3.6.2 Key milestones and decision points

Table 3.4 ▻ Key milestones in transforming the global transport sector

Category	
Road transport	• 2035: no new passenger internal combustion engine car sales globally
Aviation and shipping	• Implementation of strict carbon emissions intensity reduction targets as soon as possible.

Category		2020	2030	2050
Road transport				
Share of PHEV, BEV and FCEV in sales:	cars	5%	64%	100%
	two/three-wheelers	40%	85%	100%
	bus	3%	60%	100%
	vans	0%	72%	100%
	heavy trucks	0%	30%	99%
Biofuel blending in oil products		5%	13%	41%
Rail				
Share of electricity and hydrogen in total energy consumption		43%	65%	96%
Activity increase due to modal shift (index 2020=100)		100	100	130
Aviation				
Synthetic hydrogen-based fuels share in total aviation energy consumption		0%	2%	33%
Biofuels share in total aviation energy consumption		0%	16%	45%
Avoided demand from behaviour measures (index 2020=100)		0	20	38
Shipping				
Share in total shipping energy consumption:	Ammonia	0%	8%	46%
	Hydrogen	0%	2%	17%
	Bioenergy	0%	7%	21%
Infrastructure				
EV public charging (million units)		1.3	40	200
Hydrogen refuelling units		540	18 000	90 000
Share of electrified rail lines		34%	47%	65%

Note: PHEV = plug-in hybrid electric vehicles; BEV = battery electric vehicles; FCEV = fuel cell electric vehicles.

Electrification is the main option to reduce CO_2 emissions from road and rail modes, the technologies are already on the market and should be accelerated immediately, together with the roll-out of recharging infrastructure for EVs. Deep emission reductions in the hard-to-abate sectors (heavy trucks, shipping and aviation) require a massive scale up of the required technologies over the next decade, which today are largely at the prototype and demonstration stages, together with plans for the development of associated infrastructure, including hydrogen refuelling stations.

The transformation of transport required to be on track to reduce emissions in line with the NZE calls for a range of government decisions over the next decade. In the next few years, all governments need to eliminate fossil fuel subsidies and encourage switching to low-carbon technologies and fuels across the entire transport sector. Before 2025, governments need to define clear R&D priorities for all the technologies that can contribute to decarbonise transport in line with their strategic priorities and needs. Ideally this would be informed by international dialogue and collaboration. R&D is critical in particular for battery technology, which should be an immediate priority.

To achieve the emissions reductions required by the NZE, governments also need to move quickly to signal the end of sales of new internal combustion engine cars. Early commitments would help the private sector to make the necessary investment in new powertrains, relative supply chains and refuelling infrastructure (see section 4.3.4). This is particularly important for the supply of battery metals, which require long-term planning (IEA, 2021a).

By 2025, the large-scale deployment of EV public charging infrastructure in urban areas needs to be sufficiently advanced to allow households without access to private chargers to opt for EVs. Governments should ensure sustainable business models for companies installing chargers, remove barriers to planning and construction, and put in place regulatory, fiscal and technological measures to enable and encourage smart charging, and to ensure that EVs support electricity grid stability and stimulate the adoption of variable renewables (IEA, 2021b).

For heavy trucks, battery electric trucks are just beginning to become available on the market, and fuel cell electric technologies are expected to come to market in the next few years. Working in collaboration with truck manufacturers, governments should take steps in the near term to prioritise the rapid commercial adoption of battery electric and fuel cell electric trucks. By 2030, they should take stock of the competitive prospects for these technologies, so as to focus R&D on the most important challenges and allow adequate time for strategic infrastructure deployment, thus paving the way for large-scale adoption during the 2030s.

Governments need to define their strategies for low-carbon fuels in shipping and aviation by 2025 at the latest, given the slow turnover rate of the fleets, after which they should rapidly implement them. International co-operation and collaboration will be crucial to success. Priority action should target the most heavily used ports and airports so as to maximise the impact of initial investment. Harbours near industrial areas are ideally placed to become low-carbon fuel hubs.

Box 3.3 ▷ What would be the implications of an all-electric approach to emissions reductions in the road transport sector?

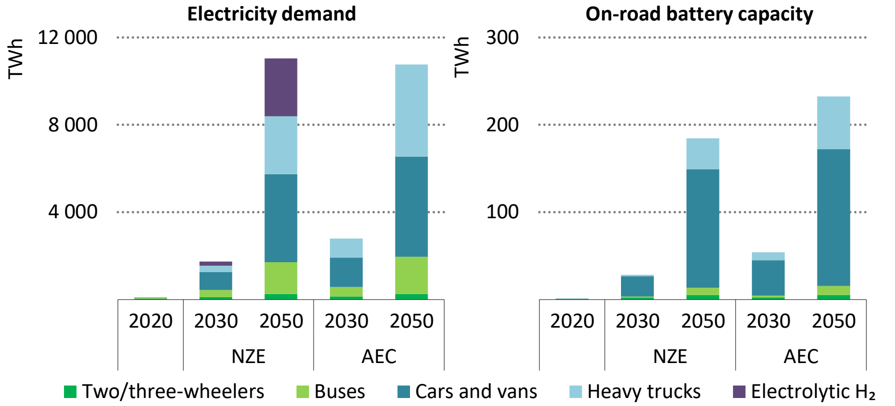
The use of a variety of fuels in road transport is a core component of the NZE. However, governments might want to consider an all-electric route to eliminate CO_2 emissions from transport, especially if other technologies such as FCEVs and advanced biofuels fail to develop as projected. We have therefore developed an *All-Electric Case* which looks at the implications of electrifying all road vehicle modes. In the NZE, decarbonisation of road transport occurs primarily via the adoption of plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) and advanced biofuels. The All-Electric Case assumes the same rate of road transport decarbonisation as the NZE, but achieved via battery electric vehicles alone.

The All-Electric Case depends on even further advances in battery technologies than the NZE that lead to energy densities of at least 400 Watt hours per kilogramme (Wh/kg) by the 2030s at costs that would make BEV trucks preferable to FCEV trucks in long-haul operations. This would mean 30% more BEVs (an additional 350 million) on the road in 2030 than in the NZE. Over sixty five million public chargers would be needed to support the vehicles, requiring a cumulative investment of around USD 300 billion, 35% higher than the NZE. This would require faster expansion of battery manufacturing. The annual global battery capacity additions for BEVs in 2030 would be almost 9 TWh, requiring 80 giga-factories (assuming 35 GWh per year output) more than in the NZE, or an average of over two per month from now to 2030.

The increased use of electricity for road transport would also create additional challenges for the electricity sector. The total electricity demand for road transport (11 000 TWh or 15% of total electricity consumption in 2050), would be roughly the same in both cases, when account is taken of demand for electrolytic hydrogen. However, the electrolytic hydrogen in the NZE can be produced flexibly, in regions and at times with surplus renewables-based capacity and from dedicated (off-grid) renewable power. Peak power demand in the All-Electric Case, taking into consideration the flexibility that enables smart charging of cars, is about one-third (2 000 GW) higher than in the NZE, mainly due to the additional evening/overnight charging of buses and trucks. If not coupled with energy storage devices, ultra-fast chargers for heavy-duty vehicles could cause additional spikes in demand, putting even more strain on electricity grids.

While full electrification of road transport is possible, it could involve additional challenges and undesirable side effects. For example, it could increase pressure on electricity grids, requiring significant additional investment, and increasing the vulnerability of the transport system to power disruptions. Fuel diversification could bring benefits in terms of resilience and energy security.

Figure 3.26 ▷ Global electricity demand and battery capacity for road transport in the NZE and the All-Electric Case



Both direct electricity consumption and vehicle battery capacity in 2050 increase by about a quarter in the All-Electric Case relative to the NZE

Note: AEC = All-Electric Case.

3.7 Buildings

3.7.1 *Energy and emission trends in the Net-Zero Emissions Scenario*

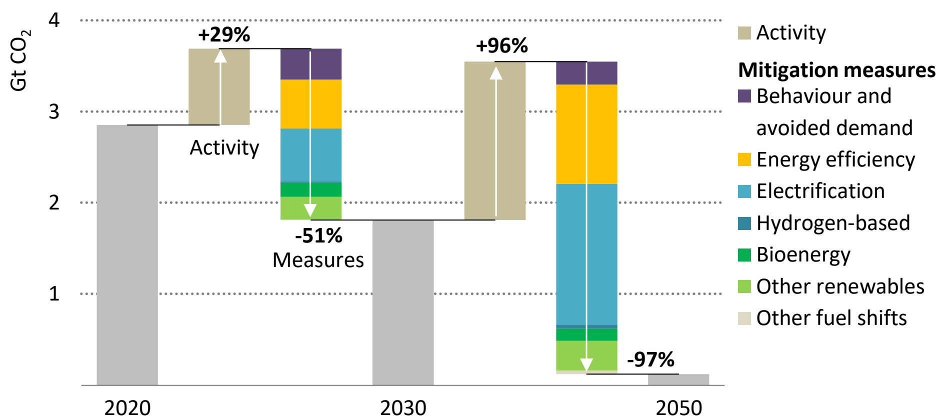
Floor area in the buildings sector worldwide is expected to increase 75% between 2020 and 2050, of which 80% is in emerging market and developing economies. Globally, floor area equivalent to the surface of the city of Paris is added every week through to 2050. Moreover, buildings in many advanced economies have long lifetimes and around half of the existing buildings stock will still be standing in 2050. Demand for appliances and cooling equipment continues to grow, especially in emerging market and developing economies where 650 million air conditioners are added by 2030 and another 2 billion by 2050 in the NZE. Despite this demand growth, total CO_2 emissions from the buildings sector decline by more than 95% from almost 3 Gt in 2020 to around 120 Mt in 2050 in the NZE.[12]

Energy efficiency and electrification are the two main drivers of decarbonisation of the buildings sector in the NZE (Figure 3.27). That transformation relies primarily on technologies

[12] All CO_2 emissions in this section refer to direct CO_2 emissions unless otherwise specified. The NZE also pursues reductions in emissions linked to construction materials used in buildings. These embodied emissions are cut by 40% per square metre of new floor area by 2030, with material efficiency strategies cutting cement and steel use by 50% by 2050 relative to today through measures at the design, construction, use and end-of-life phases.

already available on the market, including improved envelopes for new and existing buildings, heat pumps, energy-efficient appliances, and bioclimatic and material-efficient building design. Digitalisation and smart controls enable efficiency gains that reduce emissions from the buildings sector by 350 Mt CO_2 by 2050. Behaviour changes are also important in the NZE, with a reduction of almost 250 Mt CO_2 in 2030 reflecting changes in temperature settings for space heating or reducing excessive hot water temperatures. Additional behaviour changes such as greater use of cold temperature clothes washing and line drying, facilitate the decarbonisation of electricity supply. There is scope for these reductions to be achieved rapidly and at no cost.

Figure 3.27 ▷ Global direct CO_2 emissions reductions by mitigation measure in buildings in the NZE

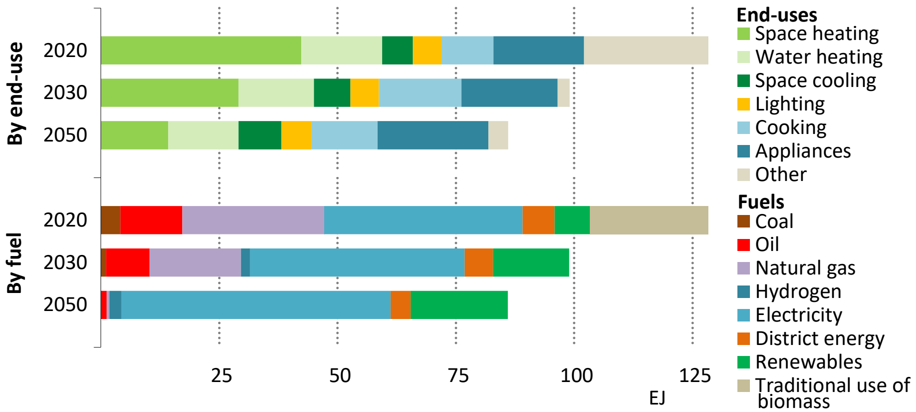


Electrification and energy efficiency account for nearly 70% of buildings-related emissions reductions through to 2050, followed by solar thermal, bioenergy and behaviour

Notes: Activity = change in energy service demand related to rising population, increased floor area and income per capita. Behaviour = change in energy service demand from user decisions, e.g. changing heating temperatures. Avoided demand = change in energy service demand from technology developments, e.g. digitalisation.

Rapid shifts to zero-carbon-ready technologies see the share of fossil fuels in energy demand in the buildings sector drop to 30% by 2030, and to 2% by 2050 in the NZE. The share of electricity in the energy mix reaches almost 50% by 2030 and 66% by 2050, up from 33% in 2020 (Figure 3.28). All end-uses today dominated by fossil fuels are increasingly electrified in the NZE, with the share of electricity in space heating, water heating and cooking increasing from less than 20% today to more than 40% in 2050. District energy networks and low-carbon gases, including hydrogen-based fuels, remain significant in 2050 in regions with high heating needs, dense urban populations and existing gas or district heat networks. Bioenergy meets nearly one-quarter of overall heat demand in the NZE by 2050, over 50% of bioenergy use is for cooking, nearly all in emerging market and developing economies, where 2.7 billion people gain access to clean cooking by 2030 in the NZE. Space heating demand drops by two-thirds between 2020 and 2050, driven by improvement in energy efficiency and behavioural changes such as the adjustment of temperature set points.

Figure 3.28 ▷ Global final energy consumption by fuel and end-use application in buildings in the NZE



Fossil fuel use in the buildings sector declines by 96% and space heating energy needs by two-thirds to 2050, thanks mainly to energy efficiency gains

Note: Other includes desalination and traditional use of solid biomass which is not allocated to a specific end-use.

Zero-carbon-ready buildings

The NZE pathway for the buildings sector requires a step change improvement in the energy efficiency and flexibility of the stock and a complete shift away from fossil fuels. To achieve this, more than 85% of buildings need to comply with zero-carbon-ready building energy codes by 2050 (Box 3.4). This means that mandatory zero-carbon-ready building energy codes for all new buildings need to be introduced in all regions by 2030, and that retrofits need to be carried out in most existing buildings by 2050 to enable them to meet zero-carbon-ready building energy codes.

Retrofit rates increase from less than 1% per year today to about 2.5% per year by 2030 in advanced economies: this means that around 10 million dwellings are retrofitted every year. In emerging market and developing economies, building lifetimes are typically lower than in advanced economies, meaning that retrofit rates by 2030 in the NZE are lower, at around 2% per year. This requires the retrofitting of 20 million dwellings per year on average to 2030. To achieve savings at the lowest cost and to minimise disruption, retrofits need to be comprehensive and one-off.

Box 3.4 ▷ Towards zero-carbon-ready buildings

Achieving decarbonisation of energy use in the sector requires almost all existing buildings to undergo a single in-depth retrofit by 2050, and new construction to meet stringent efficiency standards. Building energy codes covering new and existing buildings are the fundamental policy instrument to drive such changes. Building energy codes currently exist or are under development in only 75 countries, and codes in around 40 of these countries are mandatory for both the residential and services sub-sectors. In the NZE, comprehensive zero-carbon-ready building codes are implemented in all countries by 2030 at the latest.

What is a zero-carbon-ready building?

A zero-carbon-ready building is highly energy efficient and either uses renewable energy directly, or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat. This means that a zero-carbon-ready building will become a zero-carbon building by 2050, without any further changes to the building or its equipment.

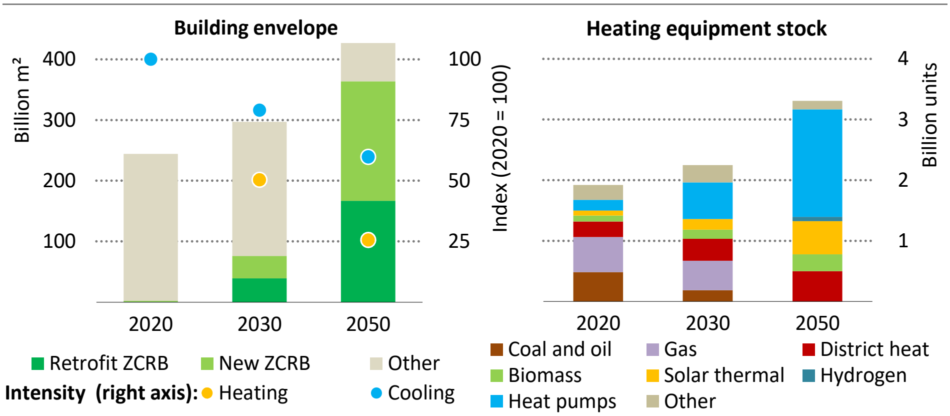
Zero-carbon-ready buildings should adjust to user needs and maximise the efficient and smart use of energy, materials and space to facilitate the decarbonisation of other sectors. Key considerations include:

- **Scope.** Zero-carbon-ready building energy codes should cover building operations (scope 1 and 2) as well as emissions from the manufacturing of building construction materials and components (scope 3 or embodied carbon emissions).
- **Energy use.** Zero-carbon-ready energy codes should recognise the important part that passive design features, building envelope improvements and high energy performance equipment play in lowering energy demand, reducing both the operating cost of buildings and the costs of decarbonising the energy supply.
- **Energy supply.** Whenever possible, new and existing zero-carbon-ready buildings should integrate locally available renewable resources, e.g. solar thermal, solar PV, PV thermal and geothermal, to reduce the need for utility-scale energy supply. Thermal or battery energy storage may be needed to support local energy generation.
- **Integration with power systems.** Zero-carbon-ready building energy codes need buildings to become a flexible resource for the energy system, using connectivity and automation to manage building electricity demand and the operation of energy storage devices, including EVs.
- **Buildings and construction value chain.** Zero-carbon-ready building energy codes should also target net-zero emissions from material use in buildings. Material efficiency strategies can cut cement and steel demand in the buildings sector by more than a third relative to baseline trends, and embodied emissions can be further reduced by more robust uptake of bio-sourced and innovative construction materials.

Heating and cooling

Building envelope improvements in zero-carbon-ready retrofit and new buildings account for the majority of heating and cooling energy intensity reductions in the NZE, but heating and cooling technology also makes a significant contribution. Space heating is transformed in the NZE, with homes heated by natural gas falling from nearly 30% of the total today to less than 0.5% in 2050, while homes using electricity for heating rise from nearly 20% of the total today to 35% in 2030 and about 55% in 2050 (Figure 3.29). High efficiency electric heat pumps become the primary technology choice for space heating in the NZE, with worldwide heat pump installations per month rising from 1.5 million today to around 5 million by 2030 and 10 million by 2050. Hybrid heat pumps are also used in some of the coldest climates, but meet no more than 5% of heating demand in 2050.

Figure 3.29 ▷ Global building and heating equipment stock by type and useful space heating and cooling demand intensity changes in the NZE



By 2050, over 85% of buildings are zero-carbon-ready, reducing average useful heating intensity by 75%, with heat pumps meeting over half of heating needs

Notes: ZCRB refers to buildings meeting zero-carbon-ready building energy codes. Other for building envelope refers to envelopes that do not meet zero-carbon-ready building energy codes. Other for heating equipment stock includes resistive heaters, and hybrid and gas heat pumps.

Not all buildings are best decarbonised with heat pumps, however, and bioenergy boilers, solar thermal, district heat, low-carbon gases in gas networks and hydrogen fuel cells all play a role in making the global building stock zero-carbon-ready by 2050. Bioenergy meets 10% of space heating needs by 2030 and more than 20% by 2050. Solar thermal is the preferred renewable technology for water heating, especially where heat demand is low; in the NZE it meets 35% of demand by 2050, up from 7% today. District heat networks remain an attractive option for many compact urban centres where heat pump installation is impractical, in the NZE they provide more than 20% of final energy demand for space heating in 2050, up from a little over 10% today.

There are no new coal and oil boilers sold globally from 2025 in the NZE. Sales of gas boilers fall by more than 40% from current levels by 2030 and by 90% by 2050. By 2025 in the NZE, any gas boilers that are sold are capable of burning 100% hydrogen and therefore are zero-carbon-ready. The share of low-carbon gases (hydrogen, biomethane, synthetic methane) in gas distributed to buildings rises from almost zero to 10% by 2030 to above 75% by 2050.

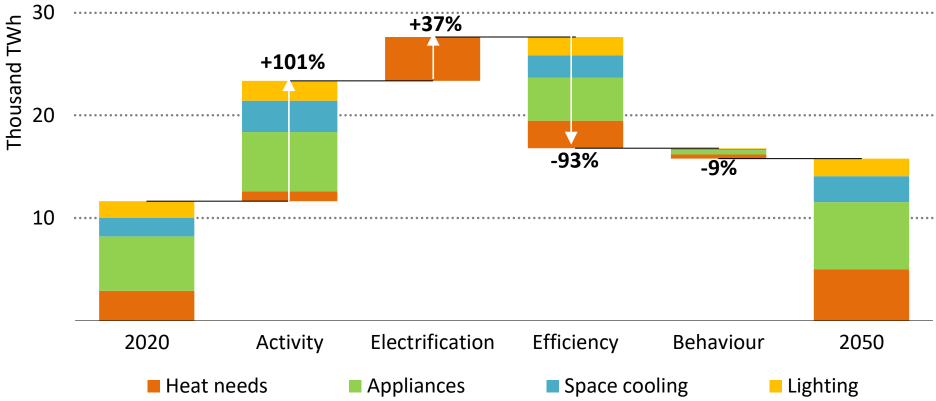
Buildings that meet the standards of zero-carbon-ready building energy codes drive down the need not only for space heating but also for space cooling – the fastest growing end-use in buildings since 2000. Space cooling represented only 5% of total buildings energy consumption worldwide in 2020, but demand for cooling is likely to grow strongly in the coming decades with rising incomes and a hotter climate. In the NZE, 60% of households have an air conditioner in 2050, up from 35% in 2020. High-performance building envelopes, including bioclimatic designs and insulation, can reduce the demand for space cooling by 30-50%, while providing greater resilience during extreme heat events. In the NZE, electricity demand for space cooling grows annually by 1% to reach 2 500 TWh in 2050. Without 2 000 TWh of savings from residential building envelope improvements and higher efficiency equipment, space cooling demand would be almost twice as high.

Appliances and lighting

Electric appliances and lighting become much more efficient over the next three decades in the NZE thanks to policy measures and technical advances. By 2025 in the NZE, over 80% of all appliances and air conditioners sold in advanced economies are the best available technologies today in these markets, and this share increases to 100% by the mid-2030s. In emerging market and developing economies, which account for over half of appliances and air conditioners by 2050, the NZE assumes a wave of policy action over the next decade which leads to 80% of equipment sold in these markets in 2030 being as efficient as the best available technologies in advanced economies today, increasing to close to 100% by 2050 (Figure 3.30). The share of light-emitting diode (LED) lamps in total lightbulb sales reaches 100% by 2025 in all regions. Minimum energy performance standards are complemented by requirements for smart control of appliances to facilitate demand-side response in all regions.

Energy use in buildings will be increasingly focused on electric, electronic and connected equipment and appliances. The share of electricity in energy consumption in buildings rises from 33% in 2020 to around two-thirds in 2050 in the NZE, with many buildings incorporating decentralised electricity generation using local solar PV panels, battery storage and EV chargers. The number of residential buildings with solar PV panels increases from 25 million to 240 million over the same period. In the NZE, smart control systems shift flexible uses of electricity in time to correspond with generation from local renewables, or to provide flexibility services to the power system, while optimised home battery and EV charging allow households to interact with the grid. These developments help improve electricity supply security and lower the cost of the energy transition by making it easier and cheaper to integrate renewables into the system.

Figure 3.30 ▷ **Global change in electricity demand by end-use in the buildings sector**



Energy efficiency is critical to mitigate electricity demand growth for appliances and air conditioning, with savings more than offsetting the impact of electrifying heat

3.7.2 Key milestones and decision points

Table 3.5 ▷ **Key milestones in transforming global buildings sector**

Category	
New buildings	• From 2030: all new buildings are zero-carbon-ready.
Existing buildings	• From 2030: 2.5% of buildings are retrofitted to be zero-carbon-ready each year.

Category	2020	2030	2050
Buildings			
Share of existing buildings retrofitted to the zero-carbon-ready level	<1%	20%	>85%
Share of zero-carbon-ready new buildings construction	5%	100%	100%
Heating and cooling			
Stock of heat pumps (million units)	180	600	1 800
Million dwellings using solar thermal	250	400	1 200
Avoided residential energy demand from behaviour	n.a.	12%	14%
Appliances and lighting			
Appliances: unit energy consumption (index 2020=100)	100	75	60
Lighting: share of LED in sales	50%	100%	100%
Energy access			
Population with access to electricity (billion people)	7.0	8.5	9.7
Population with access to clean cooking (billion people)	5.1	8.5	9.7
Energy infrastructure in buildings			
Distributed solar PV generation (TWh)	320	2 200	7 500
EV private chargers (million units)	270	1 400	3 500

Near-term government decisions are required for energy codes and standards for buildings, fossil fuel phase out, use of low-carbon gases, acceleration of retrofits and financial incentives to encourage investment in building sector energy transitions. Decisions will be most effective if they focus on decarbonising the entire value chain, taking into account not only buildings but also the energy and infrastructure networks that supply them, as well as wider considerations including the role of the construction sector and urban planning. Such decisions are likely to bring wider benefits, notably in reducing fuel poverty.

Near-term government action is needed to ensure that zero-carbon-ready buildings become the new norm across the world before 2030 for both new construction and retrofits. This requires governments to act before 2025 to ensure that zero-carbon-ready compliant building energy codes are implemented by 2030 at the latest. While this goal applies to all regions, ways to achieve zero-carbon-ready buildings vary significantly across regions and climate zones, and the same is true for heating and cooling technology strategies. Governments should consider paving the way by making public buildings zero-carbon-ready in the coming decade.

Governments will need to find ways to make new zero-carbon-ready buildings and retrofits affordable and attractive to owners and occupants by overcoming financial barriers, addressing split incentive barriers and minimising disruption to building use. Building energy performance certificates, green lease agreements, green bond financing and pay-as-you save models could all play a part.

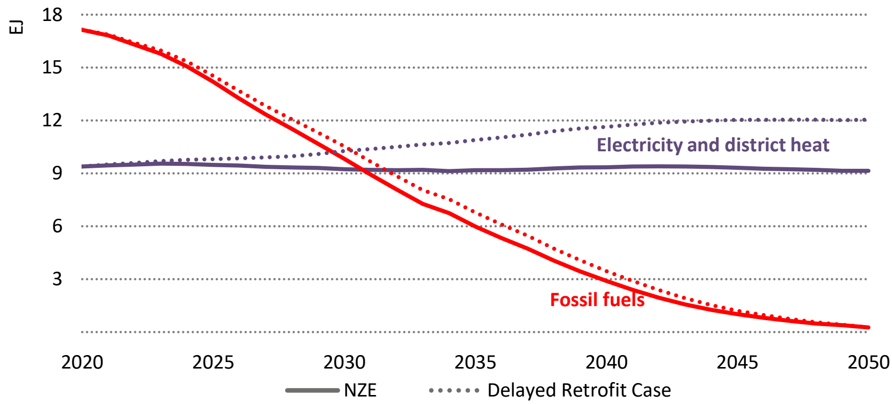
Making zero-carbon-ready building retrofits a central pillar of economic recovery strategies in the early 2020s is a no-regrets action to jumpstart progress towards a zero-emissions building sector. Foregoing the opportunity to make energy use in buildings more efficient would drive up electricity demand linked to electrification of energy use in the buildings sector and make decarbonising the energy system significantly more difficult and more costly (Box 3.5).

Box 3.5 ▹ What would be the impact of global retrofit rates not rising to 2.5%?

Decarbonising heating in existing buildings in the NZE rests upon a deep retrofit of the majority of the existing building stock. Having almost all buildings meet zero-carbon-ready building energy codes by 2050 would require retrofit rates of 2.5% each year by 2030, up from less than 1% today. Retrofits can be disruptive for occupants, require high upfront investment and may face permitting difficulties. These issues make achieving the required pace and depth of retrofits in the coming years the biggest challenge facing the buildings sector.

Any delay in reaching 2.5% of annual retrofits by 2030 would require such a steep subsequent ramp up as to make retrofitting the vast majority of buildings by 2050 virtually impossible. Modelling indicates that a delay of ten years in the acceleration of retrofitting, would increase residential space heating energy demand by 25% and space cooling demand by more than 20%, translating to a 20% increase in electricity demand in 2050 relative to the NZE (Figure 3.31). This would put more strain on the power sector, which would need to install more low-carbon generation capacity. Policies and fuel switching would still drive down fossil fuel demand in the *Delayed Retrofit Case*, but an additional 15 EJ of fossil fuels would be burned by 2050, emitting 1 Gt of CO_2.

Figure 3.31 ▷ Global residential space heating and cooling energy demand in the NZE and Delayed Retrofit Case



Delays in the ramp up of retrofit rates and depth would be almost impossible to catch up, placing further strain on the power sector and pushing up fossil fuel demand

Governments need to establish policies for coal and oil boilers and furnaces for space and water heating, which in the NZE are no longer available for sale from 2025. They also need to take action to ensure that new gas boilers are able to operate with low-carbon gases (hydrogen ready) in decarbonised gas networks. This puts a premium on the availability of compelling alternatives to the types of boilers being phased out, including the use of heat pumps, efficient wood stoves (using sustainable supplies of wood), district energy, solar PV, solar thermal and other renewable energy technologies. Which alternatives are best will depend to some extent on local conditions, but electrification will be the most energy-efficient and cost-effective low-carbon option in most cases, and decarbonising and expanding district energy networks is likely to make sense where densities allow. The use of biomethane or hydrogen in existing or upgraded gas networks may be the best option in areas where more efficient alternatives are not possible.

Governments also face decisions on minimum energy performance standards (MEPS). The NZE sees all countries introduce MEPS for all main appliance categories set at the most stringent levels prevailing in advanced economies by 2025 at the latest. Among others, this would mean ending the sale of incandescent, halogen and compact fluorescent lamps by that time. Setting MEPS at the right level will require careful planning; international collaboration to align standards and objectives could play a helpful role in keeping costs down.

The systemic nature of the NZE means that strategies and policies for buildings will work best if they are aligned with those being adopted for power systems, urban planning and mobility. This would help to ensure the successful scaling up of building-integrated PV technologies, battery storage and smart controls to make buildings active service providers to grids. It would also help to foster the deployment of smart EV charging infrastructure. Policies incentivising dense and mixed-use urban planning coupled with easy access to local services and public transport could reduce reliance on personal vehicles (see Chapter 2). There are also links between buildings strategies and measures to reduce the embodied carbon emissions of new construction, which falls by 95% by 2050 in the NZE.

Wider implications of achieving net-zero emissions

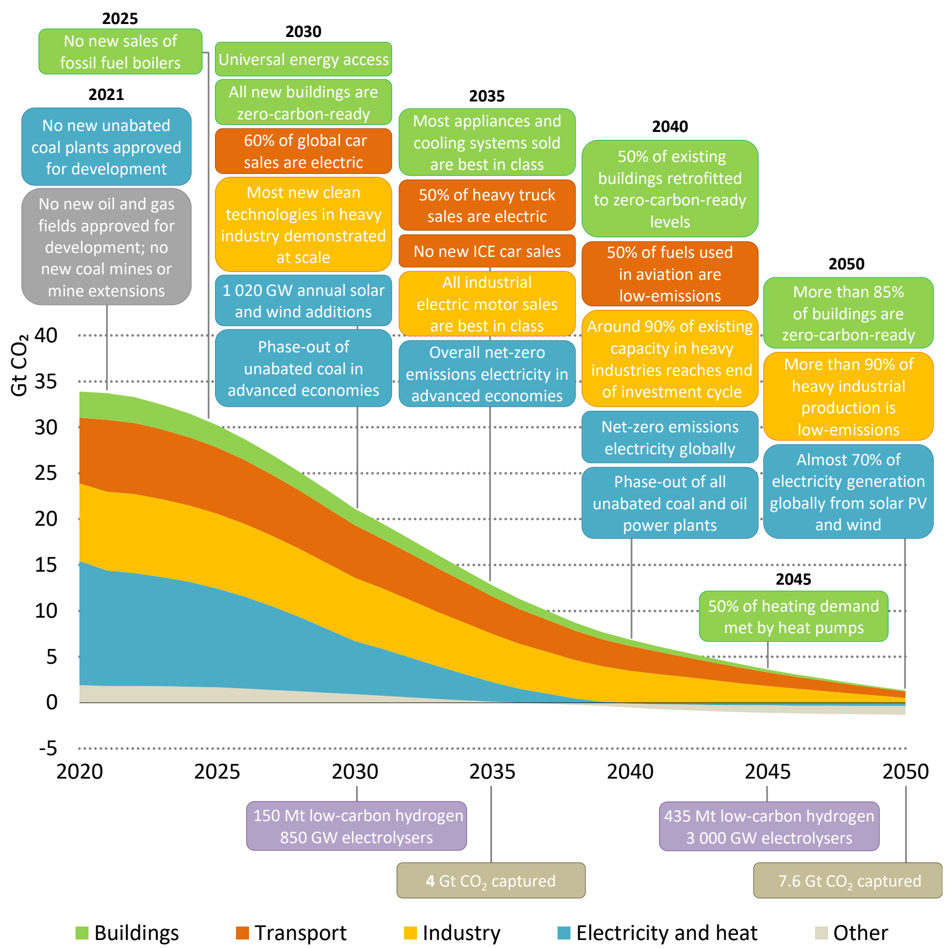
SUMMARY

- **Economy:** In our Net-Zero Emissions by 2050 Scenario (NZE), global CO_2 emissions reach net zero by 2050 and investment rises across electricity, low-emissions fuels, infrastructure and end-use sectors. Clean energy employment increases by 14 million to 2030, but employment in oil, gas and coal declines by around 5 million. There are varying results for different regions, with job gains not always occurring in the same place, or matching the same skill set, as job losses. The increase in jobs and investment stimulates economic output, resulting in a net increase in global GDP to 2030. But oil and gas revenues in producer economies are 80% lower in 2050 than in recent years and tax revenues from retail oil and gas sales in importing countries are 90% lower.
- **Energy industry:** There is a major contraction in fossil fuel production, but companies that produce these fuels have skills and resources that could play a key role in developing new low-emissions fuels and technologies. The electricity industry scales up to meet demand rising over two-and-a-half-fold to 2050 and becomes more capital intensive, focusing on renewables, sources of flexibility and grids. Large energy-consuming companies, vehicle manufacturers and their suppliers adjust designs and retool factories while improving efficiency and switching to alternative fuel supplies.
- For **citizens** who lack access to electricity and clean cooking, the NZE delivers universal access by 2030. This costs around USD 40 billion a year over the next decade and adds less than 0.2% to CO_2 emissions. For citizens the world over, the NZE brings profound changes, and their active support is essential if it is to succeed. Around three-quarters of behavioural changes in the NZE can be directly influenced or mandated by government policies. The cost of energy is also an important issue for citizens, and the proportion of disposable household income spent on energy over the period to 2050 remains stable in emerging market and developing economies, despite a large increase in demand for modern energy services.
- **Government** action is central to achieve net-zero emissions globally by 2050; it underpins the decisions made by all other actors. Four particular points are worth stressing. First, the NZE depends on actions that go far beyond the remit of energy ministers, and requires a co-ordinated cross-government approach. Second, the fall in oil and gas demand in the NZE may reduce some traditional energy security risks, but they do not disappear, while potential new vulnerabilities emerge from increasing reliance on electricity systems and critical minerals. Third, accelerated innovation is needed. The emissions cuts to 2030 in the NZE can be mostly achieved with technologies on the market today, but almost half of the reductions in 2050 depend on technologies that are currently under development. Fourth, an unprecedented level of international co-operation is needed. This helps to accelerate innovation, develop international standards and facilitate new infrastructure to link national markets. Without the co-operation assumed in the NZE, the transition to net-zero emissions would be delayed by decades.

4.1 Introduction

Achieving net-zero emissions by 2050 is a monumental task, especially against a backdrop of increasing economic and population growth. It calls for an unwavering focus from all governments, working together with industries and citizens, to ensure that the transition to global net-zero emissions proceeds in a co-ordinated way without delay. In this chapter, we look at what the changes that deliver net-zero emissions globally by 2050 in the NZE would mean for the economy, the energy industry, citizens and governments.

Figure 4.1 ▷ Selected global milestones for policies, infrastructure and technology deployment in the NZE



There are multiple milestones on the way to global net-zero emissions by 2050. If any sector lags, it may prove impossible to make up the difference elsewhere.

Wide-ranging measures and regulations in the NZE help to influence or change the purchases that individuals make, the way they heat and cool their homes, and their means of transport. Many industries, especially those that are currently involved in the production of energy or are large-scale users of energy, also face change. Some of the shifts for individuals and industries may be unpopular, underscoring the fact that it is essential to ensure that the energy transition is transparent, just and cost-effective, and to persuade citizens of the need for reform. These changes deliver significant benefits. There are around 790 million people who do not have access to electricity today and 2.6 billion people who do not have access to clean cooking options. The NZE shows how emissions reductions can go hand-in-hand with efforts to provide universal access to electricity and clean cooking, and to improve air quality. It provides significant opportunities too, with clean energy technologies providing many new business opportunities and jobs, and with innovations that stimulate new industrial capacities.

Underpinning all of these changes are decisions taken by governments. This will require wholehearted buy-in from all levels of government and from all countries. The magnitude of the changes required to reach global net-zero emissions by 2050 are not within the power of government energy or environment departments alone to deliver, nor within the power of individual countries. It will involve an unprecedented level of global collaboration, with recognition of and sensitivity to differences in the stages of development of individual countries, and an appreciation of the difficulties faced by particular communities and members of society, especially those who may be negatively affected by the transition to net-zero emissions. In the NZE, governments start by setting unequivocal long-term targets, ensuring that these are fully supported from the outset by explicit, near-term targets and policy measures that clearly set out the pathway, and that recognise each country's unique starting conditions, to support the deployment of new infrastructure and technologies (Figure 4.1).

4.2 Economy

4.2.1 Investment and financing

The transition to net-zero emissions by 2050 requires a substantial ramp up in the investment of electricity, infrastructure and the end-use sectors. The largest increase over the next decade is in electricity generation: annual investment increases from about USD 0.5 trillion over the past five years to USD 1.6 trillion in 2030 (Figure 4.2). By 2030, annual investment in renewables in the electricity sector is around USD 1.3 trillion, slightly more than the highest level ever spent on fossil fuel supply (USD 1.2 trillion in 2014). Annual investment in clean energy infrastructure increases from around USD 290 billion over the past five years to about USD 880 billion in 2030. This is for electricity networks, public electric vehicle (EV) charging stations, hydrogen refuelling stations and import and export terminals, direct air capture and CO_2 pipelines and storage facilities. Annual investment in low-carbon technologies in end-use sectors rises from USD 530 billion in recent years to USD 1.7 trillion in 2030.[1] This includes spending on deep retrofitting of buildings, transformation of industrial processes, and the purchase of new low-emissions vehicles and more efficient appliances.

After 2030, annual electricity generation investment falls by one-third to 2050. A lot of infrastructure for a low-emissions electricity sector is established within the first decade of the NZE, and the cost of renewables continues to decline after 2030. In end-use sectors, there are continued increases in investment in EVs, carbon capture, utilisation and storage (CCUS) and hydrogen use in industry and transport, and more efficient buildings and appliances.

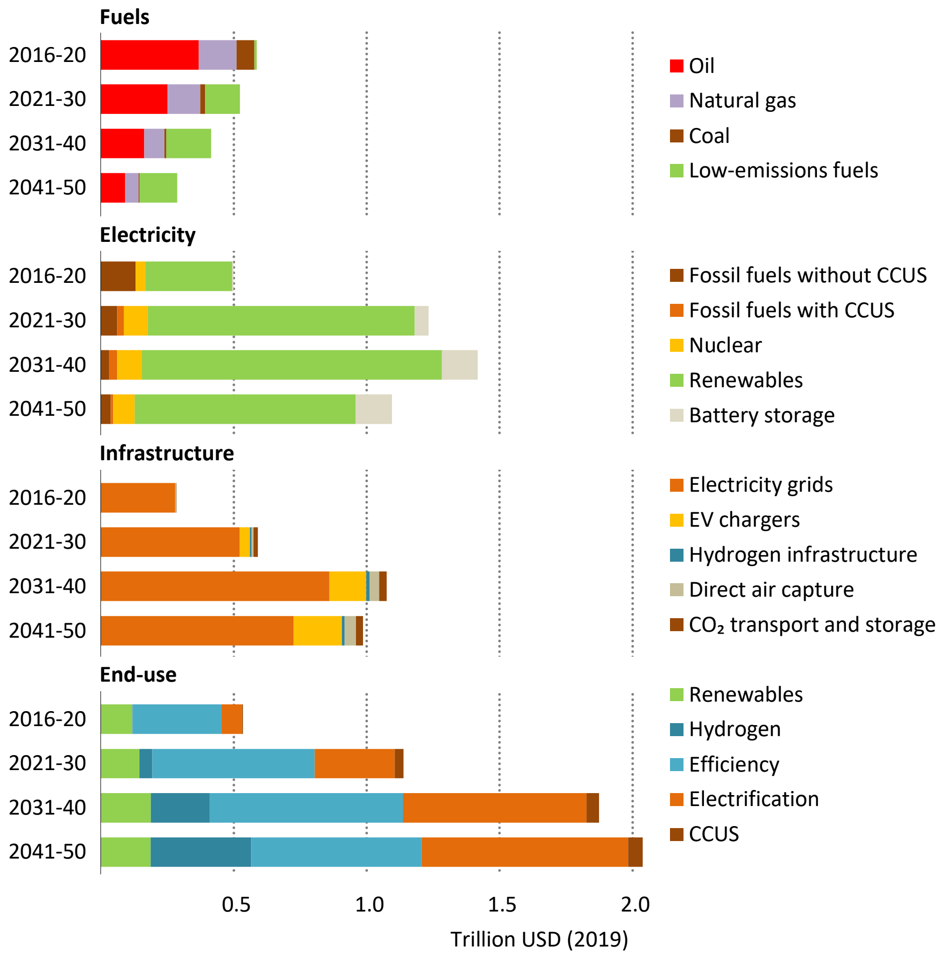
Global investment in fossil fuel supply falls steadily from about USD 575 billion on average over the past five years to USD 110 billion in 2050 in the NZE, with upstream fossil fuel investment restricted to maintaining production at existing oil and natural gas fields. This investment reflects the fact that fossil fuels are still used in 2050 in the NZE in processes where they are paired with CCUS, in non-emitting processes (such as petrochemical manufacturing), and in sectors where emissions reductions are most challenging (with emissions offset by carbon dioxide removal). Investment in low-emissions fuels increases more than thirty-fold between 2020 and 2050, reaching about USD 135 billion in 2050. This is split roughly equally between the production of hydrogen and hydrogen-based fuels, and the production of biofuels.

Over the 2021-50 period in the NZE, annual average total energy sector investment as a share of gross domestic product (GDP) is around 1% higher than over the past five years. The private sector is central to finance higher investment needs. It requires enhanced collaboration between developers, investors, public financial institutions and governments. Collaboration will be especially important over the next five to ten years for the development of large infrastructure projects and for technologies in the demonstration or prototype phase today such as some hydrogen and CCUS applications. Companies and investors have declared strong interest to invest in clean energy technologies, but turning interest into actual investment at the levels required in the NZE also depends on public policies.

Some obstacles to investment need to be tackled. Many emerging market and developing economies are reliant on public sources to finance energy projects and new industrial facilities. In some cases, improvements in regulatory and policy frameworks would facilitate the international flow of long-term capital to support the development of both new and existing clean energy technologies. The rapid growth in investment in transport and buildings in the NZE presents a different kind of challenge for policy makers. In many cases, an increase in capital spending for an efficient appliance or low-emissions vehicle would be more than offset by lower expenditure on fuels and electricity over the product lifetime, but some low-income households and small and medium enterprises may not be able to afford the upfront capital required.

[1] Investment levels presented in this report include a broader accounting of efficiency improvements in buildings and differ from that reported in the IEA World Energy Investment report (IEA, 2020a). End-use efficiency investments are the incremental cost of improving the energy performance of equipment relative to a conventional design.

Figure 4.2 ▷ Global average annual energy investment needs by sector and technology in the NZE



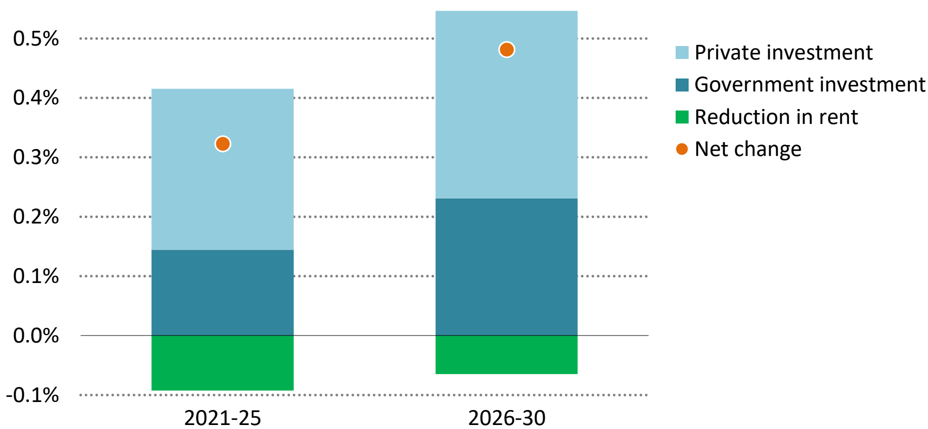
Investment increases rapidly in electricity generation, infrastructure and end-use sectors. Fossil fuel investment drops sharply, partly offset by a rise in low-emissions fuels.

Notes: CCUS = carbon capture, utilisation and storage; EV = electric vehicle. Infrastructure includes electricity networks, public EV charging, CO_2 pipelines and storage facilities, direct air capture and storage facilities, hydrogen refuelling stations, and import and export terminals for hydrogen.

4.2.2 Economic activity

The energy transition required for net-zero emissions by 2050 will affect all economic activities directly or indirectly. In co-ordination with the International Monetary Fund, we have modelled the medium-term global macroeconomic impact of the changes in the energy sector that occur in the NZE. This analysis shows that the surge in private and government spending on clean energy technologies in the NZE creates a large number of jobs and stimulates economic output in the engineering, manufacturing and construction industries. This results in annual GDP growth that is nearly 0.5% higher than the levels in the Stated Policies Scenario (STEPS)[2] during latter half of the 2020s (Figure 4.3).[3]

Figure 4.3 ▷ Change in annual growth rate of global GDP in the NZE relative to the STEPS



The surge in government and private investment in the NZE has a positive impact on global GDP, but there are large differences between regions

Notes: GDP = gross domestic product. Reduction in rents stem mainly from lower fossil fuel income.

Source: IEA analysis based on IMF.

There are large differences in macroeconomic impacts between regions. The decline in fossil fuel use and prices results in a fall in GDP in the producer economies,[4] where revenues from oil and gas sales often cover a large share of public spending on education, health care and other public services. The drop in oil and gas demand, and the consequent fall in international prices for oil and gas, cause net income in producer economies to drop to historic lows (Figure 4.4). Some countries with the lowest cost oil resources (including members of the

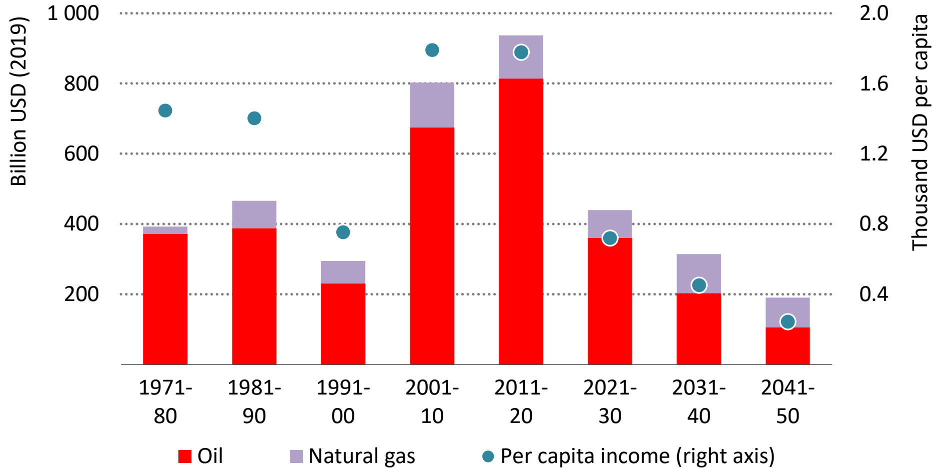
[2] The IEA Stated Policies Scenario is the projection for the global energy system based on the policies and measures that governments around the world have already put in place and on announced policies as expressed in official targets and plans, such as Nationally Determined Contributions put forward under the Paris Agreement (see Chapter 1).

[3] The estimated general equilibrium macroeconomic impact of the increase in public and private investment and the reduction in oil-related revenue contained in the NZE has been provided by the International Monetary Fund using its Global Integrated Monetary and Fiscal Model (GIMF).

[4] Producer economies are large oil and gas exporters that rely on hydrocarbon revenues to finance a significant proportion of their national budgets, including countries in the Middle East, Russia and the Caspian region.

Organization of the Petroleum Exporting Countries [OPEC]) gain market share in these circumstances, but even they would see large falls in revenues. Structural reforms would be needed to address the societal challenges, including those to accelerate the process of reforming inefficient fossil fuel subsidies and to speed up moves to use hydrocarbon resources to produce low-emissions fuels, e.g. hydrogen and hydrogen-based fuels (see section 4.3.1).

Figure 4.4 ▷ Income from oil and gas sales in producer economies in the NZE



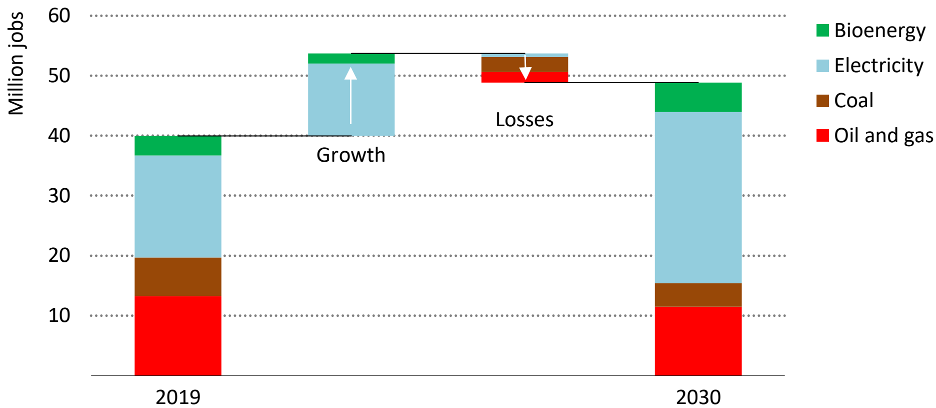
Structural reforms and new sources of revenue are needed in producer economies, but these are unlikely to compensate fully for a large drop in oil and gas income

The macroeconomic effects of the NZE are very uncertain. They depend on a host of factors including: how government expenditure is financed; benefits from improvements to health; changes in consumer bills; broad impact of changes in consumer behaviour; and potential for productivity spill-overs from accelerated energy innovation. Nonetheless, impacts are likely to be lower than assessments of the cost of climate change damages (OECD, 2015). It is also likely that a co-ordinated, orderly transition can be executed without major global systemic financial impacts, but this will require close attention from governments, financial regulators and the corporate sector.

4.2.3 Employment

Employment in the energy sector shifts markedly in the NZE in response to changes in investment and spending on energy. We estimate that today roughly 40 million people around the world work directly in the oil, gas, coal, renewables, bioenergy and energy network industries (IEA, 2020b). In the NZE, clean energy employment increases by 14 million to 2030, while employment in oil, gas and coal fuel supply and power plants declines by around 5 million, leading to a net increase of nearly 9 million jobs (Figure 4.5).

Figure 4.5 ▷ Global energy sector employment in the NZE, 2019-2030



Overall employment in the energy sector increases by almost 9 million to 2030 as jobs created in clean energy sectors outpace losses in fossil fuels

Jobs created would not necessarily be in the same area where jobs are lost, plus the skill sets required for the clean energy jobs may not be directly transferable. Job losses would be most pronounced in communities that are heavily dependent on fossil energy production or transformation activities. Even where the number of direct energy jobs lost is small, the impact on the local economy may be significant. Government support would almost certainly be needed to manage these transitions in a just, people-centred way. In preparation, a better understanding of current energy industry employment is needed. A useful action would be for governments to adopt more detailed surveying approaches for energy industry employment, such as those used in the *US Energy & Employment Report* (NASEO and Energy Futures Initiative, 2021).

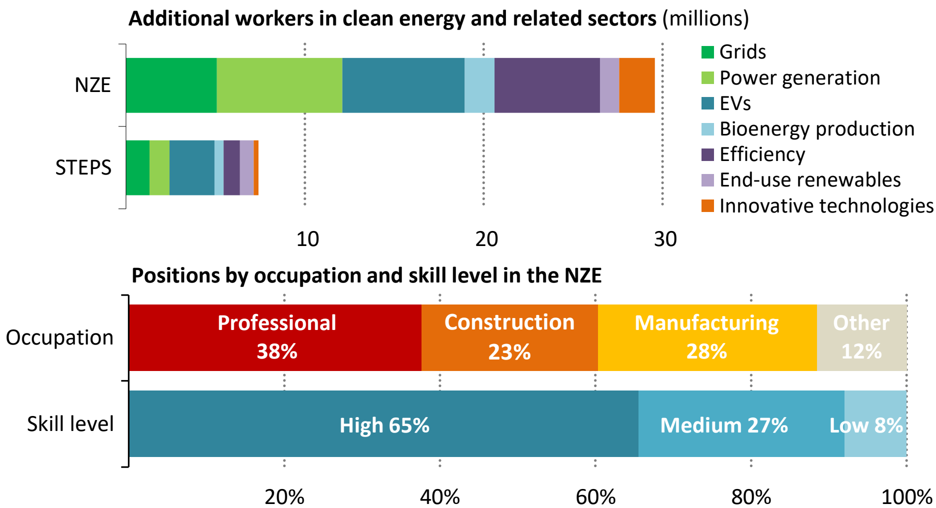
In addition to the 14 million new clean energy jobs created in the NZE, other new jobs are created by changes in spending on more efficient appliances, electric and fuel cell vehicles, and building retrofits and energy-efficient construction. These changes would require a further 16 million workers, meaning that there would be 30 million more people working in clean energy, efficiency and low-emissions technologies by 2030 in the NZE (Figure 4.6).[5] Investment in electricity generation, electricity networks, EV manufacturing and energy efficiency are among the areas that will open up new employment opportunities. For example, jobs in solar and wind more than quadruple in the NZE over current levels. Nearly two-thirds of workers in these sectors by 2030 in the NZE would be highly skilled and the

[5] This includes new jobs and jobs filled by moving current employment from one type of production to another.

majority require substantial training. In addition, with the more than doubling of total energy investment, new employment opportunities will arise in associated areas such as wholesale trading, financial and legal services.

In many cases it may be possible to shift workers to new product lines within the same company, for example in vehicle manufacturing as production reconfigures to EVs. However, there would be larger risks for specialised supply chain companies that provide products and services, e.g. internal combustion engines that are replaced by new components such as batteries.

Figure 4.6 ▻ New workers in clean energy and related sectors and shares by skill level and occupation in the NZE and the STEPS in 2030



About 30 million new workers are needed by 2030 to meet increased demand for clean energy, efficiency, and low-emissions technologies; over half are highly skilled positions

Note: EVs = electric vehicles.

The new jobs created in the NZE tend to have more geographic flexibility and a wider distribution than is the case today. Around 40% are jobs located close to where the work is being done, e.g. building efficiency improvements or wind turbine installation, and the remaining are jobs tied to manufacturing sites. Today the manufacturing capacity for a number of clean energy technologies, such as batteries and solar photovoltaic panels, is concentrated in particular areas, notably China. The rapid increase in demand for clean energy technologies in the NZE requires new production capacity to come online that could be located in any region. Those countries and companies that move first may enjoy strategic advantages in capturing burgeoning demand.

4.3 Energy industry

4.3.1 Oil and gas

The energy transition envisioned in the NZE involves a major contraction of oil and gas production with far-reaching implications for all the companies that produce these fuels. Oil demand falls from around 90 million barrels per day (mb/d) in 2020 to 24 mb/d in 2050, while natural gas demand falls from 3 900 billion cubic metres (bcm) to around 1 700 bcm. No fossil fuel exploration is required in the NZE as no new oil and natural gas fields are required beyond those that have already been approved for development. This represents a clear threat to company earnings, but there are also opportunities. The resources and skills of the oil and gas industry are a good match with some of the new technologies needed to tackle emissions in sectors where reductions are likely to be most challenging, and to produce some of the low-emissions liquids and gases for which there is a rapid increase in demand in the NZE (see Chapter 2). By partnering with governments and other stakeholders, the oil and gas industry could play a leading role in developing these fuels and technologies at scale, and in establishing new business models.

The oil and gas industry is highly diverse, and various companies could pursue very different strategies in the transition to net-zero emissions. Minimising emissions from core oil and gas operations however should be a first-order priority for all oil and gas companies. This includes tackling methane emissions that occur during operations (they fall by 75% between 2020 and 2030 in the NZE) and eliminating flaring. Companies should also electrify operations using renewable electricity wherever possible, either by purchasing electricity from the grid or by integrating off-grid renewable energy sources into upstream facilities or transport infrastructure. Producers that can demonstrate strong and effective action to reduce emissions can credibly argue that their oil and gas resources should be preferred over higher emissions options.

Some oil and gas companies may choose to become "energy companies" focused on low-emissions technologies and fuels, including renewable electricity, electricity distribution, EV charging and batteries. Several technologies that are critical to the achievement of net-zero emissions, such as CCUS, hydrogen, bioenergy and offshore wind, look especially well-suited to some of the existing skills, competencies and resources of oil and gas companies.

- **Carbon capture, utilisation and storage**. The oil and gas industry is already the global leader in developing and deploying CCUS. Of the 40 million tonnes (Mt) of CO_2 captured today at large-scale facilities, around three-quarters is captured from oil and gas operations, which often produce concentrated streams of CO_2 that are relatively easy and cost effective to capture (IEA, 2020c). The oil and gas industry also has the large-scale engineering, pipeline, sub-surface and project management skills and capabilities to handle large volumes of CO_2 and to help scale up the deployment of CCUS.