# Making Mission Possible

## Delivering a Net-Zero Economy

September 2020

**Version** 1.0

Energy Transitions Commission

# Making Mission Possible

## Delivering a Net-Zero Economy

**The Energy Transitions Commission (ETC) is a coalition of global leaders from across the energy landscape: energy producers, energy-intensive industries, equipment providers, finance players and environmental NGOs. Our mission is to work out how to build a global economy which can both enable developing countries to attain developed world standards of living and ensure that the world limits global warming to well below 2°C and as close as possible to 1.5°C. For this objective to be reached, the world needs to achieve net-zero GHG emissions by around mid-century.**

The ETC is co-chaired by Lord Adair Turner and Dr. Ajay Mathur. Our Commissioners are listed on the next page.

The Making Mission Possible report was developed by the Commissioners with the support of the ETC Secretariat, provided by SYSTEMIQ. It brings together and builds on past ETC publications, developed in close consultation with hundreds of experts from companies, industry initiatives, international organisations, non-governmental organisations and academia. The report draws upon analyses carried out by Climate Policy Initiative, Copenhagen Economics, Material Economics, McKinsey & Company, Rocky Mountain Institute, The Energy and Resources Institute, University Maritime Advisory Services, Vivid Economics and SYSTEMIQ for and in partnership with the ETC, as well as a broader literature review. We reference in particular analyses from the International Energy Agency and BloombergNEF. We warmly thank our knowledge partners and contributors for their inputs.

This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this report but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century, but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organisations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2˚C, and that many of the key actions to achieve these goals are clear and can be pursued without delay.

**Learn more at:**

www.energy-transitions.org
www.linkedin.com/company/energy-transitions-commission
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# Glossary

**Abatement cost:** The cost of reducing $CO_2$ emissions, usually expressed in US$ per tonne of $CO_2$.

**BECCS**: A technology that combines bioenergy with carbon capture and storage to produce net negative greenhouse gas emissions.

**BEV**: Battery-electric vehicle.

**Biomass or bio-feedstock**: Organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, organic waste from municipal and industrial sources, or algae.

**Bioenergy**: Renewable energy derived from biological sources, in the form of solid biomass, biogas or biofuels.

**Carbon capture and storage or use (CCS/U):** We use the term "carbon capture" to refer to the process of capturing $CO_2$ on the back of energy and industrial processes. Unless specified otherwise, we do not include direct air capture (DAC) when using this term. The term "carbon capture and storage" refers to the combination of carbon capture with underground carbon storage; while "carbon capture and use" refers to the use of carbon in carbon-based products in which $CO_2$ is sequestered over the long term (eg, in concrete, aggregates, carbon fibre). Carbon-based products that only delay emissions in the short term (eg, synfuels) are excluded when using this terminology.

**Carbon emissions / $CO_2$ emissions:** We use these terms interchangeably to describe anthropogenic emissions of carbon dioxide in the atmosphere.

**Carbon offsets**: Reductions in emissions of carbon dioxide ($CO_2$) or greenhouse gases made by a company, sector or economy to compensate for emissions made elsewhere in the economy.

**Carbon price**: A government-imposed pricing mechanism, the two main types being either a tax on products and services based on their carbon intensity, or a quota system setting a cap on permissible emissions in the country or region and allowing companies to trade the right to emit carbon (i.e. as allowances). This should be distinguished from some companies' use of what are sometimes called "internal" or "shadow" carbon prices, which are not prices or levies, but individual project screening values.

**Circular economy models:** Economic models that ensure the recirculation of resources and materials in the economy, by recycling a larger share of materials, reducing waste in production, light-weighting products and structures, extending the lifetimes of products, and deploying new business models based around sharing of cars, buildings, and more.

**Combined cycle gas turbine (CCGT):** An assembly of heat engines that work in tandem from the same source of heat to convert it into mechanical energy driving electric generators.

**Decarbonisation solutions:** We use the term "decarbonisation solutions" to describe technologies or business models that reduce anthropogenic carbon emissions by unit of product or service delivered though energy productivity improvement, fuel/feedstock switch, process change or carbon capture. This does not necessarily entail a complete elimination of $CO_2$ use, since (i) fossil fuels might still be used combined with CCS/U, (ii) the use of biomass or synthetic fuels can result in the release of $CO_2$, which would have been previously sequestered from the atmosphere though biomass growth or direct air capture, and (iii) $CO_2$ might still be embedded in the materials (eg, in plastics).

**Direct air capture (DAC):** The extraction of carbon dioxide from atmospheric air.

**Electrolysis**: A technique that uses electric current to drive an otherwise non-spontaneous chemical reaction. One form of electrolysis is the process that decomposes water into hydrogen and oxygen, taking place in an electrolyser and producing "green hydrogen". It can be zero-carbon if the electricity used is zero-carbon.

**Embedded carbon emissions:** Lifecycle carbon emissions from a product, including carbon emissions from the materials input production and manufacturing process.

**Emissions from the energy and industrial system:** All emissions arising either from the use of energy or from chemical reactions in industrial processes across the energy, industry, transport and buildings sectors. It excludes emissions from the agriculture sector and from land use changes.

**Emissions from land use: All** emissions arising from land use change, in particular deforestation, and from the management of forest, cropland and grazing land. The global land use system is currently emitting $CO_2$ as well as other greenhouse gases, but may in the future absorb more $CO_2$ than it emits.

**Energy productivity**: Energy use per unit of GDP.

**Final energy consumption**: All energy supplied to the final consumer for all energy uses.

**Fuel cell electric vehicle (FCEV):** Electric vehicle using a fuel cell generating electricity to power the motor, generally using oxygen from the air and compressed hydrogen.

**Greenhouse gases (GHGs):** Gases that trap heat in the atmosphere – $CO_2$ (76%), methane (16%), nitrous oxide (6%) and fluorinated gases (2%).

**Hydrocarbons**: An organic chemical compound composed exclusively of hydrogen and carbon atoms. Hydrocarbons are naturally occurring compounds and form the basis of crude oil, natural gas, coal and other important energy sources.

**Internal combustion engine (ICE):** A traditional engine, powered by gasoline, diesel, biofuels or natural gas. It is also possible to burn ammonia or hydrogen in an ICE.

**Levelised cost of electricity (LCOE)**: A measure of the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity-generating plant divided by a discounted sum of the actual energy amounts delivered.

**Natural carbon sinks**: Natural reservoirs storing more $CO_2$ than they emit. Forests, plants, soils and oceans are natural carbon sinks.

**Nature-based solutions:** Actions to protect, sustainably manage and restore natural or modified ecosystems which constitute natural carbon sinks, while simultaneously providing human, societal and biodiversity benefits.

**Near-total-variable-renewable power system:** We use this term to refer to a power system where 85-90% of power supply is provided by variable renewable energies (solar and wind), while 10-15% is provided by dispatchable/peaking capacity, which can be hydro, biomass plants or fossil fuels plants (combined with carbon capture to reach a zero-carbon power system).

**Net-zero-carbon-emissions / Net-zero-carbon / Net-zero**: We use these terms interchangeably to describe the situation in which the energy and industrial system as a whole or a specific economic sector releases no $CO_2$ emissions – either because it doesn't produce any or because it captures the $CO_2$ it produces to use or store. In this situation, the use of offsets from other sectors ("real net-zero") should be extremely limited and used only to compensate for residual emissions from imperfect levels of carbon capture, unavoidable end-of-life emissions, or remaining emissions from the agriculture sector.

**Primary energy consumption**: Crude energy directly used at the source or supplied to users without transformation – that is, energy that has not been subjected to a conversion or transformation process.

**Steam methane reforming (SMR):** A process in which methane from natural gas is heated and reacts with steam to produce hydrogen.

**SMR with carbon capture and storage (SMR+CCS)**: Hydrogen production from SMR, where the carbon emitted from the combustion of natural gas is captured to be stored or used.

**Sustainable biomass / bio-feedstock / bioenergy:** In this report, the term 'sustainable biomass' is used to describe biomass that is produced without triggering any destructive land use change (in particular deforestation), is grown and harvested in a way that is mindful of ecological considerations (such as biodiversity and soil health), and has a lifecycle carbon footprint at least 50% lower than the fossil fuels alternative (considering the opportunity cost of the land, as well as the timing of carbon sequestration and carbon release specific to each form of bio-feedstock and use).

**Synfuels**: Hydrocarbon liquid fuels produced synthesising hydrogen from water, carbon dioxide and electricity. They can be zero-carbon if the electricity input is zero-carbon and the $CO_2$ from direct air capture. Also known as "synthetic fuels", "power-to-fuels" or "electro-fuels".

**Zero-carbon energy sources**: Term used to refer to renewables (including solar, wind, hydro, geothermal energy), sustainable biomass, nuclear and fossil fuels if and when their use can be decarbonised through carbon capture.

# Foreword

Energy is essential to increased economic prosperity. But if global energy growth continues in line with past trends and energy supply continues to depend primarily on fossil fuels, greenhouse gas (GHG) emissions will rise to levels that threaten catastrophic climate change. Even after allowing for significant improvements in energy productivity and for the impact of announced policies, the International Energy Agency's (IEA) Current Policies Scenario shows us ***en route*** to 3°C warming.[1]

The **Energy Transitions Commission** (ETC) is a coalition of global leaders from across the energy landscape: energy producers, energy-intensive industries, equipment providers, finance players and environmental NGOs. Our mission is to work out how to build a global economy which can both enable developing countries to attain developed world standards of living and ensure that the world limits global warming to well below 2°C and as close as possible to 1.5°C. For this objective to be reached, the world needs to achieve net-zero greenhouse gas (GHG) emissions by around mid-century.

Over the last four years, the ETC has issued several reports which address aspects of that challenge [Exhibit A]. In *Better Energy, Greater Prosperity*[2] (April 2017), we argued that it was possible: (i) to drastically slow down the forecasted growth in global energy demand while still improving living standards in developing economies; and (ii) to decarbonise electricity systems far faster and cheaper than previously assumed. Reports on the Indian power system[3] (February 2019 and July 2020) confirmed that this conclusion holds true even in a challenging environment by describing how India could rapidly expand electricity supply to meet fast-growing demand without building any more coal-fired power stations. Our *Mission Possible* report[4] (December 2018) then showed that it was possible to decarbonise even the "harder-to-abate" heavy industry and heavy-duty transport sectors. And our November 2019 report on China[5] argued that China could become a zero-carbon economy by 2050 with a trivial impact on economic growth.

The overall conclusion from these reports is clear. **It is undoubtedly technically possible to achieve net-zero GHG emissions by around mid-century**, with the developed world reaching this target by 2050 and the developing world by 2060 at the latest, without relying on the permanent and significant use of offsets from afforestation, other forms of land-use change or negative emissions technologies. Technologies and business solutions to do so are either already available or close to being brought to market.

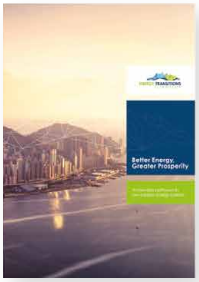
**The costs of achieving this are very small**, especially compared to the large adverse consequences that unmitigated climate change would trigger by 2050 and in subsequent years. The incremental capital investments needed over the next 30 to 40 years to achieve a zero-emissions economy, while huge in absolute dollar terms, are only about 1% to 2% of global GDP per annum. They are affordable, particularly within a macroeconomic context of low or even negative real interest rates in developed economies – although financial support for developing economies facing higher risk premiums on capital markets will be required. By 2050, the reduction in conventionally measured living standards in 2050 will be at most 0.5%.

This reconfiguration of the global energy system will generate important benefits. The transition to zero emissions will drive innovation and economic growth, and create new jobs. It will improve living standards – particularly in developing economies – through reduced local air pollution and related health impact; lower energy bills for households, thanks to cheap electricity and more efficient buildings; provide more flexible mobility services; and produce higher-quality, more durable consumer goods.

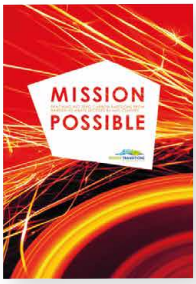
1. IEA (2019), *World Energy Outlook 2019*
2. Energy Transitions Commission (2017), *Greater Energy – Better Prosperity*
3. Spencer, T. and Awasthy, A. (2019), TERI, *Analysing and Projecting Indian Electricity Demand to 2030*. Pachouri, R., Spencer, T., and Renjith, G., TERI (2019), *Exploring Electricity Supply-Mix Scenarios to 2030*, and Udetanshi, Pierpont, B., Khurana, S. and Nelson, D., TERI (2019), *Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings*
4. Energy Transitions Commission (2018), *Mission Possible*
5. Energy Transitions Commission and Rocky Mountain Institute (2019), *China 2050: A Fully Developed Rich Zero-Carbon Economy*

# Major ETC reports and working papers

## Global reports




**Better Energy, Greater Prosperity** (2017) outlined four complementary decarbonisation strategies, positioning power decarbonisation and clean electrification as major complementary progress levers.



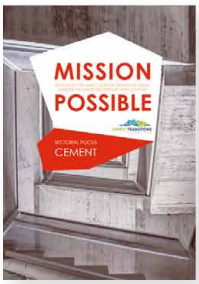

**Mission Possible** (2018) outlined pathways to reach net-zero emissions from the harder-to-abate sectors in heavy industry (cement, steel, plastics) and heavy-duty transport (trucking, shipping, aviation).

## Sectoral and cross-sectoral focuses


**Low-cost, low-carbon power systems** (2017) analysed feasibility and costs of near-total renewable-based power systems.


**The future of fossil fuels** (2017) explored the significant decrease in fossil fuels use implied by a 2-degree trajectory.


**Economic growth in a low-carbon world** (2017) analysed how to drastically reduce final energy demand globally.

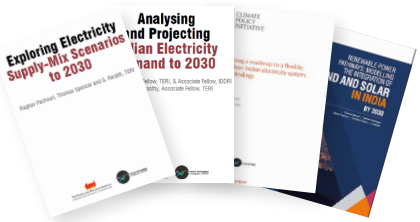


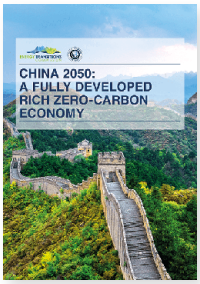

**x6**
+ building heating

**Sectoral focuses** provided detailed decarbonisation analyses on each on the six harder-to-abate sectors after the publication of the Mission Possible report (2019). Our latest **focus on building heating** (2020) details decarbonisation pathways and costs for building heating, and implications for energy systems.

## Geographical focuses

**A series of four reports on the Indian power system** (2019-2020) described how India could rapidly expand electricity supply without building more coal-fired power stations.




**China 2050: A Fully Developed Rich Zero-carbon Economy** (2019) described the possible evolution of China's energy demand sector by sector, analysing energy sources, technologies and policy interventions required to reach net-zero carbon emissions by 2050.

Exhibit A

**This report is published in an unprecedented context**: the COVID-19 pandemic has brought the world to a standstill, provoking an abrupt fall in GDP and in international trade, and demonstrating the unpreparedness of the global economy to systemic risks, despite early warnings from scientists. While the first priority is to protect populations and urgently reinforce healthcare systems, this crisis also demands an economic recovery response focused on the development of a more resilient economy. In this context, this report provides governments and private sector leaders with a vision of how to invest in the economy of the future and build a healthier, more resilient, net-zero economy. In addition, the ETC has published two reports setting out the specific actions which governments can take to drive sustainable recovery from the current crisis, outlining 7 priorities to put at the heart of the economic stimulus packages [Exhibit B].[6]

## ETC's COVID-19 response: 7 priorities to help the global economy recover while building a net-zero-emissions economy

| | Why it matters |
|---|---|
| 1 Unleash massive investment in renewable power systems | Potential of 17 million jobs globally by 2030 (IRENA)<br>US 2008 stimulus: 900,000 jobs in renewable sector |
| 2 Boost the construction sector via green buildings & infrastructure | Labour-intensive sector<br>US$50 trillion investment required in low-carbon transition by 2030 (NCE) |
| 3 Support the automotive sector while pursuing clean air | 40-80% drop in sales in affected regions<br>Link between air pollution & virus transmission and mortality |
| 4 Make the second wave of government support to businesses conditional to climate commitments | Lessen climate transition financial risks<br>ESG & green portfolios more financially sustainable than average |
| 5 Provide targeted support to innovative low-carbon activities | Innovation in technology & business model as driver of future economic growth |
| 6 Accelerate the transition of the fossil fuels industry | Low fossil fuel prices driving least competitive assets out of market & precipitating sector restructuring |
| 7 Don't let carbon pricing and regulations spiral down | Drop in carbon prices & increased lobbying for deregulation<br>But need to mitigate risk of future climate crises |

Exhibit B

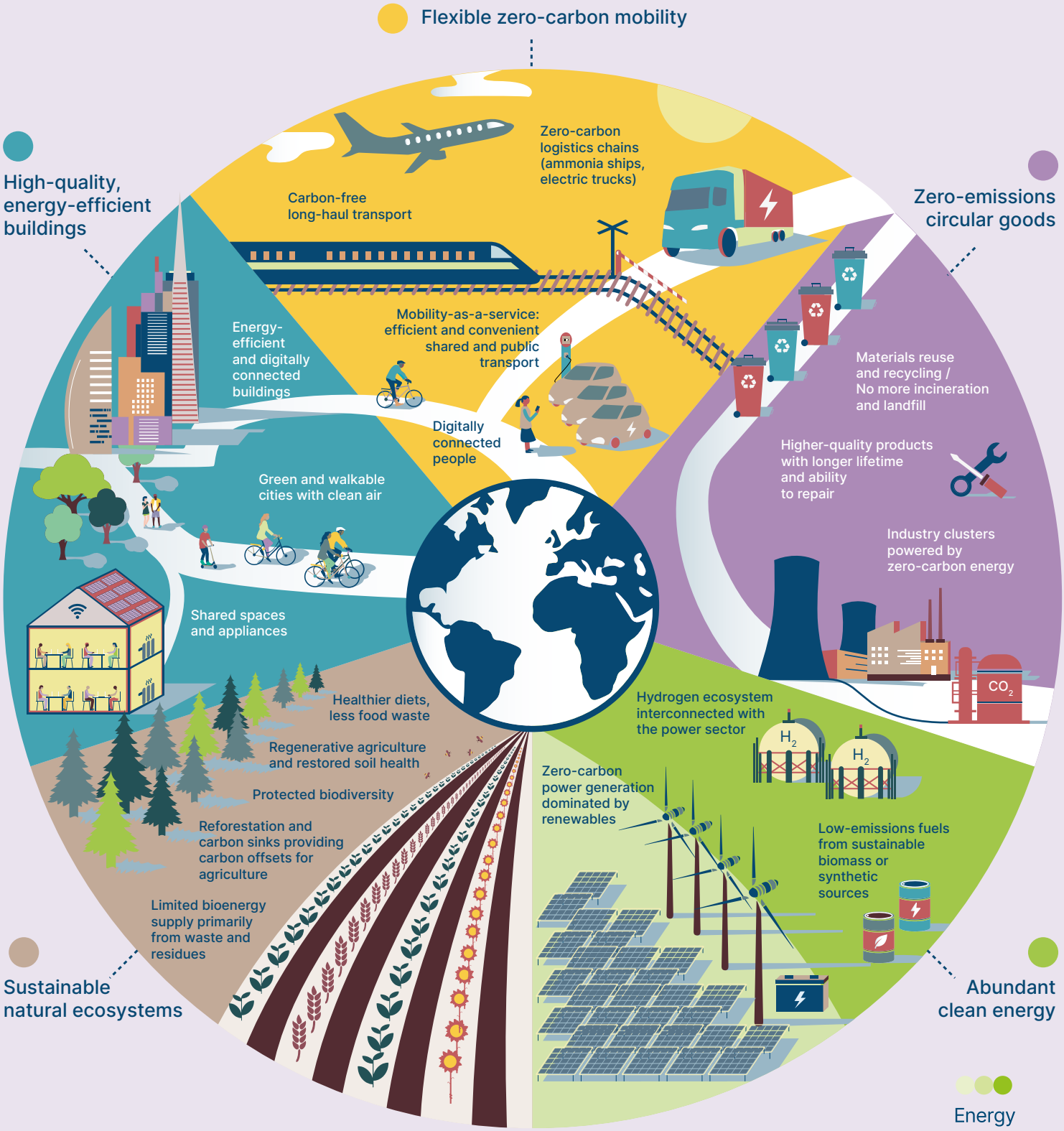
In essence, the ETC is convinced that the developed world should reach net-zero GHG emissions by 2050 and the developing world by 2060 at the latest. **This report explains why we are confident that this is feasible, how to achieve the transition and what steps need to be taken in the 2020s to put the world on the right trajectory** – integrating the findings from our previous publications, and updating our analysis to reflect the latest trends in the readiness and cost of key technologies. It describes in turn:

1. The steps to build a zero-carbon-emissions economy by mid-century
2. The costs, investments and related challenges of the transition towards net-zero emissions
3. Regional differences, challenges and opportunities
4. The actions required now to put 2050 targets within reach

6. ETC (2020), *7 Priorities to Help The Global Economy Recover*; and ETC and Rocky Mountain Institute (2020), *Achieving a Green Recovery for China: Putting Zero-Carbon Electrification at the Core*.

# A prosperous net-zero-emissions economy by mid-century is Mission Possible

- High-quality, energy-efficient buildings
- Flexible zero-carbon mobility
- Zero-emissions circular goods
- Abundant clean energy
- Sustainable natural ecosystems




Energy Transitions Commission


# Building a zero-carbon-emissions economy by mid-century

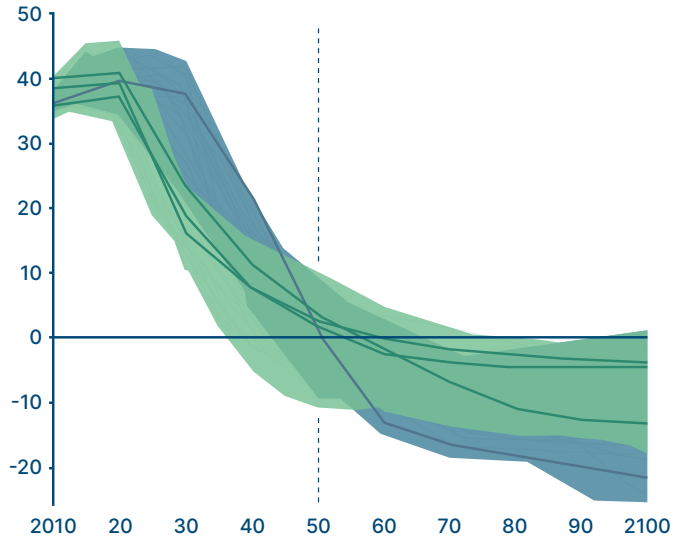
The Intergovernmental Panel on Climate Change's November 2018 report[7] argued that the world's objective should be to limit global warming to 1.5°C above pre-industrial levels, and that this would require reaching net-zero GHG emissions by around mid-century (between 2050 and 2060) [Exhibit 1.1].

Our analysis shows that a global zero-emissions economy can be achieved by mid-century without relying massively on offsets from nature-based solutions or on negative emissions technologies beyond the transition period.

Exhibit 1.1

## $CO_2$ emissions must be reduced to net-zero globally by around 2050 based on the global emissions pathways for 1.5˚C from IPCC

Global emissions pathway characteristics in the IPCC 1.5˚C report
Gt $CO_2$/year




The IPCC **generated a large number of 1.5˚C scenarios**, out of which they selected four illustrative pathways (larger lines on the graph);

In pathways limiting global warming to 1.5˚C **with no or limited overshoot**, as well as pathways **with a high overshoot**, $CO_2$ emissions are reduced **to net-zero globally by around 2050**.

**SOURCE:** IPCC (2018), *Global Warming of 1.5˚C*

The key to get there is massive clean electrification and the development of the hydrogen economy. However, these levers alone would be insufficient: there are also limited, but still vital roles for CCS/U applied to continued fossil fuel use and for bioenergy (and other uses of bio-feedstocks). Driving energy productivity improvement as rapidly as possible will make the shift to these low-carbon energy sources easier and cheaper.

**We describe this route to a zero-carbon-emissions economy by considering in turn:**

I. How to achieve dramatic improvements in energy productivity;
II. How to decarbonise all sectors of the economy, with a central but non-exclusive role for electrification;
III. The final energy and primary energy mix in 2050;
IV. Resource adequacy for zero-carbon electricity, hydrogen, sustainable bioenergy and CCS/U;
V. Investments, transition challenges and the role of offsets.

7. IPCC (2018), *Special Report on Global Warming of 1.5°C*

# Reaching net-zero emissions is technically and economically feasible

Technologies needed to fully decarbonise each sector with no offsets are known or in development

Full decarbonisation will cost less than 0.5% of global GDP

## 3 steps to a net-zero-emissions economy

**3 — Use clean energy everywhere**

- Drive **massive clean electrification** of buildings, transport and industry
- Use **hydrogen** where you can't electrify
- Decarbonise remaining energy use using **CCS/U and sustainable bioenergy**

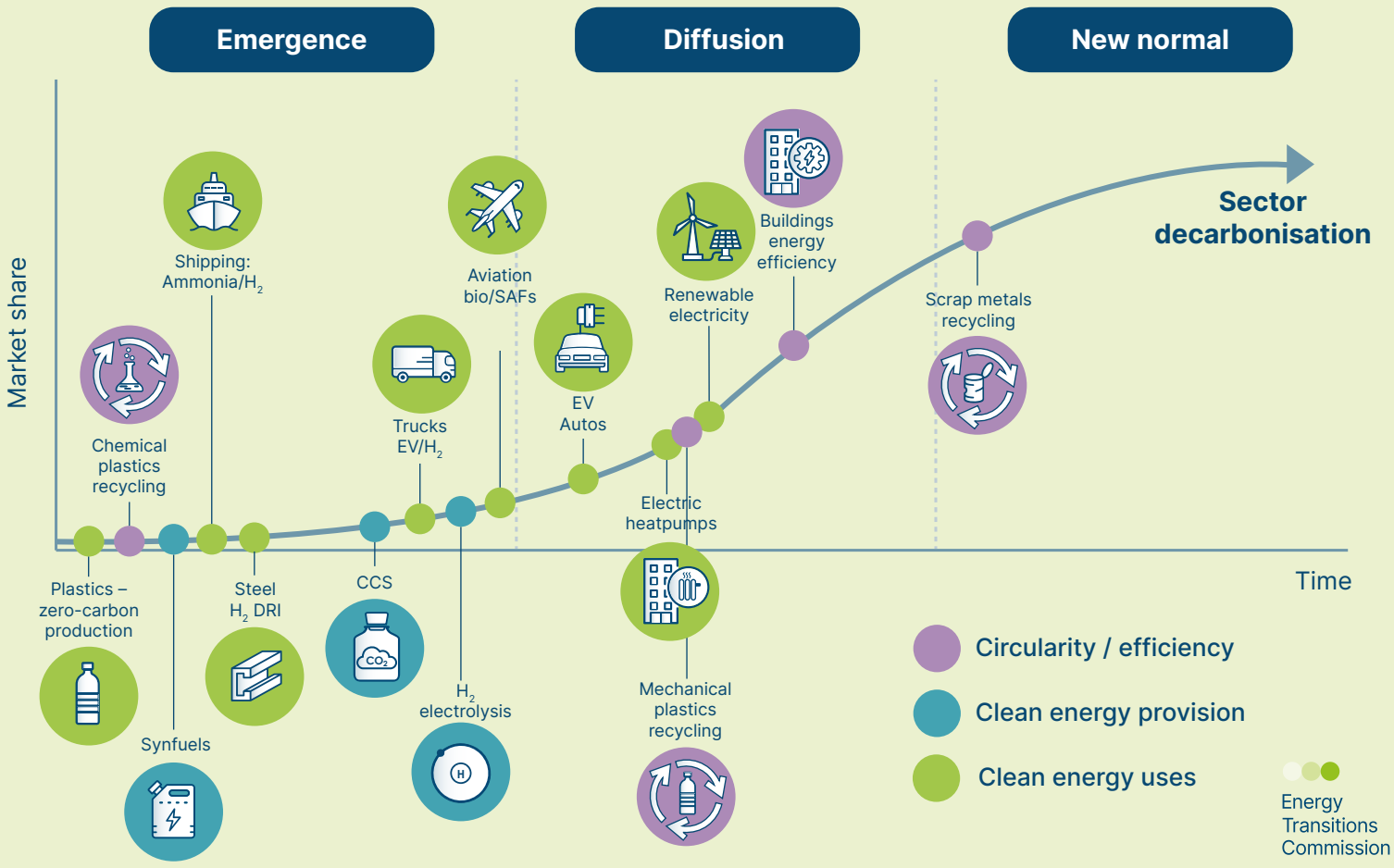
**2 — Scale up clean energy provision**

- Multiply by 10-15 **zero-carbon electricity generation**
- Scale up zero-carbon **hydrogen production** to reach 700-1,000 Mt p.a.
- Build **biofuel and synthetic fuel supply chains**

**1 — Use less energy**

- Deploy **more efficient** equipment, transport modes & production processes
- Use **less primary material input** to deliver the same goods
- **Change consumption patterns using fewer products and services** to achieve same living standards

## The journey of zero-emissions solutions



# I. Achieving dramatic improvements in energy productivity – implications for total energy needs

Global energy use has grown rapidly over the last 10 years, with the vast majority supplied by fossil fuels. But with energy use per capita varying significantly across the world, some countries will still need increased energy supply to support growth in prosperity, while the most prosperous countries should see their energy per capita decrease significantly due to energy productivity gains [Exhibit 1.2].

## Current energy per capita varies significantly across the world

Average per capita primary energy consumption; GJ/capita; 2017-18

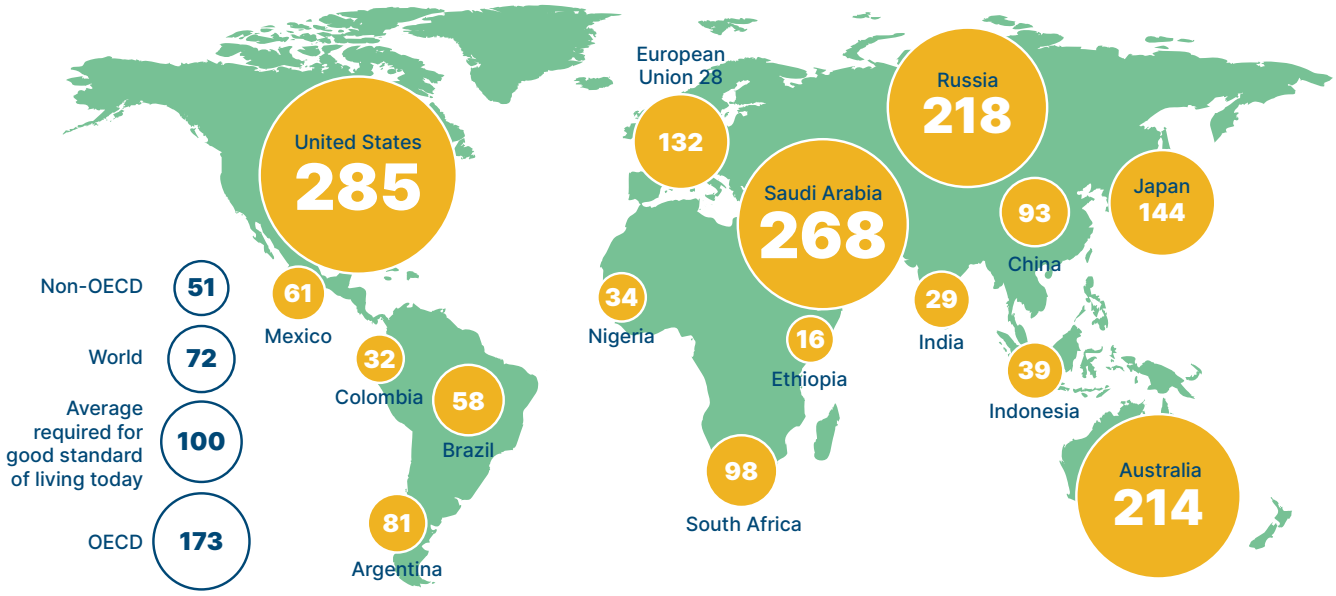



Exhibit 1.2

**SOURCE:** IEA (2019), World Energy Outlook 2019; IEA; OECD. Data are for 2018 or 2017.

There are major opportunities to improve the energy productivity by which we turn energy inputs into welfare-enhancing goods and services, reducing energy use while maintaining or even improving living standards. These opportunities lie in three areas [Exhibit 1.3]:

- **Energy efficiency:** Technical energy efficiency can still be improved across multiple applications in, for instance, transport (eg, more efficient aircraft), industry (eg, reduced energy inputs to traditional blast furnace-based steel production) and buildings (eg, better insulation and higher coefficient of performance in air-conditioning systems). Improvements of up to 50% are theoretically possible in the transport sectors; while in industry, more modest but still significant improvements of 10% to 20% could be achieved. [Exhibit 1.4].

- **Material efficiency:** There are major opportunities to reduce the primary production of energy-intensive materials, such as steel and cement, through product redesign, more efficient material use and greater materials recycling and reuse. Analysis by Material Economics[8] suggests that in theory, such measures could reduce global emissions from heavy industrial sectors by 40% below business-as-usual levels [Exhibit 1.5].

- **Service efficiency:** Finally, it is possible to deliver higher living standards while using less energy-intensive goods and services – for example, via better urban design or shared use models in transport. Here the potential depends on consumer behaviour changes and is therefore more speculative; but in principle, major reductions could be achieved [Exhibit 1.6].

Seizing these opportunities will require major changes to business value chains (eg, in product design, distribution and recycling processes), and in consumption and lifestyle choices (eg, in urban design and mobility systems).

8. Material Economics (2018) for the Energy Transitions Commission

Exhibit 1.3

## The three dimensions of energy productivity

**Energy productivity**
Less energy used for the same living standard

Energy / Living standard =

**A Energy efficiency**
More efficient equipment & production processes

Energy / Energy-using process ×

**B Material efficiency**
Less primary material input required to deliver the same level of energy-based service

Material / Product ×

**C Service efficiency**
Better utilisation of products and services to achieve same living standard

Product/services / Living standard

Eg:

- **Energy:** reduced flaring & grid losses
- **Buildings:** improved insulation, electric boilers
- **Transport:** electric engines, improved aerodynamics
- **Industry:** reuse of waste heat

Eg:

- Material circulation: improved recycling
- Material-to-product efficiency: car light-weighting

Eg:

- Product-to-service efficiency: car sharing, space optimisation
- Demand reduction and behavioural changes, e.g. in mobility (denser urban forms, modal shift, reduced use of home delivery, preference for locally-sourced product) or housing (reduced water/heating consumption)

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2019), based on Material Economics (2018), *The Circular Economy: a Powerful Force for Climate Change*

Exhibit 1.4

## There are major opportunities to achieve energy efficiency improvement in transport and buildings, and important but smaller opportunities in industry

Percentages reflect highest incremental efficiency improvement – excluding electrification

**-50%**
- Engine efficiency
- Aerodynamics and tyre design

**-30/45%**
- Engine efficiency
- Aerodynamics and tyre design

**-5-20%**
- Automated trains and traffic management

**-30/55%**
- Machinery efficiency
- Wind assistance
- Ship design, hull and propulsion

**-30/45%**
- Engine efficiency
- Aircraft design

**Building – heating: -20-50%**
- Insulation and double glazing
- Improved analytics and operation of heating controls

**Building – non heating uses: -20-60%**
- Efficiency standards on appliances
- Bans (eg incandescent light bulbs)

**-10%**
- Switch to dry kilns
- Multistage cyclone heaters
- Decrease in clinker-to-cement ratio

**-15-20%**
- Reuse of high-pressure gas
- Coke dry quenching

**-15-20%**
- Energy efficiency in monomer production
- Naphtha catalytic cracking

Exhibit 1.5

## Improving material efficiency could cut emissions from harder-to-abate industrial sectors by 40% by 2050

| | | | Energy use reduction potential |
|---|---|---|---|
| **Material efficiency** | **Material circulation** | • **Improved recycling:**<br>◦ Increased collection rates<br>◦ Design for disassembly<br>◦ Improved materials separation<br>◦ Reduced contamination and downgrading | **-18% for heavy industry sectors** |
| | **Material to product efficiency** | • **Less production waste**<br>• **Use of higher-strength material to reduce overuse**<br>• **Light-weighting, eg steel, aluminium or plastics in car manufacturing** | **-22% for heavy industry sectors if coupled with product-to-service efficiency** |

**SOURCE:** Material Economics analysis for the Energy Transitions Commission (2018)

Exhibit 1.6

## In principle, improving product/service efficiency could significantly cut building and mobility related energy use

| | | | Energy use reduction potential |
|---|---|---|---|
| **Service efficiency** | **Product-to-service efficiency** | • **Higher utilisation and intensive use of products** (car sharing, space optimisation)<br>• **Longer lifetimes**<br>• **Reuse of components** | **Major uncertainty, depending on consumer choices and society trends** |
| | **Logistics and operations efficiency** | • **Transport:**<br>◦ Platform management in aviation, trucking and shipping<br>◦ Energy-saving practices: speed reduction<br>• **Housing:** smart management of space and water heating/cooling | **~5-10% for the transport sector**<br>**20% in the housing sector** |
| | **Shift to less carbon-intensive services** | • **Transport:** modal shift from air and road to rail and shipping<br>• **Housing:** shift to apartments or denser housing<br>• **Dematerialisation and digitalisation** | **~5-10% for the transport sector**<br>**<5% in the housing sector** |
| | **Reduced demand** | • **Transport:**<br>◦ Denser urban forms<br>◦ More videoconferencing and homeworking<br>◦ Reduced use of home delivery, preference for locally-sourced products<br>• **Housing:** reduced water consumption, lower ideal room temperature | **Major uncertainty, depending on consumer choices and society trends** |

**SOURCE:** Material Economics analysis for the Energy Transitions Commission (2018)

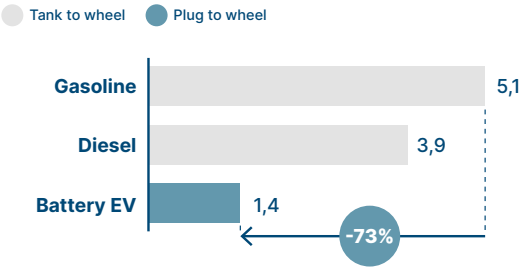
The total amount of final energy needed to support high living standards will also be strongly influenced by how far we can electrify economic activities across each industry sector. This reflects electricity's inherent efficiency advantage in several applications – in particular [Exhibit 1.7]:

- In **surface transport**, internal combustion engines turn about 60% to 80% of the energy input into unwanted heat, rather than kinetic energy to drive the vehicle forward, whereas electric engines can be 90% efficient.
- In **building heating**, the use of heat pumps makes it possible to deliver over 3 kilowatt-hours (kWh) of heat while using just 1 kWh of electricity input (an effective efficiency of over 300%, increasing to 400% to 550% with latest models and in mild climates); whereas gas boilers will never achieve more than 90%.

## Radical energy efficiency improvement can be achieved through electrification

### Transport example

**BEVs consume one-quarter of the energy of gasoline cars**
Litres of gasoline equivalent per 100 km



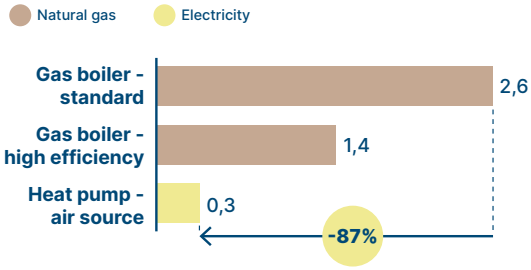

**Assumptions**

All vehicle efficiencies based on 200 km driven through New European Drive Cycle.

BEV assumes lithium-ion battery with 95% roundtrip efficiency.

### Building heating example

**Electric heat pumps are ~90% more efficient than gas boilers**
kWh final energy per kWh heat delivered




**Assumptions**

Standard gas boiler is 70% combustion efficient and 55% system efficient.

High-efficiency boiler is 90% combustion efficient and 80% system efficient.

Heat pumps have a coefficient of performance (COP) of 2.0-4.0 with average of 3.0 shown here.

**Note:** significant opportunities exist for further improvements in COPs beyond 3 or 4 since current COPs are still far below theoretical thermodynamic limits).

Exhibit 1.7

**SOURCE:** Energy Transitions Commission (2017), *Better Energy, Greater Prosperity*, based on Energy & Environmental Science (2015), *Well to wheel analysis of low carbon alternatives for road traffic*

In addition, **digital technologies** have the potential to significantly contribute to these energy productivity improvement opportunities by offering both end-use and system efficiency benefits: they can facilitate reductions in energy use in many sectors from construction to manufacturing (eg, 3D printing, light weighting); improve the monitoring of efficiency losses and the provision of automated responses in energy-intensive sectors (eg, industrial energy efficiency monitoring, load management in logistics); and enhance energy demand monitoring and management at the energy system level (eg, vehicle-to-grid, building heating management).[9]

9. IEA (2017), *Digitalization and Energy*

Numerous barriers would have to be overcome to achieve the theoretically possible emissions reductions, and it is therefore unclear how much of this potential can in reality be grasped. Indeed, as the latest IEA World Energy Outlook[10] points out, the last five years have seen a concerning deceleration in the pace of technical energy efficiency improvement.

Key barriers include:

**Technical challenges:**
A few key technologies to achieve energy productivity improvement are not yet commercially ready. For example, the steel and plastics sectors face the problem of "downcycling" due to contamination of the primary material by other materials (copper for steel, additives for plastics), limiting the increase of recycling rates. Accelerating development of key technologies is therefore vital (chemical recycling of plastics, better collection and dismantling processes, design for disassembly).

**Economic challenges:**
High upfront investment costs in infrastructure and higher costs of zero-carbon feedstock are strong impediments to the deployment of energy-efficient and material-efficient environments. Economic incentives are also often distorted by inadequate policies, such as subsidies supporting cheap fossil fuels or the absence of taxation of waste incineration.

**Institutional challenges:**
Many industries (eg, cement, plastics) are so fragmented that incentives to build an end-to-end circular and efficient value chain are limited. Collaboration across the value chain and between the private and public sector is key to build synergies and support a comprehensive innovation and deployment agenda.

Given the scale of the opportunity, though, public policy must focus on routes to overcome these barriers.

Reflecting both potential energy productivity improvements and the impact of electrification, estimates of total future final energy demand show that economic growth could be supported with only limited or even negative growth in energy use over the next three decades.

Thus:

- While the **IEA**'s Current Policies Scenario shows total final energy demand potentially growing from 417 exajoules (EJ) in 2017 to 567 EJ in 2040, its Sustainable Development Scenario describes a feasible world in which final energy demand could fall by 6% to reach 398 EJ over the next 20 years[11] [Exhibit 1.8].

- Our **ETC zero-emissions scenarios**, which assume that electricity could grow to ~65% to 70% of final energy demand, show that global final energy demand could fall by about 15% between now and 2050 if all opportunities for energy productivity were seized, while still supporting robust economic growth. Even if progress in energy productivity were disappointing, with decarbonisation achieved almost entirely via electrification and other supply-side measures, energy demand would grow only 19%, while global GDP more than doubled [Exhibit 1.9]. This in turn would have a very tangible impact on the scale of investment required in clean energy provision, reducing in particular investments required in clean power generation by 25% compared with a case with limited energy productivity improvement.

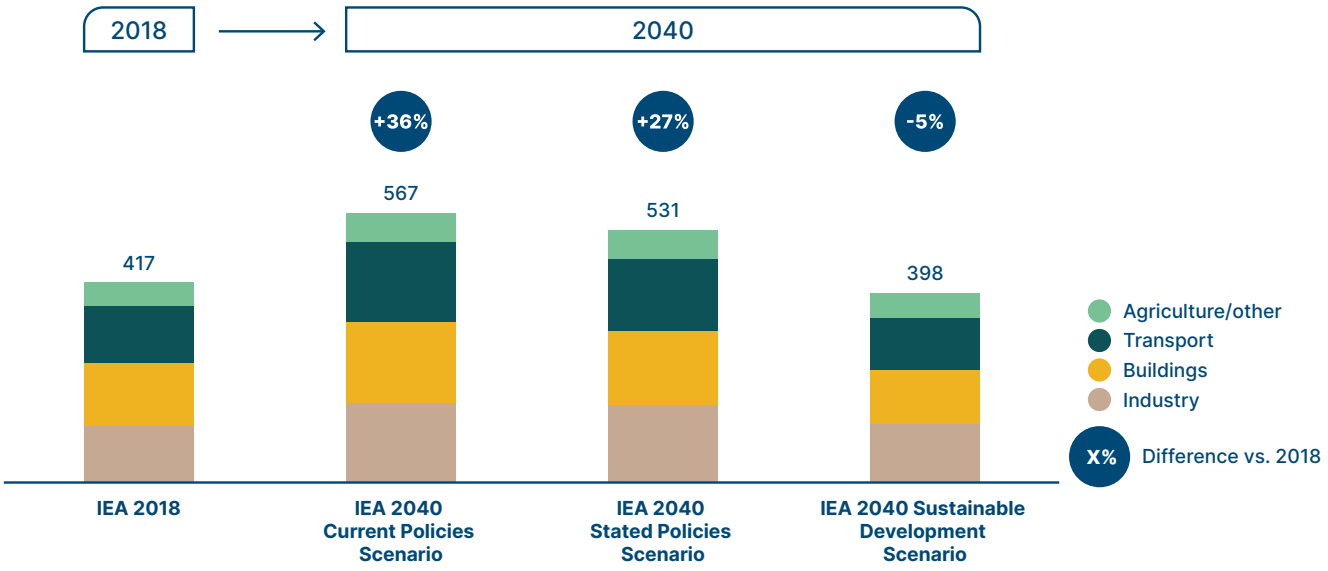
This overall global picture would still entail significant growth in energy demand in some emerging economies, offset by absolute declines in advanced economies.

10. In 2018, the annual improvement rate of Energy Intensity fell to 1.2%, around half the average rate seen since 2010, when it should ideally grow at 3% per annum. Energy intensity refers to the amount of energy used per unit of economic activity. Source: IEA (2019), *World Energy Outlook*.
11. IEA (2019), *World Energy Outlook*

Exhibit 1.8

## The IEA forecasts that 2040 global energy demand could be 5% lower than today in their Sustainable Development scenario

Final energy demand
EJ/year

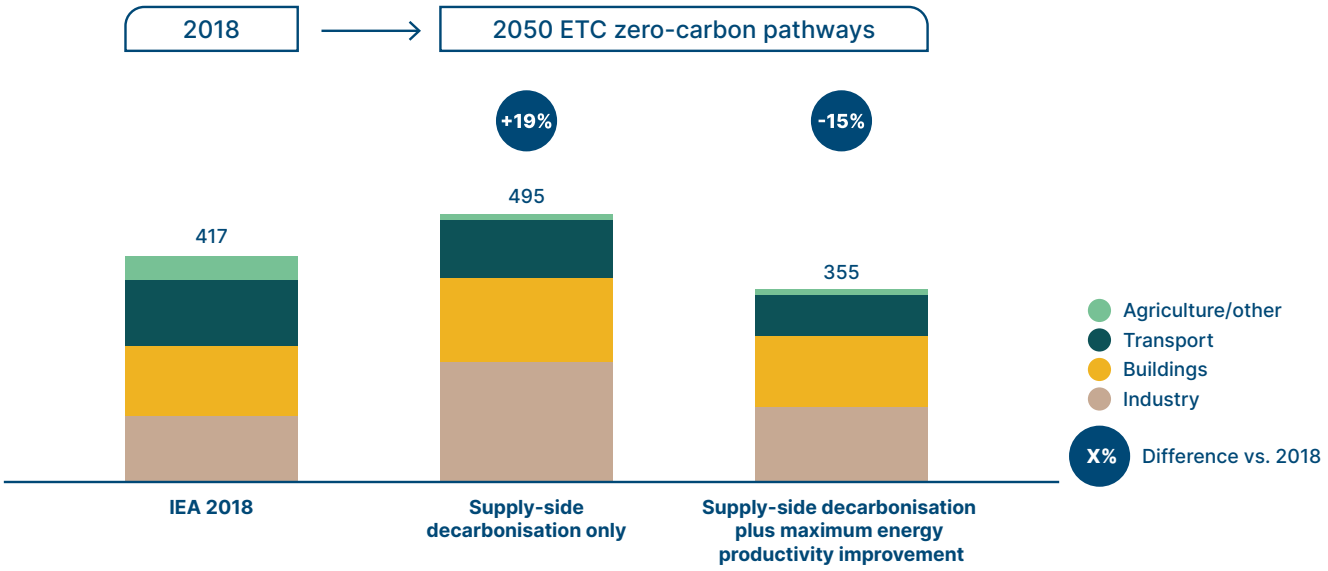



**SOURCE:** Energy Technology Perspectives; IEA (2019), *World Energy Outlook*

Exhibit 1.9

## In the ETC zero-carbon pathways, even with limited energy productivity progress, energy demand would grow only by 19%

Final energy demand
EJ/year




**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020); IEA (2017), Energy Technology Perspectives; IEA (2019), *World Energy Outlook*

# II. Decarbonising all sectors of the economy – the central but non-exclusive role of electrification

Electricity already accounts for 19%[12] of final energy demand and this percentage will undoubtedly grow with the electrification of new applications. But electrification will reduce emissions only if the electricity itself is produced in a zero-carbon fashion.

There are therefore two key questions:

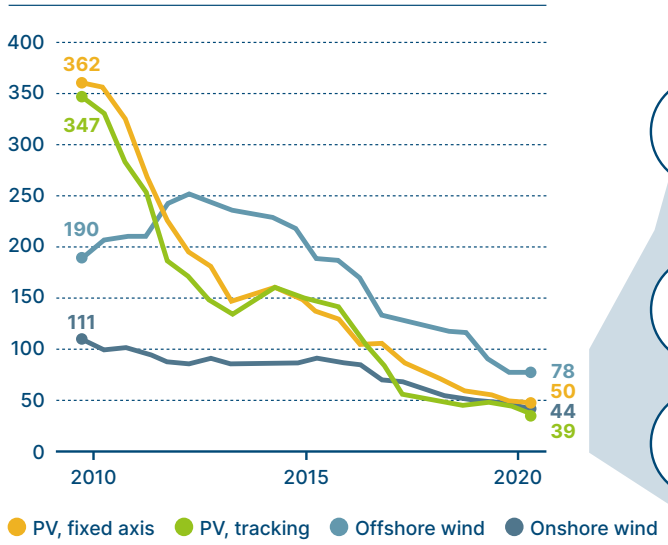
- How far, how fast and at what cost can we decarbonise electricity supply?
- How much of the economy can be electrified and what technologies must be used where this is impossible?

## 1. Decarbonising electricity: technical feasibility and declining costs

Over the last 10 years, the **cost of renewable electricity** has plummeted. Estimates of solar photovoltaic (PV) "levelised cost" have fallen by over 80% to reach US$60 per megawatt-hour (MWh); but auction prices in favourable locations are far lower still, reaching below US$20 per kWh in most favourable locations. Offshore and onshore wind power costs have also fallen by 55% since 2010, with auction prices for onshore wind approaching US$20 per MWh in some countries [Exhibit 1.10].

### Wind and solar LCOE have dramatically decreased in the last 10 years with latest lowest auction LCOEs for solar PV below US$20/MWh

**PV and wind LCOE global benchmarks**
LCOE, US$/MWh, 2019 real




**Lowest auctions prices**

**Portugal:** US$13.3/MWh (lowest offer) for 670MW (August 2020)
**India:** US$38/MWh for solar + batteries delivering 80% of hours per year (June 2020)
**Abu Dhabi:** US$13.5/MWh (lowest offer) for 2 GW (April 2020)
**Qatar:** US$15.7/MWh for 800MW (Jan 2020)
**Saudi Arabia:** US$16.9/MWh for 900MW (2019)
**California:** US$20/MWh for 400MW (June 2019)

**UK:** US$51/MWh (£39.7/MWh) for 6GW (2019)
**France:** US$48/MWh for 600GW (2019)

**Chile:** US$32.5/MWh for 240MW (mixed with solar and geothermal)
**US:** average wind price at US$20/MWh (2017)
**Mexico:** US$20.6/MWh for 250MW (2017)

Exhibit 1.10

**LEFT-HAND SIDE:** the global benchmark is a country weighted-average using the latest annual capacity additions.
**RIGHT-HAND SIDE:** economics of auction prices may be favoured by local tax treatments and other implicit subsidies.

**SOURCE:** Press research, Bloomberg New Energy Finance (2020), *1H 2020 LCOE update*

12. IEA (2019), *World Energy Outlook*

In much of the world, these costs are not only below the total costs of new coal or gas plants, but also increasingly below the marginal cost of existing thermal power plants. Moreover, renewable costs will continue to fall: BloombergNEF (BNEF) estimates that by 2050, solar PV electricity (generation only) will be available at around US$15 per MWh in countries such as India, the US, Australia and Chile, with still lower prices likely to be seen in some specific locations.[13]

The crucial question is therefore no longer the cost of generating renewable electricity, but the **cost of balancing supply and demand** in systems with high levels of variable renewable supply. In our 2017 report *Better Energy, Greater Prosperity*,[14] we argued that by the early 2030s, it would be possible to run power systems which rely up to 90% on zero-carbon technologies at total system costs fully competitive with fossil fuel generation.[15] Our updated analysis has confirmed our conclusions. In particular:

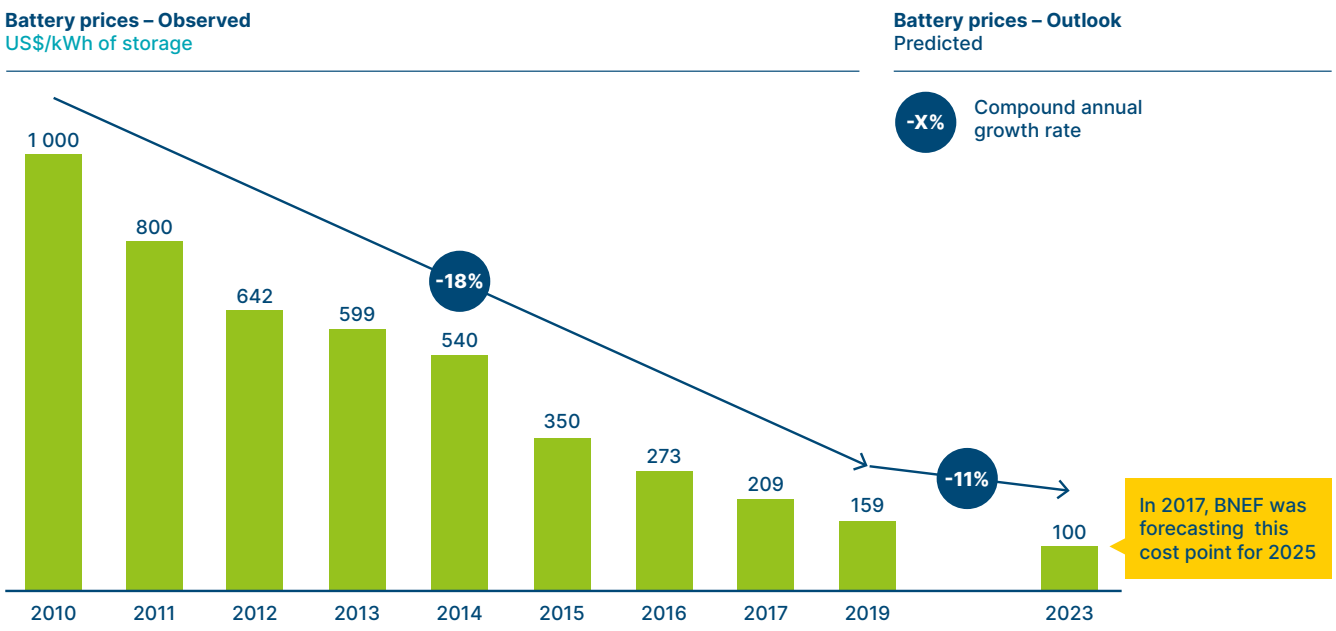
- Dramatic past and projected falls in the price of lithium ion batteries [Exhibit 1.11], together with the development of a range of alternative short-term energy storage systems (including pumped storage) and of demand management are radically reducing the costs of providing **"diurnal" balance between day and night**, and of covering short-term unpredictable variations in wind and solar supply.

- The crucial issue is how to provide **weekly or seasonal balancing** in countries where there are major seasonal swings in either supply or demand (eg, mid- and high-latitude countries with large winter heating needs), especially as variable renewables become a high share of power provision capacities. Providing such seasonal balance will always be a more complex and expensive challenge, but here too there is a wide range of possible solutions – whether via seasonal energy storage in the form of hydrogen, dispatchable hydro power or a continued role for thermal power plants. These thermal power plants would run only a small proportion of annual hours and be made zero-carbon via either the application of CCS/U to gas generation or the use of sustainable biomass which, if combined with CCS, could generate negative emissions [Exhibit 1.12].

- In addition, there is huge potential to shift power demand from both households and industry across time (day, month or year) or across locations to bring the demand profile into closer alignment with naturally arising supply [Exhibit 1.13]. **Demand shifts** from large industrial power consumers (eg, aluminium smelters) have great potential to reduce capacity constraints and can be incentivised by dynamic pricing or smart grid technologies and automated demand response. Electric vehicle (EV) charging could also rapidly become a significant source of flexibility, provided that adequate incentives are in place, transforming consumers into "prosumers" – both users and suppliers of power.

Exhibit 1.11

## Battery prices have decreased annually by 18% in the last decade and are expected to reach US$100/kWh by 2023




**SOURCE:** Bloomberg New Energy Finance (2019)

13. BNEF (April 2020), *1H 2020 LCOE Update*.
14. ETC (2017), *Better Energy, Greater Prosperity*.
15. Our analysis of electricity demand and supply profiles across several geographies indicated that about 80% of electricity demand could be met by a mix of wind and solar generation at the time of consumption, with an additional 10% met by shifting renewable electricity within the day using batteries, leaving about 10% to be met by peaking plants or seasonal storage.

Exhibit 1.12

## Energy storage solutions vary depending on storage size and discharge time performances

**Interday balancing**

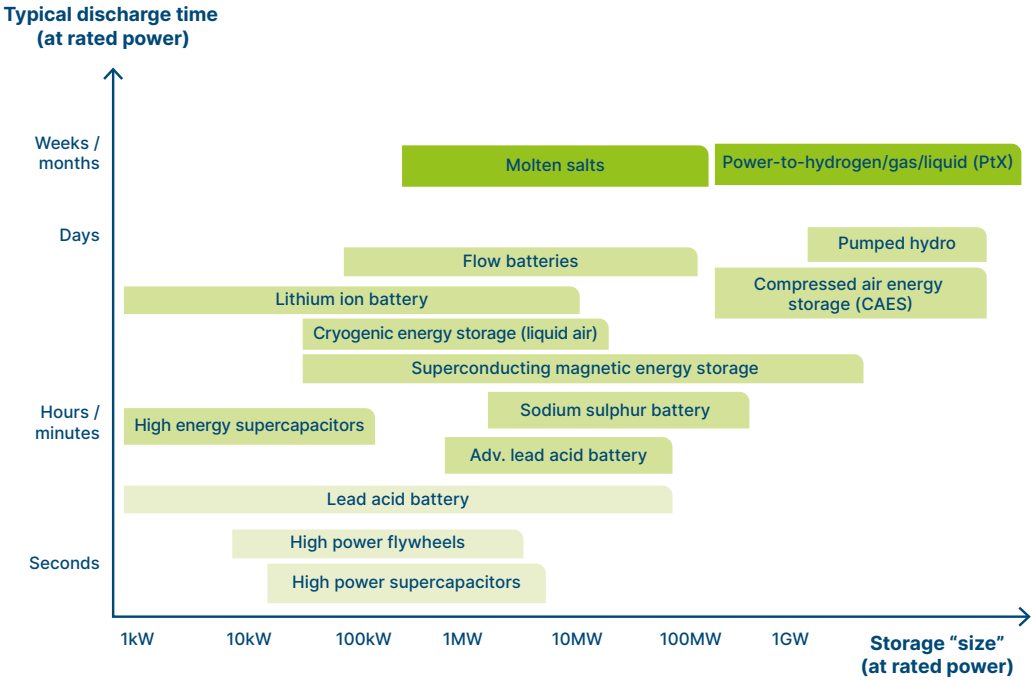
- Narrower range of technologies
- Complex and expensive challenge, with costs varying widely according to local conditions

**Daily / intraday balancing**

- Wide range of technologies
- Strong cost decrease (eg, lithium ion batteries) making zero- or low-carbon storage solutions competitive with fossil fuel peak generation

**Short-term reserves**

- Well-known cheap technologies




**SOURCE:** Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*

Exhibit 1.13

## Significant shares of both household and business electricity demand could be time shifted to help balance supply and demand

| | Seconds / minutes | Hourly and daily | Seasonal – month to month |
|---|---|---|---|
| **Household sector** | Appliances and industrial equipment shaving power demand while still operating, eg A/C systems, chill and freezer systems | Electric auto charging<br>Heating and cooling systems | Limited opportunities |
| **Business** | | Commercial EV charging<br>Commercial heating, chilling and freezing systems<br>Multiple industrial processes, including hydrogen electrolysis<br>Water pumps in agriculture and water supply | Multiple industrial processes<br>Hydrogen electrolysis<br>Aluminium smelters |

**SOURCE:** SYSTEMIQ for the Energy Transitions Commission (2020)

The implications for the total cost to provide zero-carbon electricity on demand will vary by region in light of local resource availability and variability patterns. Our updated estimates[16] suggest that [Exhibit 1.14]:

- Even in **regions where costs are higher** because of constraints on land availability or solar and wind resource, all-in costs[17] for systems which rely 90% on renewable sources will be no more than US$80 per MWh by the mid-2030s.
- In the **most favourable locations**, all-in system costs could be as low as US$30 per MWh, both because of low costs for wind and solar generation and because of more limited seasonal balancing needs in low-latitude countries.

These estimated 2035 costs are for systems with carbon intensities that are dramatically below today's typical levels (eg, about 30g per kWh), but some further costs would be entailed to reach an almost completely **zero-carbon power system** by applying CCS to any thermal plants providing flexible supply. At a CCS cost of US$70 to US$120 per tonne of $CO_2$, the average all-in costs of a fully decarbonised power system could be 8% to 14% more expensive than in Exhibit 1.14.[18] Some extremely small residual emissions would remain due to the imperfect efficiency of carbon capture processes (eg, with 5% to 10% losses implying a carbon intensity of less than 3g per kWh).

## Local cost of close-to-zero-carbon power will vary depending on climate patterns, natural resources and existing power flexibility infra

**Maximum all-in cost of power generation in a near-total-variable-renewable power system by 2035**
US$/MWh, breakdown by flexibility services

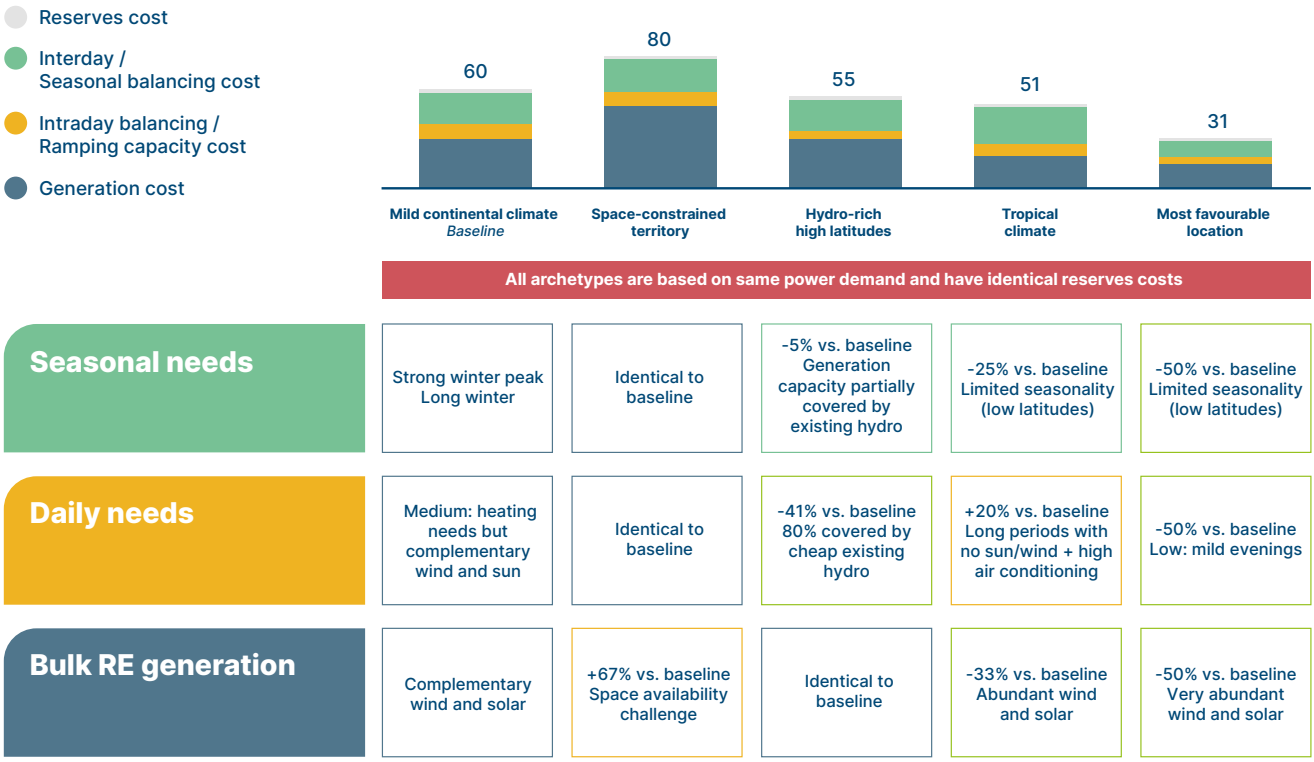



Exhibit 1.14

**SOURCE:** Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*

16. Assumptions: Power system delivering ~500TWh/year. In the baseline archetype:
    - Daily shifts represent 10% of total power demand, covered by batteries (66%) and CCGTs (34%).
    - Interday/seasonal shifts represent 10% of total power demand, entirely covered by CCGTs.
17. All-in costs cover the back-up, storage and flexibility resources required.
18. SYSTEMIQ analysis for the ETC (2020).

It is important to note that the cost calculations presented here describe a maximum theoretical cost based on a **conservative methodology**:

- Our simplified model takes into account only three flexibility technologies (batteries, gas turbines and hydro for the hydro-rich scenario only). Total costs would be even lower using a broader portfolio of flexibility options (eg, technology hybridisation allowing "round-the-clock" renewable power; low-cost, zero-carbon hydrogen for power storage).

- We don't take into account existing infrastructure, but estimate the cost of building a new power system from scratch. Using existing assets to provide peak power generation (eg, gas turbines or dispatchable hydro) would considerably decrease capital costs.

Due to technology learning curves and scale effects, these costs will continue to fall in subsequent decades and imply that, in the long term and on average across countries, decarbonisation of electricity production will impose minimal or nil ongoing cost on the economy. In favourable geographies, electricity could even become cheaper than it is today. Given these costs, all countries should aim for complete decarbonisation of electricity generation by around mid-century with massive investments in renewable power, in some cases supplemented by hydro, nuclear and biomass-based generation, as well as infrastructure scale-up to tackle the flexibility issue in a zero-carbon manner – for instance, via the use of CCS/U or hydrogen. Specific paths to decarbonisation, and in particular the pace at which existing coal capacity can be retired, will need to vary by country to reflect different starting points [see Chapter 3].

## 2. Decarbonising energy-consuming sectors: electrification, hydrogen, bioenergy and CCS/U

It is technically feasible to fully decarbonise energy-consuming sectors via a mix of already well-known technology routes.

**Direct electrification** will be the primary route to decarbonisation, since it is the cheapest and most energy-efficient option in most applications where it is technically feasible.

However, in some applications, it is not currently feasible; and in others, it is not cost effective. It is still technically feasible to decarbonise all sectors of the economy by combining direct electrification with three other technologies:

**Hydrogen** is an energy carrier whose energy density, storability and suitability for high-heat applications make it superior to electricity in some specific applications. Low- or zero-carbon hydrogen can be produced either through electrolysis of water using zero-carbon power ("green hydrogen") or from methane using either SMR or auto thermal reforming (ATR), in both cases combined with CCS[19,20] (so-called "blue hydrogen"). Hydrogen can in turn be used to produce hydrogen-based fuels (eg, ammonia, synfuels).

Aside from its potential use in making blue hydrogen, **CCS/U** can also be applied to multiple industrial processes, or to thermal power plants continuing to provide flexible power supply within primarily renewable power systems. Its cost-effective use will depend on the local availability of suitable and safe storage capacity.

**Biomass** can in principle meet a wide variety of applications, including industrial heat, chemical feedstock, flexible thermal power supply and transport fuels, but the total scale of its use across all sectors must reflect the limited potential supply of truly sustainable biomass.[21]

The costs of decarbonising sector by sector will be discussed in Chapter 2, and the portfolio of decarbonisation options in each of the harder-to-abate sectors is described in our *Mission Possible* report and the related sectoral appendices[22]. Key points by sector are that:

- **Already electrified sectors** benefit from the simplest decarbonisation route. Electricity, used directly, is already the sole or dominant form of final energy used in multiple applications, driving household appliances, lighting, cooling, much hot water heating, computing, machinery movement in manufacturing, rail and so on. Here the objective is simply to make sure that the electricity used is zero-carbon.

19. Autothermal reforming (ATR) combines the steam reforming reaction and fuel oxidation into a single unit, the exothermic oxidation providing the heat for the endothermic reforming process. ATR is popular for smaller scale hydrogen generation and affords faster start-up and response times than steam reforming.
20. It is also possible to drive hydrogen from coal, passing through an initial gasification process. This is currently the predominant production route in China.
21. See definition of 'sustainable biomass' in Glossary.
22. ETC (2018), *Mission Possible.*

- **Surface transport** is likely to become electric, in either a battery or hydrogen fuel cell electric form, well before 2050 and far faster than many projections suggest:

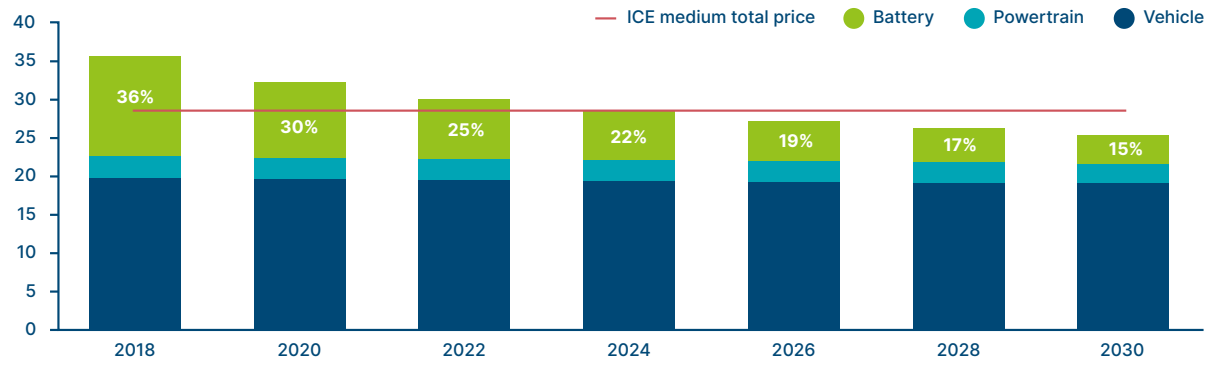
  - For **light-duty vehicles**, the inherent energy efficiency advantage of electric engines means that total lifecycle costs of owning and operating EVs are in many cases already below those for ICE vehicles; and by the mid-2020s it is likely that even the upfront capital costs of buying EVs will fall below ICE vehicles[23] [Exhibit 1.15]. As driving ranges expand and charging infrastructure is developed, EV auto and van penetration is likely to rise dramatically.

  - For **medium- and heavy-duty vehicles**, decarbonisation will likely entail either battery-based electrification or use of hydrogen in FCEVs, with the former dominating for shorter-distance intra-city applications and the latter dominating above some distance. Analysis by McKinsey suggests that for most distances and applications, the total cost of ownership will be lower for electric trucks and buses than for ICE vehicles by 2030, even if the upfront costs of purchase will still in some cases be higher[24] [Exhibit 1.16]. The trade-off between heavy-duty BEVs and FCEVs will also be a function of use patterns (eg, preferences in recharging time, optimisation of truck utilisation).

Exhibit 1.15

## By the middle of the 2020s, the average BEV in the US and Europe will be cheaper than a comparable ICE

**BEV and ICE pre-tax prices in the US and the share of battery costs in the vehicle price**
2018-30 (thousand 2018$ and %), medium size car segment

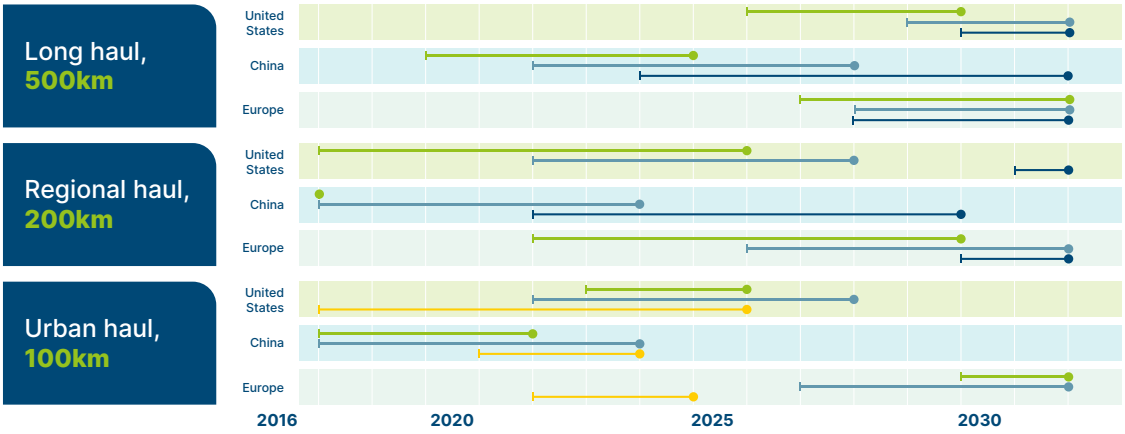



**SOURCE:** BloombergNEF (2019), *When Will EVs Be Cheaper Than Conventional Vehicles?*

Exhibit 1.16

## McKinsey estimates that long-haul BEV trucks will become cost-competitive in Europe in the 2020s and in the US in the 2030s

**Timing of battery electric vehicle total cost of ownership parity with diesel vehicle**
Year achieved range




**SOURCE:** McKinsey Center for Future Mobility (2017), *What's sparking electric-vehicle adoption in the truck industry?*

23. BloombergNEF (2019), *When Will EVs Be Cheaper Than Conventional Vehicles?*
24. McKinsey Center for Future Mobility (2017), *What's sparking electric-vehicle adoption in the truck industry?*

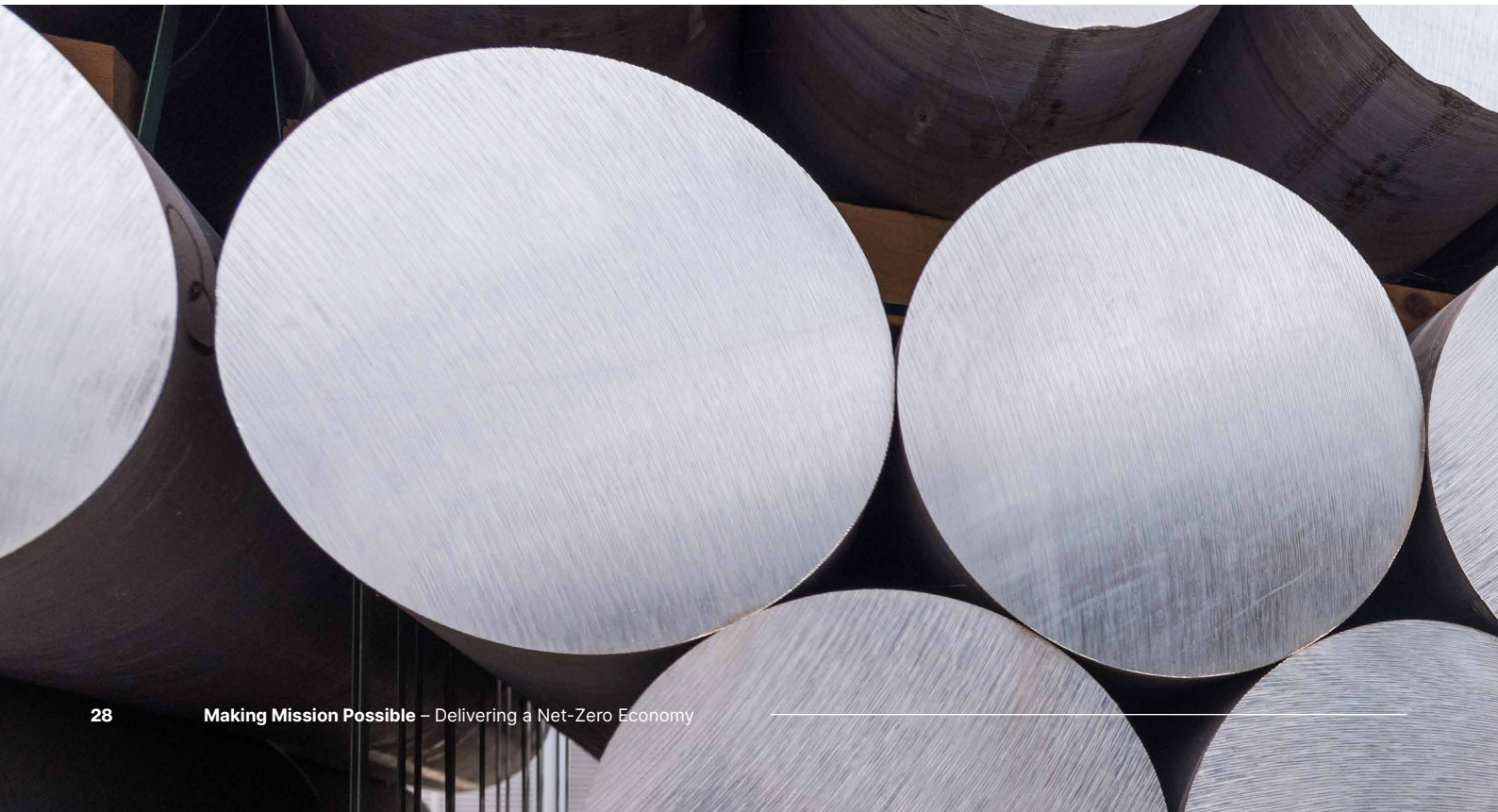
- In the **shipping and aviation sectors**, battery-based electrification and hydrogen will also play a significant role in short-distance journeys. But the limited energy density of batteries will likely make battery-powered shipping or aviation unfeasible for long-distance journeys for several decades at least; and the low volumetric density of hydrogen may also limit its role over long distances, though it is possible that the fundamental redesign of ships or aircraft might make it a relevant technology even at intercontinental distances. Feasible routes to long-distance decarbonisation will instead probably involve the use of liquid fuels that can be burnt within largely unchanged engines: either from low-carbon, sustainable bio-feedstocks (alcohols, biofuels) or from a power-to-liquid production route (ammonia in the case of shipping and synfuels in the case of aviation).

- In each of the most important **heavy industry sectors** – steel, cement, chemicals and aluminium – there are feasible ways to remove both energy-based emissions and emissions resulting from the chemical processes involved. These will entail a mix of direct electrification, use of hydrogen, use of biomass in a few regions with abundant supply of sustainable biomass, and CCS/U in applications that guarantee long-term storage. The most cost-competitive option is likely to vary by region based on local resource availability and prices, as well as on the brownfield or greenfield nature of each site [Exhibit 1.17].

- **Residential and commercial building heating** accounts for a significant proportion of total energy demand in many mid- and high-latitude countries. Some of this is already electrified, but much of it is currently delivered via gas heating or even via coal-based distributed heating systems in countries such as China. Feasible routes to decarbonisation involve the use of electric heat pumps or resistive electric heating, or the combustion of hydrogen or bio-methane, using existing gas grids and district heating systems. The optimal solution will vary by region depending on resource availability and existing infrastructure. Better insulation of buildings is particularly important to reduce peak demand and make this fuel switch – in particular, electricity-based options – more manageable from an energy system perspective.

- The ETC has not so far analysed in detail the challenge of **decarbonising food production** (whether in the form of land-based agriculture, aquaculture or fishing).[25] This is because our focus has been on how to eliminate emissions arising from fossil fuel use, and the agricultural sector accounts for only 0.7 Gt of such energy-related emissions – all of which could be eliminated by electrification (or use of e-fuels) and decarbonisation of electricity supply. In total however, agricultural and land-use emissions amount to around 11 Gt $CO_2$, with 0.4 Gt in fertiliser production; about 5 Gt resulting from agricultural processes which produce nitrous oxide ($N_2O$) or methane emissions; and another 5 Gt from forestry, land use and the land use change which results from the expansion of food, and in particular meat, production. While some supply-side technologies could help to reduce these emissions – in particular, changes in agricultural practices – it is likely that reduction and elimination will require a significant "demand-side response" in the form of major changes in diet. Box A sets out key facts on agricultural emissions, options for decarbonisation, current ETC assumptions and the follow-up analysis currently undertaken by the ETC.

25. The EAT-Lancet Commission (2019), *Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems.*



# In each industrial sector, there are technologies which could achieve partial or complete decarbonisation

-X% Maximum potential emission reduction

Further development needed before large-scale applications

| | | Routes to supply-side decarbonisation | | | | |
|---|---|---|---|---|---|---|
| | | **Direct electrification** 100% reduction if electricity is zero-carbon | **Hydrogen** | **Biomass / bioenergy** | **Carbon capture** | **Switch of feedstock** |
| **Cement** | Heat input emissions | Kiln electrification -100% | | Use of biomass for heat (transition) -50% | Carbon capture on production and process emissions -90% | Belite clinker -10%; Low-cement-intensive concrete (eg, Pozzolan) -70% |
| | Chemical process emissions | | | | | |
| **Steel** | Primary | Iron electrolysis -100% | Hydrogen-based DRI -100% | Use of charcoal in BF/BOF -90% | Carbon capture on production emissions -90% | |
| | Secondary | Scrap-based EAF -100% | | | | |
| **Plastics** | Production | Furnace electrifi-cation -100%; Electro-chemical process -100% | | For heat generation -100% | Carbon capture on production -90% | |
| | End-of-life | | | | | Bio / synthetic feedstock -100%; Use of recycled plastics -50% |
| **Aluminium** | | Zero-carbon power for existing processes (electrolysis using carbon anode) up to 75%; Electrolysis using non carbon inert anodes -100% | | | | Use of recycled aluminum -95% |

**NOTE:** 100% emission reduction for the biomass or bioenergy levers is a theoretical potential. Today, bio-based decarbonization allows for -50-70% emission reduction.

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020)

Exhibit 1.17

# Agriculture's current emissions and supply-side decarbonisation options

| | | $CO_2e$ emissions 2017, Gt | | Supply-side decarbonisation options |
|---|---|---|---|---|
| Energy inputs | Direct | 0.4 | Mainly diesel and gasoline | Electrification of farm machinery or gas based heat used in greenhouses |
| | Indirect | 0.3 | Electricity in multiple uses | Decarbonisation of electricity |
| Fertiliser production | | 0.4 | Production of $H_2$ via SMP, plus energy use in other production stages | Electrolysis-based $H_2$ production or SMR + CCS |
| $CH_4$ emissions[1] | | 2.2 | Livestock related | Some potential for animal diet change but only partial reduction |
| | | 0.6 | Manure related | Potential for improved practices but only partial reduction possible |
| | | 1.1 | Rice production related | |
| $N_2O$ emissions[1] | | 0.9 | Soil fertilisation | Significant potential for application efficiency improvement – reducing the N-fertiliser use per hectare. Potential for new agricultural practices (e.g. fertiliser consumption reduction). |
| | | 0.5 | Ruminant wastes on pastures | |
| Land use change[1] | | 4.9 | From deforestation to support crop and pasture land expansion – primarily meat related | Cultured meats and potentially synthetic carbohydrates Decreased land use by achieving higher yields per ha. |

## Diet change and land use challenges

Out of 11 Gt per annum of agriculture-related GHG emissions, a large proportion are directly or indirectly linked to red meat or dairy production, including in particular 2.2 Gt of $CO_2e$ methane emissions produced by enteric fermentation, and the 4.9 Gt resulting from deforestation which to a significant extent reflects expansion of pastureland or of cropland primarily providing feed for livestock production. On current trends total crop and pasture land could grow from 3270 million hectares (Mh) today to 3670 Mh by 2050, leading to decline in forest cover, continued further land use change emissions and loss of biodiversity[2]. Technical developments in animal diet and breeding could somewhat reduce this impact, but major reductions will almost certainly require a significant reduction in red meat consumption resulting from either:

- A major shift to plant or culture-based meats, whose costs may fall below that of natural meats. Synthetically production of carbohydrates from direct air captured $CO_2$ and green hydrogen may at some stage also become economic.
- A major change of diet, significantly reducing red meat consumption in developed economies and limiting the growth in developing economies. Such a shift would also deliver significant health benefits, as outlined in the recent "EAT Lancet" report[3] A scenario developed by the Food and Land Use Coalition (FOLU) illustrates that if the EAT Lancet diet were adopted globally, crop and pasture land could shrink to 2090 Mh, releasing 1180 Mh of land which could be devoted to either increased forest cover and biodiversity or if needed to bioenergy production.

## Agriculture, bioenergy and offsets – trade-offs in land use, and residual emissions

Land could be used to produce bioenergy, which needs to be part of the 2050 energy mix. But it is unclear how much bioenergy can be sustainably sourced without creating harmful competition for food production, loss of biodiversity, or land use changes which result in increased emissions. And if land can be freed up from agriculture, its most carbon efficient use may be as restored forest cover. The potential for such reforestation, turning land use change from net carbon source to a net sink, raises the issue of whether decarbonisation strategies can include a role for "offsets" purchased from reforestation / avoided deforestation or other land use change related initiatives. Section III sets out the ETC's current bioenergy use scenario and Section IV our current position on the use of offsets, but we will explore these issues in more detail within the Bio-economy deep-dive strand of our 2020 work programme.

Whatever the conclusion, agriculture will likely be one sector where there will still be some residual emissions in 2050. While diet changes could significantly reduce red meat consumption, they are unlikely to eliminate it; and while changed agricultural practice could significantly reduce some $CH_4$ and $N_2O$ emissions, total elimination is unlikely. Our current assumption is that residual emissions from food production of around 1-2 Gt per annum will need to be offset by negative land use change emissions beyond 2050. The implications of this for the debate about offsets are considered in Section IV.

Box A

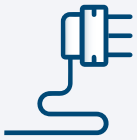
[1] World Resources Report (2019), *Creating a Sustainable Food Future*
[2] The Food and Land Use Coalition (2019), *Growing Better*
[3] *The EAT-Lancet Commission (2019), Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems*

## III. The final and primary energy mix in 2050 – from fossil fuels dominance to a world of electrons

The **optimal mix** of these different technologies will reflect the evolution of relative costs over time, and in particular the costs of direct electricity and hydrogen electrolysis relative to options based on bio-feedstocks or on fossil fuels combined with CCS/U. The costs of the electricity-based routes are highly likely to fall over time, both in absolute terms and relative to the bio and fossil fuels routes. A recent BloombergNEF report,[26] for instance, suggests that the capital cost of electrolysis equipment is about to plummet. But the costs of some specific combustion-based technologies for hydrogen production (eg, pyrolysis) could also fall rapidly. Bioenergy transformation and CCS/U costs might also be reduced significantly if those technologies were developed at large scale, though with the potential for reduction somehow limited by resource scarcity constraints in the use of bioenergy and the high infrastructure cost component of CCS/U.

As a result, it is not possible to forecast precisely what the global energy mix will be in a zero-carbon-emissions economy. But all feasible scenarios for a zero-carbon-emissions economy involve a massively expanded role for direct electricity use and a very significantly expanded role for hydrogen (with an increasing proportion produced from electrolysis).

The **ETC's illustrative scenario** for the projection of the final energy mix in a decarbonised global economy is shown in Exhibit 1.18 and Exhibit 1.19. Total final energy demand would be in the range of 355 to 495 EJ per annum, depending on how effectively the world grasped the theoretically available energy productivity improvement discussed in Section I. But in either case, there would be a dramatically changed mix of final energy sources, with:



The **direct use of electricity** accounting for about ~65% to 70% of final energy demand, versus 19% today;

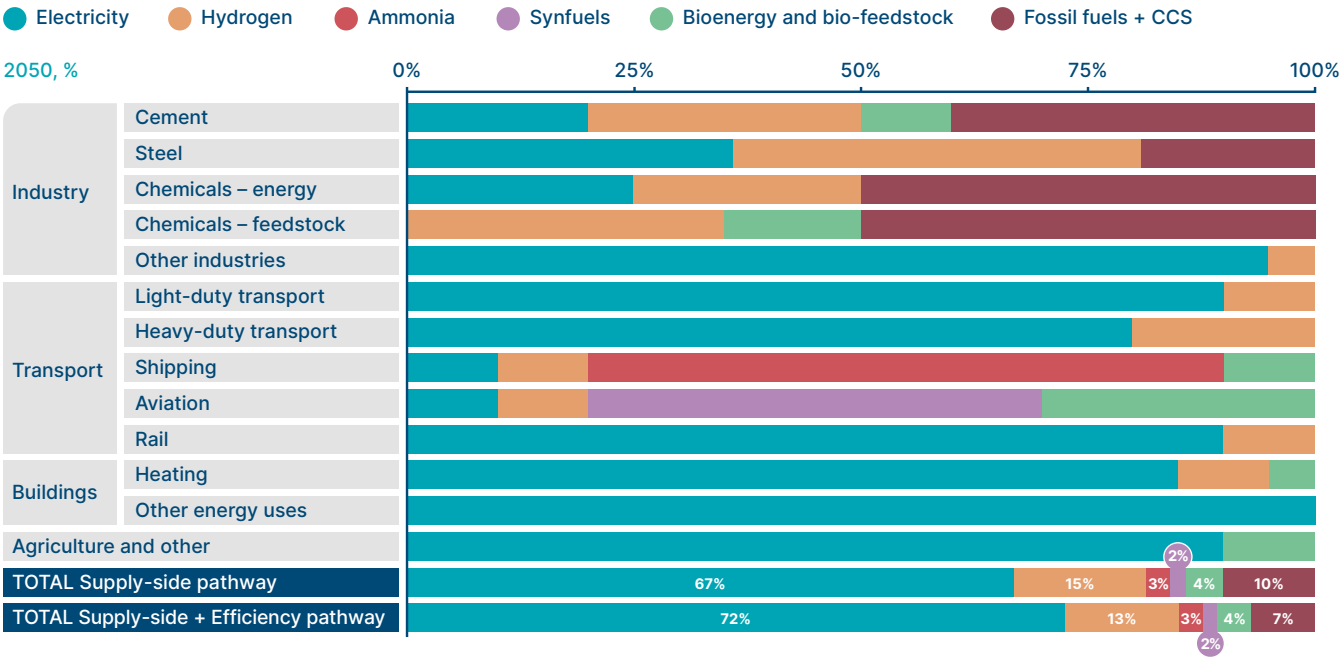

The use of **hydrogen**, or fuels derived from hydrogen, accounting for another 15% to 20% of final energy demand; and

The use of alternative **liquid or solid hydrocarbons** – whether derived from fossil fuels or from bio-feedstocks – accounting for just 10% to 15% of total final energy.

26. BloombergNEF (2019), *Hydrogen: The Economics of Production from Renewables.*

Exhibit 1.18

# Illustrative final energy mix in a zero-carbon economy by sector



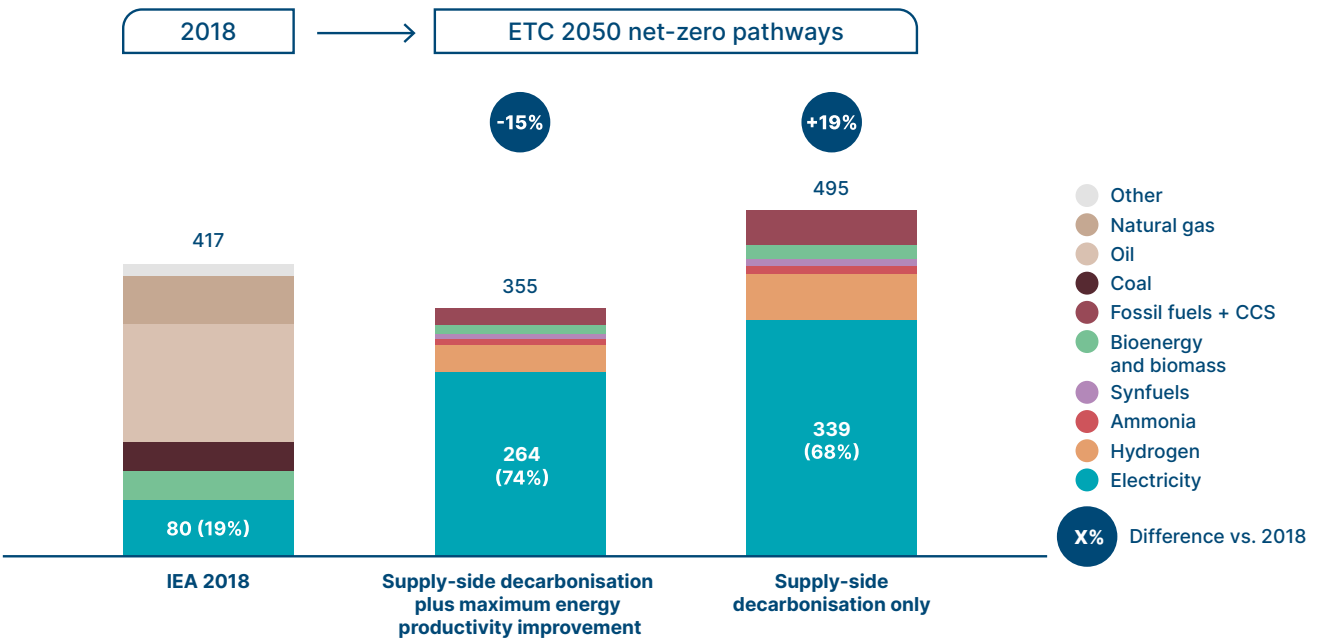

**NOTE:** Steel energy mix represents the supply-side pathway only. For chemical feedstock, inputs are not used as energy but in order to provide the molecules required to build the chemicals. In our model, for comparison we express it in EJ equivalent.

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020)

Exhibit 1.19

# Final energy mix in a zero-carbon economy: electricity will become the dominant energy vector

Final energy demand
EJ/year




**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020); IEA (2019), *World Energy Outlook*

The implications of this for **required electricity generation** depend on how much of the hydrogen is produced in a "green" (electrolysis-based) or "blue" (methane-based) fashion. If the split were 60/40, electricity demand would need to grow from today's 27,000 terawatt-hours (TWh) to somewhere between 90,000 and 115,000 TWh by mid-century [Exhibit 1.20], with 80% to 85% used in the form of direct electricity and the rest used to produce hydrogen or hydrogen-derived fuels such as ammonia or synfuels.

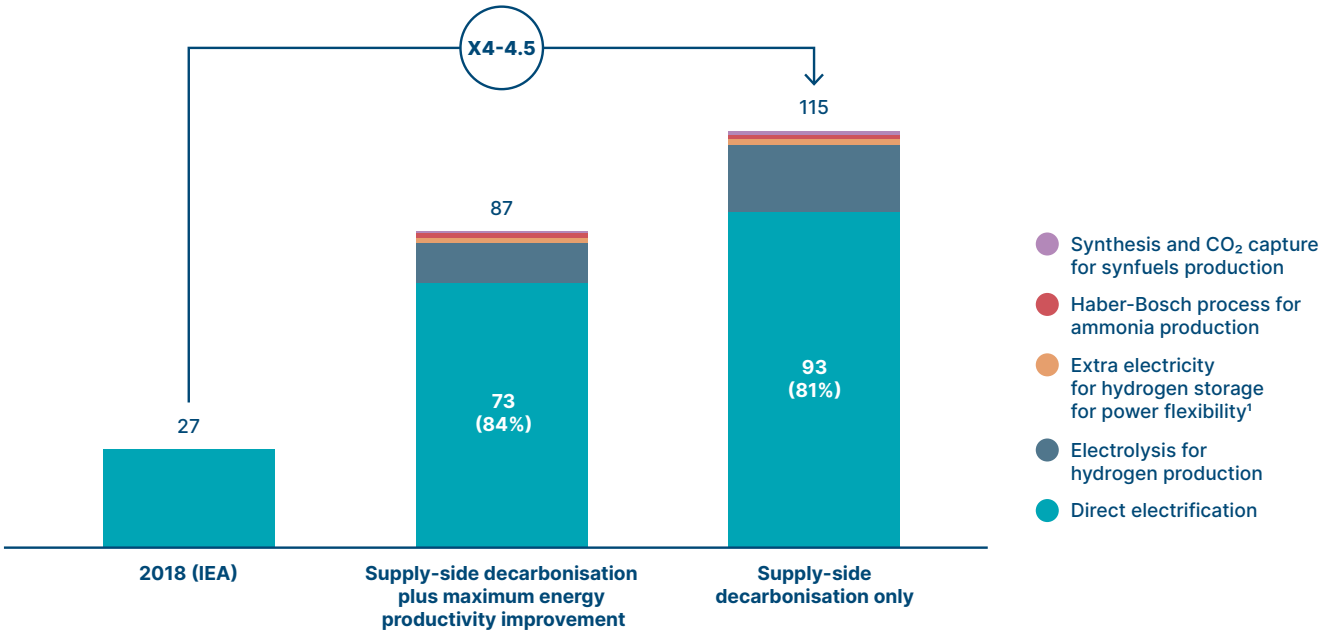
Total annual **hydrogen production** would increase from about 60 million tonnes (Mt) today to 500 to 800 Mt by mid-century, to meet the demand for hydrogen, ammonia or synfuels in end-use applications. But total hydrogen production and electricity production would increase still further if hydrogen production and storage were used to provide seasonal flexibility in the power sector. For example, an additional 80 to 110 Mt of hydrogen per year would be required to store and shift 2% of the total global power generation [Exhibit 1.21].

The only feasible zero-emissions future is therefore one in which the role of electricity in the energy sector is massively increased. Through this electrification, together with other forms of energy productivity improvement, it will be possible to deliver greatly increased prosperity across the world, while keeping final energy demand largely flat. In most applications, an electrified economy is inherently more energy efficient.

Exhibit 1.20

## Gross electricity generation will need to reach ~90,000 to ~115,000 TWh/year by 2050 in a zero-carbon economy

**Total electricity generated by 2050 in the ETC indicative pathways**
000 TWh/year




[1] Extra electricity for hydrogen storage for power flexibility only covers the electricity loss due to the transformation into hydrogen and back to electricity.

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission analysis (2020), IEA (2019), *World Energy Outlook*

## Hydrogen demand could reach 800 Mt per year by 2050, with an additional 100 Mt potentially required to balance the power system

$H_2$ for final consumption · $H_2$ for green ammonia production · $H_2$ for synfuels production · $H_2$ for power storage and flexibility

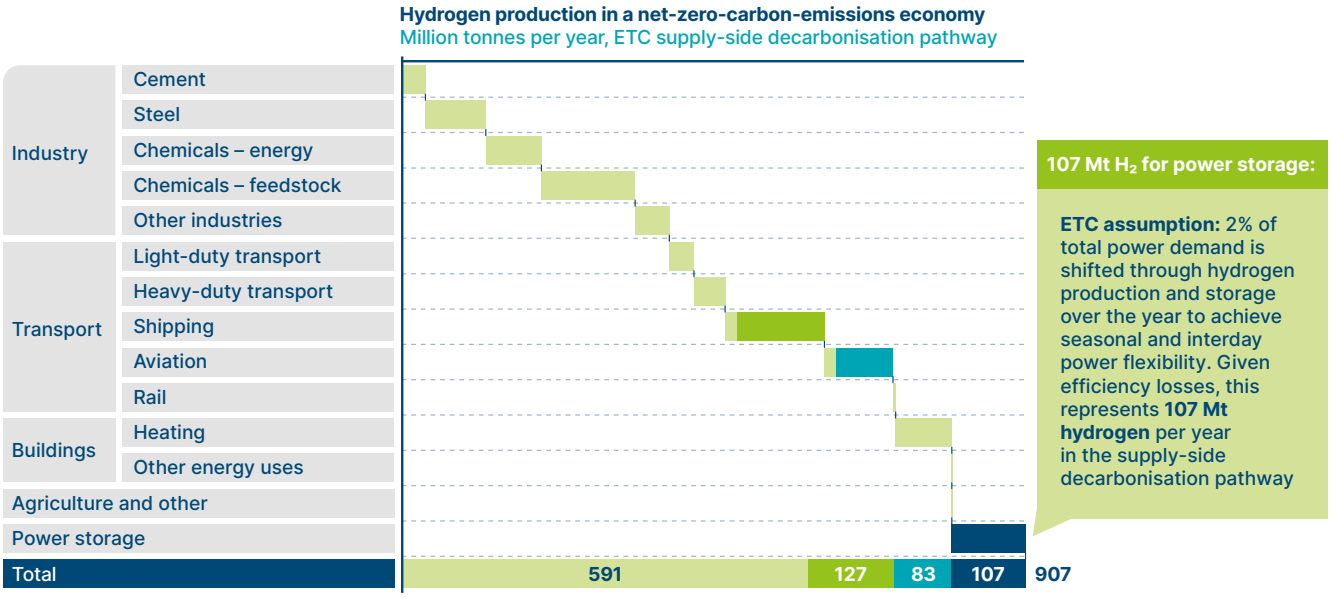



Exhibit 1.21

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission analysis (2020)

At the **primary energy** level, the improvement in energy efficiency is greater still, since producing electricity from solar, wind, hydro or nuclear sources eliminates the energy losses which inevitably result from fossil fuel extraction and thermal generation. The resulting total primary energy demand is shown in Exhibit 1.22. In the pathway where the world exploits all potential energy productivity improvements, total primary energy demand could fall by 32% (from 599 EJ in 2018 to 436 EJ in 2050); and the reduction would be 4% even if these opportunities were not grasped. Fossil fuels would account for only 20% to 25% of total primary energy supply by mid-century, versus 80% today.

## Primary energy mix in a zero-carbon economy: the shift to zero-carbon electricity generation will drive down primary energy demand

Primary energy demand
EJ/year

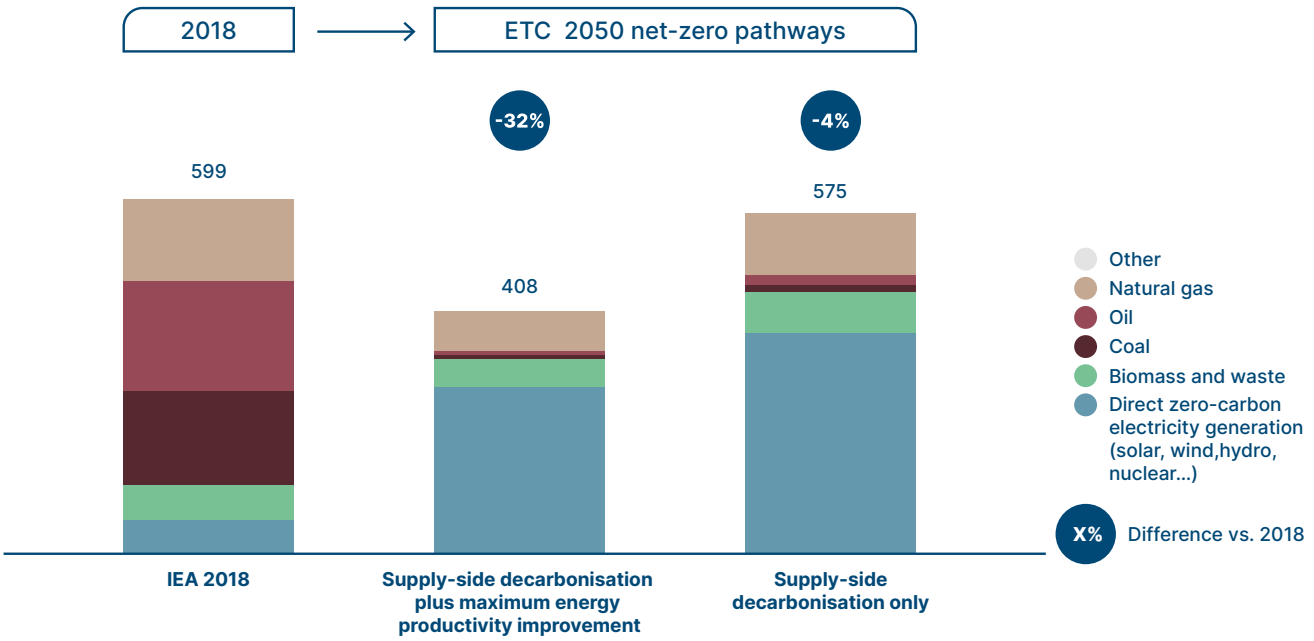



Exhibit 1.22

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020); IEA (2019), *World Energy Outlook*

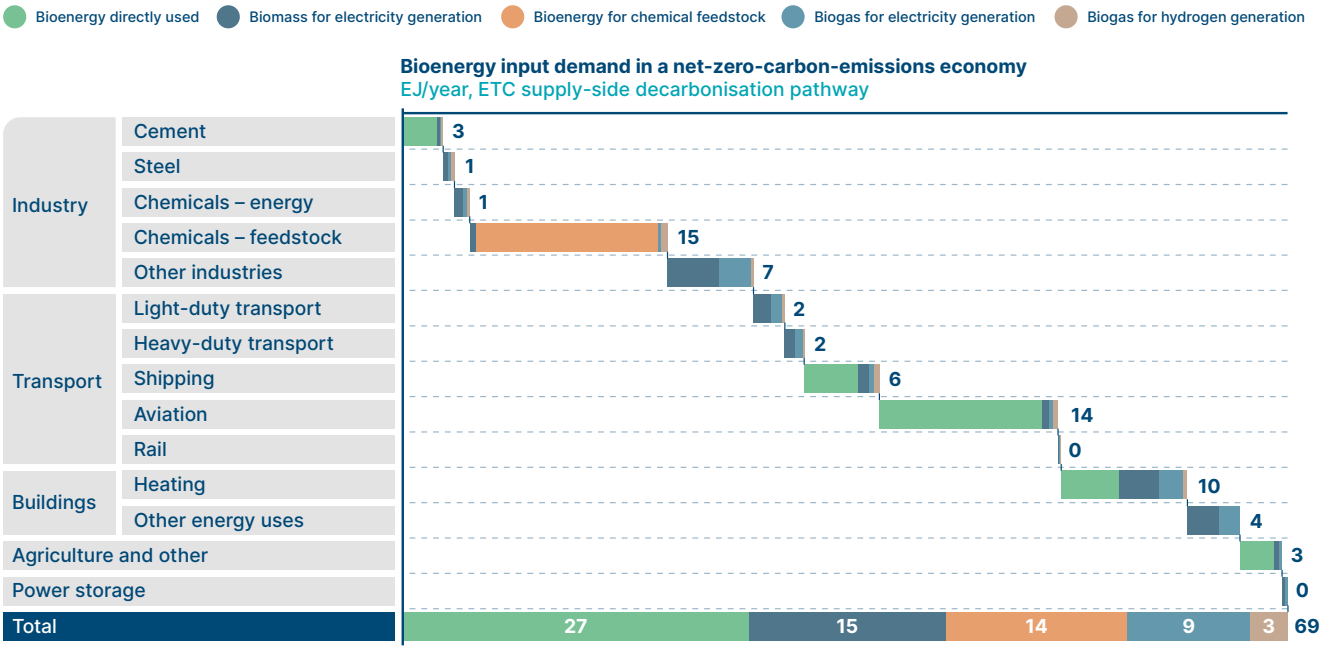
Alongside the dominant role of zero-carbon electricity and hydrogen, however, it is also important to develop two other technologies on a greatly increased scale:

- Around 6-9.5 Gt of $CO_2$ per year of **CCS/U** will be needed to make the remaining fossil fuel use near zero-carbon, in particular in heavy industry (~40% of total), hydrogen production from methane (~30% or total) and peak power generation (~20% of total).

- The scenarios presented here suggest that 46 to 69 EJ of energy would need to be derived from **bio-feedstocks**, all of which must be delivered in a low-carbon footprint, sustainable fashion [Exhibit 1.23].

Exhibit 1.23

## In a zero-carbon economy with limited progress in energy productivity, annual bioenergy needs could reach up to 69 EJ




**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission analysis (2020)

As a result, demand for fossil fuels will decline dramatically, but with big differences for the three major types of fossil fuels [Exhibit 1.24]:

- **Thermal coal use** will be almost eliminated, though there would still be a remaining role for coking coal in steel production (combined with CCS/U), and China may continue to use coal as chemical feedstock.

- **Oil demand** could be cut from 100 million barrels (MMbbl) per day in 2019 to less than 10 MMbbl per day, and potentially lower still if all opportunities for energy productivity improvement were seized. Its primary remaining role in this scenario would be as a feedstock for the plastics and chemicals production process.

- In the "supply-side only" decarbonisation pathway, **gas demand** would decline by ~30%, but could fall by 57% if all energy productivity improvement opportunities were grasped. The most important determinant of gas demand would be the extent to which methane was used to make low-carbon "blue hydrogen" via the application of CCS to SMR. In both our scenarios, we assume that 40% of the hydrogen demand (~500-800 million tonnes per year)[27] is produced via SMR plus CCS, with the other 60% produced via electrolysis. If this assumption is correct, hydrogen production could account for ~50% of total 2050 gas demand. The ETC's ongoing work on hydrogen aims to develop a more granular vision of the respective roles of gas-based and electricity-based production routes over time.

## Implications of net-zero decarbonisation for fossil fuel demand

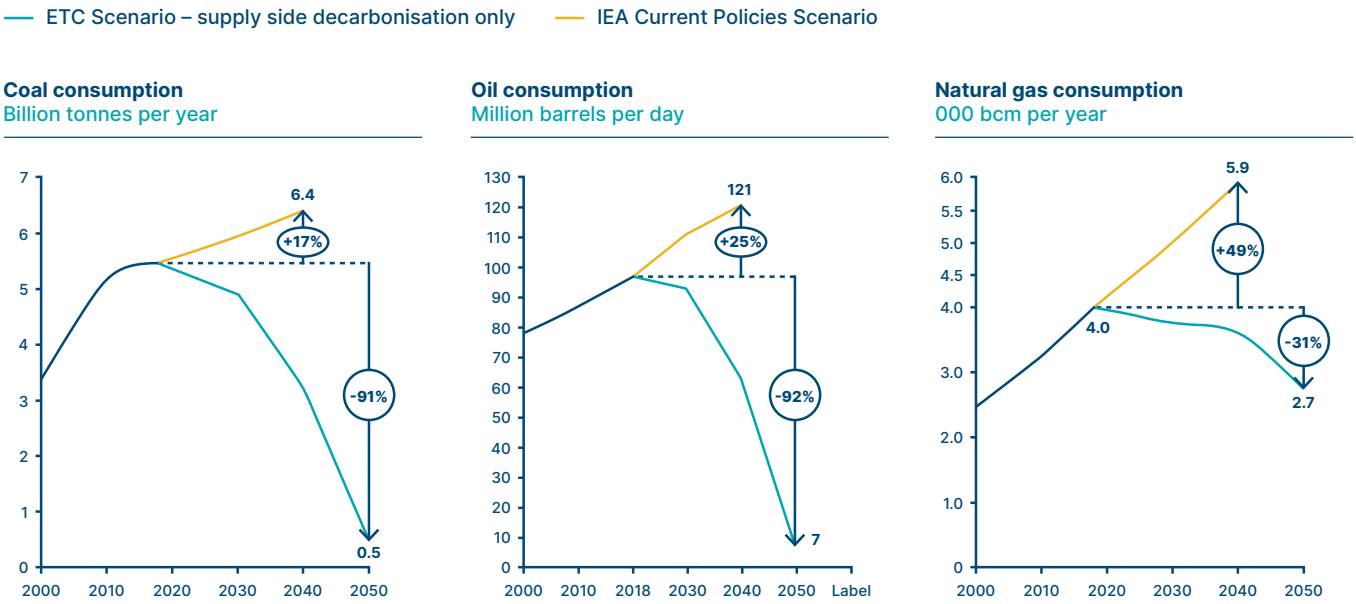



Exhibit 1.24

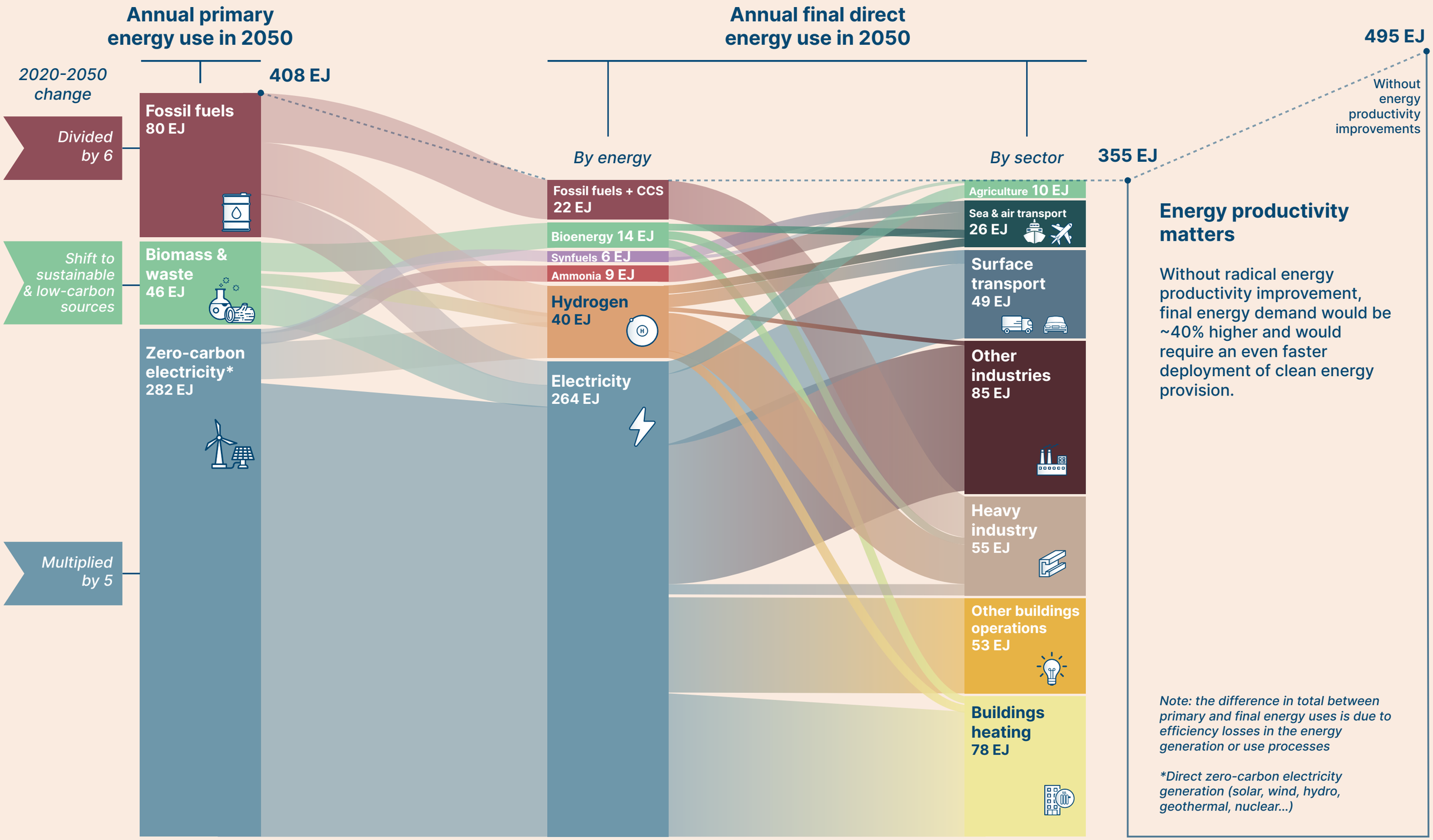
**NOTE:** ETC scenarios values for 2030 and 2040 are based on the Central Scenario from the Copenhagen Economics paper (reference below)

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020), IEA (2019), *World Energy Outlook*, Copenhagen Economics (2017), *The future of fossil fuels: How to steer fossil fuel use in a transition to a low-carbon energy system*

27. This doesn't include hydrogen produced for power storage (80-100 Mt per year in the ETC pathways), which is entirely produced via electrolysis.

Energy Transitions Commission

# A complete transformation of our energy system is required to support a zero-emissions economy




## Energy productivity matters

Without radical energy productivity improvement, final energy demand would be ~40% higher and would require an even faster deployment of clean energy provision.

*Note: the difference in total between primary and final energy uses is due to efficiency losses in the energy generation or use processes*

**Direct zero-carbon electricity generation (solar, wind, hydro, geothermal, nuclear...)*

## IV. Resource adequacy for zero-carbon electricity, hydrogen, sustainable bioenergy and CCS/U

The crucial next question is therefore whether it is feasible by mid-century to deliver annually 90,000 to 115,000 TWh of zero-carbon electricity; 580 to 910 Mt of hydrogen; 6 to 9.5 Gt of CCS/U capacity; and 46 to 69 EJ of sustainable bio-feedstock. There is no doubt that the world has the natural resources to deliver the required increase in green electricity and green hydrogen production. Adequate carbon storage capacity is likely also available globally, though with major differences by region. The greatest uncertainty relates to the scale of truly sustainable, low-carbon bio-resources.

- **Global solar resources** massively exceed those required to build a zero-carbon economy. Even if ~100,000 TWh of electricity were produced exclusively with solar PV annually, only about 1% to 1.5% of the land area of the earth would need to be devoted to solar farms, and less than 0.3% of the global surface area if it became possible to place solar panels above parts of the oceans.[28] Estimates of onshore and offshore wind power also illustrate massive potential: the IEA[29] estimates that offshore wind has the technical potential to deliver 430,000 TWh – about four times even our higher estimate of future demand. Important differences in national and regional capacity must be noted, however; these are discussed in Chapter 3.

- The **potential to store $CO_2$** permanently in underground reservoirs depends on local geography, and in particular on whether countries or regions have a significant resource of depleted oil and gas fields. Detailed analysis of available resource in China, Europe and the US suggests that there is easily enough capacity to meet the CCS demands implied by our illustrative scenario. However, in other countries, such as India, the available resource is not precisely known and it is likely that resource constraints will limit the use of CCS in some regions. If so, other routes to decarbonisation will need to play a greater role. Concerns related to safety and social acceptability of carbon storage also raise uncertainties about the future adoption of this technology.

- **Zero- or low-carbon hydrogen** can currently be produced via one of two main technologies: electrolysis using zero-carbon power or SMR/ATR combined with CCS/U. In addition, other technologies may become feasible – in particular, thermolysis using heat input (potentially from nuclear plants) or pyrolysis of a fossil fuel input producing solid carbon. The existence of several production routes will make it easier to achieve growth in production, with different technologies prevailing across different regions initially; but the expected rapid reduction in the cost of electrolysis and the possible development of international trade of hydrogen may make the electricity-based route dominant in the longer term.

- For **bioenergy, bio-feedstocks and bio-materials**, there are two crucial issues:

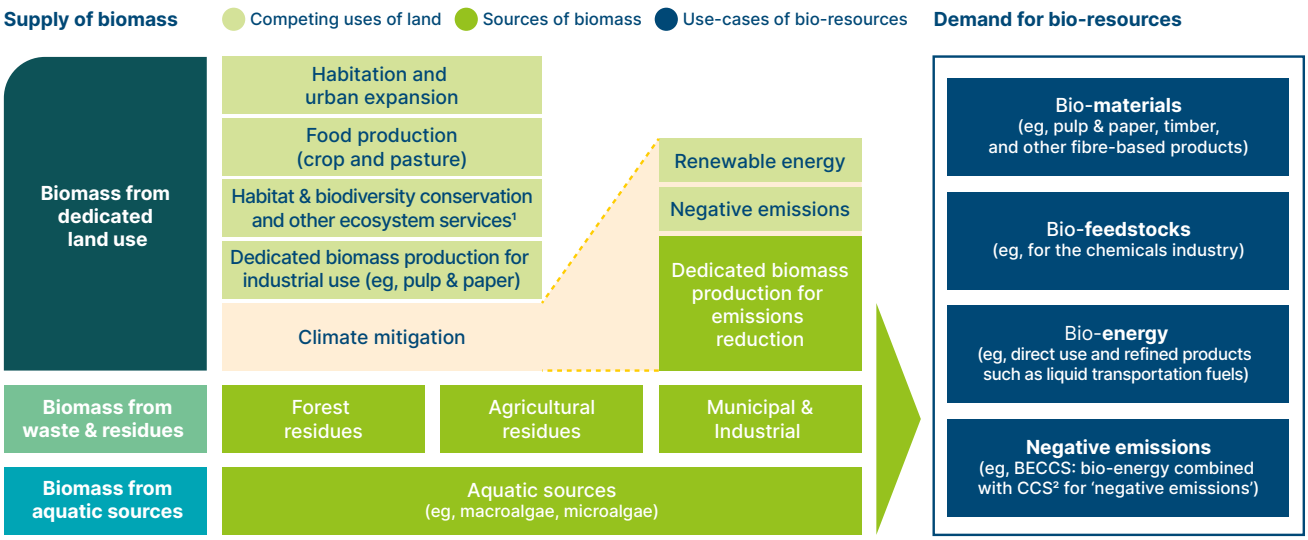
    - How much biomass we can rely upon being available for energy and industrial use without adverse consequences for food supply, land-use change (eg, deforestation), biodiversity and carbon sequestration in nature. Estimates for total global biomass potential vary substantially, driven by differing emphases on sustainability. The IEA Energy Technology Perspectives 2017 scenarios[30] assume that between 90 EJ and 140 EJ of primary biomass could be used for energy and feedstock by mid-century; but research from the World Resources Institute suggests a sustainable limit of 50 EJ or below, and argues that using land for bioenergy is inherently carbon inefficient.

    - How to ensure that biomass use produces significant lifecycle emissions reductions, accounting for the different timing and speeds of emission increases from biomass harvesting and use and $CO_2$ absorption from biomass growth.

We are addressing these questions in our 2020 analytical deep dive on bioenergy: Box B sets out analysis to be covered. Preliminary conclusions suggest sustainable sources may be at the lower end of the 46 to 69 EJ assumed in our current scenarios[31]. If so, this will increase the required reliance on the electricity, hydrogen or CCS routes, and make it essential to prioritise the use of limited supply sustainable biomass in those applications where alternatives are least available.

28. Analysis from ETC (2018), *Mission Possible.*
29. IEA (2019), *World Energy Outlook*
30. IEA (2017), *Energy Technology Perspectives*
31. Numbers are currently being stress-tested based on initial insights from our 2020 workstream on the bio-economy and are likely to evolve.

## Use-cases of bio-resources must be prioritised to balance high demand with constrained supply of sustainable, low-emissions biomass




### The challenge:

**Supply of sustainable, low-emissions biomass is constrained** by competing uses of land and sustainability considerations.

**The demand is high for biomass** in a net-zero GHG emissions economy – climate mitigation plans rely heavily on bio-resources.

**Supply/demand mismatch risks an overdraw** of bio-resources, jeopardising a successful energy transition.

### Determining an optimised and sustainable role for bio-resources:

**Which kind of resources – bio- or non-bio – are best-suited** to meet energy and industrial demands depends on the use case.

**For many demands, electricity or hydrogen can offer alternative** routes to GHG emissions reductions that are more carbon efficient than biomass.

**However, there remain use-cases where bio-resources are still needed** as complete decarbonisation via electricity or hydrogen is unrealistic.

**Remaining use-cases of bio-resources must be prioritised** to balance high demand with constrained supply.

**Key considerations for evaluating use-cases** include feasibility of non-bio alternatives, resource efficiency, costs, and emissions abatement.

Box B

[1] Includes ecosystem services such as nutrient cycling, maintaining soil quality, water regulation, limiting erosion, water / air purification, recreation, etc.

[2] BECCS: bio-energy carbon capture & storage

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission

As well as assessing these fundamental issues of zero-carbon energy resource, it is important to assess whether the growth of a zero-carbon economy might be constrained by any other resource limitations (eg, minerals for batteries), or might itself have harmful environmental impacts. We will set out detailed analysis of this issue within our reports on the power system and the hydrogen economy to be published later this year. But analysis so far suggests that:

- There are enough supplies of **lithium and other key minerals** to support the battery capacity required in a deeply electrified world, but it is vital to ensure maximum recycling and reuse of batteries and their components.
- The availability of the 17 elements collectively known as **"rare earths"** is unlikely to be a serious impediment to wider electrification, but the adverse environmental impacts of rare earth mining and refining must be dramatically reduced via best practice processes and tight regulation.
- Constraints on **water supply** will not be a major impediment to the deployment of solar panels (which may need washing) or the production of hydrogen from electrolysis. Indeed, on a global scale, the shift from a fossil fuel-based energy system to one dominated by renewable energy will significantly reduce the demand for water, given the large quantities of water used in oil and gas production (particularly fracking) and in thermal power generation. In some specific locations, however, water supply constraints could be important.

The precise mix of routes by which the world economy is decarbonised will reflect the evolution of relative costs, specific regional resource endowments and better understanding of bio-feedstock sustainability constraints, as well as local and regional political priorities and strategies. But overall, there is no doubt that the world has sufficient natural resources to transition to a zero-carbon economy. However, achieving that feasible zero-emissions economy will require a massive increase in the pace of investment and poses complex issues about appropriate transition paths. Progress will not happen without strong policy support.

## V. Massive investment, transition challenges and the role of offsets

Building a zero-carbon economy by mid-century will require a dramatic acceleration in the pace of investment:

- The pace of investment in **renewable power** will need to dramatically increase. On average, over the next 30 years, the world will need to build five to six times as much wind and solar power per year as in 2019.
- **Hydrogen** production will need to scale up from a 60 Mt annual capacity of carbon-intensive hydrogen production today to between 580 and 900 Mt annual capacity of low- or zero-carbon hydrogen by mid-century. If 60% of this derives from electrolysis, total electrolyser capacity will need to be between 1,700 and 5,800 gigawatts (GW) depending on the load factor[32], versus less than 25 GW today.
- To be able to **capture and store** 6 to 9.5 Gt of $CO_2$ per year by 2050, the world must build about 20 Mt of capacity every month for the next 30 years, or 240 Mt per year. By contrast, today only 33 Mt carbon is captured annually in CCS/U projects, mainly in North America.
- **Sustainable biofuels or synthetic fuels** will need to scale up from today's trivial levels to play a major role in aviation and perhaps shipping.
- Investments in **energy-consuming sectors** for both energy productivity improvement and the shift to lower-carbon energy sources will also be significant, especially in the buildings sector for the retrofitting of the existing building stock.

As Chapter 2 will discuss, the **macroeconomic cost** of this huge investment is clearly affordable: it amounts to just 1% to 2% of global GDP. But it will not happen unless countries set clear targets for emissions reduction and deep electrification, with policies to support key technology developments, price carbon, drive energy efficiency and ensure key infrastructure developments. International coordinated action is also required to mobilise the very large capital flows needed to finance adequately fast renewable electricity development in developing countries.

**Optimal policies** must ensure that a zero-carbon emissions economy is achieved by mid-century, but must also reflect feasible transition paths. For example, in shipping, the long-term zero-carbon solution may entail burning ammonia in ship engines, with the ammonia in turn made from zero-carbon hydrogen. But it will take many years to build the production capacity and distribution/port handling infrastructure required to support large-scale ammonia use. In addition, the carbon intensity of electricity must be below 120 grams per kWh to ensure that a shift from heavy fuel oil to ammonia produced from electrolysis results in carbon emissions reductions.

These resource and investment challenges and transition complexities – mirrored in different ways in other sectors – make it essential to develop detailed sector-by-sector decarbonisation pathways, outlining the full portfolio of decarbonisation solutions, the speed at which emissions can technically be reduced, the supporting conditions required to drive change at pace and the key milestones to be hit over the next three decades.

These should consider how far early emissions reductions can be delivered by two forms of **transitional action**: (i) the use of natural gas as a lower-carbon transition fossil fuel; and (ii) the use of "offsets" ahead of real within-sector decarbonisation.

32. The minimum and maximum load factors used are 30% and 100%.

# 1. Natural gas as a transition fuel

In some sectors, switching from coal or oil to natural gas could produce significant partial emissions reductions [Exhibit 1.25]. But the optimal role of gas must also reflect:

- The significant global warming impact of **methane leakage** in production, distribution and use which, unless dramatically curtailed, could more than offset the beneficial reduction in $CO_2$ emissions. Today, global methane emissions from oil and gas are estimated at around 80 million tonnes per year[33] or 6.7 billion metric tons of $CO_2$ equivalent (20-year horizon).

- The vital need to achieve **net-zero carbon emissions by mid-century**, which implies that gas-based transition pathways should be followed only if there is a clear subsequent path to complete decarbonisation either through the retrofitting of CCS/U or through the shift to another "green gas" – presumably hydrogen.

Given these caveats, our illustrative scenario assumes that while gas use can remain stable over the next few decades, it should not significantly increase, with our 2050 scenario suggesting a reduction of at least 16% [see Section III].

## Transitional and permanent uses of natural gas – examples

| Sector | Current or transitional role for gas | Permanent role for gas |
|---|---|---|
| Surface transport and aviation | Minimal: either inapplicable or better decarbonisation options available | Nil |
| Shipping | Could cut emissions by 20% if step to complete decarbonisation | Nil |
| Residential heating | Large current role but must be replaced by electricity or hydrogen | Nil |
| Power systems | Large current role and can cut $CO_2$ emissions by 50+% if replaces coal | Only if fitted with CCS, and primarily as peaking/ flexible supply plant |
| Chemicals production (as ethane) | Large current role may continue if CCS applied Could cut emissions significantly if replaced coal in Chinese chemicals production | Yes if fitted with CCS |
| Steel | Methane based DRI can be step towards $H_2$ DRI | Minimal - $H_2$ DRI and coking coal plus CCS likely to dominate |
| Hydrogen production | SMR+CCS alternative to electrolysis to produce low carbon $H_2$ | Possible major permanent role if combined with CCS |

Exhibit 1.25

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020)

# 2. Nature-based solutions and offsets

To limit global warming to well below 2°C and as close as possible to 1.5°C, we must not only decarbonise the energy and industrial system, but also stop and reverse the adverse impact of deforestation and other land use changes, which currently account for about 5 Gt of $CO_2$ equivalent emissions per annum[34]. These emissions derive primarily from the expansion of crop and pastureland at the expense of forests. Box A on page 30 outlines the actions (including, in particular, changes in diet) which could stop this encroachment and reverse it.

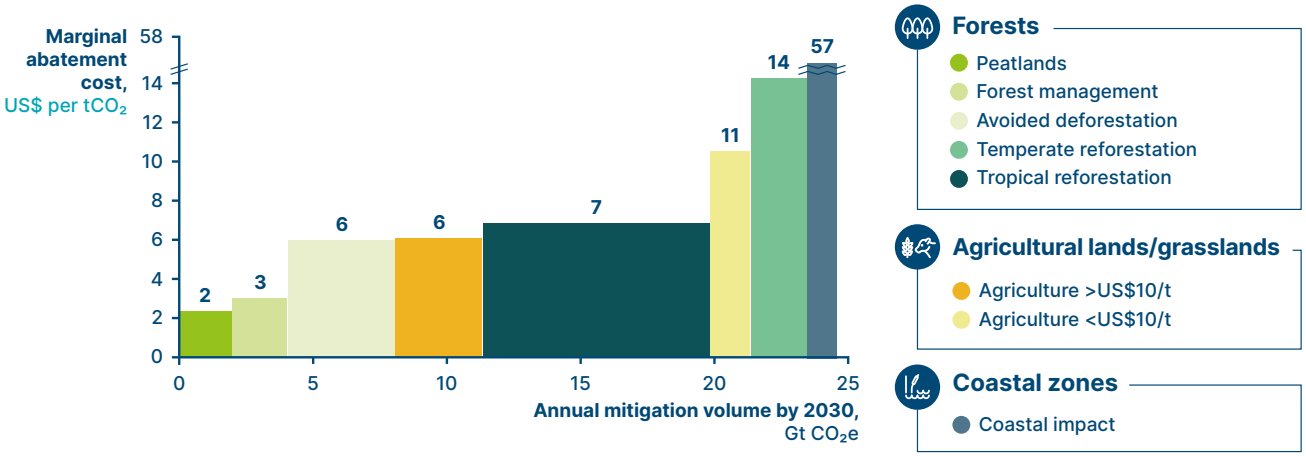
In this context, many company or sector commitments to decarbonisation assume that some emissions reductions will be achieved by buying carbon credits (or "offsets") to other sectors. For instance, the international aviation industry's Carbon Offsetting and Reduction Scheme for International Aviation programme assumes that aviation net emissions can be kept constant over the next 15 years through the purchase of offsets ("market-based instruments"), with sustainable aviation fuels making a major contribution to within-sector decarbonisation only from the 2030s onwards.[35]

33. IEA (2020), *Global methane emissions from oil and gas.*
34. World Resources Institute (2019), *World Resources Report.*
35. International Civil Aviation Organization (2019), *Destination Green – The Next Chapter.*

In principle, offsets could come from three key sources:

- **Other carbon-emitting sectors of the economy** able to sell carbon credits that they have no use for in the context of carbon trading schemes;
- **Negative emissions technologies** – either BECCS (bioenergy combined with carbon capture and storage) or DAC+CCS (direct air capture of carbon combined with carbon capture and storage);
- **Land use changes which will result in reduced emissions** (eg, reforestation). Emissions reduction can indeed be achieved via deliberate policies and projects to avoid deforestation and to stimulate reforestation or other favourable land use changes. Some estimates suggest that, in principle, such actions could deliver up to 25 Gt of carbon emissions reductions per year (for some time, but not in perpetuity, as carbon sequestration in forests plateau when forests reach maturity); and that the costs per tonne of $CO_2$ saved may compare favourably with some of the estimated costs of abatement by sector which we will present in Chapter 2[36] [Exhibit 1.26].

## Forest and peat-based offsets in the tropics could present cost-effective abatement opportunities in the early stages of the transition




A large volume of **low-cost**, **high-volume** and **high-quality** carbon credits are available in the forest and land use space, concentrated in the **tropics**.

Exhibit 1.26

**SOURCE:** McKinsey Marginal Abatement Cost Curve v2.0, Brazil, Indonesia; TNC; Bailis et al., (2015); SYSTEMIQ Analysis for the Food and Land Use Coalition (2020)

It is important to clarify whether offset purchase can be seen as a credible element within national, sector or company decarbonisation strategies. The ETC's position is informed by two key dimensions: the availability and the need for offsets.

With regards to the **availability of offsets**, one should note that two out of three sources of offsets are likely to shrink over time:

- As the decarbonisation of the economy accelerates and the amount of carbon credits in trading schemes reduces over time to reach zero by mid-century, so will the potential for one energy-consuming sector to buy carbon credits from another (eg, aviation will not be able to buy credits from the power sector any more once the whole power sector is driven to zero emissions).
- Nature-based solutions cannot provide a permanent flow of negative emissions, since all natural ecosystems tend eventually towards a carbon-neutral balance of emissions and absorption after the build-up period (30 to 40 years for reforestation).
- Consequently, in the second half of the century, any offset would likely need to come from negative emissions technologies.

36. McKinsey Marginal Abatement Cost Curve v2.0, Brazil, Indonesia; TNC; Bailis et al (2015); SYSTEMIQ Analysis for the Food and Land Use Coalition (2020).

With regards to the **need for offsets**, the ETC's analyses, summarised in this report, have made us confident that all sectors of the economy (apart from agriculture) can achieve "real net-zero emissions" by mid-century, with a role for CCS/U, but no permanent and major role for offset purchase.

Beyond 2050, the need for offsets from negative emissions should be no more than around 2 to 4 Gt $CO_2$ per annum, arising from:

- The **agricultural sector**, where – for the reasons described in Box A – it is likely that there will still be residual emissions of 1 to 2 Gt per annum[37] even if very significant diet change is achieved along with other reduction actions.

- **Residual emissions** of about 1 to 3 Gt from the energy and industrial systems arising because CCS processes do not achieve 100% $CO_2$ capture.

In that context, the ETC's position is that:

- All sectors of the economy (apart from agriculture) should achieve "**real net-zero emissions**" by mid-century, with a role for CCS/U, but no permanent and major role for offset purchase.

- **Nature-based solutions** could deliver a very large one-off increase in the carbon stock held in the terrestrial ecosystem (and a matching reduction in atmospheric GHG concentrations), and the purchase of offsets from land use by other sectors of the economy could play a positive role in financing this effort in the early stages of the transition, provided that:

    - They are in addition to (rather than instead of) as rapid as possible progress towards "real net-zero" within the sector.

    - Their assumed carbon reduction value takes account of the fact that the timing of $CO_2$ emissions reductions matters. In a world where high emissions could take the climate beyond dangerous tipping points, a tonne of $CO_2$ absorbed via many years of forest growth is not as valuable as a tonne of $CO_2$ saved immediately via within-sector actions.

    - At present, however, the world lacks well-understood and robust systems for certifying the quality of nature-based solutions. For example, a common definition of what constitutes legitimate and lasting emission reductions is required to ensure that the process of paying for 'avoided deforestation' does not create perverse incentives to bring forward possible deforestation projects. Moreover, many offsets which companies or sectors buy do not establish sufficiently high carbon prices to drive subsequent within-sector decarbonisation.

- A continued role for nature-based solutions or for other carbon removal strategies such as direct air capture plus CCS or bioenergy plus CCS will be required for a number of years beyond 2050 to reach a completely net-zero global economy. The need for this 2 to 4 Gt offset to cover **residual emissions** from agriculture and from incomplete carbon capture reinforces the importance of achieving complete emissions elimination from all other sectors of the economy by mid-century at the latest.

37. This does not include emissions from fertiliser production, which can achieve full decarbonisation.

Chapter 2

# Costs, investments and related challenges

Achieving a zero-carbon emissions economy will have only trivial gross impact (<1%) on attainable 2050 living standards in either developed or developing economies, and a hugely positive net impact on human welfare – especially once we allow for the adverse impact of unmitigated climate change. While the additional investment required is very large in absolute dollar terms, it is small relative to global GDP, savings and investments, and easily affordable – particularly in an era of low real interest rates. Achieving a zero-carbon emissions economy will, however, have important distributional impacts on some households and competitiveness impacts on companies in specific sectors, which require careful management.

**This Chapter illustrates these points, covering in turn:**

I. Costs of abatement by sector per tonne of $CO_2$ saved
II. The impact on costs faced by consumers
III. The impact on living standards and economic growth
IV. Gross and net investment requirements
V. Distributional effects on consumers and workers
VI. Competitiveness challenges in internationally traded sectors

## I. Costs of abatement by sector per tonne of $CO_2$ saved

Sectoral costs of abatement per tonne of $CO_2$ avoided[38] will vary by region and will evolve over time in the light of uncertain technological and cost trends. But it is reasonably clear which sectors can be decarbonised at low or even negative cost, and where the costs are likely to be greater [Exhibit 2.1].

- **The power system**: low-cost decarbonisation. As Chapter 1 described, by the 2030s and in most regions, zero-carbon power systems will be able to deliver electricity at costs equal to or below the cost of fossil fuel-based systems. Further incentives for maturing technologies (wind, solar, lithium-ion storage) can help drive industry scale; while initial incentives/subsidies are required to ensure that emerging clean generation technologies (next-generation nuclear, CCS/U) achieve the necessary scale to unlock further cost reductions.

- **Already electrified sectors** (eg, building appliances and cooling): low-cost decarbonisation. The decarbonisation of sectors that are already electrified will be driven by the decarbonisation of the power input and will happen at equally low cost. In some sectors and regions, the falling costs of renewable electricity could even lead to nil or negative abatement costs.

- **Surface transport**: negative abatement cost in the long term. The eventual cost of decarbonising road and rail transport will be negative, because of the inherent energy efficiency of electric engines. In many locations and applications, light-duty EVs are already lower cost than ICE vehicles on a "total cost of ownership" basis, and are likely to cost less to purchase upfront than ICE vehicles by the mid-2020s. BEVs or FCEVs are likely to become cost effective for many categories of medium-duty vehicles and heavy-duty vehicles during the course of the 2020s.

38. These costs are calculated without considering a carbon price or the externalities of carbon emissions.

- **Long-distance shipping and aviation**: significant abatement costs even in the long term. For shorter-distance aviation and shipping, battery electric or hydrogen fuel cell solutions may make the cost of decarbonisation zero or negative in the long term. But for longer distances, where decarbonisation will likely be via "drop-in" fuels in existing engines (or "quasi drop-in fuels" with limited engine and infrastructure retrofitting required), current estimates suggest abatement costs around US$100 to US$180 per tonne of $CO_2$ for aviation, and US$200 to US$300 per tonne for shipping.[39] These costs will fall with technological improvement and scale effects, but zero-carbon intercontinental shipping or aviation will probably always cost more than the fossil fuel-based alternative.

- **Heavy industry sectors:** moderate to high abatement costs. Estimates of eventual abatement costs in the harder-to-abate industrial sectors range from US$25 to US$60 per tonne for steel to US$120 to US$160 for cement, and over US$200 per tonne for the decarbonisation of plastics production (excluding switch to renewable feedstock).[40] Particularly in plastics, however, reducing primary material demand through improved material efficiency or recycling may prove a lower-cost solution.

- **Residential heat:** widely varying costs. For residential heating, abatement costs will vary significantly by region and building type, and by the technology used to achieve decarbonisation. In some cases, improved insulation could reduce emissions at low or even negative costs, with efficiency gains reducing energy use and costs, especially in mild weather countries. In other regions, the need for costly investments in supply-side decarbonisation via electric heat pumps or the use of hydrogen could result in high initial costs per tonne of $CO_2$ saved, even if long-term running costs might fall. Estimates of the total incremental costs required to decarbonise UK residential heating imply average abatement costs of about US$85 to US$120 per tonne of $CO_2$ avoided.[41]

- **Agriculture:** low to moderate costs. We have not conducted detailed analysis of the costs of decarbonising agriculture, but supply-side decarbonisation costs per tonne of $CO_2$ seem likely to be low**.** Decarbonising the direct and indirect use of energy within the agricultural sector (0.7 Gt per annum) will impose nil or negative cost, given the opportunity for low-cost electrification. And the cost of decarbonising ammonia production (in particular, the hydrogen input) is likely to be below US$50 per tonne of $CO_2$ avoided.[42] Improving agricultural practices to reduce $N_2O$ emissions might impose some cost penalty; but it is also possible that improved efficiency, by reducing the need for N-fertiliser inputs, could have a nil or even negative cost impact. Synthetic meats, while currently more expensive, may well become cheaper over time. The impact of potential changes in diet on human welfare is considered in the next section.

## Costs of supply-side decarbonisation vary greatly by sectors

**Supply-side abatement cost in a low-cost and high-cost scenarios,** US$/tonne $CO_2$

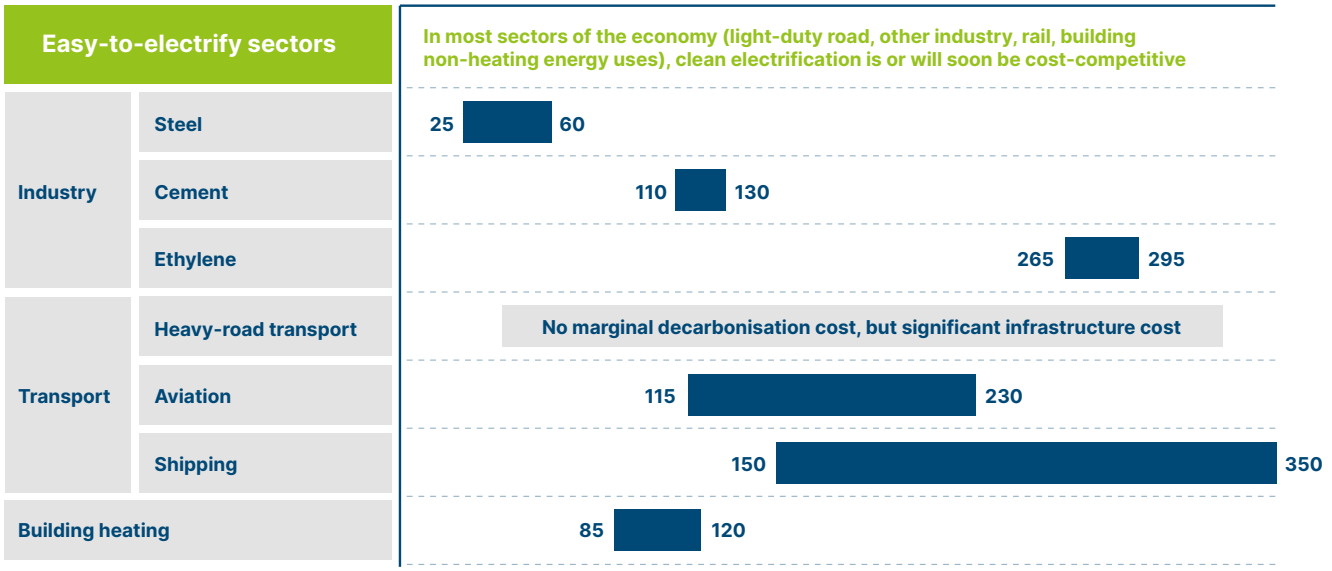



Exhibit 2.1

**SOURCE:** Industry: McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* / Shipping: UMAS analysis for the Energy Transitions Commission (2018) / Other transport sectors: SYSTEMIQ analysis for the Energy Transitions Commission (2020)

39. ETC (2018), *Mission Possible.*
40. McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier*. These are the anticipated abatement costs once the transition is complete, with implications for the long-term impact on costs to customers. The cost to achieve abatement today or in the near future would be in many cases much higher, implying the need for significant policy support to drive initial progress.
41. Element Energy (2012), *Decarbonising heat in buildings: 2030–2050, Summary report for the Climate Change Committee.*
42. McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier.*

## II. Impact on costs faced by consumers

The impact of decarbonisation on consumer living standards depends on the costs per tonne of $CO_2$ abated, the importance of energy costs within specific categories of consumer expenditure and the percentage of total consumer expenditure spent on different categories. Overall, achieving a net-zero carbon emissions economy will have a negligible impact on living standards and on growth between now and 2050. Incremental decarbonisation costs will reduce conventionally measured living standards attainable in 2050 by less than 1%. But important specific distributional effects need to be recognised:

- **Multiple sectors with negligible impact:** For many categories of consumer expenditure – which grow in importance as per capita income increases –, the incremental impact of decarbonisation will be close to zero, since energy accounts for only a very small percentage of the cost of production and energy inputs are primarily in the form of electricity. The impact of decarbonisation on the cost of healthcare and education, consumer electronics and mobile phones, telecom services, entertainment and other Internet services, clothing, restaurant meals and hotel stays will be immaterial.

- **Residential cooling:** Decarbonising residential cooling (which, throughout most of the world, is more important than heating) will also have negligible incremental cost, given the potential to deliver zero-carbon electricity at costs equal to or below the cost of fossil fuel-based systems, together with significant potential for further efficiency improvements.

- **Surface transport:** Decarbonisation of surface transport should yield positive impact on living standards, but will have important transitional distributional effects. In the long term, consumers will buy surface passenger transport services at lower cost than under a fossil fuel-based system, while road freight costs will be broadly unchanged. But during the transition from ICE vehicles to EVs, the cost and feasibility of initial adoption will vary significantly by specific location and use patterns (eg, as between urban and rural locations). Poorer households, which usually have a slower vehicle turnover and buy second-hand vehicles, may be more adversely affected or gain the benefits later.

- **Industrial sectors:** For heavy industry sectors, consumer incremental costs will be very small, even though decarbonisation will add significantly to the cost of some intermediate products. This is because intermediate products account for only a small proportion of the cost of the final goods or services. For instance, if it costs US$25 to US$60 per tonne of $CO_2$ to decarbonise steel production, this could add US$50 to US$120 (about 10% to 20%) to the cost of a tonne of steel, but will have only a trivial (less than 1%) impact on the final cost of an automobile, washing machine or other electric appliance, or on building costs.[43] Exhibit 2.2 illustrates the similarly small impact of decarbonising cement or plastics.

### In industry, decarbonisation would increase prices of intermediate products but have negligible impact on consumer prices

| | Impact on intermediate product cost<br>US$ / % price increase | | Impact on final product cost<br>US$ / % price increase | |
|---|---|---|---|---|
| Plastics | +$500 per tonne of ethylene | +50%* | +$0.01 on a bottle of soda | <1% |
| Steel | +$120 per tonne of steel | +20% | +$180 on the price of a car | +1% |
| Cement | +$100 per tonne of cement (+$30 per tonne of concrete) | +100% (+30%) | +$15,000 on a $500,000 house | +3% |

Assuming an initial price of US$1000/tonne for ethylene, although the price of ethylene is very volatile.

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020)

Exhibit 2.2

43. ETC (2018), *Mission Possible.*

- **International shipping:** Similarly, in the case of international shipping, while it is likely that the use of zero-carbon fuels will add significantly to freight costs, even in the long term and once the new technologies have become mature, the impact on the price of final consumer goods and thus on living standards will be very small [Exhibit 2.3].

- **Long-distance aviation:** Decarbonising long-distance aviation will probably require a significant increase in ticket prices versus business as usual. The size of this impact will depend on future trends in the cost of producing sustainable aviation fuels from bio or synthetic feedstocks, which are inherently uncertain. But if these alternative fuels always cost 50% more than conventional jet fuel, aviation tickets would need to rise 10% to 20% relative to current prices.[44] Given the significant opportunity to improve aircraft and engine energy efficiency, though, the real cost of flying in 2050 might still be below today's level. And since aviation accounts for only about 3% of consumer expenditure even in rich developed societies, the impact on living standards would be very small.

Exhibit 2.3

## Decarbonisation would significantly increase consumer prices in aviation but would have minimal impact in shipping

| | Impact on intermediate product cost<br>US$ / % price increase | | Impact on final product cost<br>US$ / % price increase | |
|---|---|---|---|---|
| Shipping | **+$4 million**<br>on typical bulk carrier voyage call per annum | +110% | **+$0.03**<br>per kilogram of imported sugar | <1% |
| Aviation | **+$0.3-0.6**<br>per litre of jet fuel equivalent | +50-100% | **+$40-80**<br>on a 6,500-km economy class flight | +10-20% |

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020)

- **Residential heat:** Decarbonising residential heat could have a significant impact on living standards for specific households, unless careful redistribution policies are put in place. Poorer households in insufficiently insulated buildings will bear larger energy bill increases than richer households with better-insulated homes. Estimates for the UK suggest that the total incremental cost required to fully decarbonise residential heating by 2050 could be equivalent to about 0.2% to 0.4% of GDP per annum, and about 15% to 20% of residential energy bills.[45] Much of this will take the form of initial investment followed by lower running costs, but the net impact on household budgets will vary significantly by individual household. Similar costs could be incurred in some other countries which have significant winter heating needs, but will be lower in countries that start with better insulated housing stock.

- **Agriculture:** Box A on page 30 describes the complex challenge of reducing the emissions produced directly or indirectly from food production. The impact of this on consumer living standards and human welfare will vary by specific type of emission and action, but is likely to be financially small and could indeed be positive socially:

    - Supply-side decarbonisation actions would impose only relatively small additional costs: for instance, if decarbonising hydrogen production incurred a cost of US$0.5 per kilogram, the total cost to decarbonise the 25 million tonnes of hydrogen currently used in fertiliser production would amount to US$12.5 billion, compared with a total estimated global food production cost of US$5 trillion to US$6 trillion, thus representing an increase of 0.25%.[46]

    - The crucial issue, however, is whether the methane and land use change emissions which result from meat production could be significantly reduced by diet change. If such change were achieved, the impact on conventionally measured living standards could be nil or positive (since alternative, more vegetable-intensive diets will typically reduce household food expenditures), and the wider impact on human welfare could be strongly positive because of improved health.

Another key impact of the transition on end consumers' living standards will be through the impact on the job market. This is discussed later in Section V of this chapter.

44. ETC (2018), *Mission Possible.*
45. Element Energy (2012), *Decarbonising heat in buildings: 2030–2050, Summary report for the Climate Change Committee.*
46. World Bank (2019), *Do the costs of the global food system outweigh its monetary value?*

# III. Impact on 2050 living standards and economic growth

Decarbonisation of the economy could in theory have two types of impact on conventionally measured living standards: (i) it could reduce or increase the level of GDP per capita and thus living standards attainable in 2050 once the transition is largely complete; and (ii) it could require a higher level of investment during the transition, reducing resources available for consumption, but with no measured impact on GDP. The former effect will almost certainly be trivial and possibly positive; the latter will be small and easily affordable as a percentage of global GDP.

The total **impact on attainable consumer living standards** in 2050 will depend on whether achieving a zero-carbon-emissions economy requires more capital and labour resources to be devoted to producing energy or energy-based products or services than would be required in a fossil fuel-based economy. As described above, in some respects a zero-carbon-emissions economy will actually entail equal or lower costs: renewable electricity will be as cheap as fossil fuel-based electricity and surface transport services will cost less once electrified.

Any negative impact on living standards will therefore be concentrated in the harder-to-abate sectors of heavy industry and long-distance transport, together with residential heating. Exhibit 2.4 provides estimates of these costs reflecting alternative assumptions along two dimensions: (i) the future cost of renewable electricity; and (ii) the extent to which countries are able to grasp the low-cost opportunities to improve energy productivity which are in principle available:

- Under a **high-cost scenario**, with renewable electricity costs ranging from US$20 per MWh in most favourable locations to US$70 per MWh in least favourable, the impact could lie between 0.27% (if all energy productivity improvement potential is achieved) and 0.49% (if decarbonisation is achieved entirely via supply-side actions) of 2050 GDP.

- But under a **low-cost scenario**, with renewable electricity pervasively available at US$20 to US$30 per MWh, the cost could be as low as 0.17% to 0.29% of global GDP per annum.

## Decarbonising the economy would cost significantly less if pursuing energy productivity improvements

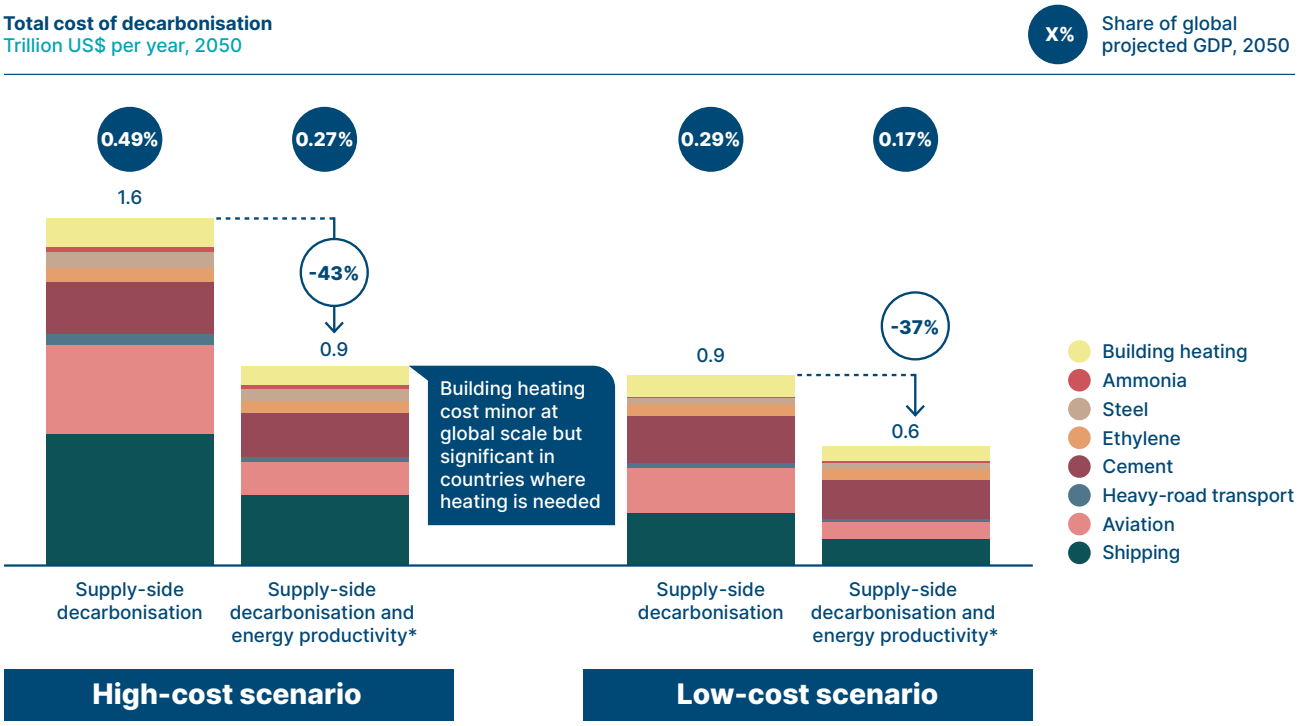



Exhibit 2.4

**NOTE:** The term "energy productivity" covers energy efficiency, material efficiency and service efficiency.

**SOURCE:** SYSTEMIQ analysis for the Energy Transitions Commission (2020) based on McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* and Material Economics analysis for the Energy Transitions Commission (2018)

These costs are dominated by **three specific sectors** – cement (and thus building costs), aviation and shipping – with residential heating decarbonisation costs very small as a percentage of global GDP, but more important within specific countries.

These figures do not, however, reflect the fact that, in other sectors of the economy, living standards could be increased by the transition to a zero-carbon economy, with individuals paying less for electrified surface transport services and less for food if they switched to less meat-intensive diets. Under certain scenarios, the impact on attainable living standards in 2050 could indeed be positive. If expenditures related to pollution and climate-related health issues were taken into account, the likelihood of a net positive impact would increase still further.

These estimates in turn imply that the **impact on economic growth** between now and 2050 will be trivial. Even if we conservatively assumed that the 2050 costs were as high as 1%, neither developed nor developing economies would see any significant impact on conventionally measured economic growth:

- In **rich developed economies**, which might expect on average to achieve 1.5% per capita GDP growth, a 1% 2050 cost would imply that living standards might reach in January 2051 the level they would otherwise achieve in April 2050, with average growth over the next 30 years reduced to 1.47%.

- In **developing countries**, which might typically achieve real per capita GDP growth of 3% per annum, this would imply reaching by January 2051 the living standard otherwise achieved in September 2050 – a level about 140% above current per capita income – and with measured growth reduced to 2.97%.

By contrast, the potential adverse consequences of unmitigated climate change could be very large even by 2050 and would increase dramatically in subsequent years. For instance, in 2019, climate change was linked to at least 15 extreme weather events costing between US$1 billion and US$10 billion each.[47] Moreover, achieving a zero-carbon economy, with massively reduced combustion of hydrocarbons – in particular, in urban environments and transport applications – will deliver major air quality improvements yielding major health benefits. Estimates suggest that premature and preventable deaths from poor air quality currently account for 4.2 million deaths worldwide every year;[48] and evidence suggests that poor air quality has played a role in increasing fatality rates from COVID-19 and other virus-related respiratory diseases.[49] The net impact of achieving a zero-carbon economy by mid-century will therefore be strongly positive for human welfare and the costs of inaction huge.

## IV. Gross and net investment requirements

The impact of achieving a zero-carbon-emissions economy on human welfare in 2050 will thus be incredibly positive. But getting there requires us to accept some transitional costs, stemming from higher investments per annum during the build-up of this new economy.

Renewable electricity and EVs will soon be cheaper than fossil fuel generation and ICE vehicles; but initial subsidies have been required to unleash the economies of scale and learning curve effects which drive down costs. In some countries and sectors, such **initial subsidies** – research, development and deployment support – are still required to drive down the cost of the next wave of low-carbon technologies, such as hydrogen production. In parallel, building massive zero-carbon electricity capacity will require large-scale investment.

Major **investments** are also required in energy and transport infrastructure, as well as in energy-intensive sectors, to deploy energy-efficient technologies and enable fuel switch. This does not reduce either GDP or employment (indeed, under some circumstances, it could increase both); but it does require an increase in investment rates as a percentage of GDP and a matching reduction in consumption as a share of income. Estimates show, however, that the required additional investments – while huge in absolute dollar terms – amount to no more than 1% to 1.5% of global GDP, and are easily affordable given current global savings and investments, which amounted in 2019 to 26.5% of global GDP;[50] even more so in the current macroeconomic context of sustained low interest rates.

47. Christian Aid (2019), *Counting the cost 2019: a year of climate breakdown.*
48. World Health Organization (2016), *Mortality and burden of disease from ambient air pollution.*
49. Yaron Ogen (2020), "Assessing nitrogen dioxide ($NO_2$) levels as a contributing factor to coronavirus (COVID-19) fatality", *Science of The Total Environment.*
50. IMF World Economic Outlook (2019), *Outlook Database October 2019.*

To provide a sense of global orders of magnitude and illustrate the relative size of different elements, Exhibit 2.5 presents estimates of some of the major capital investments required:

- By far the largest element is the investment required to build a **global power system** that can deliver 100,000 TWh of electricity per annum. This will entail:
    - Additional **wind and solar capacity** of around 13,000 GW and 18,000 GW respectively. Given current and future possible cost of wind turbines and solar PV equipment and installation, this could imply a total investment need of US$32 trillion between now and 2050 – an average of US$1 trillion per annum.
    - Related **transmission and distribution** investment. These might add another 20% to 40%[51] to the necessary investments.
    - Significant **energy storage** to provide daily and seasonal flexibility. If 5% of all TWh were stored and released in batteries on a daily cycle, the total battery investment required could be around US$1.5 trillion or US$50 billion per annum.
    - Investment in **flexibility infrastructure**. This can take the form of:
        - Carbon capture equipment and related $CO_2$ transport and storage facilities to capture emissions from thermal plants used to provide flexible supply. This would be expensive per tonne of $CO_2$ saved, due to low utilisation; and, if applied to 4,500 GW of capacity (to produce 8% of all power generation through peak thermal plants), could add another US$3,900 billion over 30 years or US$130 billion per annum – a major expenditure, but still an order of magnitude smaller than the required investments in renewable capacity.
        - Hydrogen production and storage infrastructure, to store and shift energy produced by variable renewables depending on seasonal needs. For 2% of power shifted annually, 110 Mt of hydrogen production and storage would be required, representing an investment in electrolysis in the order of US$431 billion or US$15 billion per year over 30 years.
- In addition, building a **hydrogen economy** to supply 800 Mt of hydrogen per annum for end use only would require massive investments either in electrolysis equipment or in the capital equipment for SMR plus CCS. Significant investments would also be required for hydrogen transport and storage. Total investment over 30 years could amount to around US$3.7 trillion, or US$130 billion per annum.
- **Industrial decarbonisation** will require significant investment in new steel, cement and petrochemical plants; but the total investment required in these sectors is small compared with that required in the power sector. A detailed study by Material Economics of industrial decarbonisation in Europe[52] estimates that total additional investment for EU heavy industry sectors could amount to about US$370 billion over 30 years or US$5.5 billion per annum, with the largest element being in the chemicals sector. Grossed up to reflect global production volumes, this could suggest total global investment needs of US$1,600 billion between now and 2050 or US$50 billion per annum. Although an order of magnitude smaller than the investments required in the power sector, this level of investment is far higher than the current rate of investment in industry worldwide. In Europe, for instance, investments in industrial assets would need to double.[53]
- This industrial-related investment would include capital expenditure related to **CCS/U**. In Exhibit 2.5, CCS investment is shown explicitly for the power sector, while CCS expenditure to support industrial decarbonisation or blue hydrogen production is included within the estimates shown for hydrogen and industry. The bottom line shows the total CCS expenditure for all sectors, with the investment needed to achieve 7 to 10 Gt amounting to about US$5 trillion over 30 years or US$160 billion to US$190 billion per annum.
- A **charging infrastructure** to support total road transport electrification, combining hundreds of millions of slow-speed residential charges and millions of fast and super-fast chargers, could cost about US$2 trillion or US$70 billion per annum. Much of this would not, however, count as "investment" in standard national income accounts, since it would be incurred by households installing slow-rate chargers at home.

51. Indicative number.
52. Material Economics (2018), *Industry Transformation 2050*.
53. Material Economics (2018), *Industry Transformation 2050*.

- In addition to these estimates, major investments would be required to construct **buildings** in cities in a low-carbon rather than high-carbon fashion, to retrofit the existing building stocks and to install new forms of energy-using equipment. European estimates suggest that the additional investments required in building retrofitting could be of a similar scale to investments in the power sector in developed countries. For new buildings, however, any incremental investment related to energy efficiency is likely to be limited.

In total, these major items add to about US$1.6 trillion per annum on average over the next 30 years, of which over US$1.3 trillion relates to the power sector and less than US$0.3 trillion to all other sectors.

## The scale of incremental investment required in industry and transport is dwarfed by the scale of incremental investment required in power

| | 2050 vision | | Key investment needs | Total investment 2020-2050, US$bn | Total annualised investment, US$bn pa |
|---|---|---|---|---|---|
| **Power** | **Total power generation:** 100,000 TWh / year<br>**Total capacity required:** 9,500 GW onshore wind 3,500 GW offshore wind 18,300 GW solar 4,000 GW thermal + CCS 1,268 GW nuclear | **Renewable capacity** | 9 TW extra onshore wind 3 TW extra offshore wind 18 TW extra solar | ~32,000 | ~1,000 |
| | | **Transmission and distribution** | 3-33% of generation capacity investment | ~1,000-10,000 | ~30-350 |
| | | **Battery storage** | 14 TWh per day (5% of daily generation) | ~1,500 | ~50 |
| | | **Seasonal storage:** $H_2$ storage and/or CCS on thermal plants | 4 TW thermal capacity equipped with CCS (8% of generation) | ~3,800 | ~130 |
| | | | 1.5 TW electrolysis (2% power shifted) | ~430 | ~15 |
| **Hydrogen in final use** | 800 Mt/year for final sectoral energy use | **Production** | 5.8 TW electrolysis 2 TW blue hydrogen capacity | ~2,600 | ~90 |
| | | **Transport and storage** | Salt caverns and other storage Gas pipeline retrofit | ~1,100 | ~40 |
| **Industry** | Steel, cement and petrochemicals industries achieve zero-carbon | | CCS application to cement Hydrogen DRI or CCS for steel Multiple forms of changed chemical production process | ~1,600 | ~50 |
| **Transport: charging infrastructure** | Total decarbonisation of road transport with ~2bn electric cars and ~200m electric trucks and buses | | ~1000bn slow residential, 200m moderate speed public and 10million superfast chargers, + truck and bus chargers | ~2,000 | ~70 |
| **Total** | | | | **~46,000-55,000** | **~1,475-1,800** |
| **CCS across all sectors (included in figures above)** | 6-9.5 Gt/year of gross emissions from power, hydrogen production and industrial sectors (excluding feedstock) offset by CCS/U | | Capture equipment, transport pipelines and storage facilities | ~4,800-5600 | ~160-190 |

Exhibit 2.5

**SOURCE:** : SYSTEMIQ analysis for the Energy Transitions Commission (2020), IEA (2017), *Energy Technology Perspectives, Catalysing Energy Technology Transformations*; Global Infrastructure Hub, Material Economics (2018), *Industry Transformation 2050*, IEA (2019), *World Energy Outlook*

**IEA estimates** provide an alternative indication of the relative orders of magnitude [Exhibit 2.6]:

- While renewables, nuclear and other power market investments currently run at around US$640 billion per annum, the IEA estimates that they would have to reach about US$1,470 billion by the 2030s – an increase of US$830 billion per annum.
- Incremental investments on energy using equipment and buildings might be US$1,500 billion per annum by the 2030s.
- These large additional investments would be partially offset by reduced fossil fuel investments amounting to -US$510 billion by the 2030s.
- Overall, the IEA estimates net additional investments of US$1,830 billion per annum in the 2030s.

## The IEA estimates net additional investments of US$1,830 billion per annum in the 2030s

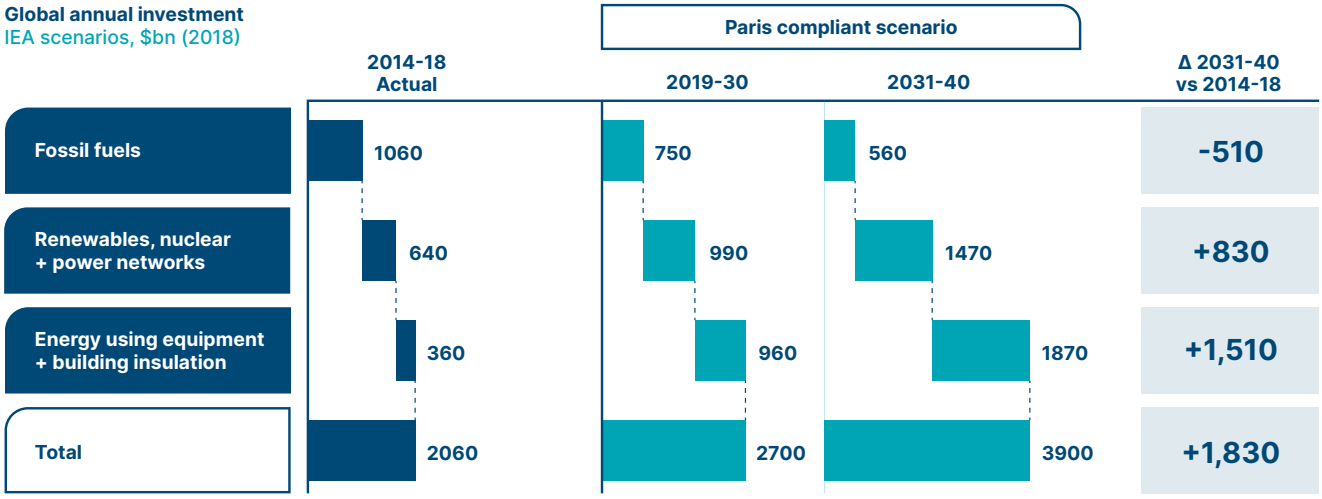



Exhibit 2.6

**SOURCE:** IEA (2019), *World Energy Outlook*

While all estimates of far future costs are inherently uncertain, the bottom-up "major item estimates" shown on Exhibit 2.5 and the IEA estimates in Exhibit 2.6 suggest the same **orders of magnitude**, which are confirmed by estimates from other organisations and by the ETC's forecasts for the Chinese economy in particular (see Chapter 3). Building a global zero-carbon-emissions economy will likely require incremental investments of some US$40 trillion to US$60 trillion over the next 30 to 40 years.

These massive figures indicate the scale of the challenge. But as a percentage of global GDP, or of global savings and investment, they are not daunting. The IEA estimate of US$1,800 billion of incremental investment in the 2030s would amount to about 1.2% of global GDP in that decade and require an increase of about 4% to 5% in global investment. The scale of required investment is small compared with the massive public spending and fiscal deficits now being dedicated to stimulating the economy after the COVID-19 crisis, providing an opportunity – if well designed – to accelerate the energy transition.

**In developed economies**, a "lack of finance" is unlikely to impede progress, given a macroeconomic environment of negative long-term real interest rates. Indeed, within the current macro environment, additional investment in the green energy system could help offset the risk of "secular stagnation", which some economists believe results from a deficiency of private investment demand relative to desired global savings rates.[54] In such circumstances, it is at least possible that increased investment in the energy transition might stimulate sufficient incremental GDP growth to completely eliminate any adverse impact on feasible consumption.

But while easily affordable at the global level, the investment required will not occur without effective public policies, including an effective use of public finance (benefiting from lower interest rates than private sector players) to directly finance or de-risk major investments. Capital availability and cost of capital constraints could be an important impediment to sufficiently rapid progress **in some emerging economies**. This and other differences by region are discussed in Chapter 3.

54. L Rachel and LH Summers (2019), *On Falling Neutral Real Rates, Fiscal Policy, and the Risk of Secular Stagnation.*

# V. Distributional effects on consumers and workers

Overall, attaining a zero-carbon-emissions economy will have no significant negative impact on average living standards in either developed or developing countries, and progress towards it will not slow the pace at which developing countries can advance towards developed country standards of living. At the macro level, there is no trade-off between decarbonisation and increased prosperity. But it is important to recognise and manage some potential distributional effects by sector and by country. Most of these effects are specific to particular sectors, countries or regions within countries, and therefore require national or regional policy responses. Global analysis can, however, identify where the challenges are likely to be more and less significant.

## 1. Distributional effects of increased consumer costs

As Section II described, the impact of decarbonisation on consumer prices will in most sectors be very small. But in three sectors, costs could change significantly, with important potential distributional implications in one of these and a transition challenge in another:

- **Aviation**, where prices may need to increase materially versus continued use of conventional jet fuel (eg, by 10% to 20%) to pay for higher-cost bio or synthetic fuel; but where the distributional impact is not concerning given that expenditure on aviation in both developed and developing countries is strongly skewed towards higher-income groups and business travellers.

- **Residential heating**, where in many cases upfront investment (eg, improved insulation or heat pumps) will deliver subsequent cost reductions, but where: (i) the return on investment will vary significantly by individual circumstance (eg, the quality of existing building insulation); (ii) the cost of capital will vary greatly by household, with lower-income people facing higher borrowing costs; and (iii) the impact of any additional cost will be greater for lower-income households, given that energy bills account for a higher proportion of their household income, and that they tend to live in less energy-efficient buildings (especially when renting).

- **Surface transport**, where the path to zero carbon will become easy for all consumers once EVs reach cost parity with ICE vehicles, and once driving ranges are sufficient for all circumstances; but where, in the transitional period, lower-income groups living in rural areas may face greater barriers to electrification than higher-income urban dwellers, due to more limited infrastructure, slower vehicle turnover and higher reliance on second-hand vehicles.

## 2. Impacts on employment by sector

Like any process of technological change, the transition to a zero-emissions economy will eliminate some existing jobs while creating new jobs elsewhere. In general, however, its employment disruption effect is likely to be far less significant than other transformations already facing both developed and developing economies, such as the automation of manufacturing, distribution and information processing; the shift of retailing from traditional to online forms; and the continual reorganisation of global supply chains as relative costs change. But significant employment impacts should be anticipated and addressed by **just transition** strategies in specific sectors and countries. In particular:

- While **oil and gas production** is in almost all countries a highly capital-intensive activity, thus minimising the employment consequences of falling demand, careful management of the regional employment consequences of a **coal phase-out** is required, especially in key regions in coal-rich developing countries where significant coal-mining and related jobs are concentrated.

- While a major shift away from meat consumption could in some circumstances be offset by new employment creation (including in more job-intensive forms of agriculture), in some specific rural locations, it will create concentrated employment effects in **the agriculture sector** which cannot easily be offset by either alternative forms of food production or alternative economic activities such as tourism.

- The shift to electric vehicles will produce a significant reduction in employment within **the auto manufacturing sector**, since EVs are far simpler and easier to manufacture. Consumers will pay less for surface transport services, but that inevitably means fewer jobs. Carefully thought-out strategies may be required to ensure offsetting employment creation in specific affected regions.

## 3. Impacts on fossil fuel producing countries

The biggest distributional impact, however, is likely to occur between nations, with oil, gas and coal producing countries facing a significant reduction in export revenues. Even if the total employment impact is in some cases small, the global energy transition is likely to disrupt the economic development model in those countries, and particularly in fossil fuel-rich regions within those countries. Countries and regions that anticipate these upcoming disruptions and diversify their economies early could significantly reduce the economic and social risks associated with the transition.

# VI. Competitiveness challenges in internationally traded sectors

The costs and distributional effects considered in Sections III to V above would arise even if all countries decarbonised in a coordinated fashion and at the same pace. But it is also important to consider the impact on competitiveness which can arise if some countries use carbon prices and other policies to drive decarbonisation faster than others.

As shown in Exhibits 2.2 and 2.3, the impact on end consumer prices of decarbonising heavy industry and shipping will in the long term be very small; and while for aviation the price impact may be significant, the consequence for consumer living standards is still very slight. But the impact on **intermediate product costs** – such as a tonne of steel or cement, or shipping freight rates – will in some cases be very significant, even in the long term and still more so during the early stages of transition. This creates a major potential competitiveness problem in a world of international trade, multiple independent state governments and imperfect mechanisms for international policy coordination. Thus, for instance:

- If in a closed economy the government imposed a carbon price of US$60 per tonne of $CO_2$, the production cost and price of a tonne of steel could rise by around US$100 per tonne.[55] Companies would face strong incentives to decarbonise production, the impact on consumer living standards would be very minor and no steel company would face a competitive disadvantage, since all would face the same carbon price and would increase steel prices by the same amount.

- But in a world where steel is extensively internationally traded, the imposition of carbon prices high enough to drive decarbonisation in one country would create a huge competitive disadvantage for its domestic industry, both in the domestic market and in export markets, with products and emissions moving to countries which did not impose an equivalent tax.

The importance of such **competitiveness effect** by sector reflects: (i) the importance of energy costs – or of carbon-generating chemical reactions – in the production process; and (ii) the extent to which products are internationally traded. They are largely irrelevant for many economic sectors, but can be important in heavy industry, in international shipping and to a lesser extent in international aviation. In these specific sectors, optimal public policy would ideally entail international coordination – whether agreed via existing international regulatory authorities (eg, the International Maritime Organization for shipping or the International Civil Aviation Organization for aviation), by nations within the United Nations Framework Convention on Climate Change (UNFCCC) framework, or via coalitions of countries that play a key role in a specific sector. Where such international coordination cannot be achieved, as a second-best policy, domestic carbon prices combined with border carbon adjustments will be needed to support decarbonisation at the pace required to meet mid-century targets. These policy implications are considered further in Chapter 4 below.

55. SYSTEMIQ analysis for the ETC (2020).

Chapter 3

# Regional differences and challenges

Many of the routes to decarbonisation are relevant in all countries; and in many sectors – such as steel, aviation and shipping – a global policy approach would be ideal. Much of the ETC's work has therefore focused on global trends in technologies and costs.

But there are important differences between regions and countries. Countries have different natural resource endowments, different economic fabrics, different income levels and very different current emissions; and they start from different positions – for instance, in relation to existing coal generation capacity.

Through its global work as well as its regional initiatives across Europe, China and India, the ETC has sought to identify major regional differences. This chapter describes implications emerging from these analyses, covering in turn:

I. Natural resource differences and their implications
II. Appropriate pace of decarbonisation in developed and developing economies
III. China: a fully developed rich zero-carbon economy by 2050
IV. India: driving power decarbonisation through renewable investment
V. Phasing out coal and getting power systems right first time
VI. Financing challenges in developing economies

## I. Natural resource differences and their implications

As Chapter 1.IV described, the world has easily enough natural resources to build a zero-carbon economy. But resources endowments vary significantly by region and country, as shown in Exhibits 3.1:

- **Solar power potential** varies greatly, with better resources at low altitudes and particularly in desert or dry climate locations. There are also major differences in both onshore and offshore wind supply. The best-placed regions are those with abundant collocated solar and wind resource, delivering renewable power for a large number of hours per year. Locations such as western China, the Sahara and Chile are particularly well placed in this regard.

- The **availability of $CO_2$ storage** is not fully documented, but it is highly likely that there are significant differences between different parts of the world.

- **Total available and sustainable biomass** supplies also vary greatly, with some countries which have large wind and solar resource less well endowed with biomass. For instance, China has much more limited biomass resource per capita than much of the Americas. Biomass stock is concentrated in humid tropical and temperate climates. The key issue, however, is how much of those resources are available in a truly sustainable way. The distribution of sustainable, low-carbon biomass for use in the energy and industrial system might be quite distinct – and indeed, concentrated in regions outside of the tropical belt with less risks of associated deforestation.

As a result, the relative cost of different decarbonisation routes will vary by region and so will the **optimal path** to sectoral decarbonisation in the sectors where multiple solutions are likely to coexist. The revised National Determined Contributions (NDCs) soon to be submitted to the UNFCCC under the Paris Agreement should explicitly assess inherent renewable natural resources and the implications for an optimal decarbonisation strategy. While NDCs look at the short-term climate policies (i.e. 5 to 10 years from today), long-term low greenhouse gas emissions development strategies (LT-LEDS) set a mid-century vision (i.e. 30 years from today). Given the many interdependencies in the planning of short-, mid- and long-term policies, it is key to ensure the coherence between both processes and their alignment with the vision of a global net-zero economy by around mid-century.

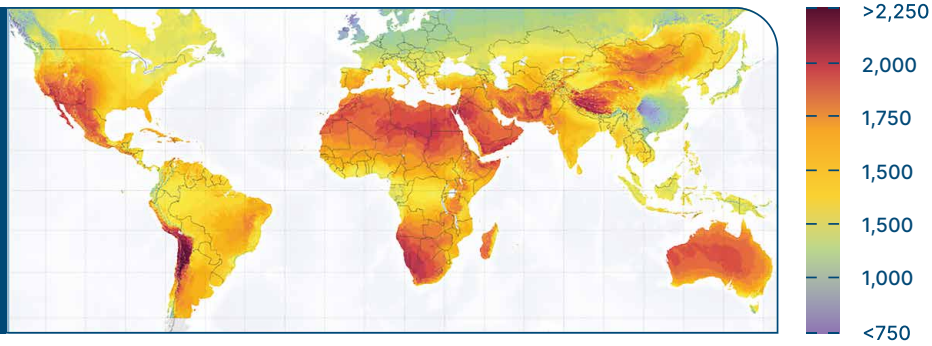
Differences in natural resource endowments may impact not only the optimal route to decarbonisation, but also the feasibility of decarbonisation based on domestic renewable energy supplies. Across the whole world, there is plenty of land to support required solar energy development, but availability may be limited in countries with very high population density. For instance, if Bangladesh consumed as much electricity per capita as Europe, it would need to cover about 6% to 10% of its entire land area to meet this demand from solar power alone, in a country where most available land is used for agriculture. Conversely, some countries are endowed with resources massively in excess of their domestic needs. If Australia covered 1% of its land area with solar panels, in a country where much of the land area is uncultivated desert, it would produce 10 times as much electricity as it currently consumes.

# Resource endowments vary significantly by region and will lead to to differentiated decarbonisation paths

Yearly total photovoltaic power potential, kWh/kWp

**NOTE:** The unit measures long-term average of photovoltaic power potential (PVOUT)

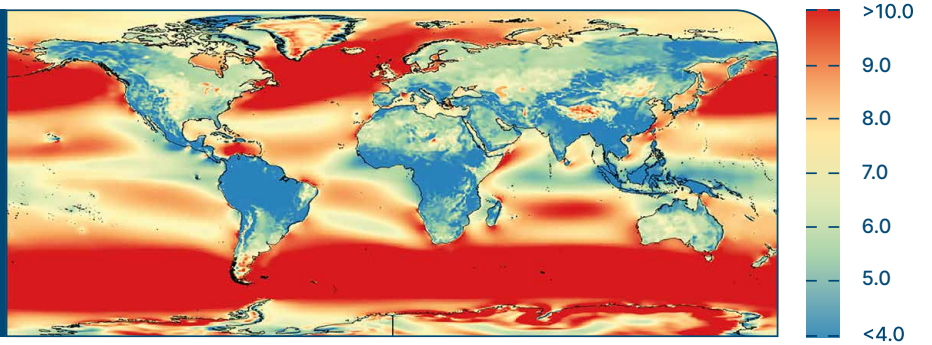
**SOURCE:** The World Bank (2019), *Global Solar Atlas 2.0* (Solar resource data: Solargis)




Average wind speed, meter per second

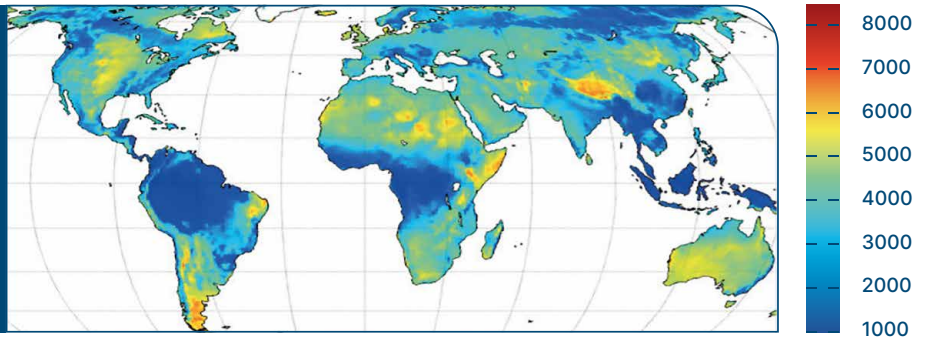
**NOTE:** Mean wind speed at 100m from MERRA reanalysis. Period 1979-2013.

**SOURCE:** Technical University of Denmark (DTU), *Global Wind Atlas 1.0*



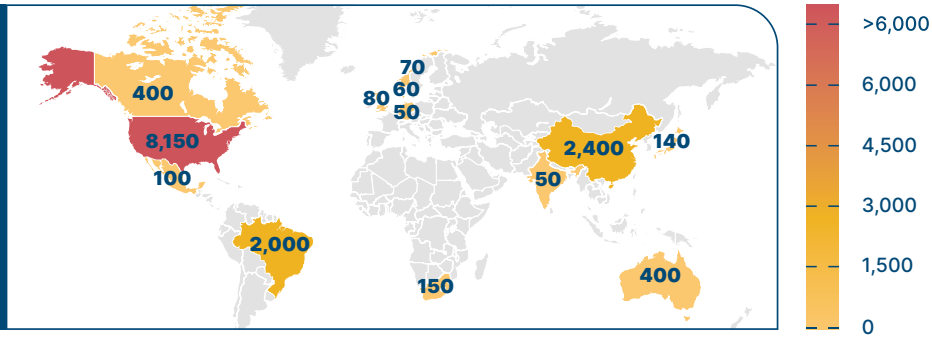

Availability of combined wind and solar resources, hours per year

**SOURCE:** IEA (2017), *Renewable Energy for Industry* (Adapted and based on Fasihi, Bogdanov and Breyer (2016), *Techno-Economic Assessment of Power-to-Liquids (PtL) Fuels Production and Global Trading Based on Hybrid PV-Wind Power Plants)*




$CO_2$ storage capacity, gigatonnes

**SOURCE:** BloombergNEF (2020), *Hydrogen Economy Outlook*, based on Global CCS Institute data and BloombergNEF




Potential biomass stock, carbon stock in gC / m²

**NOTE:** IPCC-based, FRA adjusted

**SOURCE:** Erb, Karl-Heinz & Kastner et alii(2018). *Unexpectedly large impact of forest management and grazing on global vegetation biomass*. Nature. 553. 10.1038/nature25138.

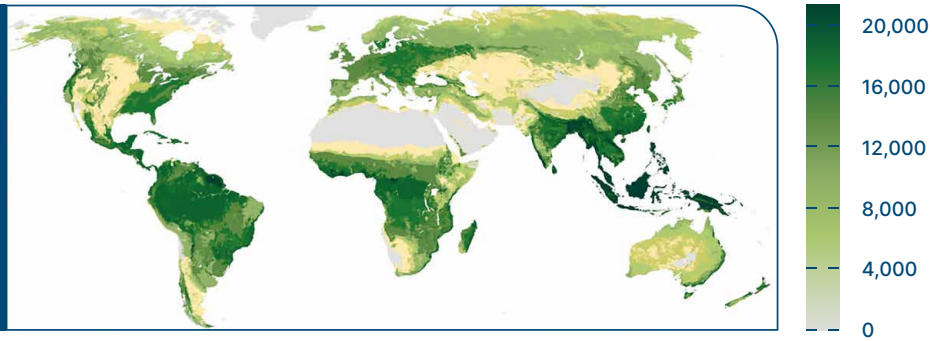



Exhibit 3.1

Three implications follow:

- First, a global zero-carbon-emissions economy may involve large-scale **trade in clean energy**, mirroring the massive current international flows of coal, oil and gas, but in new energy forms. In particular, there will be some mix of long-distance electricity transmission and hydrogen trade through pipes or ships – whether in the form of hydrogen itself, liquid organic hydrogen carriers or ammonia.[56] The exact scale of this new energy trade remains to be determined, however, given that renewable resources will be relatively better distributed across the globe than fossil fuels resources, and that the cost differential in renewable power provision between regions might not always compensate for the energy transport costs.
- Second, **global development assistance** will be needed to enable poorer countries with limited zero-carbon energy resources to afford imports of zero-carbon energy. This might also imply some role for cross-country offset trading, with resource-rich countries providing emissions reductions for resource-poorer countries.
- Third, for **energy security** reasons, some countries might choose to develop more land-efficient zero-carbon energy sources (eg, nuclear or CCS), even if these might be costlier than imported forms of energy.

56. The ETC's 2020 work programme entails detailed analysis of these options.

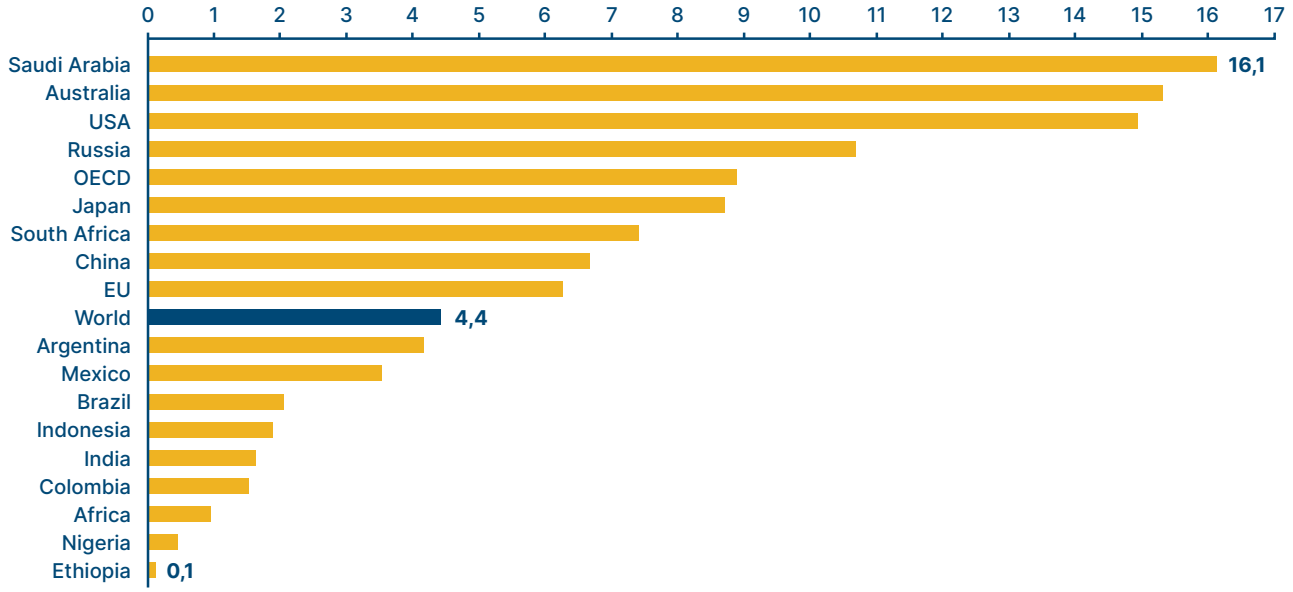
# II. Appropriate pace of decarbonisation in developed and developing economies

To limit global warming to 1.5°C, the whole global economy needs to reach net-zero emissions by around mid-century, sometime between 2050 and 2060. The pace of progress can and should reflect specific conditions, including the very large differences in current energy use per capita [Exhibit 1.2] and in emissions per capita [Exhibit 3.2] across countries. These differences in emissions per capita would be even more dramatic if considering emissions from national consumption rather than national production, as many developed countries import industrial products with a high carbon footprint produced elsewhere.

Exhibit 3.2

## Levels of carbon emissions per capita vary significantly by countries and continent

**Emissions per capita**
Emissions from fuel consumption only, tonnes per capita, 2018




**SOURCE:** IEA (2019), *World Energy Outlook*; IEA website

As a general principle, developed countries should make faster progress, to reflect both their greater responsibility for past emissions and the fact that higher income makes it easier to absorb the small impact on living standards described in Chapter 2.

The ETC therefore believes that the **overall objective** should be that:

- All developed economies reach net-zero emissions by 2050 at the latest.
- All developing countries achieve net-zero emissions by 2060 at the latest.

But some developing countries may be able to achieve full decarbonisation by 2050 or earlier at minimal additional cost relative to a 2060 objective. This is because:

- Some developing economies have extremely favourable endowments of zero-carbon resources, dramatically reducing decarbonisation costs.
- Some low-income countries, which have not yet developed significant power generation systems, could build power systems based from the start on renewable energy, avoiding the costly build-up of centralised power infrastructure and the complex transition challenge of closing down existing coal power plants.

In addition, some developing countries are well placed to become fully developed rich economies by 2050 and have the technological capability to achieve zero-carbon economies at low cost. Specific implications for China and India are discussed in the next two sections, while Sections V and VI identify some implications for Africa in particular, and for low-income developing economies in general.

# III. **China:** a fully developed rich zero-carbon economy by 2050

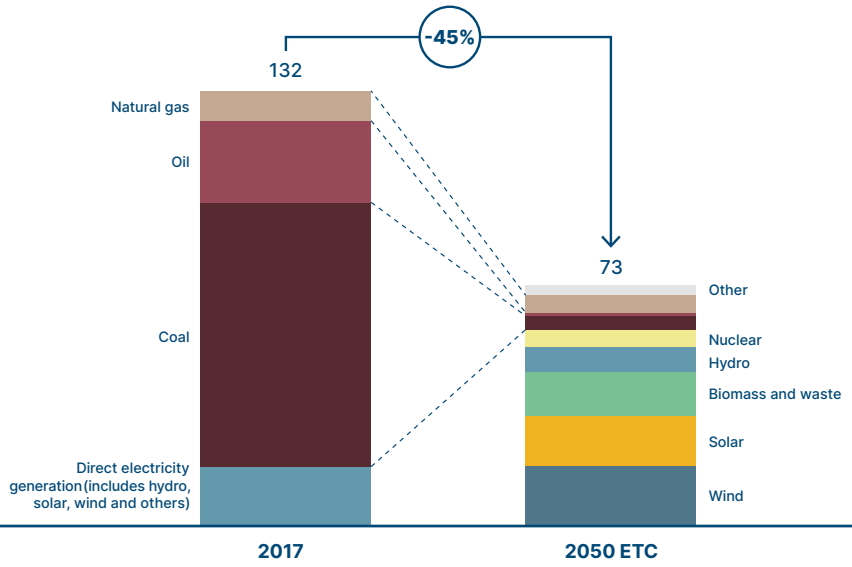
China is currently still a developing nation with a GDP per capita (power purchasing parity basis) about 40% of Western European levels. Its stated national objective is to become "a fully developed rich economy" by 2050. This is undoubtedly achievable given its past and current growth rates, its high levels of savings and investments, and its increasing technological leadership in many important sectors. The ETC's recent report *China 2050: a fully developed rich zero-carbon economy* describes how China could simultaneously achieve zero emissions by 2050 with a minimal impact on its GDP per capita – probably less than 1% and possibly nil.

China's path to decarbonisation will broadly match the pattern described in Chapter 1, with Exhibit 3.3 and Exhibit 3.4 summarising the changes in primary energy mix and final energy demand required in a zero-carbon pathway. This would entail:

- A huge increase in **electricity consumption**, rising from 6,700 TWh today to between 14,000 and 15,000 TWh in mid-century, and with about 70% of this electricity produced from wind and solar resources; nuclear (10%), hydro (14%) and thermal plant with CCS (7%) would also play important roles.
- The widespread **electrification of the economy**, including complete electrification of surface transport.
- A major growth in the **use of hydrogen**, with total consumption rising from 25 Mt today to 80 Mt by 2050.
- A significant role for **CCS**, offsetting around 1 Gt of emissions from continued fossil fuel use.
- An important role for **bioenergy**, accounting for around 13 EJ of primary energy demand in 2050, but with its role as a share of energy lower than in the global ETC scenario, given the constraints on sustainable Chinese bioenergy supply.

## The ETC China 2050 report foresees a dramatic change in China's primary energy mix, with fossil fuel use demand falling over 90%

**China's primary energy demand**
EJ/year




**NOTE:** The 2017 data is from the China Statistical Yearbook. The "Direct electricity generation" category was originally the "Others" category, including hydro, solar, wind and others.

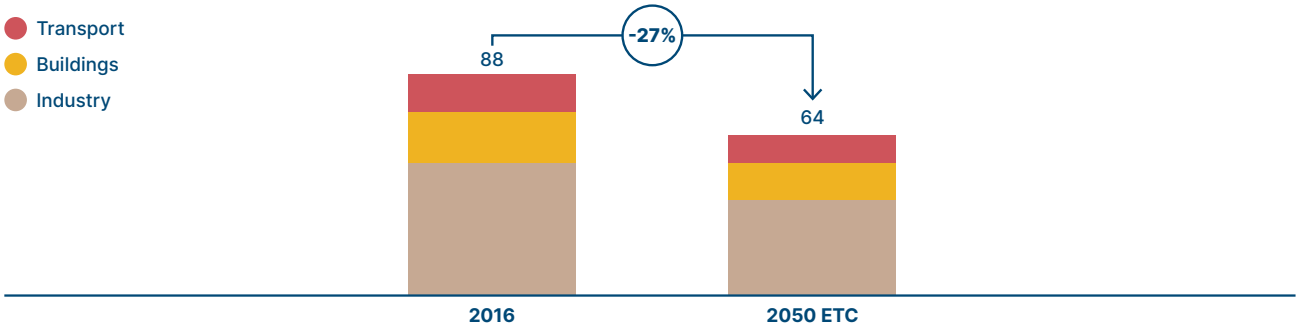
**SOURCE:** Energy Transitions Commission and Rocky Mountain Institute (2019), *China 2050: A Fully Developed Rich Zero-Carbon Economy*

Exhibit 3.3

Exhibit 3.4

## Under the ETC net-zero scenario, China would be able to reduce final energy demand from 88 EJ in 2016 to 64 EJ by 2050

**China's final energy demand**
EJ/year




**SOURCE:** Energy Transitions Commission and Rocky Mountain Institute (2019), *China 2050: A Fully Developed Rich Zero-Carbon Economy*

Achieving this 2050 endpoint would require a significant increase in the pace of China's **renewable energy investment** (about double the current annual investment in solar and three to four times that in wind), together with major investments in grid storage and flexibility resources, and rapid progress towards the decarbonisation of residential heat and industrial processes. But it is undoubtedly achievable, given China's natural resource endowment and strong industrial capability:

- As the maps in Exhibit 3.1 show, China has huge natural resources of wind and solar; it could, for instance, install the 2,500 GW of solar energy capacity required by 2050 while using less than 1% of its land area.
- China is already a leader in key technologies such as solar panels, batteries and electric vehicles, well placed to drive rapid cost reduction in electrolysis equipment and better placed to achieve rapid electrification of surface transport than many already developed economies.

Given a current savings and investment rate of over 40% of GDP, the additional investment required to create a zero-carbon-emissions economy (which we estimate at about 1% of GDP) could easily be financed. Indeed, increased green economy investment could play a useful role in rebalancing the Chinese economy away from its currently excessive reliance on real estate construction.

At present, however, and despite very large renewable energy investments, China is not yet on a clear path towards a net-zero economy and new coal investments are continuing despite evidence that renewables are now highly competitive on a new-build basis in most of China's provinces. Our current ETC China work on the power sector is therefore focused on identifying the investments and policies required to ensure that all China's growth in electricity from now on is met from zero-carbon sources: later work will turn to the challenge of how to phase out coal generation, probably after 2030.

# IV. **India:** driving power decarbonisation through renewable investment

ETC India's work has initially focused on the power sector, which, as in China, is currently dominated by coal power plants, providing around 70% of all power supply. Total **final electricity consumption** will need to grow from around 1,200 TWh in 2019 to something like 6,000 TWh by 2050 to support economic growth, rapid expansion in the use of air conditioning and the electrification of surface transport.[57] Still more may be needed to support decarbonisation of heavy industry (whether directly or via the use of hydrogen), on which ETC India is now working.

This dramatic **growth in electricity supply** could be delivered almost entirely via renewables and nuclear energy at close to no cost to electricity consumers, living standards or economic growth.

- Solar and wind energy are now the cheapest ways to deliver a kilowatt-hour of electricity in India, with BNEF estimates of total levelised cost for new-build power generation now less than that for coal or gas [Exhibit 3.5]. Estimated costs for renewables plus battery storage are also increasingly competitive with other forms of dispatchable plant; a recent auction for "round the clock" provision, which required bidders to commit to supply electricity for 80% of hours in the year, was won by a combination of solar plus batteries at a tariff of INR 2.9 per kWh (US$38 per MWh).[58]

- Wind and solar accounted in 2019 for 8% of India's on-grid generation, with nuclear, hydro, biomass and waste plants bringing total low/zero-carbon power to 25%. Detailed analysis by ETC India[59] shows that wind and solar generation could increase to about 32% of India's power generation by 2030 (with total low/zero-carbon power increasing to 47% of the total).In that high renewables penetration scenario, the total power system costs, allowing for necessary storage and flexibility resources, would not be higher than if new coal capacity were installed instead[60,61] [Exhibit 3.6].

- India can thus deliver rapid increases in electricity supply to support rising prosperity at a competitive total system cost, without building any more coal plants beyond those currently under construction.

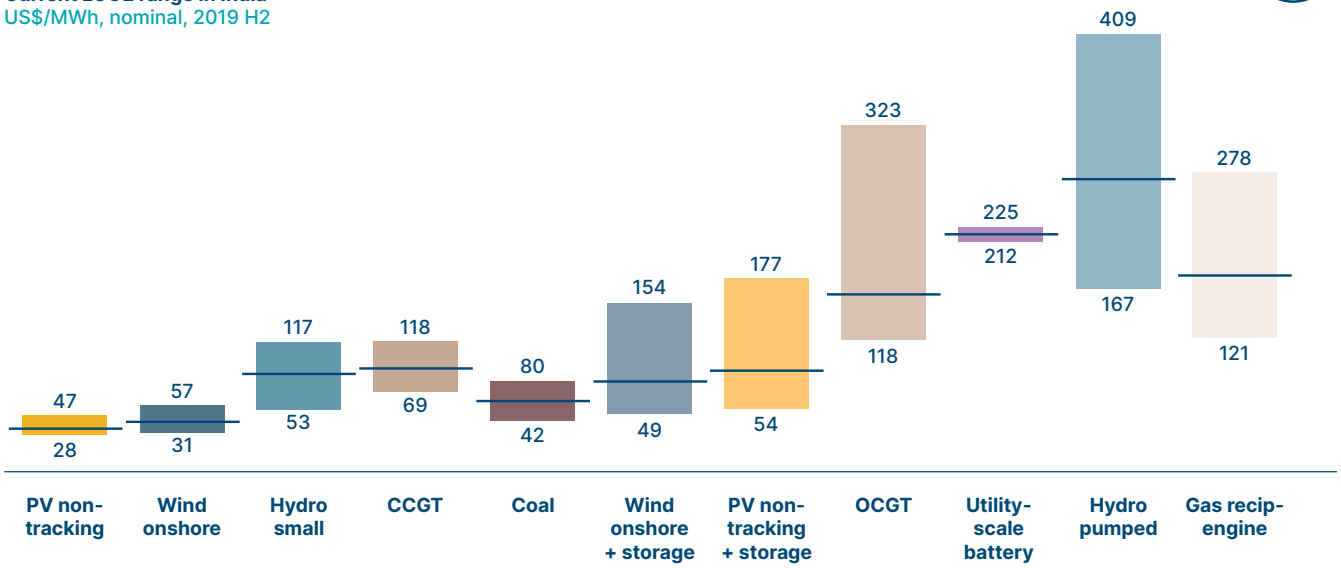
Further work by ETC India will focus on the feasibility and costs of India achieving a totally decarbonised power system by 2050, and on feasible pathways to the decarbonisation of heavy industry and heavy-duty transport by 2060 at the latest. Initial work on the power system shows that there are adequate solar and wind resources to support a zero-carbon power system delivering 6,000 TWh or more in 2050, and that total system costs of achieving that objective will be very small. Analysis will also need to consider the social and employment costs of closing or reducing existing coal capacity in the 2030s and 2040s.

57. Total generation is currently around 1,600 TWh, of which about 200 TWh is captive power generation not transmitted over the grid. The difference between total generation and consumption (about 24%) is considerably higher than in advanced economies, due to significant losses in the distribution system.
58. Ministry of New and Renewable Energy of India, (2020), *SECI, a CPSU, conducts e-Reverse Auction for the 400 MW RE projects with RTC supply.*
59. T. Spencer, N. Rodrigues, R. Pachouri, S. Thakre, G. Renjith, TERI (2020), *Renewable Power Pathways: Modelling The Integration Of Wind And Solar In India By 2030.*
60. R. Pachouri, T. Spencer and G. Renjith, TERI, (2018), *Exploring Electricity Supply-Mix Scenarios to 2030.*
61. R. Pachouri, T. Spencer, G. Renjith, S. Thakre and N. Rodrigues, TERI (2020), *Transition Pathways to a High Share of Renewables in the Indian Power Sector by 2030.*

Exhibit 3.5

## Solar and wind energy are now the cheapest ways to deliver a kilowatt-hour of electricity in India

**Current LCOE range in India**
US$/MWh, nominal, 2019 H2



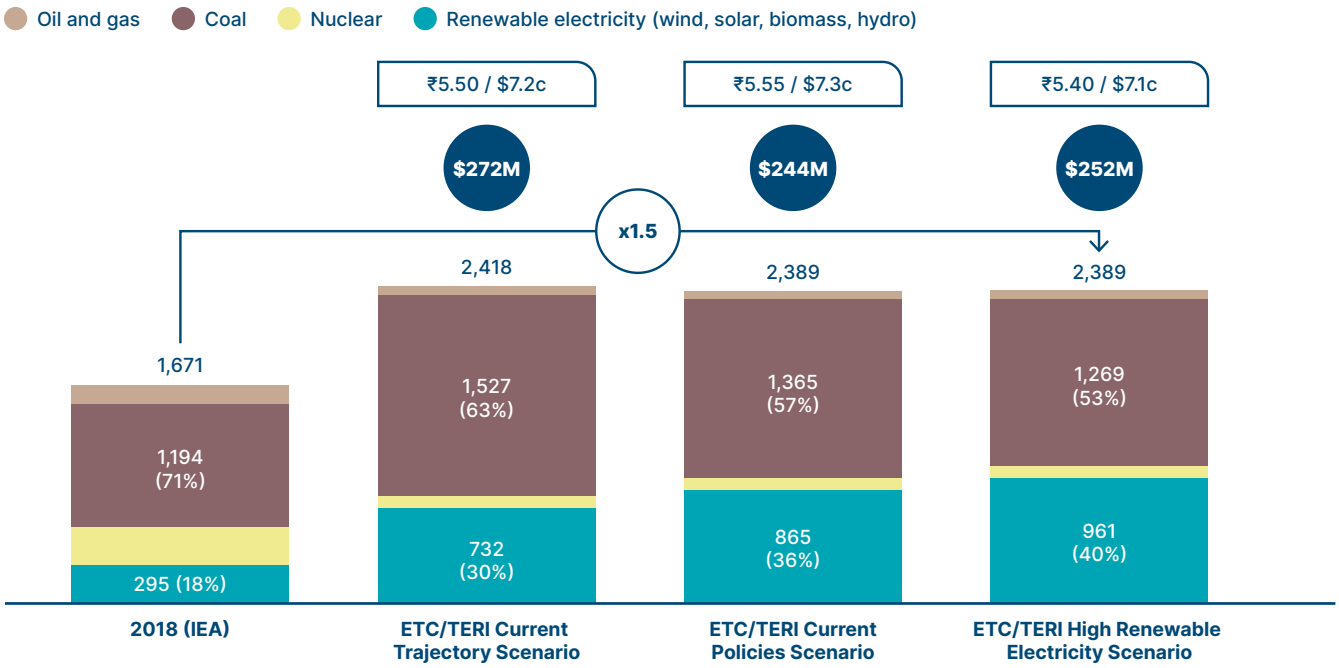

**SOURCE:** BloombergNEF (2020)

Exhibit 3.6

## Renewable electricity could grow from 18% of India's electricity supply mix to 40% by 2030 with no additional total investment

**Total electricity generated by 2030 in India in different scenarios**
000 TWh/year

System costs, R/kWh / US$ cents /kWh
Total capital investment until 2030, US$ million




**SOURCE:** IEA (2019), *World Energy Outlook; Pachouri R., Spencer T. and Renjith G., TERI, (2018), Exploring Electricity Supply-Mix Scenarios to 2030*

## V. Phasing out coal and getting new power systems right first time

Not only in India and China, but also in most other countries, **newly built renewable systems** can already deliver electricity at lower cost than new fossil fuel plants, even if the latter are not fitted with CCS/U; and BloombergNEF projections suggest that this advantage will increase dramatically over the coming years and decades [Exhibit 3.7]. Over time, moreover, the costs of renewables plus batteries or other forms of storage will also fall, reducing the costs of integrating a high share of renewables into power systems. As a result, ETC estimates – described in Chapter 1.II – show that total systems costs for power systems which are as much as 90% dependent on variable renewables are likely to be below the costs of new-build fossil fuel systems by 2035, and in many instances will become economic far earlier and will enjoy a major cost advantage. In almost all countries, there is therefore a strong economic case for ensuring that all expansion of the power system to meet growing electricity demand is zero-carbon in form. There is no need for the world to build any **new coal-fired power capacity** to support economic growth and rising living standards.

But that still leaves the challenge of how to phase out **existing coal capacity**. Current developing world emissions from coal-fired power plants, many recently built, amount to 10 Gt $CO_2$ per year and could grow to 11.8 Gt per year once coal power plants already under construction come on stream. If emissions continued at this rate for 30 years, cumulative emissions of c 300 Gt $CO_2$ would use up 40% of the total available carbon budget for a 1.5˚C climate scenario.

Credible paths to net-zero emissions must therefore also include strategies to eliminate emissions from existing coal plants at sufficiently early dates to make the 1.5°C objective attainable. In some countries, this may be possible at no net cost, with the cost of renewables falling below even the marginal cost of operating existing coal plants, which is likely to lead to the early retirement of thermal plants made uncompetitive. But in other countries, this may not occur early enough to drive coal entirely from the power system by 2050. BloombergNEF estimates for India, for instance, suggest that while solar and onshore wind may be cheaper than the marginal cost of running many existing coal plants by 2035, some existing coal plants may still have lower marginal cost [Exhibit 3.8]. In addition, coal or gas plants may need to play an important role as flexibility providers within variable renewable energy-dominated power systems.

**Strategies to reduce and eventually eliminate emissions** from existing coal (and gas) plants will need to entail some mix of:

- Maintaining coal or gas capacity, but using it only to provide peaking or seasonal backup to predominantly renewable systems.
- Adding CCS to coal and gas plants used in a peaking or seasonal backup mode, even if this will inevitably add more cost to total system operation.
- Closing coal or gas plants before end of useful life, even if the total system cost of new renewable capacity is still above the marginal cost of running an existing thermal plant.

The ETC's China, India and global work plans for 2020 include analysis of the **feasibility and costs** of these options. This analysis will consider the employment and economic development consequences of reduced coal use, particularly in regions where coal mining is concentrated, such as Shanxi province in China and the states of Jharkand and Odisha in India.[62] It will also spell out the dangers which lenders and investors may face if they fail to anticipate that existing coal assets may become uneconomic before end of technically useful life (the "stranded asset" problem).

62. Initial analysis of these issue in China shows that at the national level, the employment transition challenge is clearly manageable. Coal mining jobs in China have fallen from 5.3 to 3.3 million over the last six years, a pace of decline three times faster than needed to reduce coal jobs to zero by 2050. And with estimates suggesting that 75% of the mining workforce is over 40 years old, many workers will retire well before 2050. But with significant regional concentration (eg, one-quarter of all China's coal production is in Shanxi province), the local economic impact will need to be carefully managed.

## China: Onshore wind and PV is already cheaper than coal and gas when built from new today

**China – New-build bulk generation forecast**
LCOE, $/MWh (2019 real)

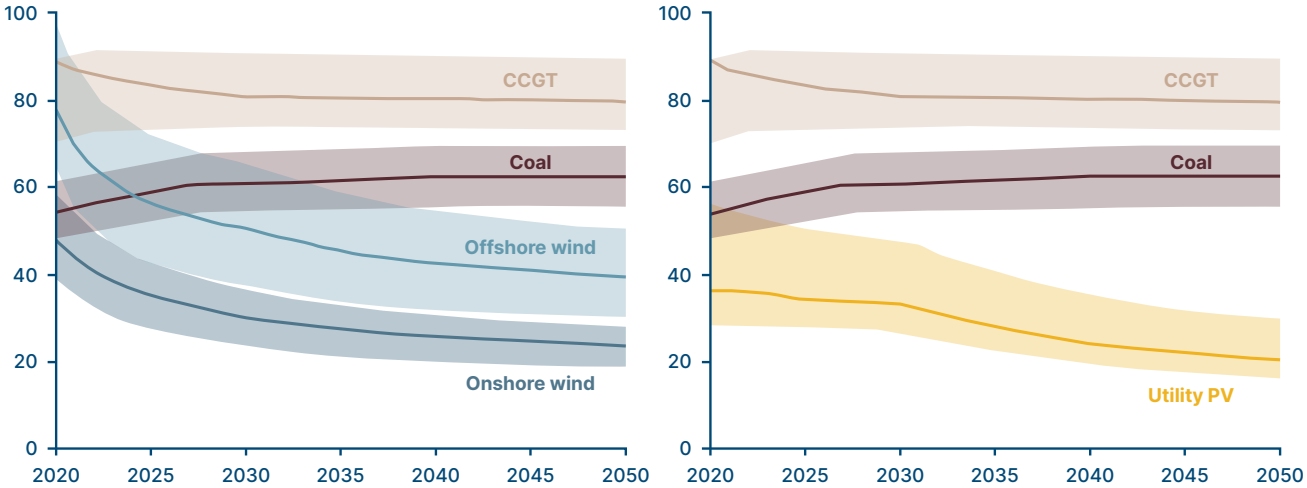



Exhibit 3.7

**SOURCE:** BloombergNEF

## India: New onshore wind and solar electricity generation may become cheaper than the marginal cost of running existing coal plants by 2035

**India – Bulk generation forecast – new-build wind & PV vs. existing coal & CCGT**
LCOE vs. running costs, $/MWh (2019 real)

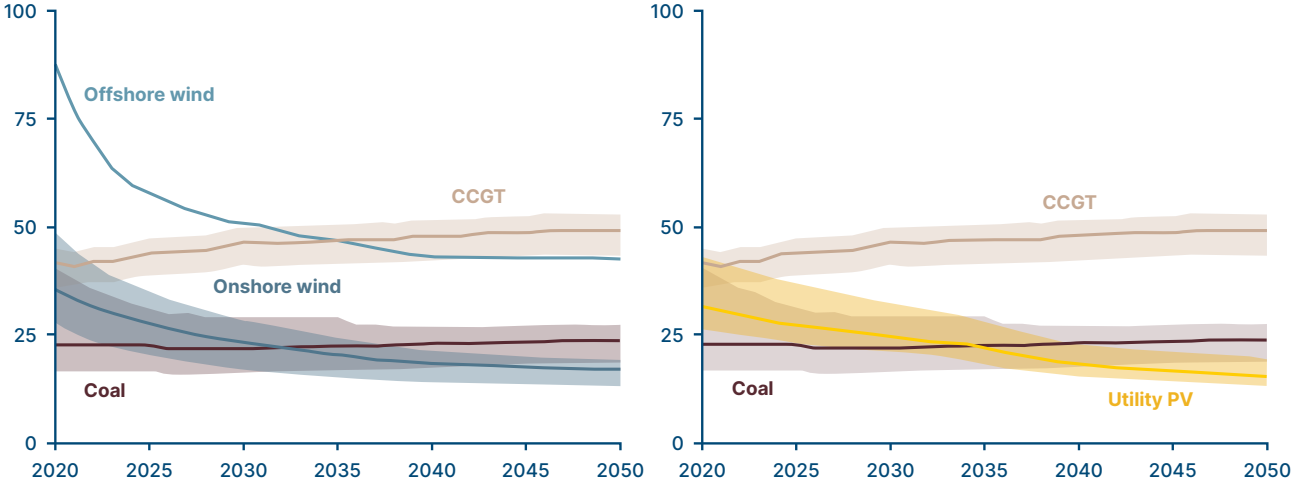



Exhibit 3.8

**SOURCE:** BloombergNEF

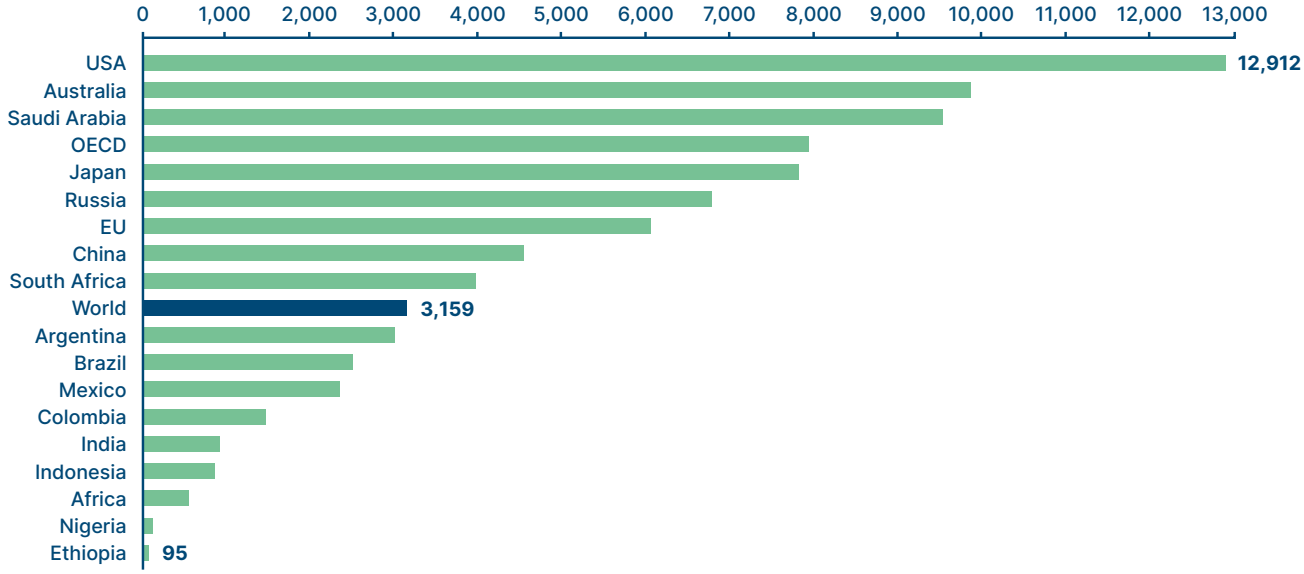
In some countries, however, present electricity consumption per capita is still so low and power systems are still so underdeveloped that the "existing coal" challenge is very small. Across the whole of **Africa**, for instance, electricity use per capita is currently just 550 kWh, compared with 900 kWh in India, 5,000 kWh in China and 12,000 kWh in the US [Exhibit 3.9]. Rapid and massive growth of electricity supply is therefore essential if Africa is to grow per capita living standards even to middle-income levels. Fortunately, the continent benefits from enormous potential solar and wind resources, making it possible to build zero-carbon energy systems right first time, using the most cost-competitive zero-carbon technologies.

However, as the latest IEA World Energy Outlook describes, the pace of renewable investment is currently minuscule: Africa currently has less installed solar capacity than the Netherlands. This minimal development reflects multiple barriers which reduce the availability and increase the cost of capital for investment in many African and other developing countries. Ensuring adequate supplies of capital to support massively increased renewable capacity in low-income countries is therefore a crucial priority.

Exhibit 3.9

## Electricity use per capita varies greatly across countries, reflecting living standards inequalities

**Electricity consumption per capita**
kWh per capita, 2018




**SOURCE:** IEA (2019), *World Energy Outlook*; IEA website

# VI. Financing challenges in developing economies

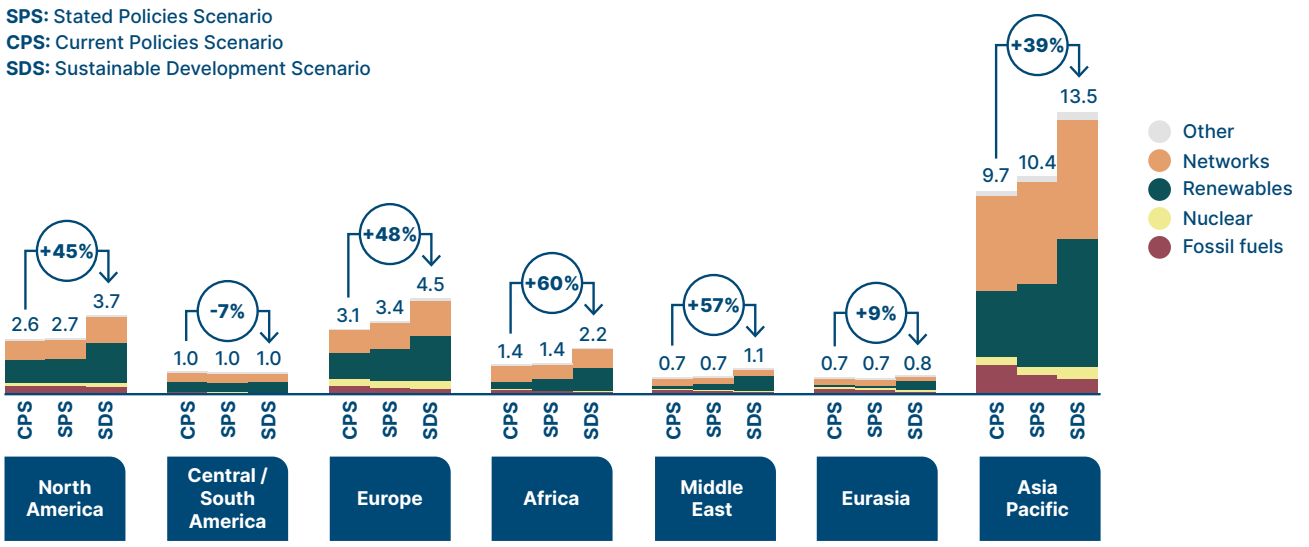
The additional investment required to build a zero-carbon emissions economy amounts to only about 1% to 1.5% of global GDP and is clearly feasible in a world where the balance of desired savings and investments currently results in real government bond yields below zero in most developed economies. Neither some aggregate "shortage of capital", nor a high "cost of capital" is likely to constrain progress towards a zero-carbon-emissions economy in already developed countries. Nor is this a constraint in China, given its very high savings and investment rates and a state-influenced financial system which ensures low-cost investment finance. In many developing economies, however, the **cost of capital** is significantly higher than in developed economies; and both the availability of capital and its cost could be a serious impediment to sufficiently rapid investment in new energy systems.

Exhibit 3.10 sets out IEA estimates of the power system investments by region required over the next 20 years to achieve even a 2°C scenario – let alone a 1.5°C scenario:

- In **Europe** and the **US**, it is likely that the required growth in investment – +$1.5 trillion for Europe and +$1.2 trillion for the US – will be available at reasonable cost, provided that policy establishes adequate incentives, in particular through appropriate power market design and carbon pricing.
- But to achieve the increase of US$0.8 trillion required in **Africa** and equally large increases in **Asia outside China** will probably require policies specifically focused on the mobilisation of adequate capital flows at adequately low cost, including concessional finance flows from developed countries.

## Adequate policy support is required for developing geographies to reach the required growth in investment in a sustainable scenario

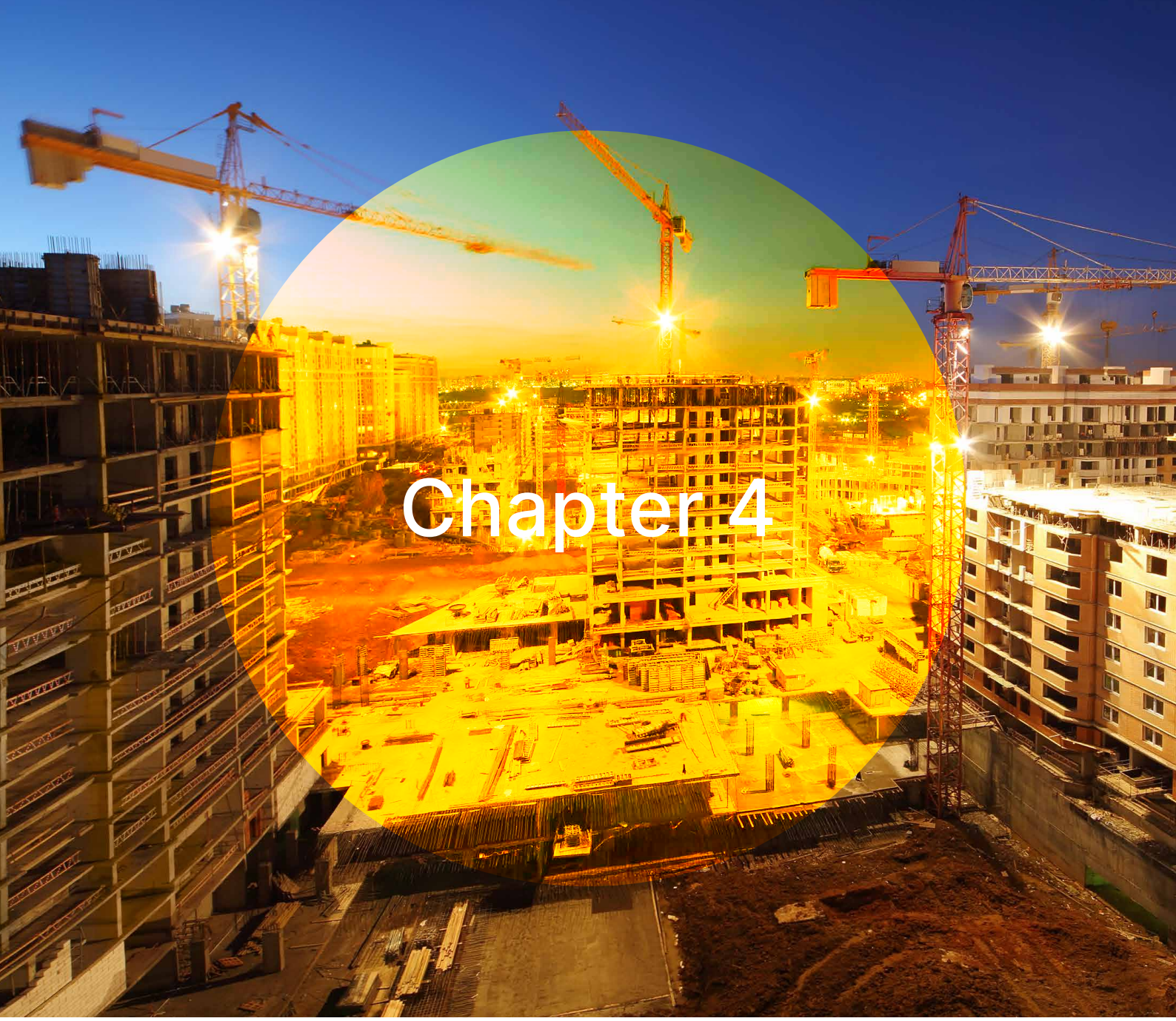
**Cumulative investment in power in the IEA scenarios**
US$ trillion, 2019-2040, cumulative




**NOTE:** Negative growth in Central and South America explained by the fall of fossil fuel investments in a Sustainable Development Scenario

**SOURCE:** IEA (2019), *World Energy Outlook*

Exhibit 3.10



Chapter 4

# Acting now to put 2050 targets within reach

# I. From vision to action

The ETC's work has thus far had a strong focus on the **feasibility and cost** of achieving a net-zero-emissions economy by 2050, and this summary report sets out our key conclusion: it is undoubtedly technically feasible and economically affordable for the whole world to achieve net-zero GHG emissions by mid-century, with all developed economies meeting that objective by 2050 and all developing economies within the following 10 years.

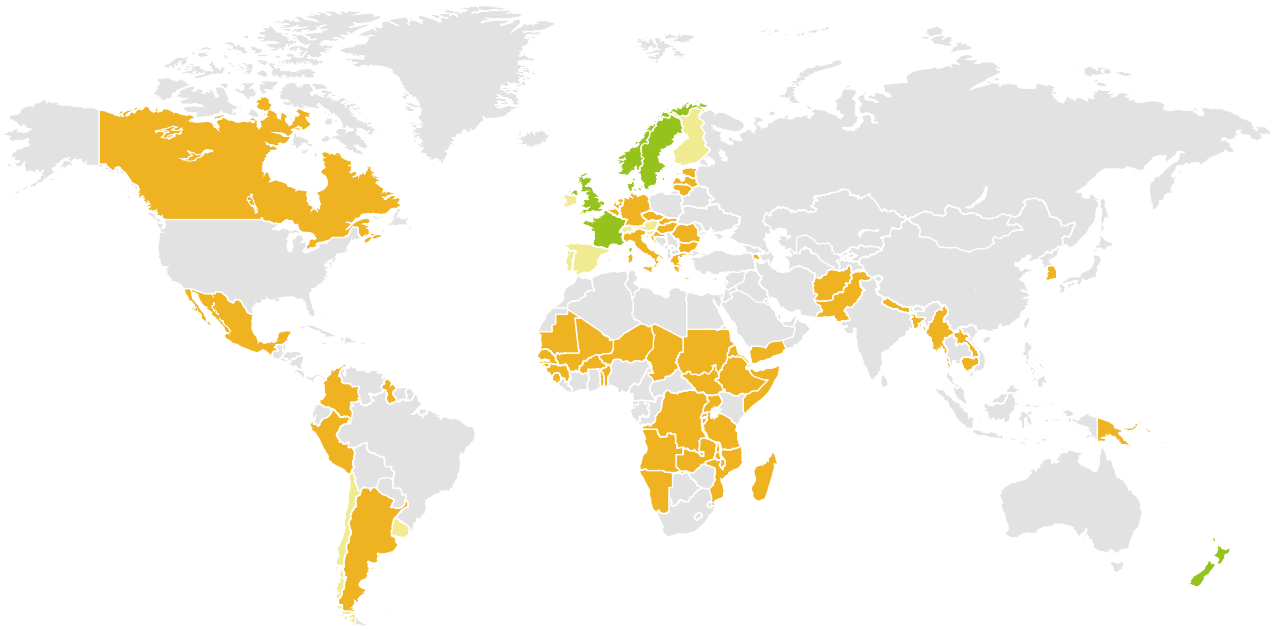
It is important to start by establishing that vision. Companies and countries need to be confident that the end point can be reached in order to commit to achieving it and to drive the policies and investments required to get there. Inspired by that confidence, an increasing number of countries, cities, companies and financial institutions have now made commitments to achieve net-zero emissions by 2050 or earlier [Exhibit 4.1].

Exhibit 4.1

## Five countries have already legislated a net-zero greenhouse gas emissions target, while over 100+ have targets proposed or under discussion

**State of net-zero legislations (February 2020)**

Legislated | Proposed or announced legislations | In discussions | None



**SOURCE:** Based on Bloomberg BNEF (2020), *Over 100 Countries Mulling Net-Zero Targets: BNEF WRAP*

With the 2050 vision established, it is now vital to identify the detailed actions and policies required over **the next decade**. This is essential for two reasons:

- First, because the world must achieve significant reductions in emissions by 2030 if it is to have any chance of limiting global warming to well below 2°C and ideally to 1.5°C. Most of the pathways compatible with a 1.5°C scenario shown on Exhibit 1.1 imply that emissions must reach 20 Gt $CO_2$ per annum by 2030 or soon thereafter: this would require a 50% reduction from current levels. But the world is far off track to achieve that reduction. The COVID-19 crisis has produced a significant short-term reduction in global emissions, but they are likely to rebound rapidly as economies recover; and underlying trends plus stated policies and commitments (as expressed in the NDCs which countries have made under the Paris Agreement) leave the world on a path towards 35 Gt $CO_2$ of emissions in 2030 and towards 3°C of warming or more by the end of the century.

- Second, because it will be impossible to achieve net-zero emissions by 2050 without significant progress along many dimensions by 2030, and current progress on investments, technologies and policies is far too slow to make a pathway to net-zero by 2050 feasible:

  - Progress in **energy productivity**, in particular energy efficiency improvements, is lagging behind. It improved by 1.2% per annum on average in 2018 whereas a minimum of 3% per annum would ideally be required[63].

  - The **pace of renewables investments** needs to accelerate dramatically to both decarbonise current power provision and support early electrification, making it feasible to deliver the 80,000 to 100,000 TWh per annum of green electricity which the world will need by 2050. In 2018, renewable power production was only 6,800 TWh globally.

  - In China, India and other developing economies, **coal power investments** are continuing despite the clear evidence that renewables are now the lower-cost option, driving up emissions in the short term and creating long-lasting high-carbon assets which will make future decarbonisation more difficult.

  - Fully electrified **surface transport** system by 2050 will not be feasible unless EVs dominate new vehicle sales by the late 2020s, but the current pace of progress towards this is far too slow (with EVs representing less than 0.1% of the global fleet in 2020).

  - Across many of the **harder-to-abate sectors**, capital investment cycles mean that significant initial investments must be made during the 2020s if full decarbonisation by 2050 is to be feasible.

  - Several **critical technologies** that need to be deployed at scale by the end of the 2020s/early 2030s still lack technological readiness (eg, synfuel production, zero-carbon primary steel production).

The **ETC's work programme for 2020 and 2021** is therefore focused on the actions required immediately and over the next 10 years both to drive initial emissions reductions and to make the path to net-zero by 2050 feasible. Exhibit 4.2 shows the key elements of this work programme, which include:

- Three workstreams focused on how to scale-up **zero-carbon energy provision** rapidly, in the form of zero-carbon power, hydrogen and bioenergy – these workstreams will fine-tune our analysis of the relative roles which these different technologies must play and on the pace at which they can be deployed. They will also be focused on the investments and policies required in the next decade to drive adequately fast progress.

- **China and India programmes**, which include a particular focus on the development of the power system over the next 10 years, identifying what needs to happen to halt new coal investment and to build zero-carbon power systems fast enough to meet all growth in electricity demand. Within our overall power workstream, we will also identify whether countries which currently have very limited power systems (particularly in Africa) could rapidly and cost-effectively develop near zero-carbon power systems while never going through a fossil fuel-based stage; and

- **The Mission Possible Platform**, developed in collaboration with the World Economic Forum, which is focused on working with companies in harder-to-abate sectors to identify the specific actions that companies, investors and finance providers need to take to drive the early development and deployment of key decarbonisation technologies.

63. IEA (2019), *World Energy Outlook*

## We will set out detailed recommendations on key dimensions of the transition towards net-zero in the course of the ETC's 2020-2021 workplan

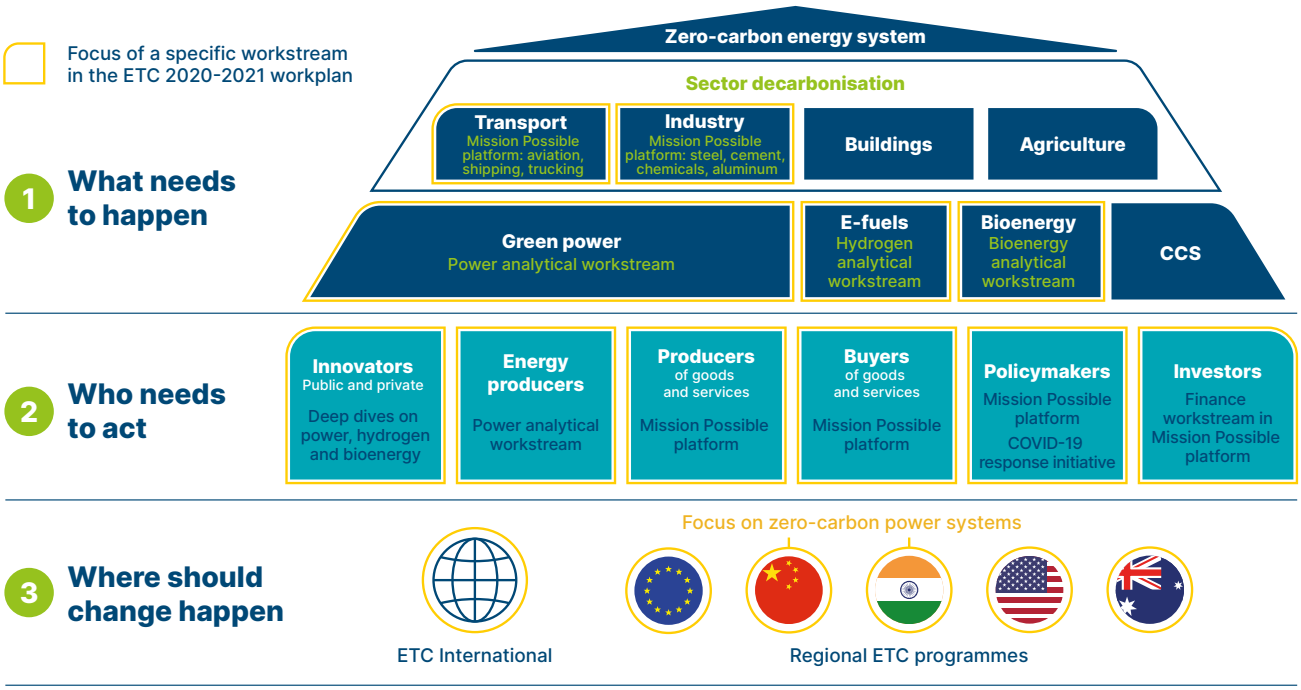



Exhibit 4.2

**SOURCE:** SYSTEMIQ for the Energy Transitions Commission (2020)

Our ongoing work on the priorities for the 2020s will identify how to make immediate government and private actions consistent with the medium-term targets required to achieve sufficient progress by 2030. The specific set of policies and business initiatives required to drive progress during the 2020s will vary by region and sector, and will be set out in detail in the reports arising from our individual 2020-2021 workstreams. But across all sectors and regions, some general principles and specific policy priorities are already clear.

These general recommendations as well as our 2020-2021 work programme, with its strong focus on the next decade, were developed before the onset of the COVID-19 pandemic, but they remain equally valid in the new economic conditions created by the crisis. **The COVID-19 crisis** has created both risks and opportunities for the energy transition:

- The risk that lower fossil fuel prices might make low carbon technologies temporarily less attractive, and that governments will be tempted to stimulate their economies in ways which boost short-term emissions and slow the required energy transformation.
- The opportunity to "build back better" – reinforcing investment in clean technologies in a world of low interest rates and supporting green jobs in a world where employment creation is now a high priority.

The ETC has therefore set out recommendations on the policies required to drive the green recovery, both at a general level and specifically in the Chinese context[64], which are in line with the recommendations for the 2020s described in the rest of this chapter.

64. ETC (2020), *7 Priorities to Help The Global Economy Recover; and ETC and Rocky Mountain Institute (2020), Achieving a Green Recovery for China: Putting Zero-Carbon Electrification at the Core.*

# II. Three objectives for the 2020s

Technology transformations can be thought of as involving three phases – the initial *emergence* of a new technology; its *diffusion* on a significant scale; and the moment it becomes the *new normal*, as the old technologies are entirely replaced.[65] The technologies which will enable us to build a zero-carbon-emissions economy – whether focused on supply-side decarbonisation or on energy efficiency improvement – are currently at different phases within this framework [Exhibit 4.3]. The nature of actions required from policy, industry and finance during the 2020s therefore differs by particular low/zero-carbon solution according to its stage of development.

## In each energy producing or consuming sector, decarbonisation typically proceeds through three phases

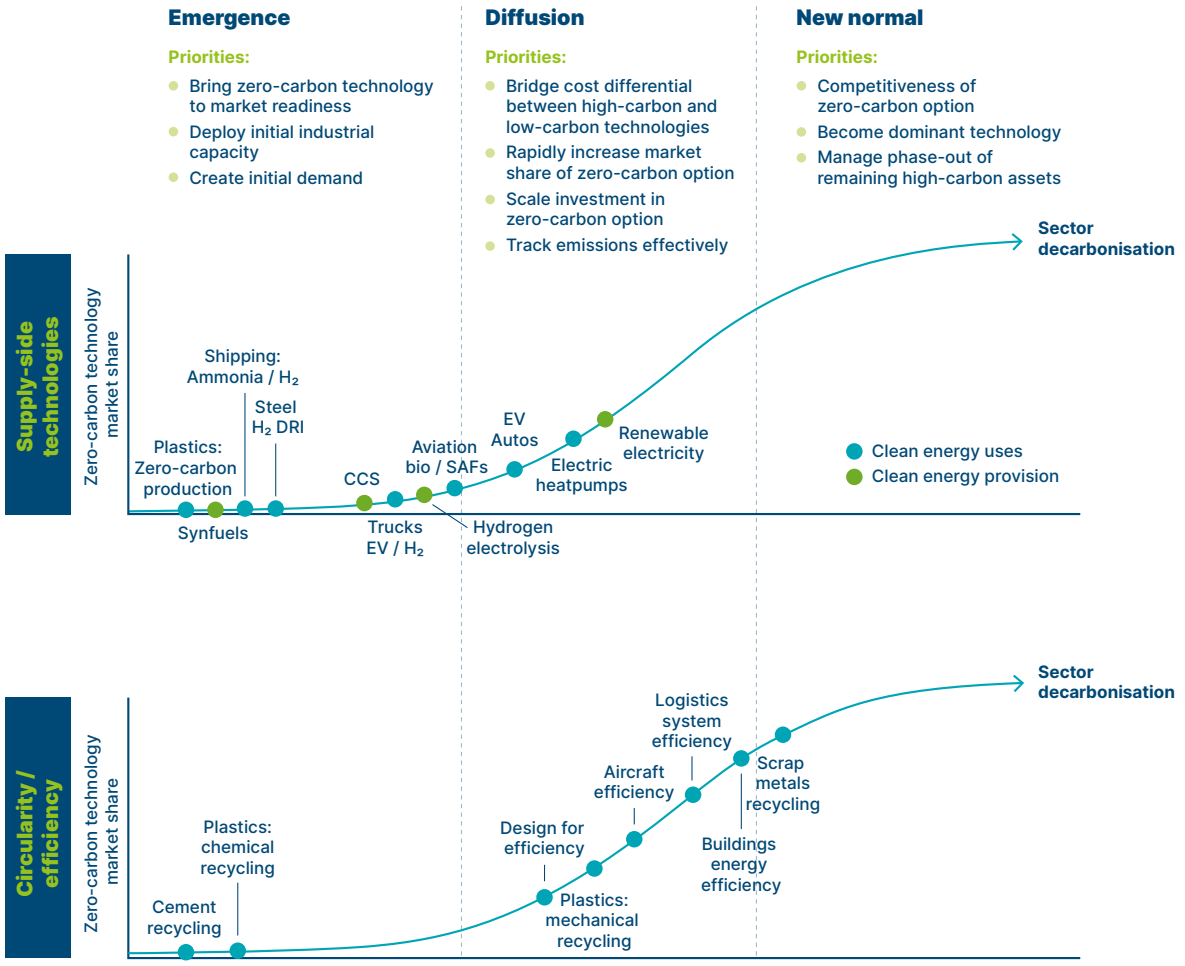



Exhibit 4.3

**SOURCE:** : SYSTEMIQ for the Energy Transitions Commission (2020), based on Source: Victor, D., Geels, F., Sharpe, S., Energy Transitions Commission (2019), *Accelerating the low-carbon transition: The case for stronger, more targeted and coordinated international action*

The ETC outlines **three objectives** which should shape both public and private action towards decarbonisation in the decade to come:

1. Speed up the deployment of zero-carbon power and other proven emissions reduction technologies and business models.
2. Create the right policy and investment environment to enable technology diffusion in all sectors where technologies are market ready, but still not cost-competitive.
3. Ensure the technologies that are still at the emergence phase are brought to market by the end of the 2020s at the latest.

65. Based on D. Victor, F. Geels and S. Sharpe, ETC (2019), *Accelerating the low-carbon transition: The case for stronger, more targeted and coordinated international action.*

## 1. Speed up deployment of proven zero-carbon solutions

Where low-carbon solutions already exist at similar or lower costs than the high-carbon alternative, the focus should be put on unlocking investment at scale to deploy rapidly in the 2020s and achieve real emissions reductions in the short term.

This implies addressing remaining **barriers to investment**, which often relate to:

- Perceived levels of risks from an investor perspective, which in turn result in higher cost of capital – new technologies and business models indeed suffer from greater uncertainty about the scale and price points of future markets and from a more limited investment track record;
- Country risks, which add up to sector-specific risks and constrain investments in developing countries;
- Consumer awareness and interest for the new product or service – especially addressing any question with regards to its robustness and ease of use (eg, addressing consumer concerns about range, charging time and availability of charging infrastructure for EVs);
- High upfront investments, which individual businesses or households may be unable to finance (eg, for buildings energy efficiency improvement);
- Deployment of the necessary underlying infrastructure (eg, charging infrastructure for EVs, grid infrastructure and flexibility provision for renewable power);
- Split incentives across the value chain, creating situations in which the person or organisation who needs to undertake the investment is not the one who stands to benefit from it (eg, split incentives between landlords and tenants in the buildings sector, between product manufacturers and the recycling industry in the consumer goods sector).

**Solutions** to these issues will come from a combination of:

- Policy – with a focus on creating greater market certainty through quantitative targets and appropriate market design, driving the development of necessary infrastructure, and addressing split incentive issues through regulations;
- Financial institutions – both private financial institutions which should scale investments in proven solutions and develop innovative financing mechanisms to overcome high upfront costs for businesses and households, and public financial institutions which contribute to infrastructure financing and de-risk private investments, especially in developing countries;
- Businesses – seizing new opportunities in improving and marketing low/zero-carbon solutions as well as in developing new business models which redistribute risks and benefits across the value chain.

### **Key priority 1:** Build massive capacities of zero-carbon power generation and transmission infrastructure

In the power sector, renewables are a proven zero-carbon technology that is already competitive with both new and existing fossil fuels in many locations and is becoming more so over time. The crucial priority now is therefore not technology development (except in some storage technologies), but rather driving the pace of renewables investment fast enough to make electrification clearly carbon-reducing and to start tangibly reducing emissions from the power sector before 2030. Required policies in the power sector will therefore entail clear quantitative objectives for the development of zero-carbon power by 2030 and for the reduction in the carbon intensity of electricity generation (measured in grams per kWh), supported by appropriate power market design and financing mechanisms [Exhibit 4.4]. Dialogue with investors and development finance institutions will be particularly important in developing economies to establish an attractive investment climate for clean power.

## The top priority in the 2020s is to deploy massive renewable power capacity to enable cheap electrification across the economy

Exhibit 4.4

**2050 vision**

**>80,000 TWh/year of green power generation**

**2020s targets**

**Cost objective**

Reach $30/MWh all-in cost in best locations and $60/MWh in worse locations before 2030

**Volume objective**

Reach >50% renewable electricity globally before 2030

**Key actions and responsibilities in the 2020s**

**Policy-makers**

- Establish **clear long-term quantitative targets for zero-carbon electricity capacity**, reflecting greatly increased supply need for green electrification:
  - **indicative targets for 2050**
  - **firm targets for 2030 to drive accelerated investment**
- Accept **long-term fixed price auctions as key feature of the "new normal" and launch large-scale auctions** to drive capacity acceleration
- **Establish market structures and incentives/ initial subsidies to drive development of storage and flexibility options**

**Investors**

- Invest massively in renewable power generation capacity
- Develop clear plans to **divest fossil fuel-based power** through time
- Increase **investment in power infrastructure** (e.g., long-distance transmission, city grids, charging infrastructure)

**Energy producers**

- **Plan for significant increases in power demand**, to be met by zero-carbon power

**Innovators** *Public and private*

- Bring **seasonal storage options** to commercial readiness
- Drive **battery cost reduction for stationary energy storage**

**Producers and buyers** *of goods and services*

- Expand zero-carbon **electricity and electrification commitments**, eg RE100 or EV100

**SOURCE:** SYSTEMIQ for the Energy Transitions Commission (2020)

## **Key priority 2:** Make the global light-duty vehicle fleet electric and build charging networks required

In sectors such as surface transport – where there is a clear low-cost path to decarbonisation, but where complete decarbonisation might be delayed by slow turnover of the vehicle stock – the crucial priority is to turbocharge deployment of electric vehicles (EVs for light-duty vehicles; a mix of EVs and FCEVs for heavy-duty vehicles) by setting deployment targets as well as clear dates beyond which the old technology cannot be sold – for instance, banning new sales of ICE light-duty vehicles in the early 2030s. This process should also be underpinned by accelerated investment in charging/ refuelling infrastructure.

## **Key priority 3:** Drive ambitious and systematic energy efficiency programmes in the building sector

Building energy efficiency is a well-known decarbonisation route, reducing both the energy requirement from the building sector and the cost of building heating decarbonisation. Building energy efficiency programmes should:

- Take into account both existing and new building stock through large-scale renovation strategies and strict energy standards for new buildings;
- Involve key public and private asset owners to cover the whole building stock (public buildings, social housing, corporate building owners, property developers...);
- Solve for high upfront investment costs by developing appropriate financing mechanisms for both businesses and households, in particular for building retrofitting;
- Target "zero-emissions" buildings for new builds, with increasingly ambitious targets covering lifecycle emissions, to kickstart demand for low-carbon materials;
- Encourage large-scale retrofitting projects at neighbourhood level to reduce costs.

Whereas the stock of housing and commercial buildings can be difficult to retrofit in existing cities, developing countries can take advantage of best available practices to build more energy-efficient buildings in the next wave of urbanisation.

## **Key priority 4:** Improve material efficiency and recycling through greater value chain collaboration

While a few material efficiency and recycling technologies are still in development (eg, chemical recycling of plastics), many of them are commercially available, but not deployed at their full potential because of split incentives across key materials value chains, like the buildings, automotive or consumer product value chains. Greater material efficiency and circularity can be achieved only through greater collaboration across the whole value chain:

- Industrial R&D focusing on designing products facilitating end-of-life dismantling and recycling;
- Regional partnerships in industrial clusters ensuring the deployment of the required materials collection and recycling infrastructure;
- Development of materials traceability mechanisms that enable the identification of recycled materials and a robust assessment of their lifecycle carbon emissions versus primary materials;
- Material buyers committing to low-lifecycle-carbon-emissions materials, in particular in the buildings and automotive sectors;
- Local and national governments using public procurement tools to boost demand for secondary materials.

Some of these collaborations might arise naturally between businesses who identify win-win solutions. But new policy mechanisms are also essential to accelerate progress, like taxation of landfilling or the application of extended producer responsibility to an increasingly large number of products.

# 2. Create the right policy and investment environment to enable technology diffusion

In multiple sectors of the economy, decarbonisation technologies are already close to technological readiness. However, their deployment is often hampered by the fact that they are presently higher cost than the high-carbon alternative. This is for instance the case of FCEVs in long-distance road transport, sustainable aviation fuels, or carbon capture for heavy industry. Although the cost differential between high-carbon and low-carbon solutions might eventually be reduced through economies of scale and learning curve effects, policy mechanisms need to be put in place to drive deployment in the 2020s.

Appropriate policies will differ from one sector to the other, depending on sectoral abatement costs and on whether there is a single foreseeable pathway to decarbonisation or a multiplicity of decarbonisation options. They will also differ by region, as they will need to be adapted to local specificities in economic structures, resource endowments, appropriate technology pathways, as well as pre-existing policy frameworks.

## **Key priority 5:** Remove fossil fuel subsidies and tax carbon (and other GHGs) to create appropriate price signals

**Fossil fuel subsidies** create a "negative carbon price", which distorts competition between energy sources, hinders decarbonisation efforts and incentivises consumption patterns that contribute to climate change. Removing them in all sectors – both at production level and at consumption level – is the first step towards a comprehensive effort to internalise externalities.

Once fossil fuel subsidies have been removed, **carbon pricing** becomes a key instrument to back the business case for low-carbon products and services. Adequate carbon pricing incentivises energy productivity improvement, stimulates the search for least-cost sustainable solutions, improves the cost-competitiveness of low/zero-carbon solutions and accelerates the deployment of capital in those solutions. It is a particularly important tool to drive decarbonisation in sectors where there is no single solution, like heavy industry.

Existing carbon pricing schemes, such as the EU-ETS, have begun to play a role in driving down carbon emissions. However, triggering a technology switch in the harder-to-abate sectors of the economy will require carbon prices of over US$100 per tonne by 2030 – well above existing carbon prices, for instance in the EU Emissions Trading Scheme (EU ETS). Three **additional challenges** have limited the effectiveness of existing carbon pricing schemes to date:

- The danger that if international agreement cannot be achieved, the imposition of carbon taxes in one country could result in shifts in the production location of internationally traded goods and services (eg, steel and aluminium), which has often led to exceptions within carbon pricing schemes (eg, free allocations in the EU ETS);
- Very different marginal abatement costs by sector which, together with high emissions caps, mean that the resulting prices may be far too low to provoke change in the higher-cost sectors (eg, heavy industry);
- The uncertainty of long-term prices in emissions trading systems, which do not provide a sufficiently strong long-term price signal to spur technology development.

To overcome these challenges, international agreements covering all sectors remain ideal and it is vital to pursue them. However, policymakers should also recognise that if the ideal is not possible, there is still an opportunity to make progress. Existing emissions trading schemes can be strengthened by developing complementary, imperfect but useful approaches. For maximum impact, these should aim to be:

- **Defined in advance**, with specific taxes or floor prices in some cases providing greater certainty and thus more powerful incentives than can be achieved through fluctuating prices;
- **Differentiated by sector**, to reflect different marginal abatement costs and technology readiness – for instance, with far higher carbon price applied in shipping than in the materials-producing industrial sectors;
- **Domestic/regional** – for instance, with a significant carbon price applied to cement, where competition is primarily domestic, even while not applied at the same level to steel, using free allocation within emissions trading schemes or compensation schemes to avoid carbon leakage dangers (with allocations/compensations combined with increasingly ambitious benchmark technology standards so as to provide incentives for innovation and investment);
- **Downstream** – that is, applied to the lifecycle carbon emissions of consumer products rather than production processes, as is the case with excise duties on gasoline and diesel, which are effectively subject to a carbon tax whatever the location of crude oil production and refining.

Carbon prices may also need to be combined with **border carbon adjustments** – including carbon tariffs on imports and carbon rebates on exports – to both protect local industry against high-carbon competition from producers who are not facing the same decarbonisation constraints and to incentivise other countries to implement equivalent climate policies.

## **Key priority 6:** Use standards and regulations to accelerate decarbonisation where price signals are insufficient

In some sectors, price signals are likely to be insufficient to drive deployment of low/zero-carbon technologies, either because non-cost drivers are blocking progress (eg, split incentives in the buildings value chain between landlords and tenants), or because the price signal that would be required for that particular sector is higher than the whole-economy carbon price reached (eg, more than US$200/tonne of $CO_2$ for aviation and shipping). In those cases – especially those where the set of solutions is well identified – standards and regulations might be more effective to drive progress by establishing explicit targets, creating greater market certainty, and therefore also facilitating investments.

These policies can take the form of:

- Increasingly ambitious GHG emissions standards, including regulations on lifecycle emissions of consumer products (like buildings or automotive);
- Renewable energy or fuel mandates with a progressive tightening of targets, in particular in the transport sectors (including shipping and aviation);
- Eventual bans on the most carbon-intensive products and services.

## **Key priority 7:** Channel investment into the transition of high-emissions activities

Achieving the full decarbonisation of the economy will require major investments in clean energy provision (power primarily, as well as hydrogen, biomass and carbon capture). It will also require investments in new industrial assets and the retrofitting of existing high-carbon assets, starting in the 2020s. These investments are comparatively smaller in aggregate terms than those required in the energy sector, but are likely to be undertaken by individual companies in harder-to-abate sectors for whom they represent a significant quantum of investment.

In this context, both equity finance and project finance will need to be mobilised to underpin the transition of high-emissions activities. Financial institutions will be expected to finance not only intrinsically "green" activities (eg, renewable power generation), but also transitioning activities (eg, steel companies which are currently high emitters but are progressively reducing their carbon footprint).

Unleashing investment in the transition requires that the following steps be undertaken – which the ETC will contribute to in 2020-2021:

- Implement the policy package described above (removal of fossil fuel subsidies, tightening of carbon pricing and new regulations), without which there would be no robust business case for investment in the transition and private finance could not be effectively mobilised;
- Develop a more granular investment roadmap mapping the nature and quantum of investment required over time to transition key value chains to low and eventually zero carbon – against which investment flows can be tracked;
- Support financial institutions in assessing transition risks and opportunities better on a sectoral basis, taking into account not only in-sector decarbonisation pathways but also probable evolutions in demand trends (through shifts in consumer patterns, circularity, etc.);
- Establish a robust transition finance taxonomy clearly identifying which activities and companies are on a trajectory aligned with climate targets and which are not – building on the work undertaken by the European Commission with the Sustainable Finance Taxonomy;
- Mobilise public finance through a range of tools (from direct subsidy to loan guarantees) to de-risk the first wave of industrial-scale investments in new activities, especially in developing economies.

# 3. Enable the emergence of the next wave of zero-carbon technologies

Company actions and public policies must also support the development of decarbonisation technologies which are still at the emergence phase, especially those that are relevant to multiple sectors. These include hydrogen from electrolysis, synthetic hydrocarbon production, capture of $CO_2$ and biofuels (where however the issue of true sustainability of feedstocks is as important as technological development).

This will still require public support at the research and development stage (including for industrial-scale demonstration); but, beyond technology development issues, it is also crucial to overcome the "chicken and egg" problem, which can slow the pace of development, with early use applications held back by high costs, which in turn makes it difficult for producers to achieve the economies of scale and learning curve effects that can rapidly reduce cost.

## **Key priority 8:** Focus public and private R&D support on critical technology targets

Complete decarbonisation of the economy could be achieved using technologies already under development. But many of them are still not market-ready and have not been deployed at commercial scale. In addition, over the coming decades, future unpredictable technological breakthroughs will almost certainly afford different and cheaper routes to decarbonisation. Both private investment and public support are required in the 2020s onwards to drive both incremental and breakthrough innovation, ensure that critical technologies are market-ready by the end of the decade and enable their early deployment to underpin cost reductions that will facilitate their diffusion in the 2030s and 2040s. Key innovation targets are summarised in Exhibit 4.5.

## **Key priority 9:** De-risk end-to-end pilots to test new technologies in the context of their value chain

The deployment of key decarbonisation technologies often requires coordinated actions at all levels of the value chain, including upstream (zero-carbon) fuel producers, energy transportation and distribution infrastructure, equipment providers, product manufacturers, service providers, and end users. Establishing the technical and market readiness of a low/zero-carbon technology therefore requires the development of end-to-end pilots involving all critical players in the value chain. For instance, piloting hydrogen-based reduction of iron for steel production is likely to require a collaborative project involving not only the steel manufacturer, but also a hydrogen producer, an iron ore producer and industrial equipment providers. Similarly, piloting zero-carbon shipping is likely to require the mobilisation of fuel providers, ship builders, engine manufacturers, fuel tank manufacturers, ship owners, ship operators, bunkering providers and ports.

To ensure the success of a commercial-scale pilot, three critical barriers need to be addressed at each step of the value chain: technology risks (in particular with regards to feasibility, safety and quality), capital investment and additional operational costs. Capex and opex requirements will vary for different stakeholders across the value chain, as will their ability to absorb or pass on additional costs to their consumers, and their ease of access to finance for the necessary capital investments.

This type of end-to-end value chain pilots is particularly difficult to finance given the combination of technology risks, investment needs, operational costs, as well as the number and diversity of stakeholders involved. Innovative risk-sharing models and public support mechanisms therefore need to be developed to facilitate their financing. Solutions might include new corporate partnerships (like joint ventures or offtake agreement), innovative financing products (including for instance new insurance mechanisms), as well as tailored public support mechanisms (eg, tax incentives, subsidies, blended finance mechanisms, public procurement, public-private partnerships).

# Key innovation areas to fully decarbonise the economy

Incremental innovation · Breakthrough innovation

## Electrification

- Cheaper and more energy-dense batteries
- Cheaper and more efficient heat pumps
- Electric furnaces for cement and chemicals
- Electrochemical reduction of iron for steel production

## Hydrogen

- Cheaper electrolysis (targeting $200/kW)
- Cheaper hydrogen fuel cells and tanks
- Long-distance transport of hydrogen via high-capacity piepline
- Large-scale geological storage (in salt or rock caverns)
- Hydrogen / ammonia burning ship engines and turbines

## Bio and synthetic chemistry

- Increased efficiency of lignocellulosis/ algal biomass transformation
- Cheaper production of synthetic fuels based on a combination of hydrogen and $CO_2$
- Electrochemical reduction of iron for steel production
- New chemical products based on bio or synthetic feedstocks

## Materials efficiency and circularity

- New designs for consumer products
- Material traceability, collection, sorting and recycling technologies
- New business models: product-as-a-service, sharing

## New materials

- Low-carbon cement and concrete chemistries
- Biomaterials for construction
- Cellulose-based fibres as a substitute for plastics

## Carbon capture and use

- More efficient carbon capture, especially for cement
- Cheaper direct air capture of $CO_2$
- Use of carbon in concrete, aggregates and carbon fibre

## Food, land and oceans

- Precision/digital agriculture and regenerative agriculture
- Improved supply chain and cold chain storage technologies
- Alternative proteins, including cultured meats
- Large-scale, sustainable ocean macroalgal (seaweed) production

Exhibit 4.5

**SOURCE:** SYSTEMIQ for the Energy Transitions Commission (2020)

## **Key priority 10:** Foster value chain collaboration to coherently develop supply and demand in key emergence sectors

Policy should build on the successful development of renewable power and battery technology. The dramatic falls in the cost of solar and wind power and of lithium ion batteries shown in Exhibits 1.10 and 1.11 did not happen automatically as a result of innovation spending, but occurred because initial subsidy support and policy mechanisms creating demand (through auctions and targets) enabled the industry to achieve a scale which unleashed dramatic cost reduction.

In the 2020s, the focus should therefore be on ensuring sufficiently rapid development of demand and supply of the next wave of decarbonisation technologies to make accelerated deployment possible in the 2030s, *en route* to a 2050 world in which all required decarbonisation technologies are deployed at scale. Unlocking the "chicken and egg" issue will require collaboration across the relevant value chains to:

- Identify the niche markets and geographical clusters that are most likely to provide early demand for the new technology, because of the market readiness and economics of that particular use case;
- Develop offtake agreements and purchasing commitments that will create greater market certainty to underpin early investments in the supply chain;
- Secure public support for both initial commercial production (in the form of innovation subsidies as well as investment support for the first wave of industrial-scale developments) and for the early demand sectors;
- Define a coherent pace of ramp-up of both supply and demand with all relevant stakeholders to limit the risk of short-term bottlenecks and market volatility;
- Identify deployment tipping points which are likely to unlock economies of scale and learning curve effects with the aim of reaching these tipping points before 2030.

Two examples of recommendations for technology deployment are presented below:

- Scaling up the hydrogen economy [Exhibit 4.6];
- Achieving a zero-carbon steel industry [Exhibit 4.7].

### Key actions to accelerate the hydrogen economy scale-up in the 2020s

**2050 vision**

**>600Mt/year green/blue $H_2$ production**

**2020s tipping point**

Adding **30-70 GW of additional electrolysis capacity** globally to **reach cost parity of green hydrogen with grey hydrogen** by 2030[1]

**Barriers and priorities**

**Innovation**
- Key technologies (eg alkaline and PEM electrolysers and fuel cells) already exist, but **further development needed to reduce costs and improve performance**
- **Safety issues** (eg, charging stations, shipping engines)

**Cost differential**
- **Today:** green $H_2$ at US$2.5-4.6/kg vs. grey hydrogen at US$0.7-2.2/kg today and blue hydrogen at US$1.3-2.9/kg
- **Levers to reach parity:** electrolysis capex, electricity price, CCS capex, carbon pricing

**Infrastructure**
- Lack of **hydrogen storage and distribution network**
- **Limited electrolyser capacity**
- Lack of uniformly distributed **carbon storage**

**Market structure**
- **Uncertainty on the supply chain model and cost trade-offs**: utility scale and centralised vs. small-scale and close to end use
- 3 options for green electrolysis: curtailed power, dedicated renewables or grid power

**Key actions and responsibilities in the 2020s**

**Policy-makers**
- **National/local $H_2$ strategies** with deployment targets
- Initial **subsidy support** targeting <$150 electrolysis by 2030
- Launch **green/blue production pilots**

**Investors**
- Evaluate **hydrogen opportunities in portfolios** (eg, electrolyser manufacture, end-use technology)
- Develop **early-stage innovation funds** to scale up hydrogen production

**Innovators, producers and buyers**

Electrolysis and fuel cell producers
- Targeted R&D on:
  - **Electrolysis:** targeting 2030 <$150/kW
  - **Key use technologies:** fuel cells

Heavy industry
- Develop **use applications**, eg, $H_2$ DRI

Trucking and logistics companies
- Collaborate and commit to either **blue/ green purchase targets or electrolysis purchase targets**

Shipping companies
- Collaborate and develop **infrastructure for ammonia handling in ports**

[1] based on *Hydrogen Council predictions from Hydrogen Council (2020), Path To Hydrogen Competitiveness, A Cost Perspective, and BNEF's optimistic case* in BloombergNEF (2020), *Hydrogen Economy Outlook*

Exhibit 4.6

# Key actions to accelerate zero-carbon steel scale-up in the 2020s

Exhibit 4.7

## 2050 vision

**100% zero-carbon primary and secondary steel**

## 2020s target

**Production deployment objective**

10 commercial-scale low-emissions carbon steel plants under construction to come online in early 2030s (1% of 2018 global steel production)

### Barriers and priorities

**Innovation**

- Hydrogen DRI at **development and early deployment stage**

**Cost differential**

- **Cost premium of energy** (hydrogen and electricity) and tech (eg, hydrogen DRI or CCS on blast furnaces)

**Asset turnover**

- Steel mills: turnover of **20-30y**
- Carbon-intensive new plants **already commissioned**

**Infrastructure**

- **No green hydrogen supply chain at scale**
- **Limited CCS infrastructure deployment** (strong political resistance)

**Market structure**

- **Competitive and trade-exposed market** requires premium markets and/or incentives (such as carbon prices with CBA)

### Key actions and responsibilities in the 2020s

**Policy-makers**

- **LCA emissions standards** for buildings and vehicles (LDVs and HDVs)
- **Preferential public procurement** for buildings and infrastructure
- Set up innovation subsidies as well as investment support for the first wave of industrial-scale developments
- **Carbon-based trade adjustment mechanism agreements** across 3-4 major producing regions

**Investors**

- Concentrate on **easier-to-scale markets**:
  - Public building/infra procurement
  - Automotive industry (esp. high-end)
  - Renewable energy manufacturers

**Innovators** *Public and private*

- **Enhanced RD&D support for industrial-scale demonstration** of greenfield and brownfield zero-carbon steel technologies

**Steel producers**

- Define detailed **decarbonisation pathways Collaborate with green finance and governments**
- **to deploy 10 commercial plants** (~1% of global steel market)

**Steel buyers** *of goods and services*

- **Voluntary 2030 purchase commitment of premium green steel** by OEMs and renewable energy manufacturers

**Energy producers**

- Collaborate with steel producers to **create industrial clusters** with cheap renewable energy and grey/green hydrogen production on site

**SOURCE:** SYSTEMIQ for the Energy Transitions Commission (2020)

Energy Transitions Commission

# Making progress by 2030 to achieve net-zero by 2050

## A shared responsibility

**Policy-makers**
create conditions for rapid private sector action & build up infrastructure

**Innovators**
bring to market and reduce the cost of zero-emissions technologies

**Energy producers**
produce low-cost and abundant zero-emissions energy

**Producers** of goods and services
transform deeply processes and business models to embrace efficiency and zero-emissions production

**Buyers** of goods and services
demand and pay for low-emissions and eventuallyzero-emis sions goods and services

**Financial institutions**
finance zero-carbon assets and companies in transition

| 2030 objectives | 10 key priorities | Primary accountability |
|---|---|---|
| Speed up deployment of proven zero-carbon solutions | 1 Build massive capacities of zero-carbon power generation and associated transmission and distribution infrastructure | |
| | 2 Make the global light-duty vehicle fleet electric and build charging networks required | |
| | 3 Drive ambitious and systematic energy efficiency programmes in the building sector | |
| | 4 Improve material efficiency and recycling through greater value chain collaboration | |
| Create the right policy and investment environment for technology diffusion | 5 Remove fossil-fuels subsidies and tax carbon and other GHGs (targeting over \$100/tonne $CO_2$ before 2030) | |
| | 6 Use standards and regulations to accelerate decarbonisation where price signals are insufficient | |
| | 7 Channel investment into the transition of high-emissions activities | |
| Enable the emergence of the next wave of zero-carbon technologies | 8 Focus public and private R&D support on critical technology targets | |
| | 9 Foster value chain collaboration to coherently develop supply and demand in key emergence sectors | |
| | 10 De-risk end-to-end pilots to test new technologies in the context of their value chain | |

# Conclusive remarks

**The Energy Transitions Commission believes it is possible to reach net-zero carbon emissions by mid-century, significantly increasing the chance of limiting global warming to 1.5°C. Actions taken in the coming decade are critical to put the global economy on the right track to achieve this objective. Succeeding in that historic endeavour would not only limit the harmful impact of climate change, but also drive prosperity and better living standards, while delivering important local environment benefits. Policymakers, investors, innovators, producers, buyers and more generally both public and private sectors have a major responsibility to collaborate and act now at the local, national, regional and global scales to achieve the 10 key priorities outlined in this document before 2030.**

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Photograph on opposite page by chuttersnap

# Making Mission Possible

## Delivering a Net-Zero Economy

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