

5 Transformations needed to achieve the Paris Agreement in electricity supply, industry, buildings and transportation

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5.1 Introduction

In light of the magnitude of the emissions gap, wide-ranging, large-scale, rapid and systemic transformation is now necessary to achieve the temperature goal of the Paris Agreement. To inform action, the emissions gap can be translated into sectoral transformations that bend the emissions trajectory by 2030 and lead to zero emissions in the longer term. The challenge is that multiple major transformations must be initiated in this decade, simultaneously across all systems. Transformations of the way we power our homes and businesses; transport people, goods and services; grow and consume food; build our cities; and manage our lands, are among the required shifts, which need to take place while simultaneously improving the livelihoods of the poorest including women and minorities, and achieving the Sustainable Development Goals. Shifts are needed from phasing out fossil fuels, to electrifying transport, to stopping deforestation, to retrofitting buildings (Intergovernmental Panel on Climate Change [IPCC] 2021).

The energy, food security and cost of living crises fuelled by the war in Ukraine, with resulting energy supply shortages and price spikes, has added an additional imperative to act. The conflict highlights the vulnerability of the current global energy system, given its dependence on fossil fuels produced from a very small number of countries. In the short term, many governments seek to secure alternatives to Russian oil and gas; in some cases, coal use is on the rise. They also aim to reduce demand for fossil fuels through behavioural measures, energy efficiency and faster investments in renewable energy. The net effect on the climate agenda and transition to renewables is still unknown (Climate Action Tracker [CAT] 2022b).

This chapter focuses on the key transformations required in electricity supply, industry, buildings and transportation, while chapter 6 focuses on the transformation of food systems, and chapter 7 on transforming the financial system. For the purposes of this report, transformation is defined as

“the reconfiguration of a system, including its component parts and the interactions between these elements, such that it leads to the formation of a new system that produces a qualitatively different outcome” (Boehm *et al.* 2021).

For each sector, the shifts required to limit warming to well below 2°C, preferably 1.5°C, including benchmarks for 2030 and 2050, are assessed and pressure points to accelerate action are identified. Sets of actions that are most critical to advance, as well as sets of actions that should be avoided given the barriers they create to accelerating change, are offered, while highlighting what various actors can do to accelerate action.

The chapter presents a global agenda. While the list of priority actions is relevant for most countries, the chapter does not offer recommendations at the national or regional level. Each nation varies in its resources, capacity and emissions composition, and accordingly, mitigation priorities and opportunities will vary.

5.2 Initiating, accelerating and accomplishing the transformation towards zero emissions

A significant challenge is that the required transformations have to happen in all sectors and all countries in parallel. The sequencing of actions can vary slightly by country, but as the remaining carbon budget is so limited that the transition needs to be initiated at an accelerated pace immediately, everywhere.

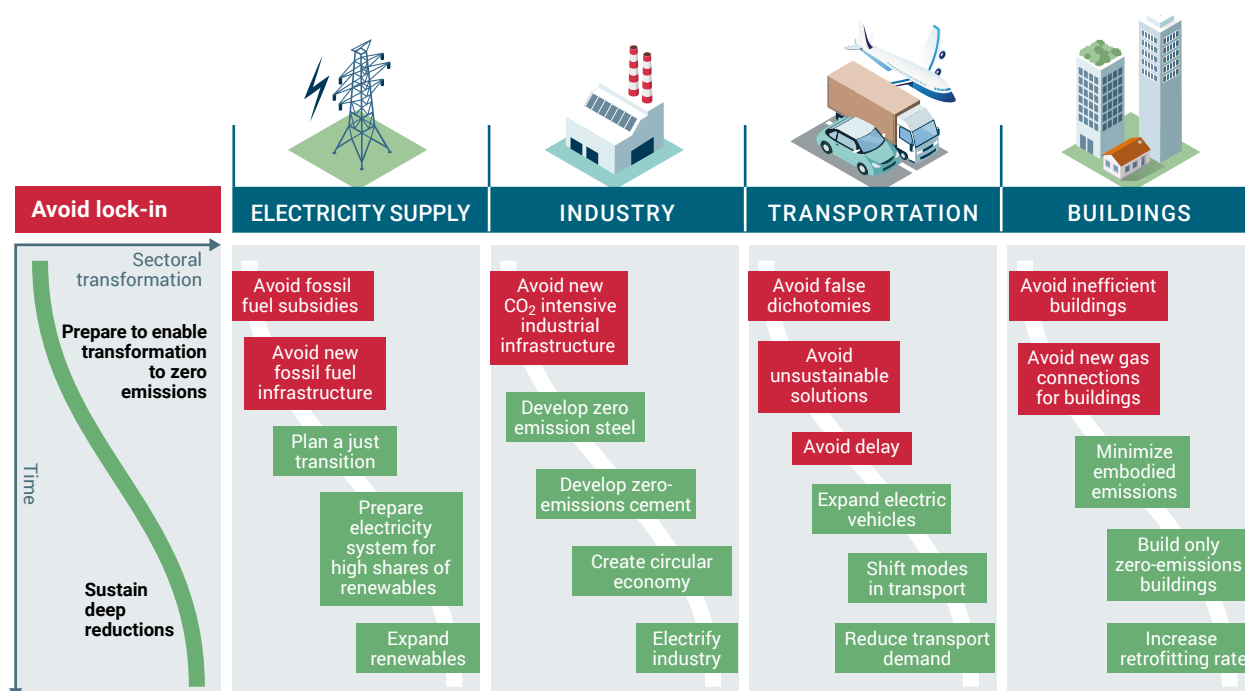
Sectoral transformation based on technological change can follow an S-curve path, with limited change initially, followed by sudden exponential growth and then by saturation (figure 5.1, also see the glossary). With the clear goal of transformation towards zero emissions, there are three broad areas of actions that need to be undertaken in all emitting sectors:

- **Avoid lock-in:** Decisions made today can define emissions trajectories for decades to come. For example, a building lasts 80 years on average; a coal-fired power plant 45 years; a cement plant 40 years (Erickson, Lazarus and Tempest 2015). Pipelines and gas connections create decade-long dependencies. Interventions can also lock in behaviour and policies that reinforce incumbent systems (Seto *et al.* 2016). Actions today that lock in a high-energy and high-carbon future for decades must be avoided, including avoiding new fossil fuel infrastructure for electricity and industry, car-centred city or regional planning, and inefficient new buildings. These actions do not always result in immediate emission reductions, but are fundamental for the long-term transition.
- **Initiate zero-carbon technological advancements:** Zero-carbon technologies, market structures and

planning for a just transformation typically need to be advanced in the beginning of a transition and are fundamental for the long-term transition. For many transformations, it will also be necessary to phase out incumbent fossil fuel-intensive industries at the same time as zero-carbon alternatives are scaled up. Focusing only on the latter is risky, as zero-carbon alternatives may not entirely replace new demand or existing infrastructure.

- **Sustain deep reductions:** For sectors and technologies that are advanced on the transformation curve, deep reductions need to be sustained, for example through further expansion of renewables, electrification of industry, electric vehicles and increasing the retrofit rate of buildings.

Figure 5.1 Selected important transformation interventions (green) and things to avoid (red) grouped by “avoiding lock-in” and different stages of the transformation S-curve



Notes: See sections 5.5–5.8 for more details.

The ability to achieve the transformations necessary depends on how a series of interrelated barriers and drivers of progress are approached. These include the following (Boehm *et al.* 2021, based on Olsson *et al.* 2004; Geels and Schot 2007; Chapin *et al.* 2010; Folke *et al.* 2010; Westley *et al.* 2011; Levin *et al.* 2012; O'Brien and Sygna 2013; Moore *et al.* 2014; Few *et al.* 2017; Patterson *et al.* 2017; Sterl *et al.* 2017; Hölscher *et al.* 2018; Reyers *et al.* 2018; Victor, Geels and Sharpe 2019; Initiative for Climate Action Transparency 2020; Levin *et al.* 2020; Otto *et al.* 2020; Sharpe and Lenton 2021):

- **Institutions:** Institutions guide decision-making, and their design can stymie or accelerate progress.
- **Policies and incentives:** Strong regulations such as mandates and standards, and incentives such as tax breaks, can either steer towards low-carbon alternatives or perpetuate an uneven playing field for new entrants.

- **Norms, culture and behaviour:** Once norms and culture that favour low-carbon alternatives are engrained in behaviour, change can take off more rapidly and is harder to reverse.
- **Actors:** Actors in their individual capacity (e.g. leaders, citizens, consumers, voters), professional capacity (e.g. town planners, builders, teachers, investors) or collective capacity (e.g. the youth climate movement) can catalyse and sustain change. At the same time, entrenched interests present significant barriers to advancing systems change. Involving diverse sets of champions can help shape durable outcomes.
- **Innovation:** Advances in technology, practice and approaches can help leapfrog current ones and hasten rates of decarbonization (Boehm *et al.* 2021). The enabling environment for innovation, e.g. spending on research and development and intellectual property rights, can be designed in a way that either advances an innovation agenda or stymies progress.
- **Exogenous shocks/change:** Conflicts, recessions, elections, etc., create openings for advancing change, or close doors to making progress. Preparing for these openings can help ensure that transformational change is catalysed rather than stalled.

5.3 Electricity supply

Achieving the temperature goal of the Paris Agreement requires rapid global transformation of the power system, which is the single largest source of energy-related CO₂ emissions globally, covering 42 per cent of total energy-related emissions (International Energy Agency [IEA] 2021c). At least four shifts need to occur to decarbonize power: (1)

steeply accelerating the share of zero-carbon power, (2) phasing out unabated coal and gas generation, (3) adapting grid/storage and demand management, and (4) ensuring reliable energy access for all (Boehm *et al.* 2022).

(1) Steeply accelerate the share of zero-carbon power in electricity generation: The share of zero-carbon power in electricity generation should be between 65 and 92 per cent by 2030, and between 98 and 100 per cent by 2050 (Monteith and Menon 2020; IEA 2021e; International Renewable Energy Agency [IRENA] 2021; Boehm *et al.* 2022).

(2) Phase out unabated coal and gas generation: The share of generation from unabated coal needs to fall to zero or near zero in 2030, requiring the pace of change to accelerate by about six times in the next eight years (IEA 2021e; IRENA 2021; Boehm *et al.* 2022). To be aligned with 1.5°C, the share of generation from unabated natural gas needs to fall to 17 per cent in 2030 before being phased out by 2040–2050, requiring a turnaround from its current upward trend (IEA 2021b; IRENA 2021; Boehm *et al.* 2022).

(3) Adapt grid/storage and demand management: A decarbonized power system relying primarily on renewables will require different grid systems than exist today. Flexibility will be key in decentralized supply, storage and demand, given the characteristics of wind and solar.

(4) Ensure reliable energy access for all: Currently, 10 per cent of the world's population has no access to electricity and over 40 per cent has unreliable access (Ayaburi *et al.* 2020; World Bank 2022). Ensuring universal energy access must be part of the shift to a global clean energy system.

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the electricity sector (table 5.1) and related actions by different groups of actors (table 5.2) are summarized below.

Table 5.1 Actions that accelerate or hinder the transformation of the electricity sector

	ELECTRICITY SECTOR TRANSFORMATION	
	MOST IMPORTANT ACTIONS 	ACTIONS TO AVOID 
	 EXPAND RENEWABLES: Renewable energy needs to be expanded as fast as possible. Removing barriers is most important, as costs are no longer the issue in many geographies. This can be achieved through policies, incentives, purchases of green electricity, removal of administrative barriers, and direct investments (Falk, Gaffney <i>et al.</i> 2020; IEA 2021e; Clarke <i>et al.</i> 2022).	 AVOID NEW FOSSIL FUEL INFRASTRUCTURE: Building new fossil fuel infrastructure needs to be avoided, as it locks in fossil fuel dependency and greenhouse gas emissions for decades, in particular for coal and gas (Falk, Gaffney <i>et al.</i> 2020; Clarke <i>et al.</i> 2022).
	 PLAN A JUST TRANSFORMATION: The transformation needs to be planned carefully in regions that are currently dependent on fossil fuel extraction for jobs and public revenue. Anticipating the change and planning for it seems essential (Falk, Gaffney <i>et al.</i> 2020; IEA 2021e).	 AVOID FOSSIL FUEL SUBSIDIES: Fossil fuel subsidies are still widely applied and stand in the way of the transformation. It is important to eliminate these subsidies in a socially acceptable manner and not to introduce new ones (Falk, Gaffney <i>et al.</i> 2020; Clarke <i>et al.</i> 2022).
	 PREPARE ELECTRICITY SYSTEM FOR HIGH SHARES OF RENEWABLES: This includes providing flexible electricity supply, short- and long-term storage, adapting the distribution grids, considering variable electricity demand, and adapting the electricity market to incentivize this (Falk, Gaffney <i>et al.</i> 2020; IEA 2021e; Clarke <i>et al.</i> 2022).	

Table 5.2 Immediate actions to accelerate the transformation of the electricity sector by actor groups



ELECTRICITY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP



NATIONAL GOVERNMENTS

- + Remove fossil fuel subsidies in a socially acceptable manner:** While all G20 members have pledged to remove fossil fuel subsidies, all G20 members still apply some fossil fuel subsidies. Due to the energy crisis, many have decreased taxes on fossil fuels, which is a form of new fossil fuel subsidies (Falk, Gaffney *et al.* 2020; CAT 2022b; Clarke *et al.* 2022).
- + Remove barriers to the expansion of renewables:** Allow production for own use, accelerate planning and provision of sites, remove bureaucratic hurdles, regulate grid access and connection, and educate workers (Falk, Gaffney *et al.* 2020).
- + Stop expansion of fossil fuel infrastructure:** This is necessary to avoid lock-in of continued high emissions or expanding stranded assets (IEA 2021e). Many coal power plants are still planned globally (Global Energy Monitor *et al.* 2022), and the current energy crisis has led to a gold rush for new fossil gas infrastructure (CAT 2022b).
- + Plan for a just fossil fuel phase-out:** All governments need to plan for fossil fuel phase-out well ahead and in a socially just manner (Falk, Gaffney *et al.* 2020). Governments should quantify any international support they need.
- + Adapt market rules of electricity system for high shares of renewables:** Adapt the electricity market to cope with the fundamentally different situation of large shares of electricity only being available under certain weather conditions (Falk, Gaffney *et al.* 2020).



INTERNATIONAL COOPERATION

- + Cooperate on and support a just fossil fuel phase-out:** National governments need to cooperate on just fossil fuel phase-out plans (IEA 2021e). Donor governments and multilateral development banks can target support for jobs, skills and investments (IEA *et al.* 2022). South Africa is an example, where a set of donors provide US\$8.5 billion for a just transition away from coal (Mason, Shalal and Rumney 2021). Donor governments should also facilitate expert exchanges, capacity-building and support for policy reforms, and leverage both public and private finance (IEA *et al.* 2022).
- + Support international initiatives on emissions-free electricity and power system flexibility and interconnection solutions:** Governments should initiate, sign and implement international initiatives on coal phase-out, the end of fossil fuel production and the end of financing fossil fuel infrastructure, and on scaling renewable electricity, including energy storage, smart grids and interconnection efforts (IEA *et al.* 2022).
- + Agree to higher energy performance standards:** In consultation with industry, governments can cooperate on higher minimum energy performance standards for high energy-consuming appliances, coupled with support for implementation of such standards. This can cut costs and growth in demand (IEA *et al.* 2022).



SUBNATIONAL GOVERNMENTS

- + Set 100 per cent renewable targets:** Subnational governments can create demand for renewable electricity by setting 100 per cent renewable targets (Falk, Gaffney *et al.* 2020).
- + Plan for a just fossil fuel phase-out:** Subnational governments need to plan for fossil fuel phase-out well ahead and in a socially just manner (Falk, Gaffney *et al.* 2020).



BUSINESSES

- + Support a 100 per cent renewable electricity future:** Businesses should purchase 100 per cent renewable power with high quality power purchase agreements or with own production (not through renewable energy credits), electrify their energy end-use, and provide demand flexibility, on-site storage, training and skills (Falk, Gaffney *et al.* 2020; Day *et al.* 2022).



INVESTORS, PRIVATE AND DEVELOPMENT BANKS

- + Engage with or divest from fossil fuel electricity utilities:** Investors need to take responsibility for their shares and engage with fossil fuel electricity utilities to incentivize change, or divest from these assets.
- + Do not invest in or insure new fossil fuel infrastructure:** Investors, banks and insurers should refrain from investing in, supporting or insuring new fossil fuel infrastructure (Falk, Gaffney *et al.* 2020).



CITIZENS

- + Purchase 100 per cent renewable electricity:** Citizens with the economic power to do so should create demand for renewable energy by purchasing 100 per cent renewable power from high quality providers (Falk, Gaffney *et al.* 2020).

5.4 Industry

The industry sector is the largest contributor to global emissions when direct and indirect emissions are included, and the second-largest contributor when only direct emissions are considered (IPCC 2022). To date, efforts to decrease emissions have mainly focused on improved energy efficiency and application of best available technologies. As many industrial processes have already reached maximum theoretically attainable energy efficiency, the key transformations needed to bring the industry sector to a Paris-compatible pathway include (1) electrifying industry and transform production processes, using (2) new fuels, and (3) specific solutions for hard-to-abate sectors; (4) accelerating material efficiency and scaling up energy efficiency everywhere, and (5) promote circular material flow.

(1) Electrify industry: To get on track for the Paris Agreement, the share of electricity in industry's final energy demand must increase to 35 per cent in 2030 and 50–55 per cent in 2050 (CAT 2020). The share of electricity reached 28.5 per cent in 2019, but decreased slightly to 28.4 per cent in 2020 (IEA 2021b).

(2) Reduce demand for and decrease carbon intensity of global cement and steel production: Demand reduction, substitution and carbon management are crucial for decarbonizing the industrial sector. The carbon intensity of global cement production needs to be reduced by 40 per cent from 2015 levels by 2030, and at least 85–91 per cent by 2050 (CAT 2020). The carbon intensity of global steel production needs to be reduced by 25–30 per cent from 2015 levels by 2030, and 93–100 per cent by 2050 (CAT 2020).

(3) Grow and integrate green hydrogen production capacity: There is vast potential for green hydrogen to help decarbonize several sectors, especially the hard-to-abate energy-intensive industry sectors that cannot use electricity. Green hydrogen production capacity needs to grow to 0.23–3.5 Mt (25 GW cumulative electrolyser capacity) by 2026 (in order to achieve costs below US\$2/kg) and then massively scale up to 500–800 Mt (2,630–20,000 GW cumulative electrolyser capacity) by 2050 (United Nations Framework Convention on Climate Change 2021), up from almost 0 tons today (IEA 2021d).

(4) Accelerate and scale up material and energy efficiency: Demand for materials has grown 2.5–3.5 times over the past 25 years (Bashmakov *et al.* 2022). Material processing and rising demand are the main drivers of industrial emissions. Basic materials production leads to increases in both direct and indirect emissions. Supply side interventions include changing the material intensity of the product used.

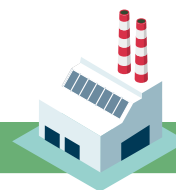
(5) Promote circular material flow: Recycling of waste materials helps to reduce emissions, but the growing complexity of product design and functionality increases the demand for materials. There are still huge gaps and regional variations in recycling. The rates of recycling across various metals varies from 20 to 85 per cent, and the recycling rate of end-of-life waste from industrial material is very low at ca 10 per cent (IPCC 2022; Teske and Pregger 2022).

A generic set of immediate actions necessary to initiate and accelerate the global transformation of the industry sector are summarized in table 5.3, and related actions by different groups of actors are summarized in table 5.4.

Table 5.3 Actions that accelerate or hinder the transformation of the industry sector

INDUSTRY TRANSFORMATION	
MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
 FULL DECARBONIZATION OF INDUSTRIAL PRODUCTION: Full decarbonization needs to be initiated today by use of electricity, green hydrogen and carbon management for heat sources and feedstock; for cement, iron and steel; and chemicals and plastics (Rissman <i>et al.</i> 2020; Roy <i>et al.</i> 2021; Bashmakov <i>et al.</i> 2022).	 AVOID NEW CO₂-INTENSIVE INFRASTRUCTURE: The pipeline of long-lived, carbon-intensive new industrial infrastructure (e.g. steel, cement, chemicals) needs to be avoided by incentivizing new low-carbon processes (Falk, Gaffney <i>et al.</i> 2020; Bashmakov <i>et al.</i> 2022).
 REDUCE MATERIAL WASTE AND RECIRCULATE MATERIALS: Costs and emissions can be lowered by using fewer materials and by increasing the usable lifetime through appropriate infrastructure, industrial parks and networks, policies and expertise (Falk, Gaffney <i>et al.</i> 2020; Rissman <i>et al.</i> 2020; Bashmakov <i>et al.</i> 2022).	 AVOID FOCUS ON NARROWLY DEFINED POLICIES: Policies that support linear production processes which generate more waste need to be avoided and to be replaced by sequential, cross-sectoral policies which have a wide impact on societal and environmental domains (Rissman <i>et al.</i> 2020; IPCC 2022)
 REDUCE DEMAND AND ENHANCE ACCESS TO ENERGY-EFFICIENT, MATERIAL-EFFICIENT AND CO₂-NEUTRAL MATERIALS: Access to material-efficient design, light-weight products, and products with longer lifetime reduces total product demand and materials needed. Promotion of sharing economy reduces the demand for automobiles and buildings, and can be facilitated by increased digitalization with strategic policies to avoid rebound in demand (Rissman <i>et al.</i> 2020; Bashmakov <i>et al.</i> 2022; Creutzig, Roy <i>et al.</i> 2022). Material use can also be reduced through process change and technology choice.	

Table 5.4 Immediate actions to accelerate the transformation of the industry sector by actor groups



INDUSTRY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP



NATIONAL GOVERNMENTS

- + **Support zero-carbon industrial processes:** Implement strategic, well-designed policy and incentives to accelerate innovation, technology deployment of clean energy and low-carbon input materials, e.g. development of new, CO₂-free processes or carbon capture (Rissman *et al.* 2020).
- + **Promote circular material flow:** Incentivize the use of recycled materials, reduce demand through material efficiency (e.g. foster shift to paper which uses less pulp), substitute low-carbon for high-carbon materials, and introduce circular economy measures such as improving product longevity, reusability and recyclability (Millward-Hopkins *et al.* 2018; Rissman *et al.* 2020).
- + **Promote electrification:** Introduce policies to incentivize electrification of the industrial processes that currently use fossil fuels (Rissman *et al.* 2020).
- + **Support alternative carbon pricing mechanisms:** Implement carbon pricing policies to incentivize industry leadership in low-carbon action, improve productivity and drive innovation (Rissman *et al.* 2020; World Bank 2021).
- + **Support research and innovation:** Remove barriers to and invest in research, development, deployment and innovation, and support energy efficiency and/or emissions standards (Falk, Gaffney *et al.* 2020; Rissman *et al.* 2020; Bashmakov *et al.* 2022).
- + **Promote low-carbon products:** Ensure labelling and government procurement of low-carbon products, information dissemination, promoting repair work, data collection and implementation of disclosure requirements, and incentives for recycling (Rissman *et al.* 2020; Bashmakov *et al.* 2022).
- + **Plan a just transformation:** Prepare national-level plans for social protection to stay gender sensitive, meet development needs of low- and middle-income countries, and enhance social acceptance of new production systems with the aim to ensure a just transformation for displaced workers and affected communities (Rissman *et al.* 2020).



INTERNATIONAL COOPERATION

- + **Cooperate on zero-carbon basic materials:** International cooperation and coordination may be particularly important in enabling change in emissions-intensive and highly traded basic materials industries (IPCC 2022). This can include procurement commitments, strategic dialogues, shared learning on pilot projects, and standard adoption (IEA *et al.* 2022). Additionally, funding will need to be significantly increased to support the industrial transition (IEA *et al.* 2022).
- + **Share best practice:** There needs to be support for low- and middle-income countries while making the International Organization for Standardization more progressive, helping in the development of standards and regulations, sharing technology, and accounting to reduce waste in the global supply chain. Global decarbonization efforts need to acknowledge various starting points and stages of human and economic development (Rissman *et al.* 2020; Bashmakov *et al.* 2022).
- + **Cooperate on hydrogen:** International cooperation and coordination is important to develop a market for hydrogen from renewable sources, with coordinated targets, standards, and bilateral and multilateral cooperation agreements and blended finance (IEA *et al.* 2022).



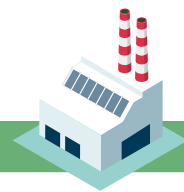
SUBNATIONAL GOVERNMENTS

- + **Regional planning and regulation:** Reconsider regional spatial planning and regulations, reform procurement guidelines, explore carbon pricing instruments, engage in labelling, align regulations to facilitate implementation, and ensure accountability for emissions (Bashmakov *et al.* 2022).
- + **Cooperate with various stakeholders:** Mitigation actions are implemented at subnational levels, so subnational governments must cooperate with national governments, industry and citizens in implementing mitigation actions (IPCC 2022).



BUSINESSES

- + **Plan and implement zero-emission transformation:** Companies, including those operating in hard-to-abate sectors, need to plan their operations to become zero carbon and to implement these plans (Falk, Bergmark *et al.* 2020; Roy *et al.* 2021).
- + **Design long-lived products:** Industrial service providers should lead in design of long-lived repairable products and help in the digitization of the processes (Rissman *et al.* 2020; Bashmakov *et al.* 2022; Creutzig, Roy *et al.* 2022).
- + **Create circular supply chains:** Create circular and value-free supply chains through collaboration with suppliers and customers (Falk, Gaffney *et al.* 2020).



INDUSTRY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP



INVESTORS, PRIVATE AND DEVELOPMENT BANKS

+ Engage with or divest from emissions-intensive industry:

Investors can actively engage with the companies they own shares of to move them towards zero emissions. If this is not successful, they should divest (Creutzig, Roy *et al.* 2022).

+ Invest in low-carbon energy and process technologies:

Investors and banks should enable investment in low-carbon energy and process technologies and novel chemistries. Investments to significantly reduce costs of new technologies and innovations will be essential for uptake by developing countries (Rissman *et al.* 2020).

+ Drive awareness of climate risk:

Despite various regulatory and voluntary initiatives, climate-related financial risks remain grossly underestimated. Banks and financial institutions can drive awareness and actions (Roy 2021).



CITIZENS

+ Consume sustainably: Users can practice sustainable consumption by intensive use of longer-lived repairable products and avoiding short lifespan products (Creutzig, Roy *et al.* 2022).

+ Lobby: Citizens can join various lobby groups to advocate new narratives to influence social norms, corporate advertisements and public policy. Professionals can engage in monitoring, develop and communicate embodied emissions (Creutzig, Roy *et al.* 2022).

5.5 Transportation

Transportation is the second-largest source of energy-related CO₂ emissions globally, contributing 25 per cent of total energy-related CO₂ emissions (IEA 2021c). Transformation of the transportation system requires a number of shifts: (1) a shift to low-emitting modes of transport, (2) an acceleration of the move to zero-carbon cars and trucks, and (3) preparation for the move to zero-carbon aviation and shipping. In addition, car and plane use by frequent travellers should be abated. These shifts should be promoted simultaneously, and many actions can address more than one shift.

(1) Shift to low-emitting modes of transport: A significant shift to lower emitting modes, including public transport, walking and cycling, is required alongside the electrification of transport modes to align with a well-below 2°C and 1.5°C pathway (Institute for Transportation and Development Policy [ITDP] and University of California Davis 2021). Currently, private light-duty vehicles make up 53.2 per cent of all trips (as at 2015, International Transport Forum 2021). The number of trips made by private light-duty vehicles needs to decrease by 4–14 per cent below business-as-usual levels by 2030. The number of kilometres of public transit per 1,000 inhabitants must be doubled by 2030, while the number of kilometres of high-quality bicycle lanes per 1,000 inhabitants should be increased fivefold (Transformative Urban Mobility Initiative 2021; Boehm *et al.* 2022).

(2) Accelerate the move to zero-carbon cars and trucks:

Light-duty electric vehicle sales reached 8.3 per cent of total sales in 2021 (Irle 2021). This must increase to between 35 per cent and 95 per cent by 2030, and reach 100 per cent

by 2035, requiring an increase in the rate of change by 1.8 to 6 times in the next eight years (Bloomberg New Energy Finance [BloombergNEF] 2018; ICCT 2021; IEA 2021e; IRENA 2021; McKerracher *et al.* 2022; Boehm *et al.* 2022; Cheung and O'Donovan 2022). Heavier vehicles, including buses and medium- and heavy-duty vehicles (MHDVs), should also be decarbonized. Buses have proven to be a success story for vehicle electrification, reaching a high of 43 per cent of bus sales in 2017, driven largely by demand in China (BloombergNEF 2021). However, sales have slowed since then, falling to 39 per cent in 2020, whereas the share needs to increase to 60–100 per cent in 2030 and 100 per cent in 2050 (ICCT 2021; IEA 2021e; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022). Zero-carbon options for MHDVs have only just begun to hit the market, reaching 0.2 per cent of sales in 2020 (BloombergNEF 2021). Electric and fuel cell MHDVs are required to reach between 5 and 45 per cent of sales in 2030, and 100 per cent between 2040 and 2050 (IEA 2021e; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022; Xie, Dallmann and Muncrief 2022).

(3) Transformation to zero-carbon aviation and shipping:

Sustainable aviation fuels are required to meet 13–18 per cent of aviation fuel needs in 2030 and 78–100 per cent in 2050, requiring a significant increase in uptake (IEA 2021e; University Maritime Advisory Services 2021; Boehm *et al.* 2022; Graver *et al.* 2022). Maritime shipping faces similar problems, with a dearth of options for decarbonization outside zero-emissions fuels. Vessels have not yet begun to use zero-emissions shipping fuels, but zero-emissions fuels will need to meet 5–17 per cent of maritime shipping needs in 2030 and 84–93 per cent by 2050 (IEA 2021e; Boehm *et al.* 2022).

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the transport sector (table 5.5) and related actions by different groups of actors (table 5.6) are summarized below.

Table 5.5 Actions that accelerate or hinder the transformation of the transport sector



TRANSPORT SECTOR TRANSFORMATION	
MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
 AVOID: Adopt integrated land-use planning to avoid transport need by prioritizing moving people and improving transport access over private cars.	 AVOID UNSUSTAINABLE SOLUTIONS: Avoid supporting technologies that are incompatible with deep decarbonization, such as natural gas in road transport and biofuels that lead to deforestation and/or compete with food production (Searchinger <i>et al.</i> 2019).
 SHIFT: Make investments in, establish pricing for and shift towards low-carbon modes of transport (trains, public transport, cycling).	 AVOID DELAY: It is important not to delay transport electrification until the electricity grids are cleaner (Sen <i>et al.</i> 2021).
 IMPROVE: Complete transformation to zero-emissions vehicle technologies for cars, vans, buses and trucks, and for ships and planes in combination with zero-emissions fuels.	 AVOID FALSE DICHOTOMIES: A 1.5°C pathway requires both electrification of transportation and investment in more compact cities (public transit, walking, biking).

Table 5.6 Immediate actions to accelerate the transformation of the transport sector by actor groups



TRANSPORT SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP	
NATIONAL GOVERNMENTS	
 + Set mandates to switch to zero-emissions road vehicles by specific dates: Governments, regions and cities can set regulations to shift towards 100 per cent zero-emissions vehicle sales for new buses by 2030, cars and vans by 2035, and trucks by 2040 (Hall <i>et al.</i> 2021; Sen and Miller 2022). These can be complemented with demand-side action to accelerate uptake. Setting CO₂ standards for manufacturers will also help accelerate the transition.	+ Regulate and incentivize zero-carbon fuels for aviation: Develop regulations and support fiscal policies to transition to 100 per cent low-carbon fuels for aviation and marine sectors by 2050, including advanced biofuels, green hydrogen, renewable electricity, and e-fuels generated with additional renewable electricity (Graver <i>et al.</i> 2022; Pavlenko and O'Malley 2022).
	+ Adjust taxation/pricing schemes: Align pricing, taxes and fees on vehicle sales (Wappelhorst 2022), ownership, fuels and transportation activity to support environmental objectives (technology changes, mode shift, avoided travel) (Jaramillo <i>et al.</i> 2022).
	+ Invest in zero-emissions transport infrastructure: Align transportation infrastructure funding to invest in high quality zero-emissions public transport, rail, walking/bicycling facilities, ships, aeroplanes and vehicle-charging infrastructure (Minjares <i>et al.</i> 2021; Jaramillo <i>et al.</i> 2022; Ragon <i>et al.</i> 2022).



TRANSPORT SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP



INTERNATIONAL COOPERATION

+ **Cooperate on financing and policy development:**

Enhance the offer of international financial and technical assistance to support more ambitious transformations and policy development in emerging markets and developing economies (Khan *et al.* 2022). In addition, governments should exchange best practice and improve rules governing trade of vehicles (IEA *et al.* 2022).

+ **Coordination on target setting and standards:** Governments and vehicle manufacturers can agree on targets for achieving net-zero vehicle sales, harmonized standards, and scaling up related infrastructure (IEA *et al.* 2022).



SUBNATIONAL GOVERNMENTS

+ **Plan infrastructure and supporting policies to reduce travel demand:**

Initiate or intensify systemic planning and infrastructure changes that reduce transport demand (ITDP and University of California Davis 2021; Creutzig, Niamir *et al.* 2022; Creutzig, Roy *et al.* 2022; Jaramillo *et al.* 2022). This can include the development of low- and zero-emission zones to accelerate shifts to zero-emissions vehicles in cities (Cui, Gode and Wappelhorst 2021).

+ **Plan infrastructure and supporting policies for zero-emissions vehicles:** Invest in smart-charging infrastructure and support regulation for the acceleration of rapid deployment.

+ **Adjust taxation/pricing schemes:** Regional and local government should align on local pricing (Basma *et al.* 2022), taxes and fees on car ownership, parking and car access to cities, and public transport to support transformation (technology changes, mode shift, avoided travel) (Jaramillo *et al.* 2022).



BUSINESSES

+ **Work towards zero-emissions transport:** Business fleet owners and operators, and shared mobility platforms, can work towards 100 per cent zero-emissions cars (Climate Group 2022), vans, trucks, buses, vessels (Martin 2021) and aeroplane fleets (see action E in Austria *et al.* 2022).

+ **Reduce travel in operations:** This especially applies to long-haul flights, and can include the promotion of telecommuting, and provision of workplace charging of electric vehicles.



INVESTORS, PRIVATE AND DEVELOPMENT BANKS

+ **Invest in zero-emissions transport infrastructure:** Invest in transit and active transport infrastructure (Jaramillo *et al.* 2022).

+ **Support zero-emissions vehicles, vessels and planes:** Support an accelerated transition to zero-emissions vehicles by proactive engagement with investees, encouraging all their holdings to decarbonize their fleets, by making capital and financial products available for consumers, businesses and charging infrastructure manufacturers (see actions F and G in Austria *et al.* 2022).



CITIZENS

+ **Adopt active mobility practices:** Opt for walking and cycling where ability and distance allows, and use teleworking or telecommuting in other cases (Creutzig, Roy *et al.* 2022).

+ **Use public transit:** Opt for public transit such as (ideally zero-emissions) buses and trains for commuting where available, and when active modes of transport are not practical.

+ **Use zero-emissions vehicles:** Choose zero-emissions vehicles when purchasing, leasing or renting (where possible).

+ **Avoid long-haul flights:** Avoid the use of private jets and limit long flights whenever alternatives exist, such as trains or electric vehicles (Creutzig, Roy *et al.* 2022).

5.6 Buildings

Direct emissions through building operations are relatively small compared to other sectors and are estimated at 5 per cent of global greenhouse gas emissions, but this number increases to 17 per cent when accounting for indirect emissions from electricity and heat consumption (IPCC 2022). While direct emissions have remained relatively stable at 3 gigatons of CO₂ per year, indirect emissions have almost doubled since 1990 (IEA 2020). To decrease emissions in the building sector, four major shifts are necessary: (1) excess floor area must be minimized, (2) energy intensity must be reduced, (3) the emissions intensity of energy use must decline, and (4) embodied emissions from construction must be reduced (Boehm *et al.* 2022).

(1) Reduce excess floor area: Energy use and emissions from space and water heating and cooling are directly linked to the total amount of floor area that undergoes active thermal control. Furthermore, the greater the extent of new floor area that is constructed, the more materials are required, and the higher are the embodied emissions. The amount of floor area used per person vastly differs across countries, but also within countries. Minimizing the amount of floor area which is well above the area necessary to meet basic needs, can have a large effect on emissions in the sector.

(2) Reduce energy intensity of buildings: The energy that is used for heating, cooling and appliances per square metre of floor area, needs to decrease globally by 10–30 per cent in commercial buildings and 20–30 per cent in residential buildings, relative to 2015 levels, by 2030 (CAT 2020). Global average energy intensity in buildings reduced by 19 per cent between 2000 and 2015, but the reduction has slowed in recent years, with only an additional 2 per cent between 2015 and 2019 (Boehm *et al.* 2022).

(3) Reduce emissions intensity of energy use in buildings:

Emissions intensity, or the amount of CO₂ emitted per floor area, is related to energy intensity, but adds the decarbonization factor, meaning that a switch from fossil fuels to electric power (sourced from renewable energy) is needed. In buildings, this entails installing and replacing cooking and heating devices with cleaner technologies, such as heat pumps instead of oil or gas heating, or district heating in dense urban areas (CAT 2020). Emissions intensity in buildings needs to be reduced by 45–65 per cent for residential buildings and 65–75 per cent for commercial buildings compared to 2015 levels by 2030, and 95–100 per cent by 2050 (CAT 2020). Although emissions intensity has decreased steadily, the pace needs to be accelerated to meet these targets (Boehm *et al.* 2022).

(4) Reduce emissions from construction: The production of materials such as steel, cement and concrete to construct buildings is a highly energy- and emissions-intensive process. While measures to reduce the emissions intensity of these materials should be pursued (see section on industry above), further reductions can be achieved by more efficient use of these materials. This can include reconstructing existing buildings (rather than demolition and new construction), minimizing the volume of materials required and substituting alternative construction materials (Energy Transitions Commission 2019). Integrated planning and design can be used to minimize energy demand throughout the building construction phase, including transport and on-site energy use. Furnishing the interior of buildings can also be energy intensive, with circular economy principles providing opportunities for lifecycle emission reductions.

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the buildings sector (table 5.7) and related actions by different groups of actors (table 5.8) are summarized below.

Table 5.7 Actions that accelerate or hinder the transformation of the buildings sector


BUILDINGS SECTOR TRANSFORMATION	
MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
 EFFICIENT BUILDING SHELL: Optimize building shells to minimize the need for active heating and cooling.	 AVOID INEFFICIENT BUILDINGS: Due to the long lifetime of buildings, the lock-in effect of inefficient new buildings is significant and currently potentially incentivized by low ambition or no building codes (Cabeza <i>et al.</i> 2022).
 SCALE UP ZERO-EMISSIONS HEATING AND COOLING TECHNOLOGY: Highly efficient air conditioners and heat pumps without hydrofluorocarbons can be powered by renewables, either on-site or supplied off-site through electricity.	 AVOID NEW FOSSIL GAS CONNECTIONS: New gas connections should be avoided to not create a lock-in, which would last decades. Improved insulation and electric heating and cooling can reduce fossil gas demand.
 ALL NEW BUILDINGS SHOULD BE ZERO CARBON IN OPERATION: New buildings should be designed and constructed so that they are zero carbon in operation, with a minimal energy demand that is met through zero-carbon sources (IEA 2021e).	 PHASE OUT FOSSIL FUEL SUBSIDIES: Several countries subsidize fossil fuel use in buildings, directly or indirectly.
 MINIMIZE EMBODIED EMISSIONS: Emissions from construction materials should be minimized by reducing the emissions intensity of steel and cement production and substituting lower carbon materials, including recycled materials, where possible.	
 INCREASE RETROFITTING RATE: 2.5–3.5 per cent of buildings need to be retrofitted every year, but recent rates are below 1 per cent per year (IEA 2021a).	

Table 5.8 Recommendations from immediate actions to accelerate the transformation of the buildings sector by actor groups



BUILDINGS SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP	
	NATIONAL GOVERNMENTS
+ Regulate towards zero-carbon building stock: Require all new buildings to be zero carbon in operation and introduce minimum energy performance standards for existing buildings to increase retrofit rates, both accompanied by a comprehensive enforcement strategy (CAT 2022a). Buildings codes can be used to accelerate the transition to using low-carbon building materials for construction, and in limiting emissions during the end-of-life phase of a building. Setting requirements to calculate and monitor these embodied emissions is an important first step (Jordan <i>et al.</i> 2020).	+ Incentivize zero-carbon building stock: Modify cost structures in favour of zero-carbon options through taxes and subsidies, provide incentives for 'best in class' technologies and practices, improve access to finance, and address the landlord-tenant dilemma (CAT 2022a). + Facilitate zero-carbon building stock: Ensure an appropriately skilled workforce and increase institutional capacity for enforcement and awareness-raising (CAT 2022a).
	INTERNATIONAL COOPERATION
+ Provide access and favourable conditions to finance: Support, de-risk or guarantee the upfront investments required to achieve a zero-carbon building stock (GlobalABC and UNEP 2022).	+ Support skills and knowledge growth: Expand the massively needed skills training and knowledge exchange (GlobalABC and UNEP 2022).
	SUBNATIONAL GOVERNMENTS
+ Implement zero-emissions building stock plans: Subnational governments in particular cities should plan and implement how to arrive at an 100 per cent zero-emissions building stock (Burrows <i>et al.</i> 2021). Particularly important is that the design of any new construction is fossil fuel free, and the presence of a vision to rapidly reduce embodied emissions.	+ Integrate low emissions requirements in urban planning: This includes zoning and parks (Jordan <i>et al.</i> 2020). + Add requirements on top of national requirements: Stronger requirements at subnational level can accelerate the transformation (Falk, Gaffney <i>et al.</i> 2020). Several examples exist where, for example, cities add renewable obligations or low/no interest loans for low-income households that are not required at the national level (CAT 2022a).
	BUSINESSES
+ Construction and building material companies review business models: Make and implement zero-emissions plans with zero-carbon building materials if the business model relies on carbon intensive raw materials and high energy buildings (Falk, Gaffney <i>et al.</i> 2020).	+ Achieve zero-carbon owned or rented building stock: Building owners should make their building stock zero carbon without overburdening tenants. Companies that own or rent buildings for their operation, such as offices, shops, warehouses and factories, should do the same (Falk, Gaffney <i>et al.</i> 2020; World Economic Forum 2021).
	INVESTORS, PRIVATE AND DEVELOPMENT BANKS
+ Adjust strategy and investment criteria for zero-carbon building stock: Review strategies and align investment criteria with a zero-carbon building stock. This includes the high need for long-term, low-interest loans for zero-carbon buildings with their higher upfront investment and lower operating costs.	+ Support building retrofits: Financial institutions, in particular banks, should actively support building retrofits with favourable conditions.
	CITIZENS
+ Retrofit: Private homeowners should retrofit their buildings to become zero carbon, where relevant. + Tenants challenge landlords: Tenants should actively approach their landlords and ask for zero-carbon buildings and necessary retrofits.	+ Adopt energy-saving behaviour: Citizens should save energy by choosing desired inside temperatures that do not greatly differ from outside temperatures, switching off unnecessary lights and being mindful when using appliances (Creutzig, Roy <i>et al.</i> 2022).