated with taxes, emission trading systems also have an important role to play. By far the largest is the EU emissions trading scheme, which includes about 40% of total greenhouse gas emissions in the EU, mostly big industry, power plants, and EU-internal flights. After a weak start, the system was substantially strengthened in early 2019 by accelerating the reduction of emitted emissions rights, and adding new regulations regarding annulments of emission rights.

The system is now a much stronger policy instrument though still far from the level required to meet the carbon law. At this point, since the system includes only the parts of the economy that should be easiest to decarbonise, it either needs strengthening to reduce the emissions further, or to include a wider range of emissions. It must also be complemented with other measures, such as those related to land use change and forestry, or the international transport sector.

Accelerating the transition

There is no silver bullet. Beyond carbon pricing and trade systems, the carbon law demands coherent policy packages focused on a transition to net neutrality by 2050. These must simultaneously curb diffusion of old technologies, accelerate new technology development and diffusion, and change behaviours to reduce demand. First, frameworks must be created to suppress emissions and carbon-intensive processes, removing lock-in effects from old technologies and creating space for low-emissions alternatives to thrive by removing barriers to their development.

This process necessitates the removal of high-carbon policies and incentives, which may include fossil-fuel subsidies, fossil-fuel supply and infrastructure and anything that leads to deforestation. Sovereign wealth funds and development bank investments must also be refocused on climate resilience, halving emissions by 2030, and reaching net zero emissions by 2050.

Additionally, policymakers must consider how best to enable technologies and business models that can deliver deep and rapid decarbonisation of all sectors. For instance, the fast development of solar and wind was driven by early experimentation and market creation through feed-in tariffs. This means, among other things, that cost, efficiency and the sequential aspects of technology diffusion must be taken into account.

Policymakers may consider, for example, policies that drive rapid scaling of new low-carbon technologies and processes, as well as policies that help companies to manage financial transition risks through public-private partnerships and risk-sharing policies. There is also a need to support the diffusion of low-carbon solutions to low- and middle- income countries.

Transformative policies – the case of Norway

Electric vehicles are growing in Norway due to a consistent policy approach, including tax and VAT reductions, and toll road and ferry discounts.

The combined market share of electric and plug-in hybrid vehicles in Norway is about 50%.

Demand & supply

Demand-side policies, such as energy efficiency regulations and implementation of circular economy principles, have a huge role to play in the decarbonisation process and are covered extensively throughout the report. Such policies include, for example, stimulating demand for low-carbon solutions through public procurement and infrastructure investments, stop dates for high-carbon legacy technology and systems, and also policies that drive behavioural changes.

Electricity can be easily decarbonised, so rapid electrification of energy use is key. Other policy options to reduce demand include well-proven energy efficiency standards, open competition, support for low-carbon technologies, third-party financing of low-emission technologies, digital monitoring, repurposing of infrastructure, recognition and awards, and design competitions.[23]

The combined effects of these policies can be substantial. The American Council for an Energy Efficient Economy (ACEEE) says that efficiency measures have the potential to reduce emissions in the US by 600 million tonnes by 2030, increase GDP by US$17 billion, create 611,000 new jobs, and lower the average American's utility bills.[24]

Beyond energy efficiency, general resource efficiency and circular economy approaches have significant climate implications and deserve similar attention. Policy approaches in this area include, for example, materials efficiency standards and coalitions to drive adoption of these standards and practices.[25]

While the demand-side measures are vitally important and have been in focus for the past two decades, supply-side policies could complement these. Such policies may include transition support, incentives for companies with high climate ambitions through tax deductions, favoured status in procurement and recognition through certification schemes.

EU lighting efficiency

The EU has expanded its successful electricity efficiency limits to cover halogen bulbs.

This is expected to save 3.4 million tonnes of CO_2 emissions and 9.4 TWh annually.

On the supply side, there is also increasing evidence that policies that restrict the supply of fossil-fuels can also play a vital role.[25,26,27,28] Decreasing fossil-fuel production, in line with the goals of the Paris Agreement, can help avoid carbon lock-in and prevent stranded communities and assets. These policies also come with major benefits for human health and the local environment[29] and, given their narrower focus, can be easier and cheaper to administer than many demand-side policies.[27]

These approaches are gaining traction, including bans on oil exploration in Costa Rica, France and Belize and the shuttering of outdated coal mines in China.[30] Various countries have also begun to develop plans and policies to support workers and communities as they transition away from fossil-fuels.[31, 32, 33, 34, 35] Policies in this area include taxes related to resource production and export, cap-and-trade systems for production rights, restricted leasing of state-owned lands and waters, and prohibiting specific technologies, just to mention a few.

Nevertheless, a recent analysis of countries' NDCs and long-term low greenhouse gas emission development strategies (LT-LEDS) shows that fossil-fuel producers are not yet aligning their investment, extraction and delivery systems with the Paris Agreement's goals.[36] The establishment of an extraction-based accounting system – in parallel with existing territorial greenhouse gas accounting approaches – would push countries to integrate their fossil-fuel production in their climate strategies.[37,38]

Impacting behaviours

While many of the solutions needed for a global halving of emissions rely on scaling new and better technologies, others rely primarily on changing existing practices. Here, policymakers can play a major role in considering how to influence individual behaviour and raise awareness to enhance the uptake of low-carbon solutions and go beyond pure market mechanisms. Behavioural strategies can have a major impact, alongside digital solutions in policy design, analysis and communication.

A focus on other benefits can also drive emissions reductions. Health may be a faster road towards lowered meat consumption and reducing transportation emissions, while safety, independence and resilience might be a strong driver for the growth of solar power. Labelling, taxes, and bans have fundamentally changed the way smoking is seen in many countries – could climate damaging practices be phased out in a similar way?

A balanced, flexible and just transition

Policies related to climate recovery are as important as those that drive a transition towards low-carbon technologies and processes. These include policies for nature-based solutions that drive reforestation and sustainable intensification of agriculture, as well as policies for the development of carbon capture and storage. In this area, adaptation and resilience need careful consideration, in particular the risks of new technologies and coordination of climate and biodiversity strategies.

Any policies implemented must balance short-term emissions reductions with the long-term societal transitions demanded by the carbon law, and align with local targets, technologies and contexts. They must be both predictable enough for companies to build business models on, and flexible enough to handle rapid decarbonisation and change in a dynamic society.

It is also fundamental for policy acceptance and success to avoid disproportionate impact on vulnerable groups and ensure a just transition. To achieve this, measures such as financial compensation and social programmes could be directly funded by the revenues from carbon pricing. This applies at both local and global scales.[39] As an example, while many jobs could potentially be lost in coal regions, local economies can adapt and create new opportunities in clean energy.[40]

Finally, it is important to consider gender aspects.[41] Habits and environmental footprints can differ a lot between men and women, and they may be affected differently by climate policies and adopt them differently. Of particular importance is the connection between climate impact, population growth and the empowerment of women across the world. Project Drawdown includes educating girls and family planning in its top ten climate solutions, as these limit population growth.[42]

Digital climate strategies

The transition to a zero-carbon society will happen in parallel with the fourth industrial revolution, but the digital revolution and sustainability are often considered independently, with a lack of cross-policy coordination. By integrating climate change and technology policies, not least in strategy and planning processes, the best low-carbon solutions rise to the top.

In addition to establishing a proper digital infrastructure for the coming decades, policymakers should also incentivise the innovation, use and scaling of digital solutions for deep decarbonisation, provide space for new solutions and infrastructure, dismantle barriers to their implementation, and work to anticipate and suppress undesired side effects. Building expertise on a global level, ensuring equal access to data, reaching across traditional barriers and focusing on overall system benefits are also key priorities.[43]

The policy process

Designing and implementing policy is not always straightforward. Barriers can include a lack of awareness of solutions available and their benefits, limited administrative capacity and lack of access to capital. An the other end, leadership engagement, informed stakeholders, and governance and capacity building are key to success. Digital tools can help both to reduce barriers and to enhance opportunities.

A more systematic sharing of policies across the globe can address the problem of countries failing to learn from others. Existing climate policy databases could be grown into intelligent open-access platforms, with automated collection of policies and dynamic identification and surfacing of top practices in different areas, driven by machine learning.

Drafting new policies or interaction around specific policies could happen in online meeting rooms, and artificial intelligence could analyse policy ideas and the effects of complex policy packages.

Developing transformative policies, especially at the pace demanded by the carbon law, involves large uncertainties – which calls for collaborative, iterative and adaptive approaches with multiple pathways to facilitate gradual learning.[44] This is a situation that is regularly experienced in the digital industry, which must constantly tackle short timelines and a market that is continually disrupted by new entrants.

Success here has involved jointly developed standards, and scalable, standardised products. Translating these learnings into the public sector by seeing policies as scalable products could mean adopting techniques like experimentation, pilot schemes, rapid iterative development models, open-source sharing and even crowdsourcing and policy hackathons to brainstorm ideas and demonstrate real-world feasibility.

Advanced data analysis and visualisation techniques may also be used to anchor policy proposals and show progress and politicians' commitments, as well as the consequences of policy launches and withdrawals. ClimateView, the platform adopted in this project, clearly shows how digital solutions can provide a comprehensive overview of policies in use.[45] Engaging with citizens and businesses is critical for the success of policy, and even the strongest incentive will not help if people don't know about it. Already, digital solutions are used in measuring and monitoring climate impacts and the effects of policies, and this could be further enhanced through new technologies.

Policy collections

The UNFCCC Policy Options Database collects good mitigation practices. It also registers climate action by non-state actors in the NAZCA portal.
unfccc.int/resource/climateaction2020/tep/policy-options/index.html

The Green Growth Knowledge Platform (GGKP) was established by the Global Green Growth Institute, the OECD, the UNEP and the World Bank and offers guidance to policymakers.
www.greengrowthknowledge.org/

The German NewClimate Institute for Climate Policy and Global Sustainability covers 3,600 existing climate change mitigation policies and practices.
www.climatepolicydatabase.org/

The Grantham Institute's Climate Change Laws of the World includes 1,500 examples of climate legislation.
www.lse.ac.uk/GranthamInstitute/climate-change-laws-of-the-world/

The American Council for an Energy Efficient Economy (ACEEE) offers energy-efficiency policy guidance to states.
aceee.org/sector/state-policy/toolkit

CALL TO ACTION

- All countries must enhance their NDCs in line with 1.5°C trajectories by 2020 which means halving emissions by 2030 at the latest and reaching net zero by 2050.
- Ensure that national decision-making, budgets, tax systems and technology strategies are aligned with a 1.5°C world.
- Policies to reduce emissions throughout society must roll out in parallel. This means coherent policy packages which support technologies and business models for deep decarbonisation, while suppressing carbon-intensive processes.
- All sectors need concrete emissions reduction roadmaps. Currently, the largest focus is on the energy sector – transport, buildings, food, agriculture and industry must follow.
- All fossil-fuel subsidies should be phased out without delay and these commitments must be integrated with NDCs alongside stronger standards on emissions, efficiency and performance, supply-side measures and a wide range of policies to support this transition.
- Set stop dates for fossil-fuel extraction and use.
- Carbon pricing must be implemented at sufficient price levels and coverage to scale swiftly and globally.
- Climate policies must be implemented in a way that ensures a just transition – protecting vulnerable communities and without violating other planetary boundaries.
- Technology and climate strategies must become one and the same thing, with extensive mutual reinforcement.
- Digital tools to accelerate reuse of efficient decarbonisation policies globally must be created and widely adopted.
- Circular economy, digital economy and sharing economy models must be incentivised and directed towards decarbonisation.
- Behavioural changes, like shifts towards healthy diets, cycling and public transport, must be incentivised and accelerated.
- The development of nature-based solutions, which create carbon sinks and enhance biodiversity, must be prioritised alongside technology and behavioural changes and agricultural subsidies should be revised.


OPEN DATA FOR
CLIMATE ACTION

The climate challenge is unlike other challenges facing the world, in that most nations, cities and companies share a common goal: Transitioning to an economy and society largely free from fossil-fuels in order to safeguard humanity. To track the change, open and accessible data is crucial.

This report sets out a pathway to achieve that goal within the bounds of existing societal frameworks. That path relies on a complex combination of mutually reinforcing actions by society, markets and governments – from policies, to technology, to behavioural change.

Drawing up a detailed plan for 15 years ahead is not easy. We cannot expect to correctly predict the effects of incentives, the costs of new technologies, or the momentum of social change. The challenge is complex, with many unknowns and many actors involved.

So instead, this report takes a different approach. It outlines the direction and speed required and the first steps in more detail, so we can immediately begin. But the later stages are left deliberately imprecise, so the combination of needed actions and solutions can evolve along the way. By asking questions like: "Where do we stand now?", "What has worked and what has not?", "Where is action needed?" and "What is going well?", we can accelerate the experience and knowledge sharing that will drive an effective transition to a low-emissions world.

The question becomes not "how do we set up a detailed master roadmap?" but "how do we provide governments, businesses and citizens with shared roadmaps that show the way, which can be defined and redefined as we go?".

"If you can't measure it, you can't improve it."

Peter Drucker
Founder of modern management

A strong open data ecosystem would help:

- Companies to set targets and shift revenues to projects aligned with a carbon law trajectory, and track their progress.
- To drive circular economy and zero-carbon value chains – by tracking products, materials and component data.
- The finance sector to benchmark companies and shift to climate-positive portfolios.
- Cities and institutions to set requirements on public procurement, low-carbon infrastructure and building projects.
- Consumers and citizens to determine their carbon footprint and change their lifestyle to align with a 1.5°C world
- Nations and cities to pursue low-carbon strategies and policies.

Construction data transparency

A tool developed by Skanska will make emissions data available for 10,000 different construction materials.

Embodied carbon makes up 11% of total global greenhouse gas emissions.

Accessible data

All of the data needed to create these common roadmaps is already accessible. For example, most government policies and roadmaps are public and so are emission statistics, energy consumption and most other data describing a nation's or a city's economy and governance. New technologies, success cases, and research are readily available and published.

However "available" does not mean "accessible" – it has not yet been collected and visualised together. Today the data is spread out, not comparable, not indexed or categorised in a common framework. If we want to use data to facilitate change, that data has to be accessible, understandable and clearly visualised.

Successful emissions cuts will depend on assembling and organising data of all kinds, so that relationships are clear, cause and effect are manifested, and diverging opinions and assumptions explained. By methodically presenting open data in this way, we can see exactly where we stand, focus on the right actions, hold stakeholders accountable and spread best practice. In doing so, roadmaps become vital tools that can be used to drive action and guide strategies.

We need open data which is well organised, scalable, maintainable, and can be accessed programmatically (i.e. through open APIs). We need to provide a data structure that lets users follow policies and solutions, see their effect on leading indicators, and quantify their impact on emissions savings. A structure that makes it possible to update, compare and share these findings across nations, sectors and businesses.

Example: Panorama – Sweden's Climate Dashboard

One case study of open data being used to accelerate a climate transition is Sweden's Climate Dashboard. This service was created by the Swedish Climate Policy Council, Environment Protection Agency and Energy Agency, as a means to support the nation in its commitment to become a fossil-free state by 2045.

Panorama, which is based on a global platform called ClimateView, takes the form of an easily explorable online dashboard. By zooming in and out, the dashboard provides both an overview of the government's work towards tackling climate change as well as the ability to drill down into the more granular detail, including the current CO_2 emissions per sector, proposed and approved policies, and indicators of the progress made.

The dashboard is updated on a monthly basis, and is collated and edited by the Swedish Climate Policy council. Stakeholders such as NGOs and businesses can make suggestions and feedback, directly in the dashboard, thus creating a common language and place to continuously update and share the rate of the transition and possible pathways ahead.

Built on the principles of agile methods, open data and transparency and populated with emissions data, solution potential, indicators and actions, Panorama allows the long term goal of a fossil-free society to be broken down into shorter-term indicators that can be measured and responded to on a quarterly basis.

In Sweden, this common platform is already allowing a new kind of collaboration to develop, and the goal is to build on that momentum to deliver change for everyone involved in the transition, from citizens, to politics, to business. With the data publicly available and accessible, it allows anyone to become a watchdog for the nation's transition.

www.klimatpolitiskaradet.se/panorama

Food data – show your numbers

Oatly is labelling all its products with carbon footprints and has called on the food industry to do the same in outdoor advertising.

Oat milk has less than half the emissions footprint of a glass of dairy milk.

CALL TO ACTION

- Climate data is often fragmented and of poor quality. It must be standardised and published on open platforms.
- Data on targets, strategies, implementation and success should be published openly to allow knowledge-sharing between citizens, industries, companies, cities and nations.
- Key performance indicators should be developed for companies and organisations, allowing for comparisons, benchmarking and target-setting.
- Value chains can be decarbonised and efficiency boosted by global, automated tracking of the carbon footprints of components, products, materials and services.
- The digital technology sector can fund global, open initiatives to gather and organise this data rapidly, boosting its impact.

FINANCING THE TRANSITION

The economic benefit of a low-carbon future is US$26 trillion by 2030 compared with staying on the current high-carbon pathway. The markets are beginning to notice the benefits. As prices of low-carbon solutions tumble, the finance sector has reached a tipping point. Confidence in the most exposed parts of the fossil-fuel industry (coal) is wavering. This risks a carbon bubble. But leadership is emerging to help ensure an orderly transition to a low-carbon economy.

This chapter outlines how the carbon law can be integrated into investment decisions to accelerate the economic transformation. It also looks at places with disruptive potential. Fintech and innovations in finance like crowdfunding promise new opportunities to support societal goals and accelerate this transition.

"If some companies and industries fail to adjust to this new world, they will fail to exist."

Mark Carney
governor of the Bank of England

François Villeroy de Galhau
governor of Banque de France

Frank Elderson
chair of the Network for Greening the Financial System

The carbon law trajectory demands that capital flows rapidly shift from high-emissions investments towards sustainable investments. Low-carbon infrastructure, while qualitatively different to carbon-intensive options, is now comparable on price – and the price is falling rapidly. In 2019, the UK became the first G7 country to announce it will reach net zero-emissions by 2050. The estimated cost is likely to be no greater than the UK's existing legally binding commitment to reduce emissions 80% by 2050, which is around 1-2% of the UK's GDP, and will bring many economic and health benefits.[1] Worldwide, US$90 trillion will be invested in infrastructure between now and 2030.[2] How, then, do we ensure that capital flows in the right direction and this redistribution benefits the most people?

Ant forest

With 800 million customers, China's Ant Financial has captured over half China's US$13 trillion mobile payments market. Its "Ant Forest" platform gamifies and rewards low-emissions behaviour. More than 300 million people have signed up.

Crowdfunding low-emissions ideas

In the UK, Abundance Investment crowdsources funds for sustainable energy and building projects. Since its founding in 2012, investors have raised £73.9m in 31 projects with £11.5m paid in returns.

The demand for environmentally sustainable investments already exceeds supply. Investors with assets worth US$24 trillion are calling for the creation of more green financial products, according to the G20 Sustainable Finance Synthesis report (2018).[3] Renewable energy, plant-based foods, circular economy, vehicle-sharing, and smart buildings are all sectors that could benefit from this opportunity, forcing legacy incumbents towards a more sustainable path. But of the world's unicorns (private companies with a one billion dollar or more valuation), few are focused on zero-carbon futures.

Climate finance is not just about changing capital flows away from fossil-fuels. Research in 2018 also highlighted the role of international capital flows in reducing the resilience of the Amazon and boreal forests, potentially accelerating these regions towards dangerous tipping points that could accelerate climate change.[4] New incentives are needed to ensure investors stop supporting economic activities that are undermining the resilience of these critical biomes.

Big data and real estate

In the Netherlands, ING Real Estate Finance helps borrowers identify energy-efficiency improvements in buildings that provide the best financial returns and greatest emissions reductions. The newly-developed app recommends the top ten strategies per building.

A new app has scanned 18,000 buildings and identified over US$40 million in savings through energy efficiency.[25]

ESG made simple

Fintech company TruValue Labs uses AI to help investors identify sustainable investments. Machine learning and natural language processing (NLP) are used to analyze data in real time to provide insights to investors.[3] A second new company, Arabesque, is a "quant" asset manager that examines the sustainability of over 7000 of the world's largest listed companies. Its technology combines over 200 ESG measures to rank companies.[26]

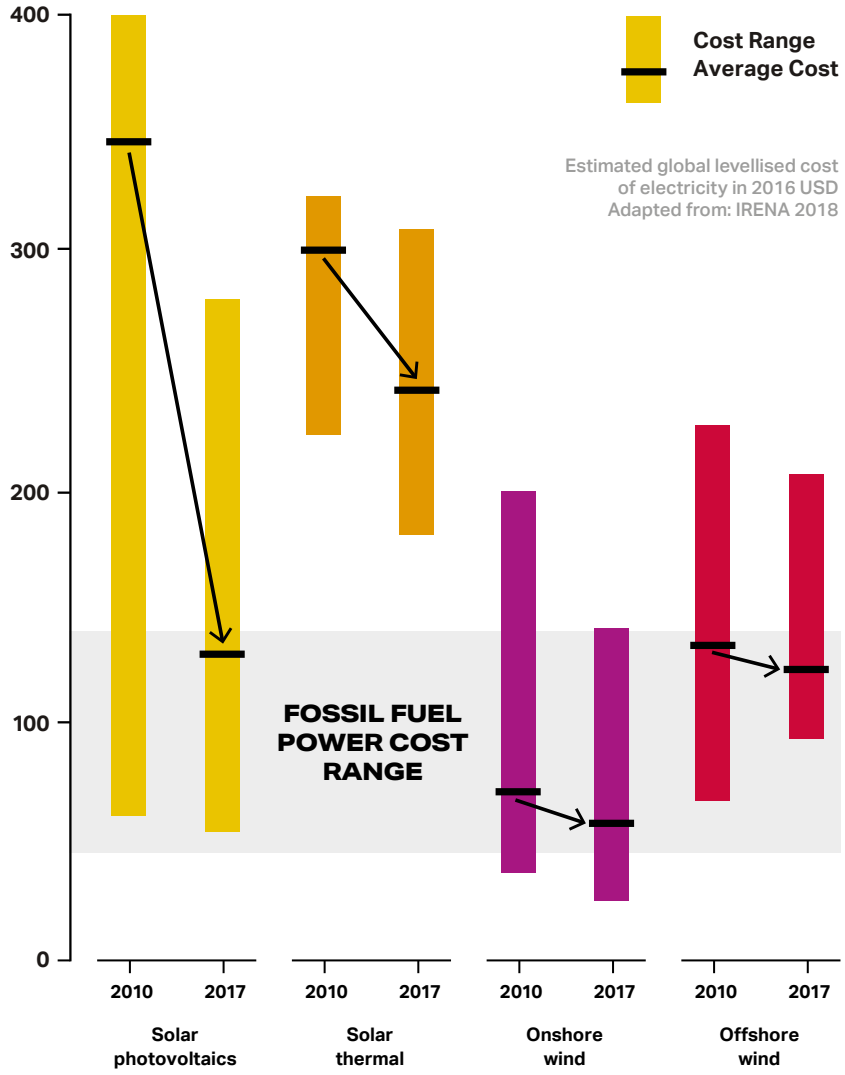


Figure 16. Cost of wind and solar power generation.
The world has crossed an economic tipping point for renewable energy. The global weighted average cost of new renewables is now within the cost range of fossil-fuels and still falling.[5]

Crossing economic tipping points

In most parts of the world, renewables are now the cheapest source of new power generation.[5] They have reached market maturity and outcompete fossil-fuel incumbents on price, performance and pollution. Take solar photovoltaic (PV) as an example of non-linear cost dynamics. Between 1975 and 2016, PV prices fell 99.5%. Every doubling of installed capacity came with a 20% fall in price and PV installation has grown at 38% per year for about a decade.[6] Improvements in price and performance continue to defy predictions while innovations in the coal and oil industries stagnate. In 2018, PV prices fell a further 13% on the previous year, as did onshore wind.[5] Indeed, in the electricity sector the additional cost of halving emissions 50% by 2030 is likely to be zero. In some places it is cheaper to build new renewable installations than to keep existing fossil-fuel plants running.

The world has reached a tipping point (see figure). With the economics for renewables changing rapidly, the real risk to fossil-fuel firms is the pace at which other sectors innovate and electrify away from petroleum as well as how quickly national grids move away from fossil-fuels. Expect the unexpected. Fossil-fuel companies are dropping out of the top ten most valuable companies as tech giants surge past US$1 trillion valuations. With the right financial instruments, a very rapid economic transformation that beats most predictions is now tenable. Bold policies can accelerate the transformation. Indeed, the economic benefit of a low-carbon future by 2030 is US$26 trillion compared with staying on the current high-carbon pathway.[7] But policies are sending mixed signals to markets, and the cost of these mixed signals is potentially US$12 trillion of stranded fossil-fuel assets by 2035.[7]

TEN POLICY PRIORITIES FOR FINANCE

Fiscal policies in almost all countries are not aligned with the carbon law. Policies either do not exist or carbon pricing is too low and inconsistent. With political will this can change rapidly because businesses, the finance community and citizens are demanding fair and equitable fiscal policies to address climate. The immediate policy priorities needed by the end of 2020 to redirect capital flows to support the economic transformation are:

01

Build trust and public support for carbon law compatible financial instruments.
Public support for carbon pricing has been hampered by poor policy design and communication coupled with widespread misinformation by politicians opposed to the policy. Equitable policies that redistribute income, for example reducing income tax while raising carbon prices such as "carbon fee and dividend", may be more likely to succeed. Likewise, starting low and ratcheting carbon prices annually is more acceptable than going in off the deep end.

02

Go beyond electricity generation.
Financial instruments must reach all parts of the economy, and the biosphere. Investments beyond wind, solar and energy storage need significant ramping up immediately in all sectors highlights in this report. Also investments are needed in carbon storage (forests and peatlands), sustainable agriculture and marine resilience.

03

Price carbon.
The IPCC's special report on 1.5°C suggests an appropriate carbon price in 2030 would be between US$135–6050/t$CO_2$e to deliver the needed economic shift. There are country differences though. A carbon tax of US$70 per tonne of CO_2 in addition to existing measures could reduce emissions more than 40% in some countries, for example India and China, according to the UNEP Emissions Gap report. Sweden has the world's highest carbon price – US$139 per tonne of CO_2. Since the carbon tax introduction in 1991, the Swedish economy grew 60% and carbon emissions fell 25%.[8] Carbon pricing is spreading rapidly, and will reach 20% of global emissions in 2020 as China implements pricing, but it needs to accelerate rapidly in the early 2020s to all major economies.[12, 13] Nevertheless, it is important to keep in mind that carbon price alone is not going to lead to deep decarbonisation at a sufficient speed. In Sweden, a price on carbon did not drive emission reductions without energy infrastructure development, for example in transport.

04

Stop subsidising fossil-fuels.
If all fossil-fuel subsidies were phased out, carbon emissions would fall up to 10% by 2030.[6] Direct fossil-fuel subsidies amount to around US$330-680 billion annually, and indirect impacts have been estimated at US$5.3 trillion annually, or 6.5% of GDP.[9] The G20 has recommended ending these subsidies by 2025. This is too late. They should be redirected to renewables while ensuring a just transition for workers exposed to job losses.

05

Revolutionise agricultural subsidies.
Agricultural subsidies are worth over US$620 billion a year representing around 15% of gross farm receipts in 51 major food-producing nations.[10] Most agricultural policies are not aligned with the urgent need for sustainable agriculture, improved diets and carbon storage. Processes are needed to revolutionise these subsidies within the next five years to turn agriculture from a source of emissions to a net sink.

06

Make climate disclosure mandatory and more transparent – including all a business's emissions, so-called Scope 1, 2 & 3.
More than 800 companies and institutions overseeing US$118 trillion in assets support Mark Carney's (chair of the G20 Financial Stability Board) call for businesses to disclose climate risk. Carney's Task Force on Climate-related Financial Disclosure (TCFD) is now rallying companies around this goal, but the task force must set more ambitious targets and, ultimately, climate disclosure should be mandatory. The next frontier in this discussion is influencing consumer emissions caused by a company's products.

07

Demand green public procurement.
Public procurement accounts for 15–20% of global GDP,[11] and is a major opportunity to rapidly transform investment flows to low-carbon infrastructure. In 2017, local governments across the globe joined forces to agree a framework for green public procurement contracts. This network needs to expand rapidly.

08

Demand low-carbon infrastructure projects.
Ensure major infrastructure investments such as China's Belt and Road are aligned with the carbon law.

09

Reduce risks for venture capital and private equity to drive low-energy demand solutions.
Incentivise venture capital and private equity towards businesses driving energy efficiencies, circular economies and zero-carbon innovations. Conversely, remove incentives for investing in high-polluting innovation and integrate climate risk into the cost of capital through assessment of borrower's emissions exposure, physical risk, stranded asset risk and potential climate opportunities.

10

Expand fintech and financial innovation for a 1.5°C planet.
The carbon law demands accelerating finance innovation. Establish many more green/sustainable fintech hubs to accelerate innovation for a 1.5°C planet and provide the policy landscape to make it easy for start-ups to thrive.

The carbon bubble

Recent research indicates demand for fossil-fuels has the potential to drop precipitously in the near future, risking a carbon bubble up to 16 times bigger than the bubble that led to the 2008 financial crisis. If the bubble is not carefully deflated now, this could lead to losses on the scale of trillions of dollars by 2035. China and parts of Europe importing fossil-fuels stand to benefit most from the bursting carbon bubble, while the US, Canada and Russia stand to lose the most – up to US$4 trillion – if climate action is delayed.[14] The fossil-fuel industry is worth around US$5 trillion.

In 2017, 34 central banks joined forces to ensure a smooth transition to a low-carbon economy: the Network for Greening the Financial System (NGFS). This network, including the Bank of England and the Banque de France, represents half of global greenhouse gas emissions and the supervision of two thirds of the global systemically important banks and insurers. In 2019, it provided four recommendations for all central banks, supervisors and the financial community to avoid a climate-driven "Minsky moment" – the term for an abrupt collapse in asset prices:

01 Integrate the monitoring of climate-related financial risks into day-to-day supervisory work, financial stability monitoring and board risk management.

02 Lead by example, specifically central banks are encouraged to integrate sustainability into their own portfolio management.

03 Collaborate to bridge the data gaps to enhance the assessment of climate-related risks. Public authorities should share and if possible make publicly available any climate-risk data.

04 Build in-house capacity and share knowledge with other stakeholders on management of climate-related financial risks.

Advocacy groups are attempting to accelerate the investment transformation out of fossil-fuels with some success. The global divestment movement – persuading investors to divest from assets linked to fossil-fuels – has grown rapidly since its beginnings in 2011, fuelled in part by high-profile social media campaigns to mobilise citizens and investors. At the time of writing, over 1,000 organisations with assets worth US$10 trillion have committed to divest from fossil-fuels[15]. In 2018, Ireland announced plans to divest from fossil-fuels – the first nation to do so. In 2019, Norway's parliament gave its US$1 trillion sovereign wealth fund the green light to dump more than US$13 billion in fossil-fuel stocks, a move that did not go as far as many advocacy groups had hoped.

Markets are heavily influenced by sentiment and divestment stigmatises companies and changes the public discourse – this affects market confidence. Modelling results show that about 10% minority of environmentally conscious investors could tip the market and lead to the bursting of the carbon bubble.[16,17]

Blockchain for green finance

The Shenzhen Green Finance Committee is piloting the use of blockchain to digitize the green certification and verification process.[3] In France, Nespresso has launched a blockchain-based register to track climate-positive actions to share positive social and environmental impacts with shareholders.

Sustainable investment

Sustainable investments now total around US$31 trillion, according to recent data[18] though defining a sustainable investment is tricky and these figures are disputed. This includes US$17.5 trillion in assets that have adopted some sort of environmental, social and governance (ESG) criteria. For comparison, assets controlled by financial institutions around the globe are worth US$88 trillion. Mutual funds, pension funds and insurance companies own approximately US$30 trillion of these assets.

ESG funds have grown more than two thirds in two years, according to the Financial Times. This is one of the fastest growing asset classes.[10] Evidence suggests that ESG assets are aligned with better performance, or at least do not reduce performance.[19] For more rapid climate action we must also shift from ESG criteria to financial portfolios aligned with the Paris Agreement. This requires greater transparency within ESG portfolios – something fintech can help enable.

Finally, green bonds can finance major projects related to renewable energy, sustainable transport, and energy-efficient buildings and construction.[20] The market for green bonds is now growing rapidly, reaching US$170 billion in 2018 and is expected to top US$250 billion in 2019[21]. This growth needs to double every year to reach US$1 trillion by 2021. However, green bonds currently only represent a tiny share (<0.5%) of outstanding bonds.[22] We must now see the whole bond market align with an economic transition for a 1.5°C planet. Moreover, we need to see investments shift away from activities that reduce the resilience of the Earth system, for example unsustainable (and often inefficient) agricultural expansion in the Amazon.

Is fintech the solution or part of the problem?

Finance technology, or fintech, has enormous disruptive potential to reshape the finance sector. But its value in reducing emissions remains underappreciated.[23] From peer-to-peer money transfers to crowdfunding solar arrays, like Sweden's Swish and Trine respectively, digital technologies are unlocking new financial opportunities and business models. While fintech is experiencing high growth and countries are keen to establish themselves as leaders in this field, green fintech hubs and resources are thin on the ground and the companies that do exist are niche not mainstream. We were only able to identify a single green fintech hub, based in Stockholm.

Potential ways in which fintech could help reduce emissions:[24]

- The data held by technology giants and traditional banks can be used to reduce greenhouse gas emissions. Artificial intelligence and machine learning can analyse consumer emissions related to spending and incentivise low emissions behaviour. One example is using digital applications to help individuals understand their pension investments and switch to carbon law compatible options. With its 2.2 billion users, Facebook's entry into fintech through its announcement to launch its own currency, Libra, indicates the direction personal finance may begin to move in the next decade with opportunities for supporting societal goals, but major risks for privacy, security and surveillance.

- Blockchain for trade of carbon credits, supply-chain transparency and property rights, though, as a high-emitting technology, blockchain must become more efficient.

- ESG reporting is mired in difficulties due to a lack of standardisation. Digital technologies to mine and analyse data from multiple sources can be used to provide clarity and standardisation.

Crowdfunding

Crowdfunding is emerging in some markets as an alternative to venture capital and private equity for financing new businesses and new business models. Investment in small and medium-sized businesses in emerging markets, like solar powered mini-grids in Africa, is often difficult. Lack of knowledge and information coupled with concerns over accountability, corruption and transparency in some regions makes investment risky. This means that access to low-cost capital is very limited.

Crowdfunding, where a large number of small-scale investors gain equity in the company or interest on loans, has emerged as an important bridge to span this gap. Digital platforms mediate and provide solutions to manage risk. This is now a big business, estimated to reach US$687 billion in loans by around 2022,[15] which has begun competing directly with traditional venture capital and traditional lending.

EXPONENTIAL TECHNOLOGIES AND SOLUTIONS

Exponential technologies and solutions are those where performance is constantly and rapidly improving at the same time as costs fall – the price/performance ratio is accelerating. This dynamic can have a disruptive impact on industries used to incremental change. Indeed, it can lead to entirely new business models. If leveraged to solve societal challenges, those technologies and solutions can change society for the better. That is why they are critical to enable rapid decarbonisation. To date, however, the impact of many exponential technologies on total greenhouse gas emissions has either been ambiguous or they have driven emissions upwards.

For decades, exponential development in the digital industry has been the primary business model. The sector is used to unceasing rapid change. In the next decade, this pace of change needs to be adopted by other sectors, and supported by policies, in order to enable the speed and scaling required to avoid the most severe consequences of climate change.

This chapter will discuss the role that exponential technologies in general and the digital industries in particular will play in shaping the future of our planet.

Moore's Law and Exponential Technologies

The original example of an exponential technology is the silicon chip – since the mid-1960s, the power of computer chips has doubled every couple of years and the price has halved. This phenomenon has been dubbed Moore's Law after Intel founder Gordon Moore and this development has changed the world – delivering computers, the internet, smartphones, and the cloud. Today, a chip containing 30 billion transistors can rest on your thumb. But this is just the beginning – other key exponential technologies, sometimes building on these chips, include mobile telephony and broadband, artificial intelligence and machine learning, robotics, digital biotechnology, nanotechnology and digital fabrication. Other examples are solar and wind power, battery technology and nanomaterials.

Exponential technology and solutions often grow slowly in the beginning, but when they pass the inflection point where performance goes up as costs fall, they can enter a virtuous cycle leading to rapid adoption and expansion. Naturally, humans tend to overestimate the growth of these technologies in the short term but underestimate them in the long term.

The digital technology industry has grown to become the most valued and powerful in the world. But with great power comes great responsibility, and this industry will influence how far global temperatures will rise. The digital sector is already well on track to reduce its own emissions, which represent 1.4% of the global total,[1] and it can contribute significantly to cutting emissions in half across all sectors by 2030 while driving exponential performance growth. But digital technology also guides the behaviour of four billion people daily and drives the modern economy, which provides a unique opportunity to influence decisions and behaviours.

In the critical next decade, the digital revolution is expected to disrupt and transform transportation, buildings, industry, energy, farming, retail, food and finance and can help to substantially reduce these sectors' emissions.[2] Through these opportunities, digitalisation is the key to halving emissions by 2030 – it can directly enable around a third of the emissions cuts necessary[2] and influences the rest.

Innovations are scaling faster

While it took telephony 75 years to reach 50 million users, it took the internet seven years, and Pokémon Go just 19 days.[3] Mobile internet is constructed so that new innovations can utilise underlying technology platforms which have taken decades and billions of dollars to develop. It is no surprise that a vast majority of start-ups worth over US$1 billion are digital.

Search engines, e-commerce, social media platforms and smartphones all enable new, unexpected innovations. It would have been impossible to predict that Google's investments in mapping would lead to Uber, for example, or that the iPhone would birth Twitter, but neither technology would be possible without its progenitor. Smaller, granular technologies like mobile phones, cars or solar power, can diffuse globally much faster than big infrastructure like nuclear plants – and internet-based services can scale incredibly fast.

Exponential technologies often enable disruption and transformation of industries through new business models with the potential to be far more efficient than the previous ones, driven by digitalisation. Some key examples are Spotify in music, Uber in taxis, WeWork in business space and Airbnb in home rental. The effect of these companies entering the scene is that the incumbent companies must transform or perish, which tends to trigger a transformation of the entire industry. Tesla's impact on the car industry, which is now accelerating electrification of vehicles, is a good example.

Disruption and transformation are essential to achieve rapid climate mitigation – the world needs rapid innovation cycles to break free of old fossil-fuel pathways, but without a compass direction, innovation could as easily drive up emissions. Uber and Lyft, for example, have claimed they can make cities better places to live by reducing the need for car ownership and so reducing congestion. However, in some cities where these services are popular they contribute to congestion. In the long run, if they encourage people away from mass transportation systems, they may push emissions even higher.

Key technologies for climate mitigation

Halving emissions by 2030 will be enabled by scaling technologies at different levels of development. The International Energy Agency highlights 45 technology areas which are specifically important for climate mitigation (4x). Key technologies such as solar photovoltaics, wind energy, LED lighting, energy storage, electric vehicles, datacentres and bioenergy are growing fast and following exponential trajectories. Others, however, are not. Heating and cooling technologies for buildings, smart grids, concentrated solar power, geothermal energy and low-carbon materials must all scale faster.[4]

Furthermore, mature digital technologies such as mobile internet, cloud computing, big data, apps, smart devices and first-generation industrial automation are a foundation for efficiency gains in all industries. The next digital technologies down the ramp are artificial intelligence, 5G networks, digital fabrication, large-scale deployment of the internet of things, blockchain and drones. These may enable significant emissions cuts before 2030.[5] Other notable technologies include immersive user experiences like virtual and augmented reality, 3D printing, gene editing, advanced robotics, and digital assistants. At this stage it is impossible to quantify their potential impact on emissions.

Ultimately, the trillions of consumer and business decisions made each year will determine whether we end up in a 1.5°C world or a 3°C world – and technology can influence those decisions while still allowing freedom of choice. For example – hidden algorithms are integral to e-commerce: they determine what consumers see and how they navigate websites. These algorithms could be programmed to prioritise products with a small carbon footprint in addition to merely those with a high profit margin. Software used to design buildings could use sustainable materials as the default building material. Even actively displaying the carbon footprint of a product at the point of sale can make a substantial difference.

Finally, there are increasing calls for greater governance over technology companies. As countries commit to zero-emissions by 2050, new models to achieve these goals could explore regulation of the use of technology that accelerates global warming.

Table 2: Examples of digital technologies which can help limit global warming or accelerate global warming and how.

Key digital technologies	What does it mean	How they can help limit global warming to 1.5°C	How they risk accelerating global warming towards 4°C
Social media	Interactive technologies that facilitate the creation and sharing of information via networks while collecting personal data for behavioural insights.	Support democracy. Promote fact-based worldviews. Tackle misinformation. Utilise behavioural insights to enable sustainable lifestyles. Enable global climate movements. Help displace the need for physical travel.	Spread misinformation eg climate denial. Undermine democratic processes. Encourage unsustainable consumption.
E-commerce	Buying or selling of products and services over the internet.	Support a shift to sustainable, low-carbon products and services through information and nudging.	Simplify high-carbon consumption through low prices, fast delivery and heavy promotion, leading to increased waste of material, energy and transportation.
Internet of Things	Connecting devices and everyday objects to each other and online services.	Optimise any type of system to save energy, materials and to enable a circular economy. Enable distributed demand response to help balance electricity grids.	Increase efficiency of oil and gas extraction and production of high-carbon products thereby delaying the shift to low-carbon alternatives.
AI, machine and deep learning	The ability of a machine or computer programme to think and learn.	Continuous improvement of energy systems, factories, buildings and vehicles. Drive down costs and carbon footprint, while improving performance and functionality. Linking with social media and other technologies, it can also help people to understand their footprint and nudge them in a sustainable direction.	Accelerate high-carbon consumption, long-distance travel and goods transportation through biased algorithms and profiled online advertising.
5G mobile networks	5th generation cellular network technology providing higher speed connectivity to people, enterprises and objects.	Mass scale, global connection of electric grids, buildings, industries, cities, vehicles and things combined with AI and machine learning enable efficiency of systems. Virtual meetings and virtual and augmented reality reduces need for travelling. Resource-efficient manufacturing flows and autonomous services brings down use of resources.	Enable acceleration of high-carbon intense industries and digital platforms which drives high-carbon consumption.
Blockchain	An open distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way.	Allows greater transparency throughout the value chain of goods and services making it easier to drive decarbonisation. Enable distributed coordinating of physical energy flows and financial flows.	Current cryptocurrencies using blockchain technologies have a high energy demand – currently equivalent to a small developed country.
Digital twin	A digital replica of a living or non-living physical system.	Allows designers and engineers to test and simulate how systems such as cities and grids can be improved, optimised and transformed.	Can be deployed to accelerate fossil-based high-carbon systems.

*These lists are not mutually exclusive

KEY EXPONENTIAL TECHNOLOGY STRATEGIES TO HELP HALVE CARBON EMISSIONS BY 2030

Exponential technologies can help dramatically reduce energy, material and waste, including food waste, while supporting global health, sustainability and economic goals.[6,7,8,9] They are instrumental to enable a rapid reduction of both production- and consumption-related emissions.

01

Energy
Four exponential technologies working in tandem will enable renewable energy; solar, wind, storage and smart grid technology for balancing and predictions. By enabling and accelerating renewable energy investments in buildings and industries at block and city level, incumbent energy companies will be forced to accelerate renewable investments to survive and a virtuous circle of change towards renewable energy can be achieved. Decentralisation of energy may also play a disruptive role in the energy transition.

02

Buildings
Most buildings are inefficiently heated, cooled, ventilated and lit. Digitalisation can help drive down energy waste by adjusting to occupancy and need and help double or quadruple space utilisation through new sharing business models, while simultaneously improving productivity and reducing costs.

03

Transport
The future of transport is not cars, it is data. The 2020s look set to see the biggest disruption of the automobile industry since Henry Ford unveiled the Model T in 1908. Two seismic shifts are on their way – first, electric cars already compete favourably with petrol engines on range and will reach an inflection point within a few years, once their price competes favourably. Most major car manufacturers have set end dates for production of internal combustion engines, but the change may come even sooner through usership models – service-based business models which maximise vehicle occupancy and use while minimising travel costs, congestion, and pollution.

Second, a rapid shift away from privately owned vehicles may be close. Only 5% of cars are in use at any one time and 70% of car seats are estimated to go empty.[10,11] Usership models can help tap this unused value, dramatically reducing cost and emissions.[12] AI can also help bundle together shipments and schedule routes to minimise emissions from transportation. Driverless vehicles will shift the traditional business model of vehicle ownership towards mobility and transportation as a service. This means fewer people will own a car, instead ordering shared rides from driverless electric vehicles or catching a driverless bus. But there are risks: ride sharing can take travellers away from more efficient mass transit systems.

Next generation immersive, virtual meetings and conferencing also has the potential to replace many business trips, saving cost, time, and carbon emissions.

04

Manufacturing and materials
Almost everything is designed with computer software, from buildings to mobile phones to consumer packaging. Using AI to design products for re-purpose, sharing, reuse and recycling can become the new default. High-precision manufacturing through 5G and other technologies can also save materials and energy usage in manufacturing and there is also a potential for distributed manufacturing to reduce distances of product supply chains.

Reverse logistics and real-time tracing of material, components and products will make it possible to increase utilisation rates of consumer goods, vehicles, and physical infrastructure and also to adopt sharing-economy and circular business models and cut huge amounts of material waste. Also, AI can be applied to rapidly develop the next generation of low-carbon materials.[13]

05

Food
Innovative, plant-based food companies focusing on sustainability and health, such as Oatly[14] and Impossible Foods,[15] are growing rapidly. Revolutions in choice architecture and transparency of climate and planetary impact could support positive diet choices, reduce meat consumption and slash greenhouse gas emissions as a result. In parallel, using AI for better prediction of supply and demand can reduce waste in the supply chain.

06

Forests and agriculture
Digital technology makes it possible to track and predict deforestation in order to take proactive action. It can also boost reforestation and protect peat marshes. It can help farmers to transform to regenerative agriculture which is positive for the planet, predicting which crops to plant and when, and reward farmers for emissions cuts.

07

Cities and infrastructure
The need for more roads and physical infrastructure can be dramatically reduced by optimising existing physical infrastructure instead of investing in new buildings and roads. Using digital technology to connect, model and measure cities, and making this information accessible to all, makes it possible to visualise what a healthy and fossil-free city looks like. This enables the creation of a common vision for an environment- and user-oriented innovation, involving citizens and various stakeholders in accelerating a sustainable transformation.

08

Sustainable consumption
More and more consumers want to make sustainable decisions. A wide range of carbon calculators and applications make it possible for people to calculate their own carbon footprint and some even suggest how start shift consumption in a sustainable direction

But a bigger opportunity will come from pushing low-carbon choices in mainstream e-commerce sites and using digital assistants to shift consumption and investment decisions, including pension choices, in a sustainable direction. Algorithms and information architecture can be designed to nudge consumer behaviour towards low-carbon choices, for example by making those options the default.

Half of global advertising revenue will soon be online, and largely streaming towards just a small handful of companies. These companies could make a huge difference by limiting advertising of high-emissions products such as cheap flights and promoting sustainable, low-carbon choices and healthy lifestyles.

CALL TO ACTION

Society could naturally demand technology companies to contribute wherever possible to emission reductions and to enable sustainable transformation as part of a social contract.

Technology companies can become genuine climate leaders by integrating climate action in everything from their value propositions and mission statements to daily decisions which ensure that their solutions and products support a 1.5°C future. The world will come closer to this goal by:

- Shifting digital industry resources towards the energy and material revolution and the circular economy in energy, buildings, industry, transportation, cities and agriculture.
- Incentivising usership business models rather than ownership, improving the rate of use of products and services, and rethinking business models with sustainability in mind.
- Committing to use technology for the good of society, promising to make low-carbon the default, rewarding low-carbon lifestyles among consumers, and promoting fact-based worldviews.
- Stepping up investment in digital solutions, value-chain transparency and solutions which enable and encourage consumers, businesses and investors to make climate-smart decisions.
- Avoiding actions which accelerate global warming such as fossil extraction.

Flexible work space

WeWork is present in 100 cities, offering co-working space and services for small businesses.

WeWork claims to be 2.5-4x more efficient with space than a traditional office.

Einride

Einride's solution is based on autonomous, all-electric vehicles, coordinated by an intelligent routing software to optimize battery life and energy consumption.

Road transportation is responsible for approx. 20% of global CO_2 emissions.

Control buildings with artificial intelligence

The AI-based "BEAD" system analyses and optimises a building's energy management by measuring real-time data.

It could reduce annual CO_2e emissions by 319 Mt CO_2e by 2030.

“It always seems impossible until it’s done”

Nelson Mandela

FINAL WORDS

Slow policy progress over 30 years means that incremental decarbonisation is no longer an option. Only decisive and rapid action can reduce the risk of catastrophic climate change, and simultaneously improve the quality of life for millions of people. Without decisive action to drive the fastest and fairest economic transition in history, this generation of leaders is handing the next generation an increasingly destabilised climate and Earth system. Indeed, decisions made today about infrastructure investments in energy systems, roads, railways, ships, aircraft and buildings will influence whether global warming can be stabilised around 1.5°C or not this century.

Ten years ago a global goal to reach net zero emissions by 2050 seemed politically unlikely. Now, the latest science clearly shows this goal is necessary, achievable and desirable – a 1.5°C planet will provide the greatest good for the most people. And countries are starting to adopt goals and legislation more closely aligned with this science. Halving emissions every decade using proven measures across society and the economy can deliver on this goal. Achieving it will substantially reduce risks of catastrophic climatic impacts, but not eliminate these risks entirely. The technologies and solutions needed to cut emissions rapidly are available, can scale quickly and are affordable. They must be accelerated by strong policy, climate leadership, exponential technology and finance. The economic transition will bring significant benefits from reduced pollution to improved health and economic growth. Indeed, the transformation is the biggest economic opportunity of this generation.

Reaching the 2050 goal of net zero emissions globally will help ensure the continuation of the conditions that have allowed human civilisation to flourish over the past 10,000 years. This is every child's birthright.

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