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Global Energy and Climate Outlook 2023

Investment Needs in a Decarbonised World

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Contents

Abstract

This edition of the Global Energy and Climate Outlook (GECO 2023) presents an updated view on the implications of energy and climate policies worldwide to reaching the goals of the Paris Agreement, and contributes to JRC's work in the UNFCCC policy process. This report provides insight into the investment and related new jobs required by the transition to a low-carbon economy.

Current climate policy pledges and targets imply a rapid decline in greenhouse gas emissions. Still, there remains both an implementation gap in adopting policies aligned with countries' mid-term Nationally Determined Contributions and Long-Term Strategies, and a collective ambition gap in reducing emissions to reach the Paris Agreement targets of pursuing efforts to limit global warming to 1.5°C. Global emissions are projected to peak during the current decade, but failing to implement additional policies puts the world on a trajectory towards a long-term temperature increase of 3°C.

The current decade is key for keeping the 1.5°C target possible. GECO 2023 highlights the global investment needs of the 1.5°C scenario. Accelerated decarbonisation efforts are needed across all sectors of the economy. Energy sector investments need to triple this decade, doubling energy efficiency rates and bringing renewables deployment to 11 TW by 2030. This transition comes along with substantial investment spill-over and stimulus effects, boosting investment and employment across value chains, e.g. in the construction and electrical and equipment goods manufacturing.

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The economic modelling was performed by Rafael Garaffa, Jose Ordonez, Camille Van Der Vorst and Matthias Weitzel.

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Executive summary

This edition of the Global Energy and Climate Outlook (GECO) presents an updated view of the implications of energy and climate policies around the world. Since the previous edition, clean energy deployment has accelerated further, putting a peak of global emissions within reach. Calls have multiplied for mobilising global action towards tripling the installed renewable energy capacity to 11 TW and doubling the rate of improvement in energy efficiency by 2030. This report aims to look at investments in energy production, transformation, supply and demand and how they need to pick up pace during the current decade in order to align the global trajectory of emissions with a 1.5°C-compatible pathway, as well as highlighting implications for employment.

Policy context

In 2023, the impacts of climate change are already been felt with unprecedented extreme weather events and hot temperatures, showing the urgency for acting on climate mitigation and adaptation. 2023 has also seen unprecedented levels of investment in clean technologies.

In this year's Conference of the Parties (Council of the EU, 2023a) of the United Nations Framework Convention on Climate Change (UNFCCC), the global stocktake ends, looking back at the progress made collectively in reaching the objectives of the Paris Agreement of 2015. Whilst countries have made a number of announcements and set themselves targets for the medium and long term, the combined result reveals an ambition gap that asks for additional effort.

This report explores the effects on the energy markets of the latest Nationally Determined Contributions (NDC), Long-Term Strategies (LTS) and Net-Zero Targets submitted or announced in the context of the UNFCCC. It examines how the energy mix should transform and how investments need to be mobilised in order to reach the collective goal of limiting climate change to 1.5°C.

Key conclusions

Meeting the 1.5°C target set out in the Paris Agreement requires a rapid shift to energy systems dominated by renewable sources. Along with energy efficiency improvements, far-reaching electrification of end-uses drives down total volumes of fossil fuel extraction.

Projections with current legislated energy-climate policies point to global emissions peaking within the current decade, which is an important shift in expectations compared to earlier years. However, there remain both a significant implementation gap to reach announced targets and an ambition gap to align targets with a 1.5°C trajectory.

The current decade is a key period for accelerating investments in clean technologies and slashing emissions to keep the 1.5°C target possible. During this decade, global investments in clean technologies should triple, renewables deployment should accelerate to reach 11 TW and annual energy efficiency improvements should double.

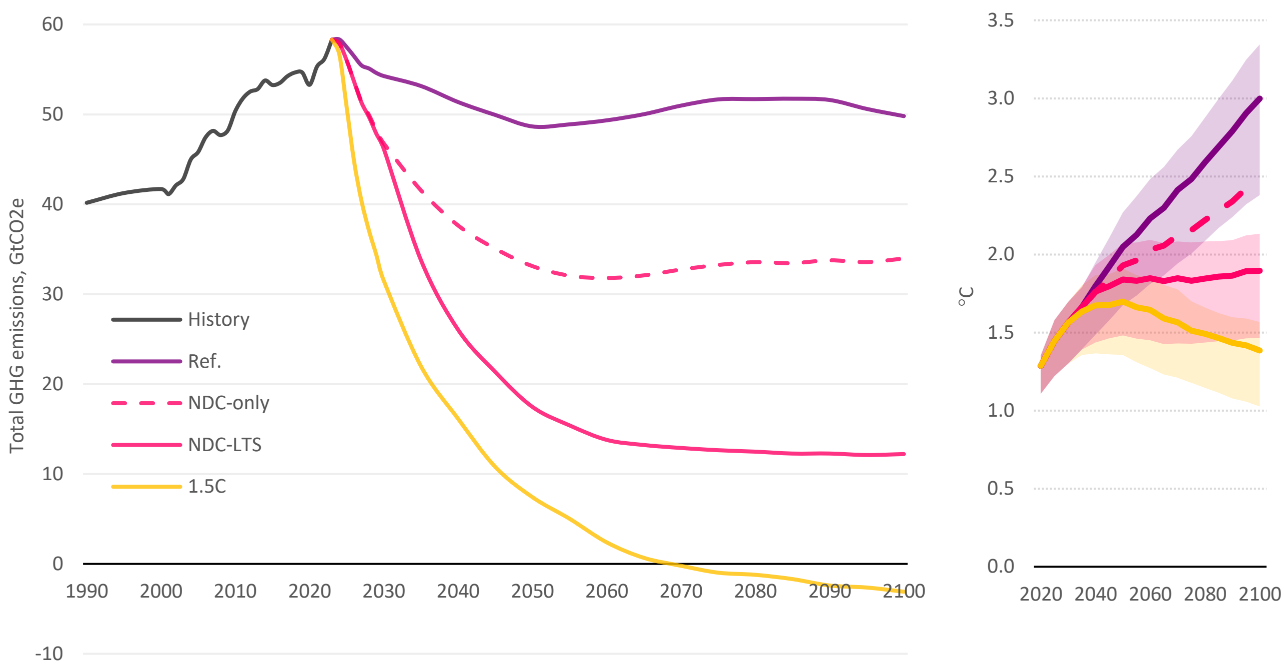
Main findings

Global emissions are still not on track to deliver on the temperature targets of the Paris Agreement. Both the Reference Scenario, which captures the current policy settings, and the NDC-LTS Scenario, which captures the current announced climate targets globally, fall short of limiting temperature rise to 1.5°C.

Progress is being made. Policy action in major economies, continued cost reductions and accelerated deployment of low-emissions technologies in the past year lead to emissions in the Reference scenario peaking within this decade and decreasing down to 2017 levels by 2030, leading to a 3.0°C temperature change by 2100.

Current climate policy pledges and targets in the NDC-LTS scenario imply a rapid decline in greenhouse gas emissions, but gaps remain in implementation (8 $GtCO_2e$ in 2030 compared to Reference) and in ambition (10 $GtCO_2e$ in 2050 compared to 1.5°C).

Figure 1: Global emissions and global mean temperature change, by scenario



Source: POLES-JRC model; liveMAGICC (probabilistic setting). The temperature lines refer to 67% probability; the ranges refer to the 83% and 17% percentile ranges. The overshoot in the 1.5°C scenario is limited to 1.6°C at median probability and 1.7°C at 67% probability.

In the 1.5°C scenario, the share of renewables in total new annually installed capacity increases from 58% in 2021 to 83% in 2030, while the share of non-renewables in total installed capacity halves. The world must move quickly in the coming decade to the point where the bulk of new power generation capacities is renewables. Renewable power generation technologies reach 11 TW of deployed capacity in 2030, while the annual rate of energy efficiency improvements more than doubles this decade compared to the previous.

A fossil fuel subsidies phase-out scenario, which assumes all global fossil fuel subsidies are completely phased out by 2025, sees significant emissions reductions compared to the Reference scenario, 4% in 2030 and 9% in 2050. This corresponds to a 13% reduction in cumulated emissions by the end of the century, leading to an end-of-century temperature increase of 0.2°C lower than in the Reference scenario. To give some context to the magnitude of emissions reductions in this scenario, the decrease achieved in 2030 is equivalent to one-third of the emissions reductions in the NDC-only scenario, which is a result of emissions reductions derived from the Nationally Determined Contributions of 193 countries.

Keeping 1.5°C possible requires accelerating energy-related investments in the current decade. Annual spending on energy production and supply equipment increases by 70% this decade, and almost doubles to reach $3.8 trillion by the middle of the century, with a particularly sharp increase in renewalble power generation investment in the current decade. Nevertheless, energy-related investment as a share of global GDP remains at the historical average of 1.4% through the projection period.

Spending on batteries for electric vehicles increases 12-fold to 2030, to represent the largest investment in clean technologies. Investments in the production of hydrogen and hydrogen-derived fuels (e-fuels and ammonia) represent around a quarter of total clean technologies investments by 2050. Despite their minor role in the aggregate final energy consumption, these are crucial in decarbonising specific sectors such as aviation, shipping, and steel production and replacing grey hydrogen in fertiliser production.

GECO 2023 shows that scaling up investments in clean technologies in line with a 1.5°C decarbonisation trajectory bears potential benefits, beyond delivering the energy transition and its multiple environmental and climate benefits. Scaling up investments in clean technologies compensates for declining investments in fossil fuels, boosting demand for investment across different sectors in the economy, such as the construction and manufacturing sectors. The demand for investment also creates substantial employment opportunities across the value chain, as more workers are needed, both directly in the sectors as well as in the upstream sectors that produce goods required for the energy transition.

Related and future JRC work

The Global Energy and Climate Outlook (GECO) is published annually since 2015. It contributes to the JRC work in the UNFCCC policy process, the IPCC Assessment Reports and the UNEP Emissions Gap Reports.

Quick guide

After an introduction describing the motivation and scope of the GECO this year, Section 2 provides details on the climate policy scenarios, Section 3 presents key results for emissions and energy systems on the global level. Section 4 takes a deep dive into the investment needs in energy supply and demand to make the transition a reality. A final Section provides key metrics for G20 countries.

1 Introduction

The year 2023 was a year of records. According to the World Meteorological Organization, 2023 is set to be the warmest year on record, at about 1.40 °C (+/-0.12 °C) above pre-industrial levels (WMO, 2023). Extreme weather events, such as heat waves, droughts and wildfires, increased in 2023, with their economic impact roughly estimated to amount to 0.6% of global GDP (Allianz, 2023), up from about 0.2% for the 2000-2019 period (Newman and Noy, 2023) . This situation underscores the gravity of climate change and its tangible impacts on global ecosystems, human societies, and infrastructure, with climate science expecting an increasing frequency and intensity of such events. The urgency with which climate adaptation and mitigation measures have to be pursued presents an unparalleled challenge for human civilisation.

The Paris Agreement's objective to pursue efforts to limit temperature increase to 1.5°C is in danger of becoming impossible, at least not without overshoot and later temperature decrease with active carbon dioxide removal from the atmosphere. CO_2 emissions are still rising and have exceeded pre-Covid-19 levels, with an estimated increase of 1% (+/- 0.5%) in 2023 (Sandanger and Peters, 2023). International fossil fuel prices are returning to lower levels after the disruptive upheaval instigated by Russia's war of aggression in Ukraine in 2022. However, the lasting impacts of these events continue to reverberate, underscoring the need for resilience-building measures within supply chains and energy markets. Concurrent with this, considerable investments in fossil fuel infrastructure are still happening. A large fleet of new fossil fuel power plants are still being constructed or planned – over 1000 GW of coal and gas projects at different stages from announcement to construction (Global Energy Monitor, 2023a, 2023b) -- which, along with the existing fleet, would exhaust the world's remaining carbon budget if operated under business-as-usual conditions. Fossil fuel extraction projects also largely exceed the remaining carbon budget to 1.5°C (Kühne et al., 2022).

At the same time, there are signs of change. Investments in clean technologies are also breaking records in 2023, with an estimated 8-22% increase over 2022 (BNEF, 2023; IEA, 2023a); sales of electric vehicles are growing fast, with 2023 sales expected to be about 35% higher than the record-breaking 2022 (IEA, 2023b; King, 2023). Many technologies are exponentially growing, anticipating an upcoming tide turn in the energy mix. Policy support, technological development and shifting investor preferences appear to align – with a strengthened ambition to deploy new technologies and effectively reduce emissions. Accordingly, global clean energy supply chains are scaling up and contributing to increasing collaboration between nations and reducing dependency on conventional energy sources.

This year sees the first global stocktake of the Paris Agreement of the UNFCCC, a process for countries and stakeholders to see where they collectively stand and how they are making progress towards meeting the goals of the Agreement since 2015. Previous editions of the GECO reports have pointed out the significant implementation and ambition gaps that remain to be closed. This year's report examines where the world's emissions and energy markets are heading, what impact announced targets can make, and what investments are required to limit the global temperature increase to 1.5°C.

GECO 2023 first investigates how policies, updated energy prices and technology cost evolutions will impact the global energy system; emissions projections and associated temperature increases are presented in three scenarios (Section 3). The report then provides a deep dive into investments in clean technologies and associated supply chain effects in capital and labour (Section 4). Finally, it presents fact sheets with key metrics for major economies (Section 6).

Box 1. Differences with GECO 2022

The POLES-JRC model has been updated with the latest historical data. Supply-side and demand-side technologies costs as well as learning rates were extensively updated with recent literature (CETO B2, 2024). Fuel/technology preference parameters were revised to reflect the updated data. The carbon price in the 1.5°C scenario was revised to reflect urgent action to limit temperature overshoot; the carbon price trajectory follows a sigmoid curve with an inflection point before 2030.

Historical CO_2 emissions from agriculture, land use, land use change and forestry (AFOLU) are based on (Grassi et al., 2023) and thus follow the conventions of national GHG inventories to UNFCCC for all countries. Land use fluxes projections follow the same logic as previous GECO reports by reporting changes compared to the base year (based on data provided by the GLOBIOM-G4M models). For the reporting at the global level, CO_2 AFOLU emissions were harmonised to global book-keeping models, as used in the Shared Socioeconomic Pathways (Riahi et al., 2017) and IPCC AR6 WGIII (Intergovernmental Panel on Climate Change (IPCC), 2023), through a constant adjustment to match 2015 emissions of CMIP6. In other studies this adjustment is variable, trying to take into account the expected impact of the CO_2 fertilisation effect on the future strength of the land sink (Grassi et al., 2021, Gidden et al., 2023), which influences the future net global anthropogenic emissions and the remaining carbon budget.

The JRC-GEM-E3 was modified to include an investment matrix which creates a direct link between investing sectors and sectors supplying the purchased investment goods (Norman et al., 2023). This captures heterogeneity across investing sectors, in particular power generation technologies.

At all times, monetary values ($) are constant US dollars of 2022.

The results in this report do not prejudge the upcoming results of the 2040 Climate Target Framework.

2 Scenarios and definitions

GECO 2023 was produced based on results from the partial equilibrium global energy model POLES-JRC and the general equilibrium model JRC-GEM-E3 that covers the interactions between the global economy, the energy system and the environment. A description of the POLES-JRC model used in GECO 2023 can be found in Annex 1, and the JRC-GEM-E3 model description is in Annex 2. In addition, detail on socio-economic assumptions and fossil fuel prices can be found in Annex 3.

This section provides a description of the assumptions made for the projections presented in this report. The following scenarios were modelled:

Reference scenario: corresponds to a world where existing policies related to energy supply and demand policies and targets, as well as legislated GHG policies and targets that are backed by concrete supporting energy-sector policies, are enacted. No additional policies are considered compared to what had been legislated as of June 2023. Exogenous macroeconomic projections (GDP and population), with endogenously calculated energy prices and technological development specific to the POLES-JRC model, together with the effect of enacted policies, result in projections of the energy system and GHG emissions. As a consequence, this scenario may differ from energy and emissions projections from official national sources and international organisations. See Annex 4 for the list of policies considered in the Reference scenario.

This scenario does not aim to reach stated policies or targets, whether legislated or not, that have not been accompanied by concrete action plans.

A **Fossil fuels subsidies phase-out** scenario was also modelled, starting from the Reference scenario and assuming a total phase-out of explicit and implicit subsidies in 2025, to assess the impact of one of the main COP28 topics. The methodology and results are discussed in the dedicated section 3.5.

NDC-LTS scenario: considers the targets of NDCs in the medium term and the LTSs in the longer term. This scenario assumes that the objectives in the NDCs (including conditional objectives) are reached in their relevant target year (2030 in most cases). To this end, carbon values and other regulatory instruments are put in place on top of the existing, legislated measures of the Reference scenario to reach sector-specific or economy-wide targets. Beyond 2030, the objectives of the countries' LTS, where they exist, are pursued; if the country has not announced an LTS, it is assumed that no additional decarbonisation effort is made, and carbon values, if any, are kept constant to their 2030 level. This scenario includes the net zero targets announced by many countries. The NDC-LTS scenario also considers decarbonisation proposals related to international aviation and maritime transportation sectors. See Annex 4 for a list of NDC and LTS objectives included in this scenario.

This report's projections differ from national modelling exercises in the NDCs, mostly due to different key macroeconomic assumptions and consequently energy demand growth, but also operating patterns of the power sector. This can lead to some sectoral targets in an NDC not being reached in the NDC-LTS scenario; however, effort has been made to achieve the most important targets regarding renewables and emissions reductions.

An **NDC-Only case** was also modelled, where the effect of the LTSs was removed from the NDC-LTS scenario in order to quantify the impact of each mechanism; carbon prices of the NDC-LTS scenario, if any, were kept constant after 2030 in the NDC-Only case.

1.5°C scenario: this scenario is designed to limit global temperature increase over the century to 1.5°C at the end of the century and limit overshoot of 1.5°C in the intervening decades. In this scenario, the global carbon budget (cumulated net CO_2 emissions) from 2020 until the year when net-zero CO_2 emissions are reached is of approximately 530 $GtCO_2$. Along with non-CO_2 emissions and air pollutant emissions projections, this results in an approximately 77% probability of not exceeding the 1.5°C temperature limit in 2100[1].

A single global carbon price for all regions is used in this scenario, starting immediately (2024) and strongly increasing. Bottom-up policy drivers (such as renewables targets) from the NDC-LTS scenario are not included

[1] Global mean surface temperatures obtained with the online tool liveMAGICC, based on GHG and air pollutant emissions projections from POLES-JRC (Live MAGICC, 2023). 77% probability derived as a linear interpolation between the provided probabilities of 67% and 83%.

here, as this scenario is constructed based on the policy settings of the Reference scenario. The global carbon price is the sole additional policy driver in this scenario. This scenario is therefore a stylised representations of an economically-efficient pathway to the temperature targets, as the uniform global carbon price ensures that emissions are reduced where abatement costs are lowest. This scenario does not consider financial transfers between countries to implement mitigation measures. The use of negative emissions technologies, including the land use sinks, is considerable (26 $GtCO_2$/year in 2100, including CO_2 captured for the production of synthetic fuels); CO_2 capture from combustion and CO_2 direct air capture technologies are made available progressively beyond 2030 (<10 $GtCO_2$/year in 2050). The mobilisation of biomass as an energy resource is relatively limited (remaining below 200 EJ/year for all years), in order to reflect the use of only sustainably-grown biomass[2]. Within the above economic and technological constraints, the overshoot of the temperature target was kept low (with a peak temperature at 1.6°C in 2050, at median probability).

Unless stated otherwise, all monetary values in this report are in 2022 USD.

[2] There appears to be a moderate agreement in the literature for the potential of biomass for energy use of about 200 EJ/year, and a higher level of agreement for the more conventional figure of 90 EJ/year (Creutzig et al., 2015).

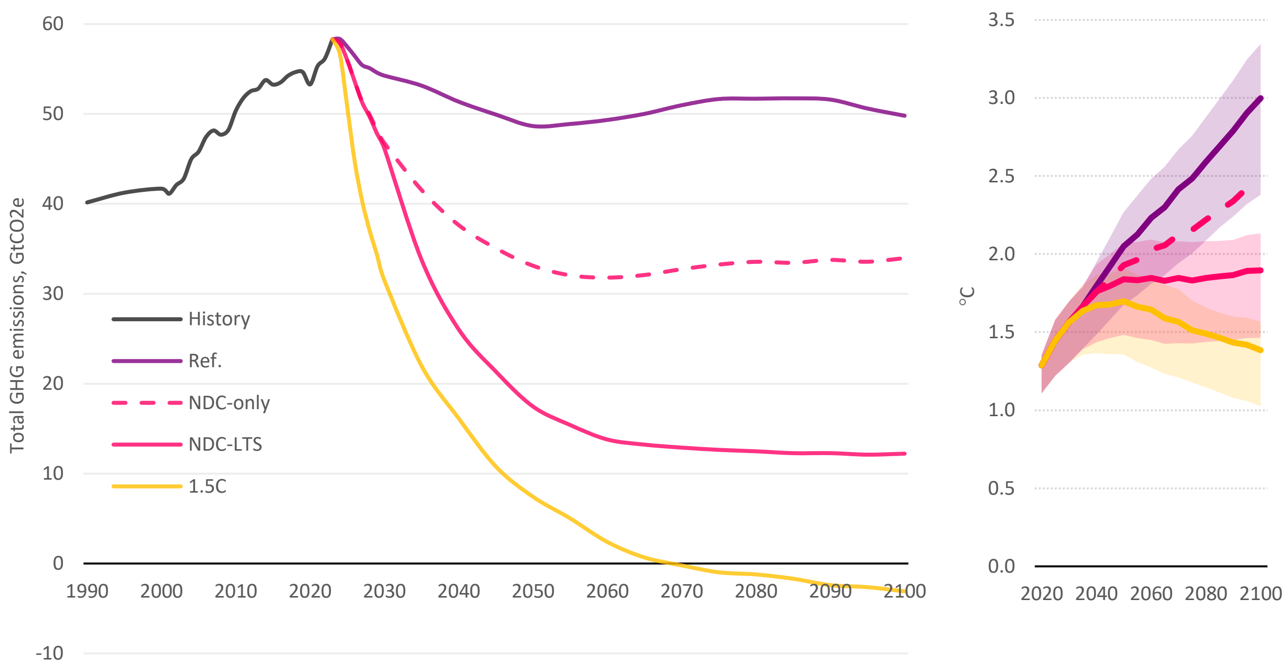
3 Global emissions, and energy supply and demand

3.1 Greenhouse gas emissions and temperature change

Despite the continued deployment of renewables, electric vehicles (EVs) and other low-emission technologies, global emissions in the Reference scenario are broadly in line with those presented in GECO 2022, reaching approximately 50 $GtCO_2eq$ by the middle of the century. The Reference scenario results in an end-of-century temperature rise of 3.0°C at a 67% probability. However, progress is being made as global emissions are projected to peak in the middle of this decade and decreasing down to 2017 levels by 2030.

While the post-Covid-19 economic recovery was slightly faster than expected[3], longer-term projections are of an overall slower economic growth[4]. As a consequence, total global GDP (in PPP terms) is projected to be 4.3% lower in 2050 compared to last year's projections.

Figure 2: Global emissions and global mean temperature change, by scenario



Source: POLES-JRC model; liveMAGICC (probabilistic setting). The temperature lines refer to 67% probability; the ranges refer to the 83% and 17% percentile ranges. The overshoot in the 1.5°C scenario is limited to 1.6°C (median probability). End-of-century values for median probability are: 2.7°C for Reference; 2.2°C for NDC-only; 1.7°C for NDC-LTS; and 1.2°C for 1.5°C.

The NDC-LTS scenario shows that if all pledges are fully achieved, the resulting temperature rise by the end of the century is 1.9°C (67% probability), indicating that more effort on both implementation and ambition are required.

The NDC-only case, which shows the result of the submitted nationally-determined contributions and excludes the impact of countries' long-term strategies, which are mostly net zero targets, sees emissions stabilise post 2050 and leads to a temperature increase of 2.5°C (67% probability) by the end of the century. The 1.5°C scenario sees net zero emissions globally achieved before 2070, and overshoot limited to 1.6°C.

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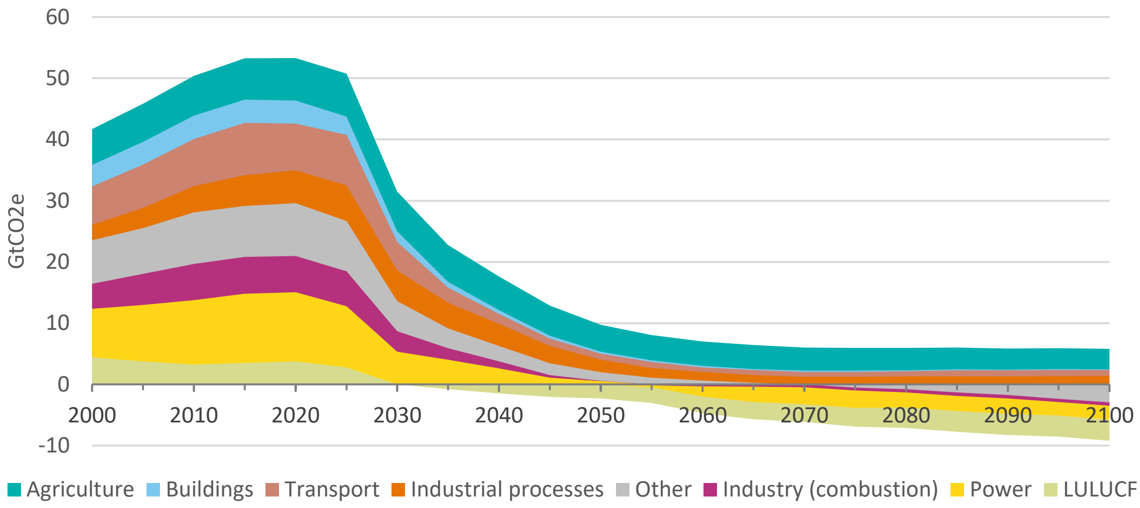
[3] +0.2%/year GDP growth in 2022-2023 compared to last year's estimates.

[4] -0.2%/year GDP growth over 2024-2040, -0.3%/year over 2041-2070 and -0.2%/year over 2071-2100 compared to last year's estimates.

Figure 3: Global emissions, by sector, 1.5°C Scenario



Source: POLES-JRC model. Other includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production) as well as the sink from the direct air capture of CO_2.

Breaking down the 1.5°C scenario pathway by sector highlights where and when effort needs to be focussed:

- Significant rates of emission reductions occur in power generation, transport, buildings and industry in this decade and the next one in order to put the world on a 1.5°C trajectory. Transport, buildings and industry (combustion) reach unprecedented rates of emission reduction, around 10% on average annually in the 2030-2040 decade. The power sector sees a sustained 7% reduction annually in the current and coming decades and a sharp decline (15%) in the 2040-2050 decade.
- Carbon capture and sequestration (CCS) contributes to decreasing emissions and leads to net-negative emissions in the power sector, industry (mainly in cement production), and direct air capture (where the CO_2 that is not used to produce hydrogen-derived fuels is sequestered), after 2050.
- The LULUCF sector sees sharp emission reductions occurring almost immediately, and turns from a source to a net sink of emissions post 2030. After that date, reforestation, afforestation and better land management practices are required for the land sector to become a significant sink of emissions throughout the century.

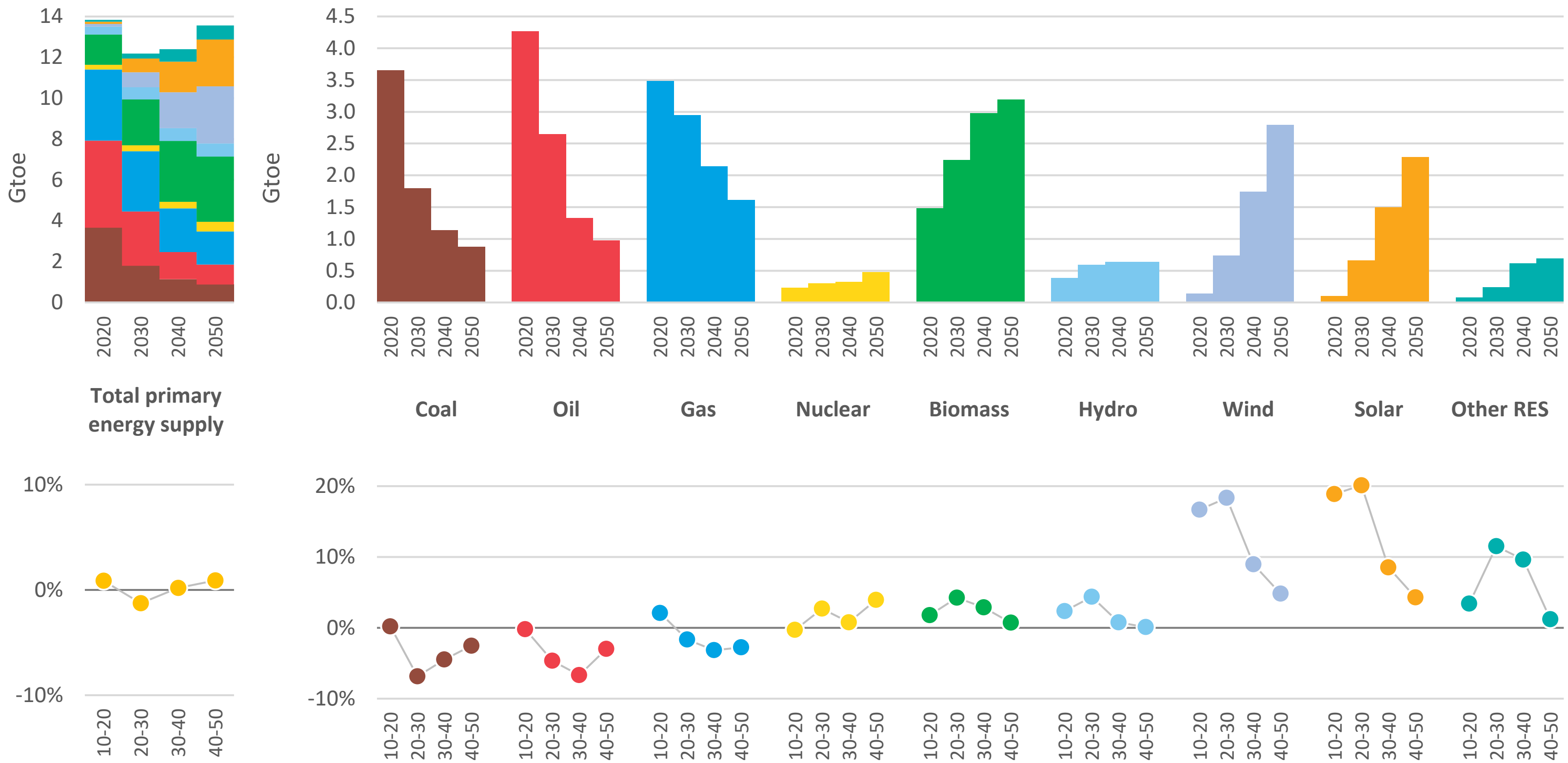
3.2 Energy supply in the 1.5°C scenario

3.2.1 Total primary energy supply

In the 1.5°C scenario, the rapid decarbonisation leads to a transformation of the primary energy supply:

- The primary energy supply from all fossil energy carriers (coal, oil, and gas) declines through to 2050. The energy supplied from coal halves in this decade and then halves again between 2030 and 2050, to reach 0.9 Gtoe in 2050. Primary oil supply declines to 1.0 Gtoe in 2050, falling at an average of 7% annually in the 2030-2040 decade. The energy supply from gas presents a slight but sustained reduction in the coming decades, declining from 3.5 Gtoe in 2020 to 1.6 Gtoe in 2050. Unlike coal and oil, gas still represents more than 10% of the total primary energy supply in 2050.
- A reduction in energy demand this decade occurs as a result of rapid electrification in the 1.5°C scenario, and higher energy prices in this scenario.
- Energy supply from solar and wind continues to expand, but at a slower rate over the projection period than today. The remarkable expansion of the current decade, with an average annual growth rate of 20% for solar and 18% for wind, decreases to 5% annually each in the 2030-2040 decade. Together, wind and solar represent around 37% of total primary energy supply in 2050.

Figure 4: Global total primary energy supply by fuel, and decadal growth rates, 1.5°C scenario



Source: POLES-JRC model. Notes: Other RES: geothermal and ocean

- Strong growth in biomass sees it doubling its supply in the coming two decades, from 1.5 Gtoe in 2020 to 3.2 Gtoe in 2050. Hydroelectricity growth levels off after 2030, while other renewables, geothermal and ocean, grow at a high rate but from relatively low levels.
- Nuclear sees steady growth throughout the projection period, from 0.2 to 0.5 Gtoe, at approximately 3% annually.

3.2.2 Power generation

In the 1.5°C scenario, total power generation increases 2.5 times between 2020 and 2050. This increase is accompanied by a transformation that leads to several striking results in individual technologies:

- The transformative expansion in solar and wind: these two technologies combined increase from 9% of total generation in 2020 to 37% in 2030 and 62% in 2050. This implies a five-fold increase from 2020 to 2030, with an average annual growth rate of 16% for wind and 21% for solar in this decade. Other renewables, mostly hydro and geothermal, increase markedly, taking off in 2030.
- The retirement of coal: at the same time that renewables are introduced at increasing speed, coal generation decreases at an average of 11% annually in the current decade and around 4% after 2030. Coal fitted with CCS plays a minor role, reaching 0.3% of power generation in 2050.
- Fossil gas generation is stable in the coming decade and then slightly decreases starting in 2040. The dispatchability of gas provides renewables balancing services in the next decade; beyond that, gas starts to retire as batteries take over with emissions-free balancing. Gas plants fitted with CCS also play only a minor role, reaching 0.4% of power generation in 2050.
- Biomass generation doubles by 2030 and sees a six-fold increase by 2040, mostly to provide net-negative emissions through bioenergy with CCS (BECCS).
- Nuclear capacity experiences a comparably modest growth, almost doubling by 2050 as an important source of zero-emissions electricity, particularly in countries with an existing nuclear industry and those with relatively more limited renewables resources.

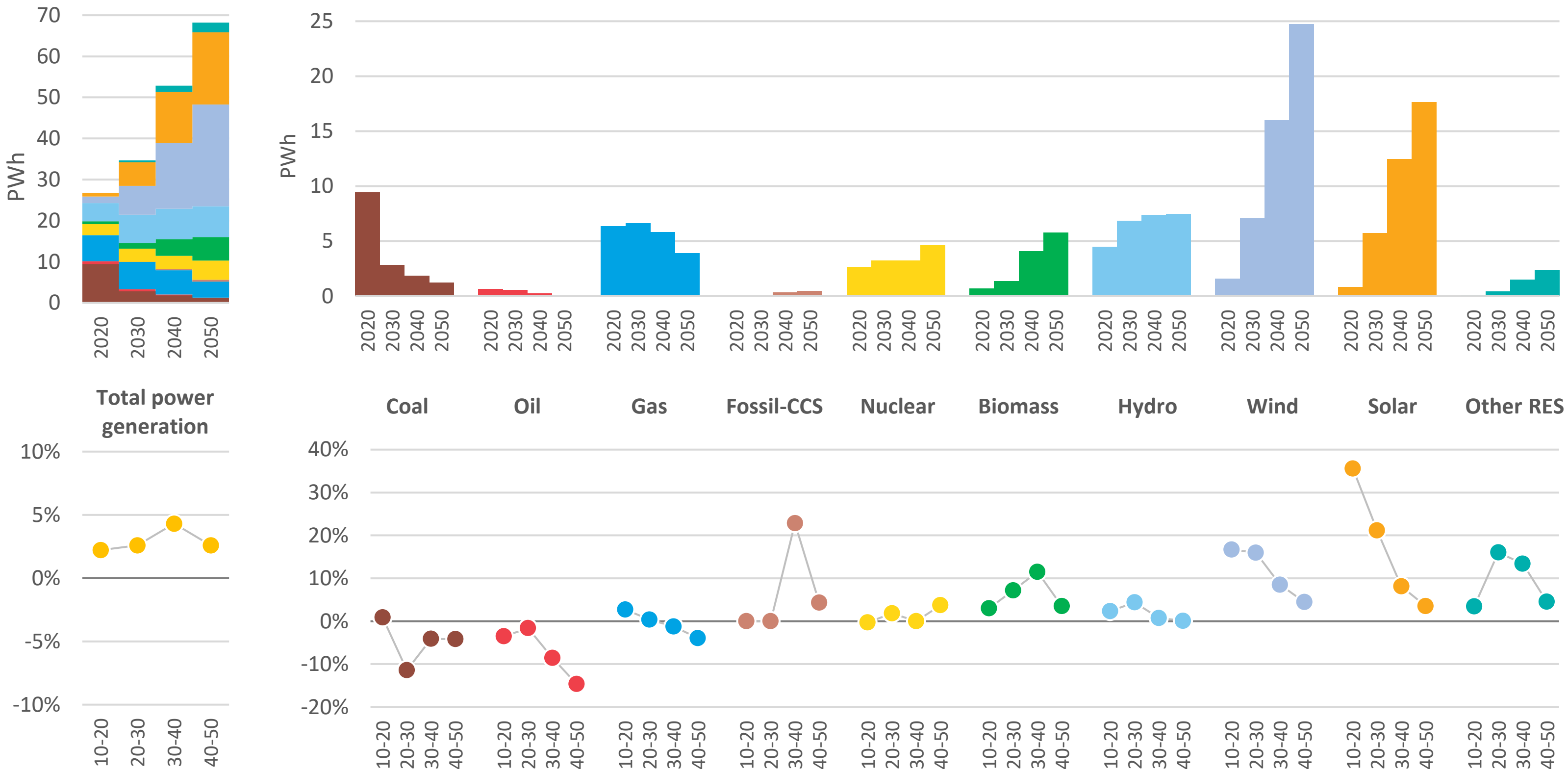
3.3 Final energy demand

3.3.1 Industry

Decarbonisation in the 1.5°C scenario sees the industry sector change from one with a diversified energy mix today to one that is dominated by electricity in 2050:

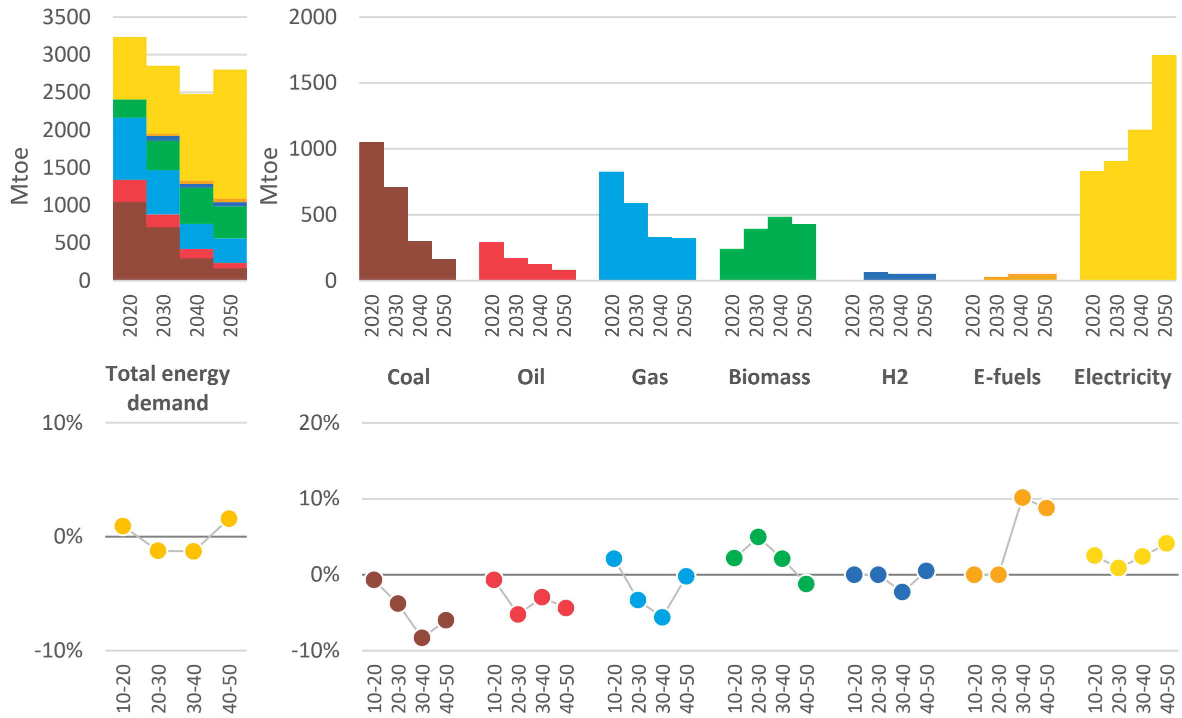
- Total industrial energy demand remains stable through to 2050, as significant electrification improves energy efficiency and offsets increases from a growing industrial output.
- Electricity increases its share of total industrial energy demand from approximately one quarter to 58% in 2050 (excluding non-energy uses in industry), at a modest growth rate of 2% per annum, as an increasing range of applications are electrified.
- The share of coal in final energy demand decreases from approximately one third today to 5% by 2050, as many applications switch to electricity use. Gas demand remains more robust, more than halving from today to 2050, as it is used in both energy and non-energy applications (feedstock).
- Other fuels play niche roles, including hydrogen and e-fuels, which both represent a combined share of 8% of total industrial demand in 2050.
- Biomass doubles its share from 8% today to 15% in 2050.

Figure 5: Global power generation by technology, and decadal growth rates, 1.5°C scenario



Source: POLES-JRC model. Notes: Fossil-CCS: Coal-CCS and Gas-CCS; Biomass: Biomass and Biomass-CCS; Other RES: geothermal and ocean.

Figure 6: Global industry energy demand by fuel, and decadal growth rates, 1.5°C scenario



Source: POLES-JRC model

3.3.2 Transport

In the opposite trend from that seen in industry, the transport sector transforms from one dominated by one fuel today, oil, to a more diversified fuel mix by 2050. Oil demand rapidly diminishes as decarbonisation pushes towards first accelerating electricity demand and then taking up hydrogen and e-fuels after 2040.

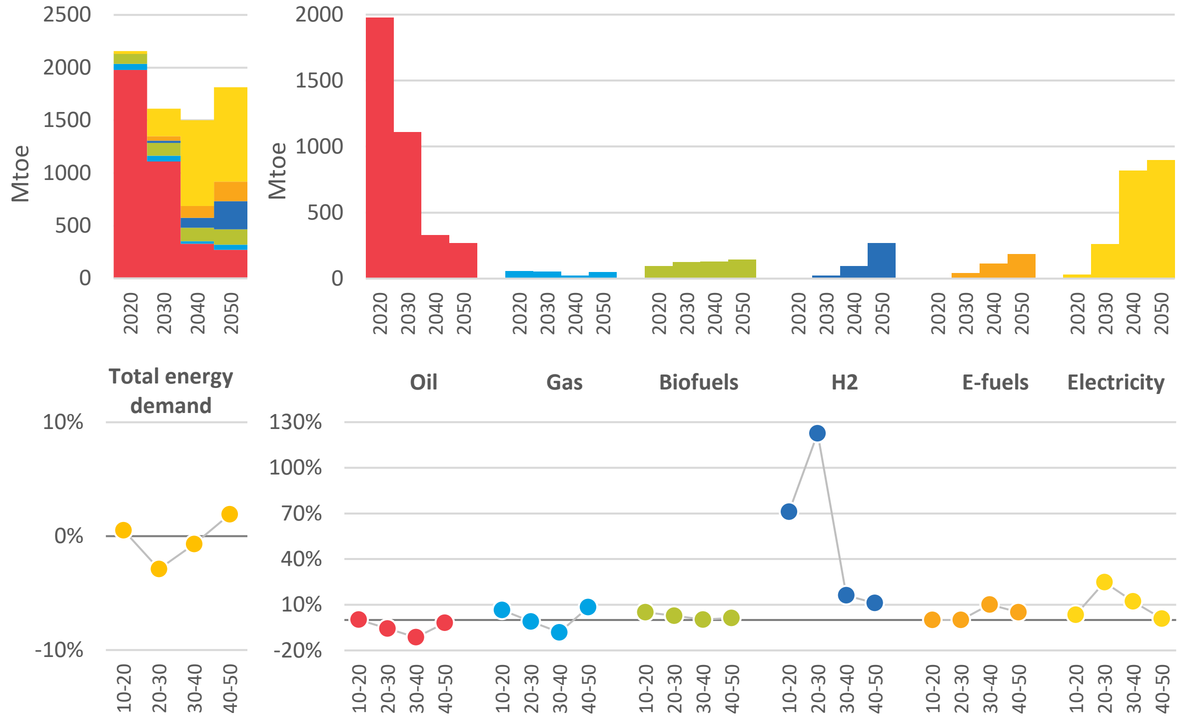
— Oil demand starts to reduce immediately in the 1.5°C scenario, driven by the rapid expansion of EVs. The current and next decades see the most significant decrease in oil consumption in transport, with an average annual decline of 6% and 11% in each decade.

— At the same time, electricity use expands with an average annual growth rate of 25% and 12% in the current and next decades. The greater energy efficiency of electrified transport leads to a reduction in total transport energy demand over time. By 2050, electricity accounts for around half of the final energy demand in transport.

— Hydrogen and e-fuels start to play a role in heavy transport, aviation and maritime post-2040, with annual growth rates between 10-15%. By 2050, these two energy vectors combined meet around a quarter of the sector's final energy demand.

— Biofuels use expands, but not as dramatically as the above. They double in volume by 2050 and increase their share from 4% today to 8% by 2050.

Figure 7: Global transport energy demand by fuel, and decadal growth rates, 1.5°C scenario



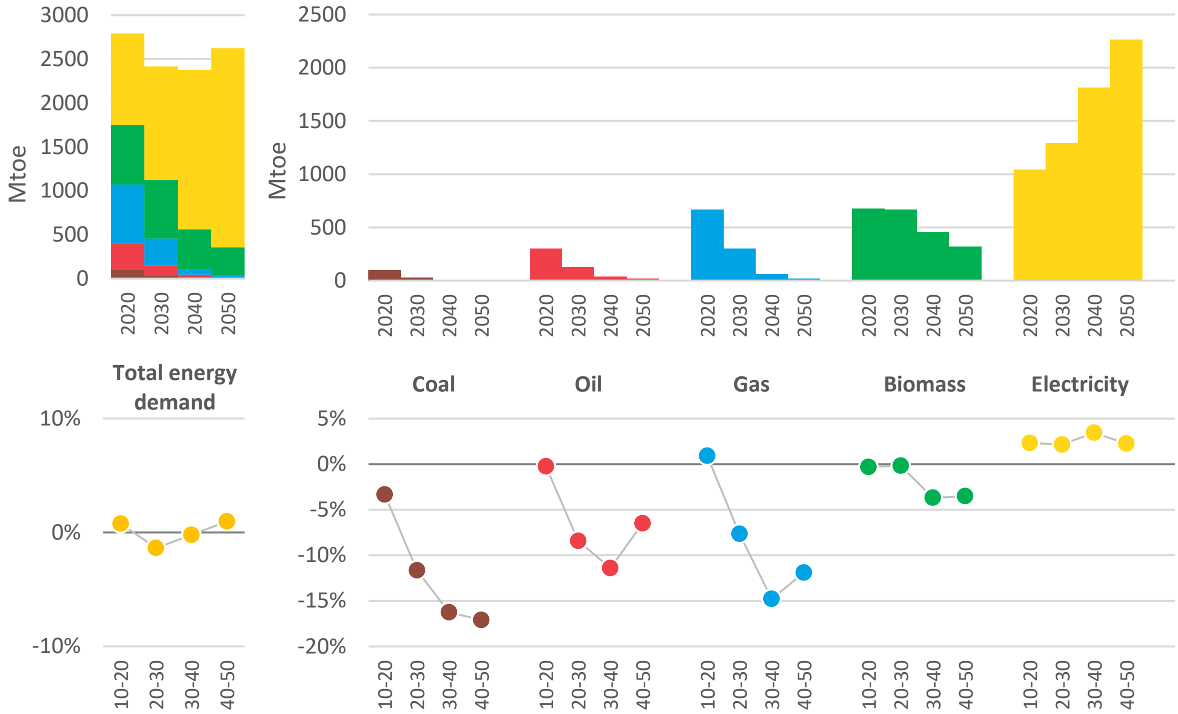
Source: POLES-JRC model

3.3.3 Buildings

Similar to the other end-use sectors, the buildings sector undergoes significant decarbonisation in the 1.5°C scenario, mostly via electrification:

- At the annual average growth rate of 2.6%, electricity increases its share of total buildings energy demand from 37% today to 86% by 2050.
- The dominance of electricity comes at the expense of oil and gas which reduce at 11% for oil and 15% for gas in the 2030-2040 decade.
- While traditional uses of biomass are phased out, there is a transient role for modern forms of biomass as a substitute for fossil heating systems; however, modern forms of biomass also decrease after 2030.
- There is no significant role for hydrogen and e-fuels in the building sector in the 1.5°C scenario, remaining below 20 Mtoe through 2050.

Figure 8: Global buildings energy demand by fuel, and decadal growth rates, 1.5°C scenario



Source: POLES-JRC model

3.4 Global renewable and energy efficiency indicators

In recent months, international discussions took place in the context of the G20 works about the need to accelerate climate protection targets. In this regard, the G20 members have promised in the New Delhi Declaration in September 2023 to pursue and encourage efforts towards increased global renewables (RE) and energy efficiency (EE) targets easing the energy transition at global level (G20, 2030). These targets were endorsed by the European Council as the EU's position for COP28 (Council of the EU, 2023b) and were laid out as a Global Pledge by the President of the European Commission in COP28 (European Commission, 2023). They have been quantified as:

— 11 TW of installed renewable energy power generation by 2030 globally (COP28 President-Designate, 2023), representing a tripling of installed capacity (IEA, 2023c; IRENA, 2023).

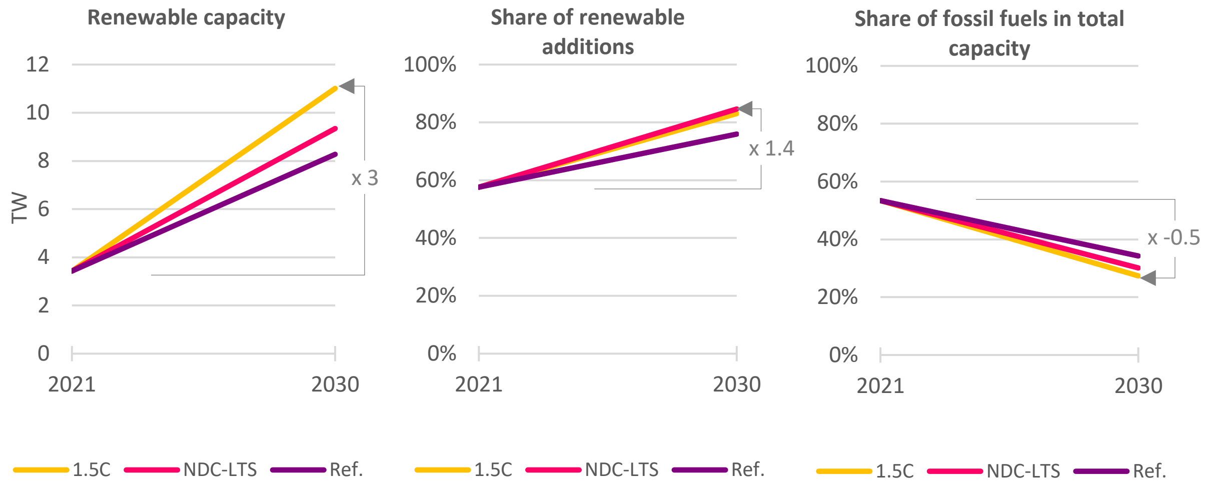
— Doubling annual energy efficiency improvements globally from about 2% to over 4% by 2030[5].

The scenarios in this report can be used to illustrate how these targets are approximated or met.

Indicators of these two targets are represented in Figure 9 and Figure 10 for the three main scenarios of this report. The 1.5°C scenario sees the global installed capacity of renewables increase from 3 TW in 2021 to 11 TW in 2030 (comprising of renewables in power generation for final electricity demand, for hydrogen production and for direct air capture of CO_2). The NDC-LTS scenario reaches 9 TW in 2030, indicating that many countries have the possibility to increase their current renewables plans to contribute to the global target.

The share of renewables in total new annually installed capacity increases from 58% in 2021 to 83% in 2030 in the 1.5°C scenario, indicating that the world must move quickly in the coming decade to the point where the bulk of new generation is renewable. The inverse is also true, as the share of non-renewables in total installed capacity in 2030 is half of that in 2021 in the 1.5°C scenario.

Figure 9: Power indicators - 1.5°C, NDC-LTS and Reference scenarios

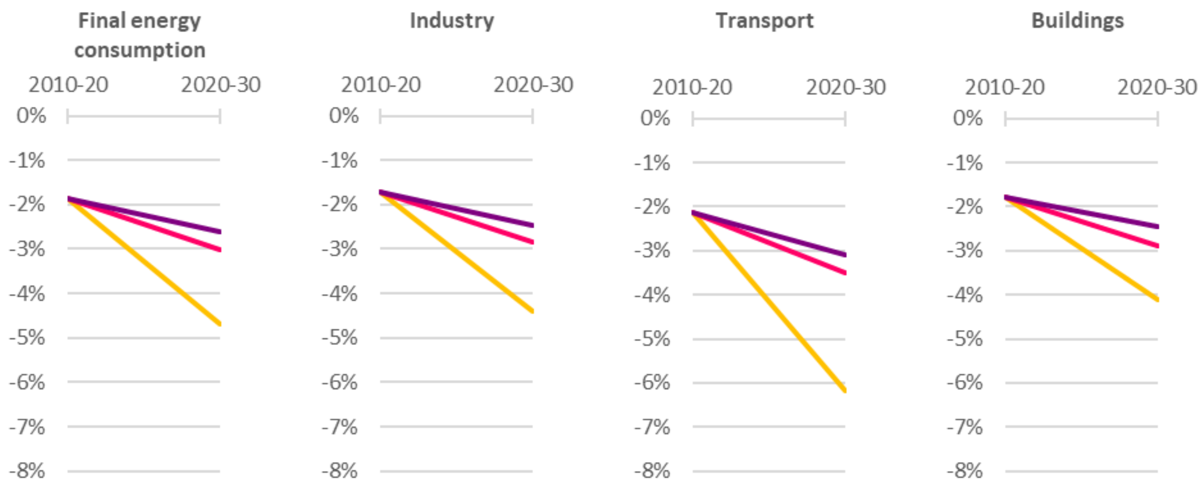


Source: POLES-JRC model

The 1.5°C scenario sees the final energy efficiency improvement rate[6] more than doubling by 2030 compared to the previous decade, i.e. the evolution over 2020-2030 compared to 2010-2020. Looking at the end-use sub-sectors shows diverse patterns. The improvement in energy efficiency in the industry sector[7], which was limited until recently, is set to increase in all scenarios, showing a more than two-fold increase in the 1.5°C scenario and reflecting a relatively large untapped potential. Energy efficiency improvements in transport[8] have accelerated recently given the increasing penetration of electric vehicles; accordingly, the Reference scenario shows a high level of improvement already, with further acceleration in the 1.5°C. Likewise, the buildings sector[9] more than double compared to historical levels by 2030, mostly due to electrification.

[6] Calculated as the annual evolution of the ratio of total final energy consumption over GDP. The improvement rate of total primary energy consumption over GDP yields a similar doubling by 2030.
[7] Calculated as the annual evolution of the ratio of sectoral final energy consumption over industry value added.
[8] Calculated as the annual evolution of the ratio of sectoral final energy consumption over private cars' vehicle-kilometres.
[9] Calculated as the annual evolution of the ratio of sectoral final energy consumption over floor surface of residential and services.

Figure 10: Global final energy efficiency indicators, 1.5°C, NDC-LTS and Reference scenarios



Source: POLES-JRC model. Note: these graphs show the rate of energy efficiency improvements in end-use sectors, the "10-20" value shows the average rate from 2010-2020, the "20-30" value shows the rate from 2020-2030.

The renewable and energy efficiency targets being discussed are intertwined, as hitting the global efficiency target will likely require increased electrification, thus leading to increased need for new electricity capacity most of which is renewable. Likewise, further penetration of renewable power generation capacity can lead to lower electricity prices, thus improving the economics of electricity-consuming end-use equipment which are often considerably more energy efficient than fossil fuel alternatives. Achieving one target facilitates the achievement of the other, therefore justifying their continued discussion of a pair of targets to be pursued in parallel.

3.5 Fossil fuel subsidies phase-out

Discussion on the importance of phasing out fossil fuels featured prominently at COP28. The explicit subsidies to fossil fuels set a new record in 2022 (reaching USD 1.3 trillion); together with indirect subsidies, total subsidies amounted to USD 7 trillion (IMF, 2023a). Commitments agreed by countries in the past few years to decrease fossil fuels support have been followed by few concrete actions. In November 2023, in the lead-up to COP28, the Members of the European Parliament voted in favour of ending all implicit and explicit subsidies "as soon as possible and by 2025 the latest" (European Parliament, 2023).

An additional scenario, not reported in Section 3.1, is reported here to indicate the important impact that fossil fuel subsidy phase out can have on global emissions.

In POLES, energy subsidies are calculated with a price-gap approach between sectoral end-use prices and reference prices (which are the import price for importing countries, the export price for exporting countries, or the closest regional market price when the former are unavailable; and are increased by a cost of fuel distribution and value-added tax). This approach covers implicit and explicit subsidies. Subsidised sectoral prices are thus affected by changes in the international prices proportionally to their situation in the last historical statistics.

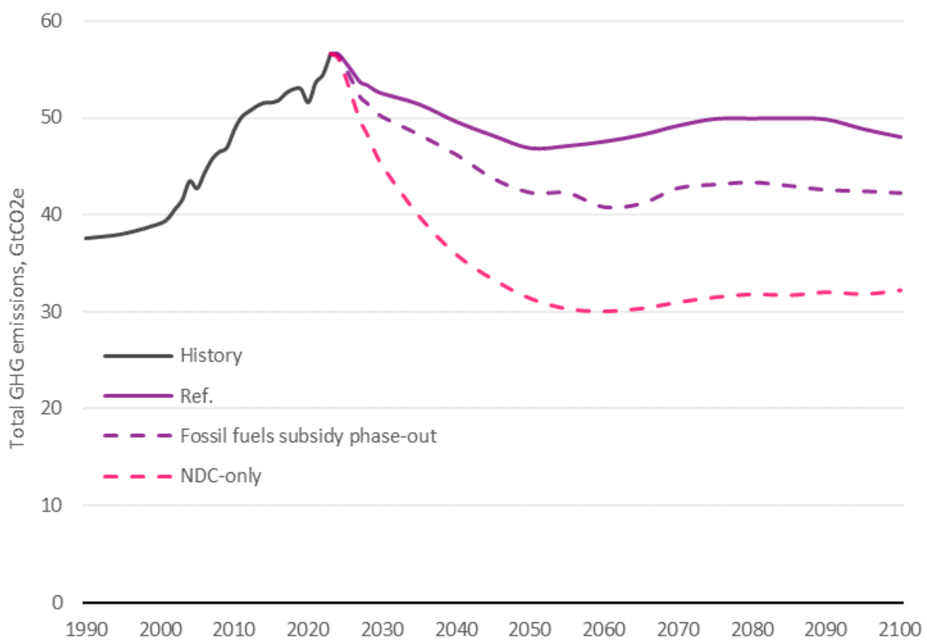
If that ratio reveals a subsidy, it is kept in the projections of the Reference scenario. In the subsidies phase-out scenario, for the applicable sectors, that ratio moves to 1 in 2025; this results in all global fossil fuel subsidies completely phased out by 2025.

This scenario leads to significant sizeable greenhouse gases emissions reductions at the global level compared to the Reference scenario (Figure 11). Total emissions are 2.4 $GtCO_2e$ lower in 2030 (a 5% reduction) and 4.6 $GtCO_2e$ lower in 2050 (a 9% reduction), similar to findings in literature (Jewell et al., 2018; Kitous et al., 2016). This corresponds to a 13% reduction in cumulated CO_2 emissions (all sectors) by the end of the century, which leads to the end-of-century temperature increase being 0.2°C lower than in the Reference scenario. Up to 6%

decrease in primary energy demand is observed through the century, reaching a 21% reduction of fossil fuels supply in 2100 (**Error! Reference source not found.**).

To give some context to the magnitude of impact of the fossil fuel subsidies phase-out scenario, the emissions reductions achieved in 2030 are equivalent to one-third of the reductions in the NDC-only scenario, which is a result of emissions reductions derived from the Nationally Determined Contributions of 193 countries (Figure 11).

Figure 11: Global GHG emissions, by scenario



Source: POLES-JRC model.

The most significant emissions impact of the subsidy removal is seen in power sector decarbonisation, where technologies present more – and cheaper – options than in other sectors. The global power sector would indeed foresee substantial emissions reductions of more than 25% in 2050 (**Error! Reference source not found.**).

Table 1: Fossil fuel subsidy phase-out scenario results compared to the Reference scenario

Year	2030	2050	2100
Emissions reduction: all GHGs	-4.5%	-9.4%	-11.6%
Emissions reduction: CO_2-energy	-7.1%	-15.5%	-19.4%
Emissions reduction: CO_2 from power generation	-13.3%	-25.2%	-30.7%
Primary energy demand	-4.2%	-6.3%	-5.8%
Fossil fuels primary energy demand	-7.0%	-14.2%	-20.9%

Source: POLES-JRC model.

In addition, this leads to a reduction in electricity generation (2000 TWh in 2030, equivalent to India's total current electricity production), mainly due to electricity demand reduction in buildings and non-energy-intensive industry.

Interestingly, this scenario would require an 8% increase in cumulated investments in electricity and hydrogen production by 2100, but also a 6% decrease in fossil fuels extraction investments.

4 Energy investment needs in the 1.5°C scenario

Investment[10] can promote economic growth by increasing the capital stock and the productive capacity of the economy and, therefore, its aggregate income. While the share of total investment in the economy typically varies by country, it historically lies within the range between 15% and 25% as a percentage of GDP in advanced economies (e.g., in 2022, 25% of GDP in the EU, and 18% of GDP in the United States). This indicator reaches higher values in emerging economies, e.g. about 40% in China, and 30% in India or Indonesia (World Bank, 2023).

Most investments in the economy take place outside the energy sector. Across the projection period and scenarios, global energy investments alone represent a mere 1% to 2% of the GDP (Figure 13, section 4.1), with expenditures in machinery and equipment representing the bulk of these investments. Of note, the comparison of new capital stock figures in clean technologies across different reports (e.g., (IEA, 2023d; McKinsey, 2023)) requires careful interpretation, as they often rely on different accounting approaches (e.g. the consideration or omission of investments across the value chain, sales of EVs).

Energy investments typically involve long-term cycles, from the planning phase, through their implementation, until reaching the operation and return on investment stages. GECO 2023 projects the scale-up of investments in renewables to happen mostly over the next decade (see also (Bertram et al., 2021) for a discussion on how investments in the coming decade can avoid the lock-in on emissions intensive technologies). This reflects that new capital stock decisions and their implementation may be concentrated in time. Their lifecycle, however, is long, as the return on renewable energy investments often spreads over decades until the end of the assets' lifespan. Nonetheless, at the regional level, countries go through different investment patterns in the GECO 2023 scenarios, with investment cycles depending on the available mitigation options, and the scenarios' assumptions (as described in section 2). In addition, when transitioning to an energy system in which electricity is produced by renewables, not only capital returns to investment are relevant. As presented in GECO 2022 (Keramidas et al., 2022) investment in renewables increases energy security by reducing trade dependency, also promoting cheaper electricity (and competitiveness) in the long-term.

Investments age over time and are vulnerable to different risks. Depreciation accounts for the decline in the value of fixed assets due to normal use and aging, but not due to major catastrophes, unforeseen obsolescence and natural resources' depletion. On the one hand, there may be climate change impacts on the capital stock (e.g., infrastructure at risk of being hit by natural disasters and extreme events, see (Feyen et al., 2020). On the other hand, misaligned investments lock the energy system into emissions-intensive infrastructure and may increase the probability of them becoming prematurely stranded assets, as discussed in section 4.1.2. To avoid this risk and accelerate the energy transition in emerging economies, internationally coordinated climate action is needed (see Box 2 for a discussion on the role of Just Energy Transition Partnerships (JETPs)).

GECO 2023 shows that scaling up investments in clean technologies in line with a 1.5°C decarbonisation trajectory bears potential benefits, beyond delivering the energy transition and its multiple environmental and climate benefits. Scaling up investments in clean technologies compensates for declining investments in fossil fuels, boosting demand for capital formation across different investment delivery sectors, such as the construction, equipment, and electrical goods sectors (see section **Error! Reference source not found.**), while creating substantial employment opportunities across the value chain (see section 4.3.2). Because clean energy infrastructure is often more capital intensive than fossil fuel infrastructure, aggregate investments increase under scenarios that foster the transition to clean energy.

Figure 12 shows differences at the macro level in the NDC-LTS and the 1.5°C scenarios compared to the Reference, indicating a visible increase of investments. This increase in investments leads to a decline in private consumption due to crowding out, as the assumption of the JRC-GEM-E3 model is that the economy is supply constrained. Additionally, the figure illustrates the relative changes in GDP, which indicate that the reduction in private consumption outweighs the increase in investment.[11]

[10] The gross fixed capital formation (GFCF), simply referred as 'investment', reflects the investments, deducting disposals, in tangible or intangible assets produced as outputs from the various production processes in the economy (Eurostat., 2023).

[11] There are no (net) trade effects when considering global GDP. With regard to government expenditure, this is kept fixed in the analysis and thus does not lead to any relative changes compared to the Reference. It is also worth noting that within the consumption

Figure 12: Investment and consumption changes' contribution to changes in global GDP

Source: JRC-GEM-E3

Global GDP decreases slightly compared to the Reference in each time period and in both mitigation scenarios. However, these relative changes in GDP never amount to more than 2%, meaning that the ratio of mitigation costs to GDP is rather low. In the NDC-LTS, global GDP decreases by 0.95% compared to the Reference, while in the 1.5°C it decreases by 1.65% in 2050, reflecting the mitigation costs needed to achieve a more ambitious target. As GDP decreases and investment increases, the share of investment in GDP increases in the policy scenarios. By 2050, global investment as a percentage of GDP reaches 26.2% in the NDC-LTS and 26.4% in the 1.5°C, with the Reference projecting it as 25.7% of GDP. As the following sections will demonstrate, this relative increase in investment is driven by the expansion of renewable power generation and electricity supply. Also within the consumption category, we observe a shift to durable consumption goods, with additional expenditures for renovations, including heating equipment, and electric vehicles, resulting in lower energy consumption. For example, overall consumption declines by 1.1% in the 1.5°C scenario compared to the Reference in 2030, while the consumption of durables increases by 1.3% and the consumption of non-durables decreases by 1.2%.

category in national accounts, there are changes towards durable consumption (e.g., purchases of heating and cooking appliances or private vehicles), especially over the next decade. While purchases of durable consumption goods is akin to investment (and are counted as such by energy models), it is not accounted as such in the system of national accounts.

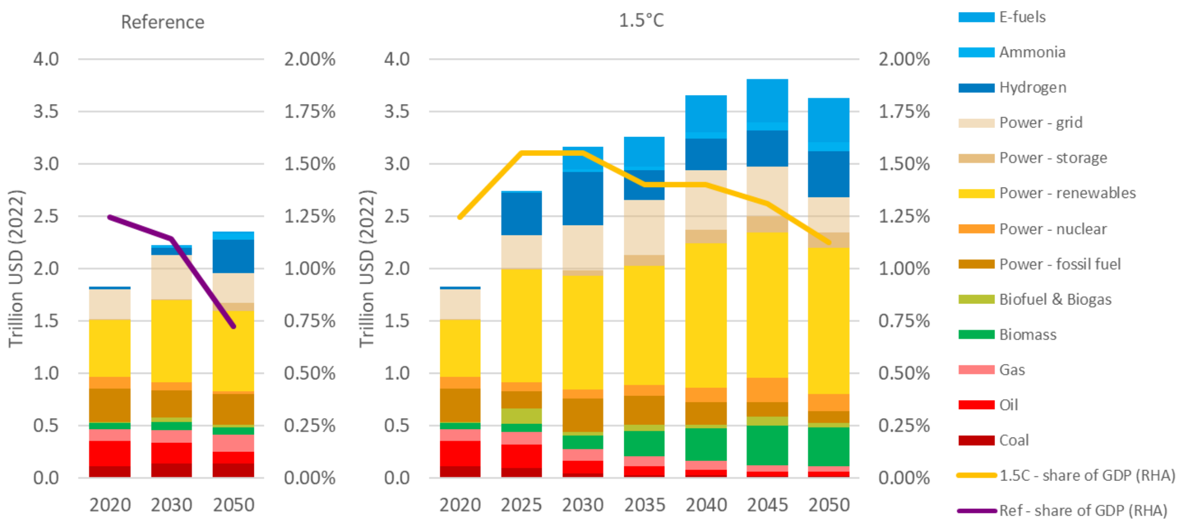
4.1 Investments in energy supply

Investments in energy supply increase from today's levels in the 1.5°C scenario over the projection period. The upfront, overnight investment in many low-emission technologies is higher than their high-emitting competitors, however the total lifetime cost, including running costs, is often lower due to lower operating costs.

Annual spending on equipment to produce and supply energy increases to $3.8 trillion by 2045 in the 1.5°C scenario, up from $2 trillion in 2022. The increase in investment requirements is particularly sharp during the current decade, which sees a 70% increase, and is less pronounced thereafter towards 2050. In comparison, the investments the Reference scenario rise by 30% by 2050, representing two-thirds of the 1.5°C scenario needs.

Despite the increase in investments, energy system investments as a share of global GDP remain at an average of 1.4% through the projection period in the 1.5°C scenario, suggesting that by spending the same share as we have in the past the world can achieve its decarbonisation targets. Reflecting the sharp increase in investments this decade, the share of global GDP spent on energy supply increases throughout 2030 but then stabilises and decreases to be lower than today by the middle of the century.

Figure 13: Global annual energy supply investments, Reference and 1.5°C scenarios



Source: POLES-JRC model.

Note: Transmission investment refers only to investment to expand the grid, it excludes maintenance and renewal investment.

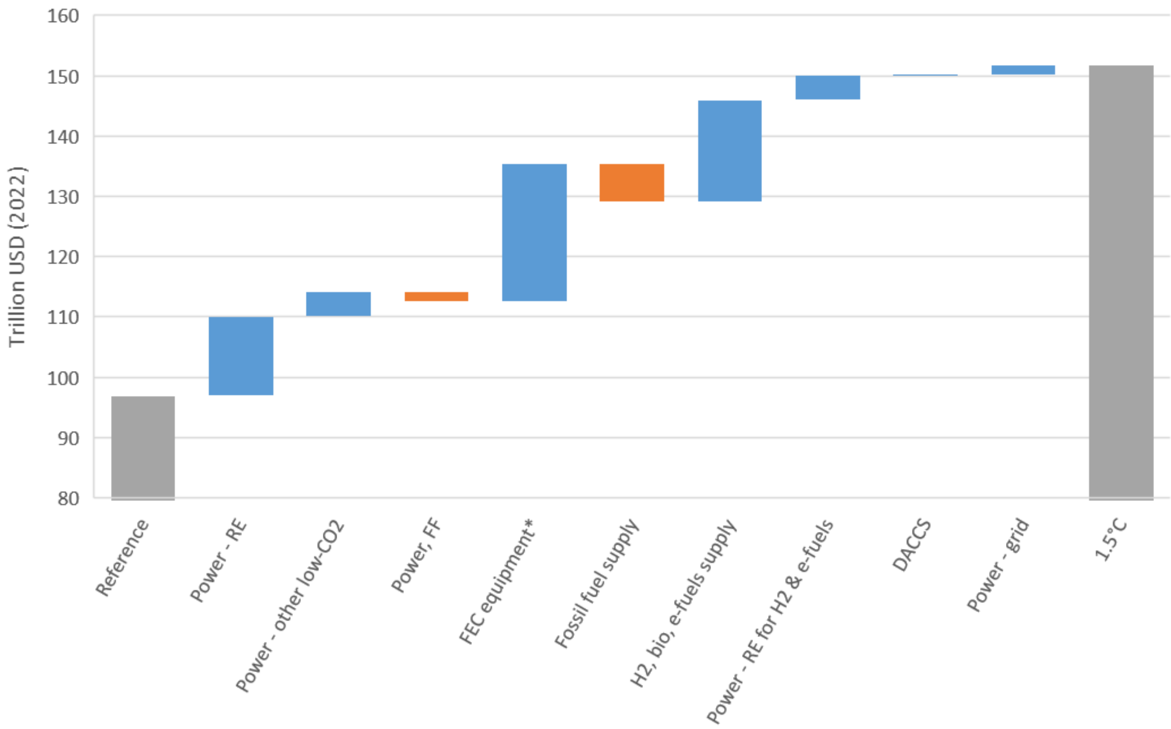
Underpinning a decarbonised power system, renewable electricity takes the largest share, accounting for a third of total energy supply investment this decade. Annual investments in producing renewable electricity almost triple by 2030 as installed capacity triples and is offset by reductions in the cost per unit installed.

A systemic view of investments

Total energy investments are larger in the 1.5°C scenario than in the Reference scenario over the projection period, but this result is a combination of reduced investments in some areas and increased investments in other areas. Figure 14 shows a systemic perspective of changes in investment patterns as the world decarbonises.

We see significant investment in additional renewables and low-CO_2 power generation in the 1.5°C compared to the Reference scenario, which is partly offset by reduced investment in fossil fuel power generation. By focusing on investments, this representation precludes the fact that a decarbonised energy system might have similar or even lower total system costs than a fossil fuel-based system, as higher investment needs are compensated by lower running costs. Increased investment in clean energy technologies in end-use sectors such as industry, transport and buildings (e.g., electric vehicles and heat pumps) is offset by reduced spending on the production of fossil fuels used in power generation and end-use sectors. Finally, the 1.5°C scenario sees an increase in expenditures on low-emissions fuels such as hydrogen, e-fuels and bio-based fuels, alongside increased spending on power grid and direct air capture with carbon storage (DACCS).

Figure 14: Difference in cumulative (2020-2050) global energy sector investments between the Reference and 1.5°C scenarios



Source: POLES-JRC model. "FEC equipment" refers to investments in energy-consuming equipment in the industry, transport and buildings sectors.

4.1.1 Power generation sector

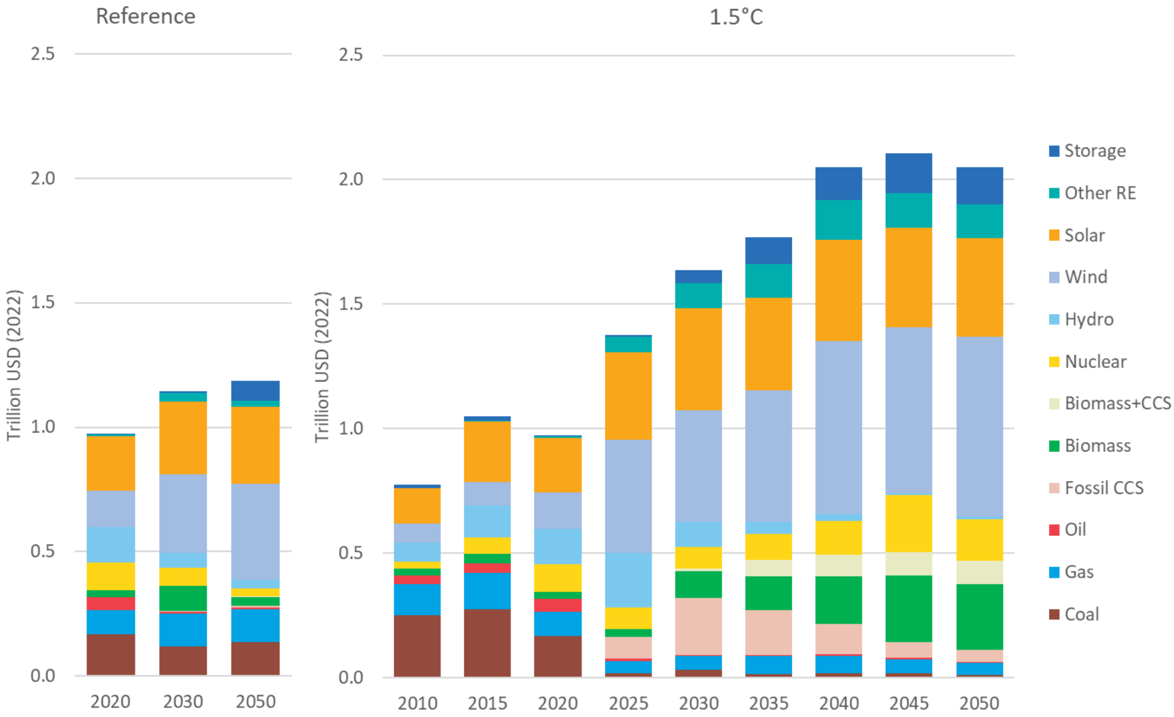
Global annual investments in the power sector double by the middle of the century under the 1.5°C scenario, as an almost 4-fold increase in installed capacity is offset by significant unit cost reductions. In the Reference scenario, it only increases by 22% by 2050 while fossil fuels still represent almost one-quarter of the investments.

Power sector investments are dominated by wind and solar, which account for over half of all investments throughout the projection period.

Investment in coal generation virtually disappears by 2025, and gas investment decreases significantly but retains a small role in the power generation mix for its flexibility in a renewables dominated electricity mix. There is only marginal investment in fossil fuel capacity fitted with CCS.

By 2030 investment in storage emerges, two-thirds of which are batteries, and represents 7% of power sector investment needs by the middle of the century.

Figure 15: Global annual power sector investments, Reference and 1.5°C scenarios



Source: POLES-JRC model.

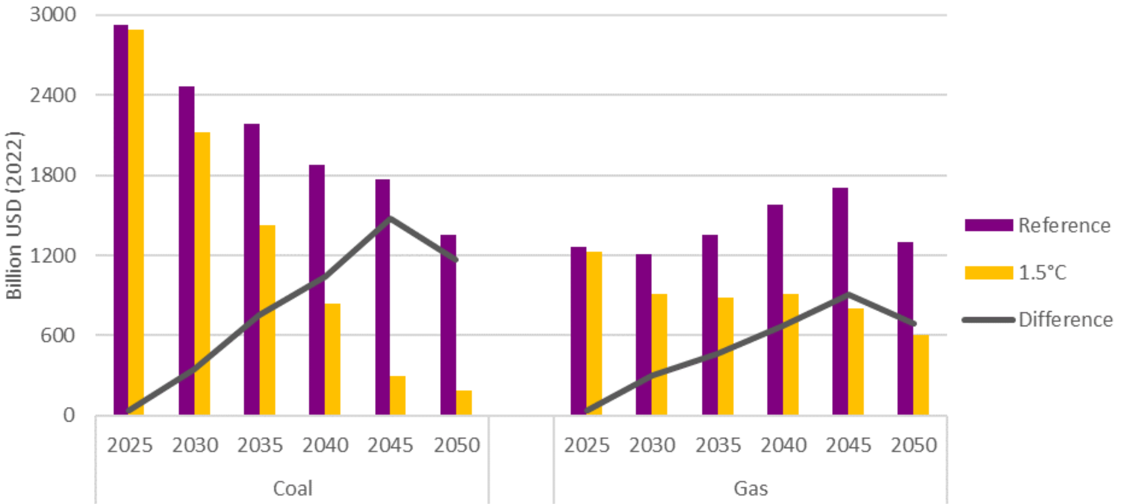
Storage includes batteries, hydro pumped storage, compressed air, stationary batteries, EVs-to-grid, stationary fuel cells.

4.1.2 Potential stranded assets in power generation in the 1.5°C scenario

Stranded assets in the power sector refer to power plants retired earlier than their initially expected lifetime. Investments in coal- and gas-fired power plants not aligned with a 1.5°C trajectory pose a risk of becoming stranded assets, if climate policy brings about their premature decommissioning to align the power sector composition with a 1.5°C scenario. The prevailing trend of deploying unabated coal- and gas-fired power plants in the Reference scenario therefore carries the risk of their premature decommissioning.

To assess the value and regional distribution of misaligned investments in coal- and gas-fired power plants, Figure 16 compares the economic value of the global coal and gas power plant fleet between the Reference and the 1.5°C scenarios. Using overnight capital expenditures, and assuming a 30-year economic lifetime and a linear depreciation schedule, the economic value of the global power plant fleet is calculated at various points in time by summing the remaining undepreciated value of the fleet at each year. At each point in time, older coal power plants contribute only with the fraction of their remaining, non-depreciated value to the global fleet. The value of the global power plant fleet changes over time, growing if new investments surpass depreciation and shrinking otherwise.

Figure 16: Value of global unabated coal and gas power plant fleet in the Reference and 1.5°C scenarios



Source: POLES-JRC model and own calculations.

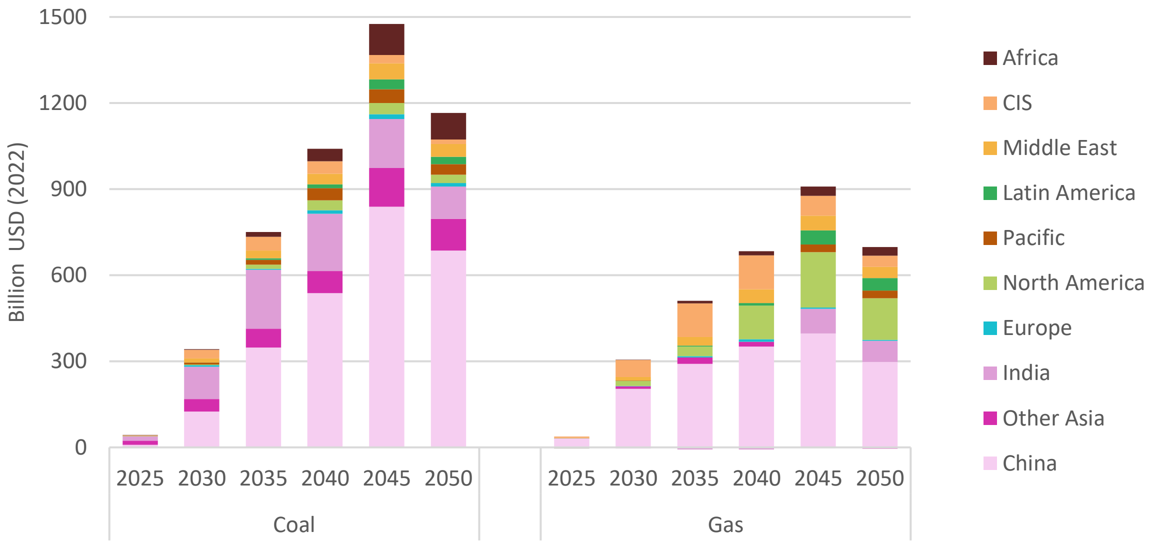
To assess the value of investments at risk of premature decommissioning, Figure 17 shows the difference in the value of the global coal and gas power fleet at any point in time between the Reference and 1.5°C trajectories. This metric, indicates the potential value of *misaligned investments*, and represents the maximum value at risk of becoming stranded, if climate policy were to depreciate misaligned investments at a given point in time overnight. As such, this analysis represents an upper bound of the value potentially at risk of becoming stranded.

On the one hand, an early retirement of coal and gas power plants will occur over time rather than overnight, with retirement schedules starting with older, depreciated power plants, thereby minimising stranded assets. On the other hand, the realisation that the transition is underway will impact investment decisions over time, partly averting the deployment of unabated coal and gas power plants, and reducing the value of investments at risk of being misaligned.

Under the construction of this analysis, the calculated upper bound of misaligned coal investments (Figure 17, left) is projected to reach over USD 300 billion by 2030 and increase to approximately USD 1,500 billion by 2045. Notably, the Asian contintent accounts for over 80% of misaligned coal invetments over the projection period. By 2030, China and India account each for about 30% of misaligned coal invesments. China's share grows to 60% by 2050, while India (10%) and other Asian countries (10%) decrease their relative importance. African countries, the Middle East and other regions contribute to the remaining 20% of globally misaligned coal invesments by the middle of the century.

Despite its lower value as compared to coal, misaligned investments in gas power plants (Figure 17, right) are projected to be substantial, as well. The estimated value of misaligned gas power plant investments is projected to reach USD 300 billion by 2030, increasing to about USD 900 billion by 2045. While China (85%) and the Middle East (15%) represent nearly the totality of misaligned gas investments towads 2030, the share of North America (20%), India (10%), Latin America and other regions (each 5%) increase by the middle of the cenutry.

Figure 17: Value of global misaligned coal and gas power plant investments as estimate of potentially stranded assets



Source: POLES-JRC model and own calculations.

To avert misaligned investments in fossil fuels, while accelerating the energy transition with a view to a 1.5°C in emerging economies, Just Energy Transition Partnerships (JETPs) between developed and developing nations in the Asian and African continent have been esttablished in previous years (Box 2).

Box 2: Just Energy Transition Partnerships

Aiming to boost investments in clean energy and accelerate the energy transition in emerging economies, bilateral Just Energy Transition Partnerships (JETPs) were established in recent years between developed nations and South Africa, Indonesia, Vietnam, and Senegal. JETPs aim to provide financial support to accelerate the energy transition of partner countries, provisional on reaching a set of energy and climate targets.

The first JETP was established between South Africa and the International Partners Group (IPG) during COP26 in 2021. It committed to mobilizing an initial financial volume of USD 8.5 billion within 3-5 years to support South Africa's most ambitious NDC target. In 2022, Indonesia and Vietnam established JETPs with the IPG, with initial support volumes of USD 20 and 15.5 billion, respectively. Most recently, Senegal established a USD 2.5 billion JETP with the IPG. These initial financial support packages are envisioned to consist of 50% public and 50% private finance[12].

While the financial volumes of these partnerships only represent a fraction of the total investment needs, they aim to catalyse a substantial upscaling of international and domestic private finance flows to the energy sector of the respective countries. By developing regulatory reform roadmaps[13] to deliver the committed investment volumes, JETPs aim to structurally improve the regulatory framework in the energy and finance sector and, thereby, promote a favourable investment environment for clean technologies.

4.2 Investments in clean energy technologies

Global annual investment in clean energy technologies increases 6-fold from 2022 to 2030 in the 1.5°C scenario, up from $1.0 trillion today to $5.7 trillion in 2030. It represents almost twice the investment in the Reference scenario. Annual investment in vehicle batteries expands 14-fold by 2030, as a result of a deployment increase of a factor of 29 by 2030 and a cost reduction of batteries of 60% by 2030. A similar

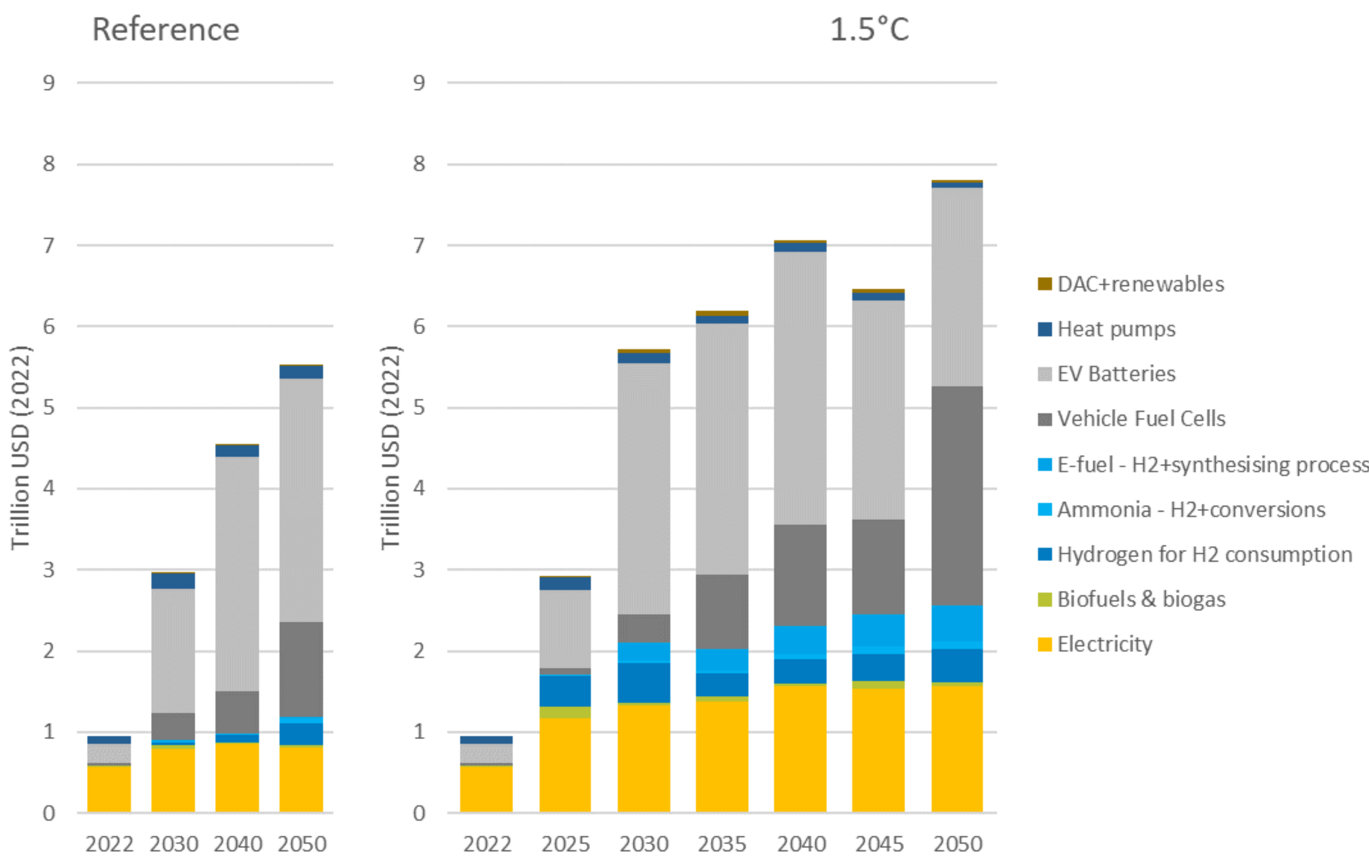
[12] See political declarations and joint statements establishing the JETP with South Africa, Indonesia, Vietnam and Senegal.
[13] See investment plans for South Africa, Indonesia and Vietnam.

growth is observed in the Reference scenario, with electric vehicles investments reaching more than half the total in 2030.

Annual investment in clean technologies for electricity production double from 2022 to 2030. Annual new capacities of wind off-shore and on-shore increase by 8-fold and 2-fold, while unit costs experience a decrease of 16% and 20%, respectively. Total installed capacities of PV increase by 270%, which is offset by a decrease of unit costs of 35%.

Heat pump investments to decarbonise heating are increasing in this decade, but then decline due to cost reductions. Overall, these investments are only a relatively minor share of overall investment needs. Investments in e-fuel production emerge by 2030, and investment for ammonia production for use in shipping starts in 2035. Between 2030 and 2040 the largest absolute increase in annual investments occurs in fuel cells for vehicles, which more than double over the decade, followed by the increases of ammonia and e-fuels of 180% and 60%, respectively.

Figure 18: Global annual clean energy technology investments, Reference and 1.5°C scenarios



Source: POLES-JRC model.

4.3 Supply chain implications of energy investments

Ramping up energy investment will also affect other sectors of the economy that produce investment goods. Here, using the aggregate sectors of the JRC-GEM-E3 model, we cannot represent specific supply chain issues of interest, such as rare earth minerals. Instead, we are looking at this from a macroeconomic perspective, shedding light on the sectors affected through supply chains, including the impacts on induced employment in these sectors. We juxtapose these jobs with direct jobs in renewables. In this section, we present results for 2040, given that GECO 2023 projects the scale-up of investments in renewables to happen mostly over the next decade.

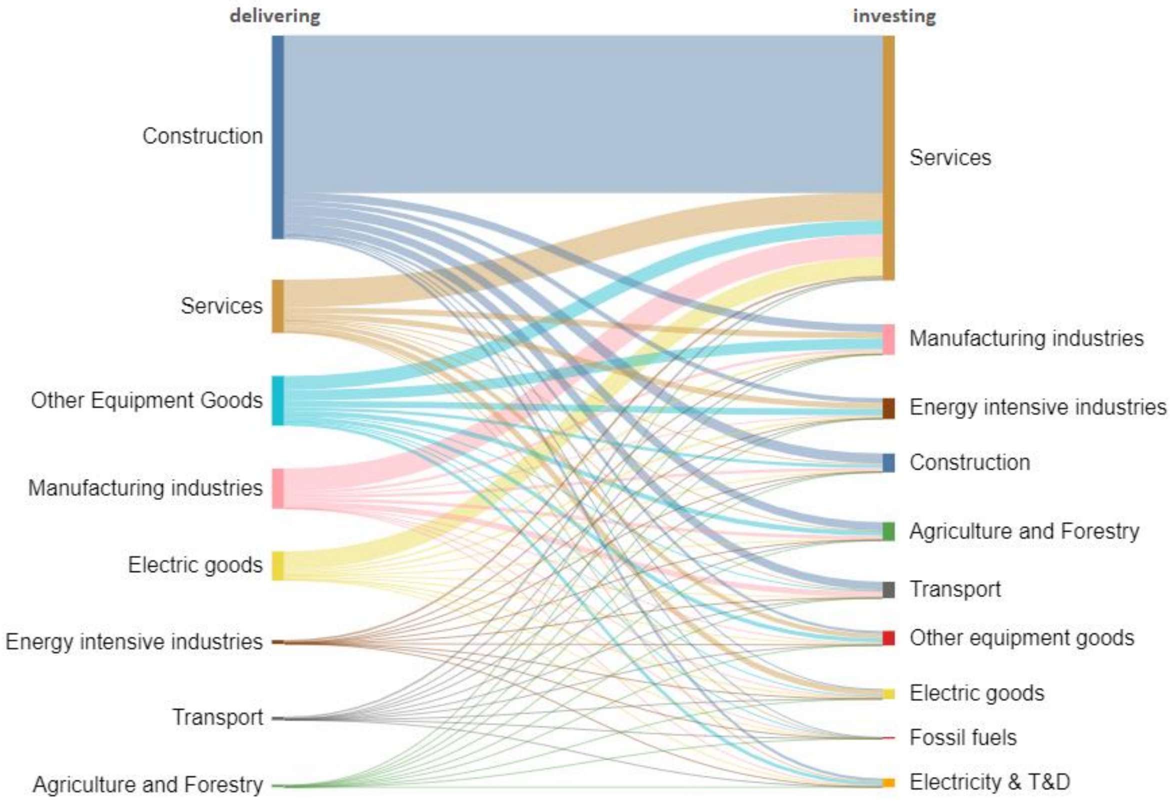
4.3.1 Investment spillovers and stimulus to other sectors

When investments occur in physical infrastructure, the investing sectors rely on other sectors of the economy to deliver the goods and services (hereafter referred to as delivering sectors) to build this new physical infrastructure. For example, investment in the wind energy sector (classified as the investing sector in our analysis) requires the manufacturing sector to produce equipment goods (e.g., nacelle, rotors and generators) and the construction sector to build the physical infrastructure (e.g., construction workers to clean and prepare the construction sites, welders to merge metal parts), these are classified as the delivering sectors in our analysis.

Figure 19 visualises the distribution of global deliveries for annual economy-wide investment in the year 2040 in the 1.5°C scenario. Investment-delivering sectors are shown on the left and the investing sectors on the right. The construction sector is the largest delivering sector to build additional capital stock on the investment needs of all sectors of the economy, accounting for 53% of global investment deliveries with a total value of around USD 23 trillion. It is followed by the services sector (USD 6 trillion, 14%) which also accounts for intellectual property, other equipment goods (USD 4.6 trillion, 12%), manufacturing industries (USD 4.4 trillion, 10%) and electrical goods (USD 3.4 trillion, 8%). Together, these sectors account for 97% of total investment delivers to build additional capital.

At the same time, the services sector is by far the largest investor, with around USD 28 trillion of capital formation or 64% of total investing sectors, as it takes up a large share of economic activity. It is followed by the manufacturing industries (USD 3.5 trillion, 8%), construction, energy intensive industries, agriculture (approx. USD 2.2 trillion each, 5%). The electricity generation and transmission and distribution (T&D) sector accounts for USD 990 billion, a mere 2.6% of total global investments. So while there is a large relative increase in energy investment (see also section 4.1), the additional investments remain only a fraction of aggregate investment and explain why economy-wide investment activity increases only by a small amount.

Figure 19: Global investment in 2040 by delivering (left) and investing (right) sectors in the 1.5°C scenario



Source: JRC-GEM-E3

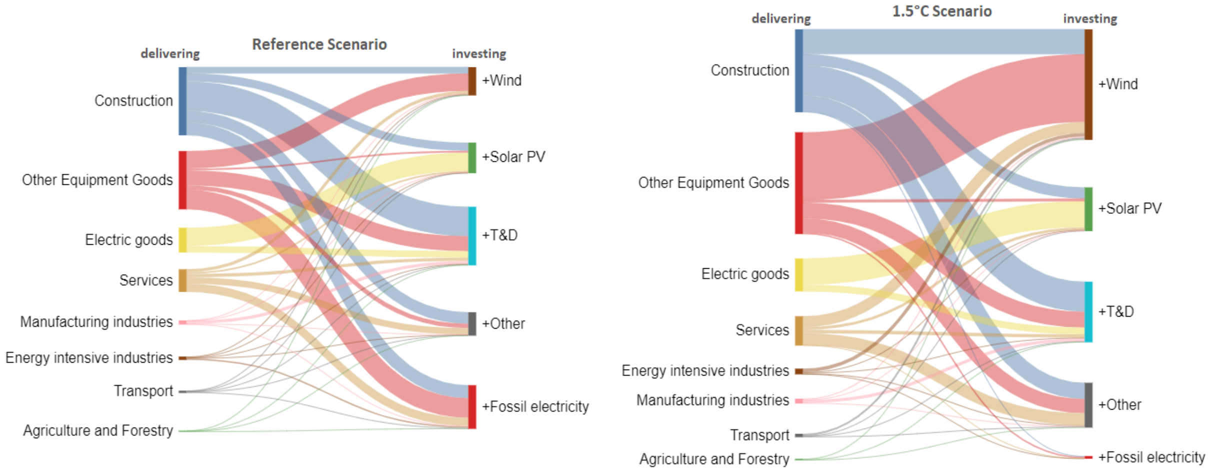
Figure 20 also shows the global investment deliveries, but providing a closer look into the electricity and T&D as investing sectors in 2040. In the 1.5°C scenario (**Error! Reference source not found.**, right), annual global investments in electricity generation and T&D combined is 50% higher than in the Reference scenario, while still representing only about 1.5% of global investment needs. Driven somewhat by annual investments in the wind power sector being 3.5 times higher than in the Reference scenario, and solar PV about 1.5 times higher. Annual investments in transmission and distribution are about 10% higher, while fossil fuel investments become negligible as the economy decarbonises.

The higher investments in clean power technologies compensate the decline of investment deliveries to fossil fuel based power technologies, which rely primarily on the construction, equipment goods and services sectors to build additional capital stock. Accordingly, annual investment deliveries from the construction and electric goods sectors grow by 30%, services by 50%, and equipment goods by 80% as compared to the Reference scenario.

Thereby, the delivery patterns of each power sector technology contribute differently to the boost in investment-deliveries by sectors:

- Wind power capital formation is composed of 70% of equipment goods (e.g, wind turbines, generators), boosting the investment-deliveries of this sector and representing two-thirds of its total annual investment-demand.
- Solar PV capital formation is composed of 60% of electrical goods (e.g, solar PV panels, invertors, and other electrical equipment), accounting for approx. 80% of total investment-demand for electric goods, with the remainder going to the T&D capital formation.
- The T&D sector's capital formation is composed of 50% of investment-deliveries from the construction sector, reflecting the high construction demand to build power grids. Investment-deliveries of the construction sector to the T&D sector represent one-third of its total annual investment-demand from the power sector, followed by deliveries to the wind sector (30%), others (20%), and the solar PV sector (14%).

Figure 20: Global investments in 2040 by delivering sector to the electricity and T&D sectors in the Reference and 1.5°C scenarios

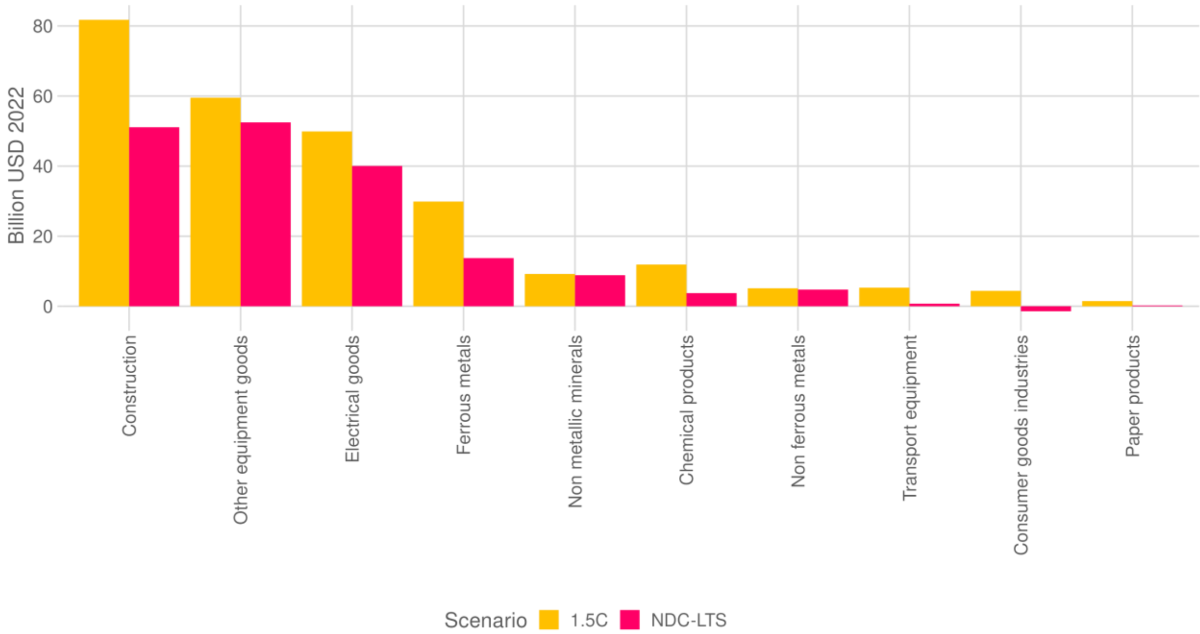


Source: JRC-GEM-E3

The additional investment in the NDC-LTS and 1.5°C scenarios have knock-on effects on the investment needs of the main delivering sectors: construction, electrical goods, and other equipment goods. To meet the additional demand for investment goods, these delivering sectors need to expand their own capital stock. In other words, there is investment necessary to expand some of the upstream parts of the supply chains of the power technologies. Additionally, sectors such as construction also react to the increasing demand for renovations as buildings are made more energy-efficient.

This is visualised in Figure 21, which shows the absolute change in worldwide sectoral investment in 2040 compared to the Reference for both the NDC-LTS and the 1.5°C scenarios, focusing on the effects on industry. Overall, investment increases compared to the Reference, with a slightly stronger increase in the 1.5°C than in the NDC-LTS. It is clear that investment by construction and equipment goods expands the most compared to the Reference, because they are expanding their production capacities to deal with increased investment demand by other sectors. In 2040, there is around USD 80 billion of additional investment by the construction sector in the 1.5°C scenario, and around USD 50 billion of additional investment in the NDC-LTS scenario. In the equipment and electrical goods sectors, there is additional investment worth between USD 40 – 60 billion, depending on the scenario. Additional investment by these sectors is greater in the 1.5°C scenario than in the NDC-LTS scenario, reflecting the increased expansion of renewable energy technologies in the former scenario.

Figure 21: Absolute change in sectoral investment compared to the Reference worldwide by 2040



Source: JRC-GEM-E3

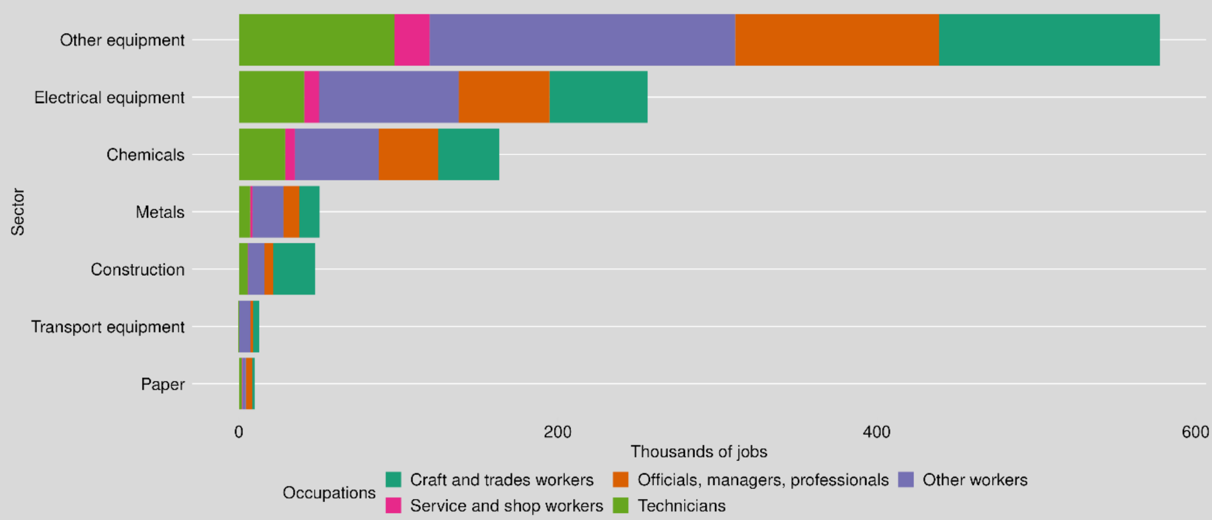
Box 3. Job requirements in the EU industry in 2040

As discussed in Section 4.3.2, increased demand for investment goods by the power generation sector creates additional employment in the sectors delivering these investment goods. This leads to shifts in sectoral employment in the 'delivering sectors', which in turn changes the demand for the different types of occupations that are employed there.

Figure 22 visualises the absolute differences in selected sectors' employment between the 1.5°C scenario and the Reference for the EU in 2040, broken down by occupation. Similarly to Figure 21, Figure 22 focuses on the industrial sectors as those are some of the sub-sectors that are impacted the most by the decarbonisation investments in the 1.5°C scenario.

In the 1.5°C scenario, there is more demand for employment in the industrial sectors in the EU, compared to the Reference. As discussed in sections 4.3.1 and 4.3.2, the expansion of these industry sectors is the result of an increased demand for investment goods, particularly due to investments in renewable power technologies. Hence, additional demand for capital formation leads to additional upstream jobs in the equipment and construction sectors.

Figure 22: Absolute changes in employment per sector in EU in 2040 in the 1.5°C scenario compared to the Reference



Source: JRC-GEM-E3 and (Cedefop, 2023)

The occupational breakdown of Figure 22 demonstrates that the increase of employment in the industrial sectors leads to more demand for some occupations, such as craft and trades workers, officials, and technicians. In the electrical and other equipment sectors, there is additional demand for around 200 thousand craft and trades workers, and additional demand for around 180 thousand officials, managers and professionals. In the construction sector, another sector that supplies investment goods, there is additional demand for around 30 thousand craft and trades workers.

4.3.2 Employment shifts as a result of additional investment demand

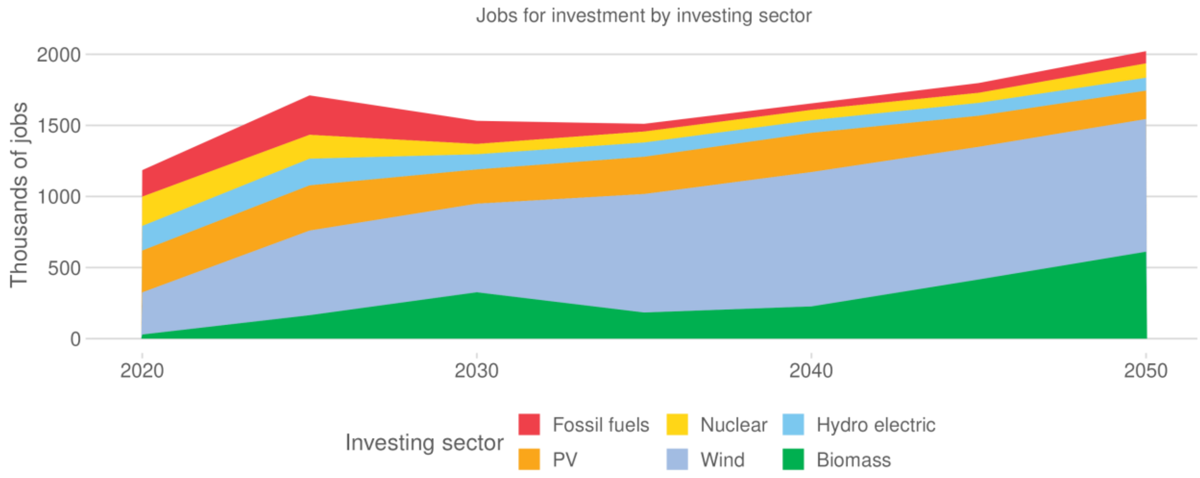
Changes in the investment flows and volumes in the NDC-LTS and 1.5°C scenarios also affect sectoral employment. As illustrated in Figure 20, changes in investments by different power technologies lead to different investment patterns in delivering sectors. This has an effect on the employment needed to make deliveries for investment, also referred to as the indirect employment. Importantly, the calculations for indirect employment in this report only capture the first round effects of investment when creating indirect jobs. Purchases of intermediate inputs by the delivering sectors would also create economic activity and require additional workforce to produce, but are not accounted for.

Figure 23 and Figure 24 visualise these indirect employment effects as a result of investment by the power generation sectors, in the 1.5°C scenario. First, Figure 23 shows the amount of worldwide indirect jobs that are created per power technology. As investment by the fossil fuel sectors declines over time, the number of indirect jobs related to fossil fuel investment sees a similar decrease. Overall, however, there is an increase in the number of indirect jobs created by investment in power technologies, caused by the expansion of renewables. From 2020 to 2050, there is a clear shift of indirect employment from the fossil fuels sectors to renewable and nuclear energy.

Figure 24 illustrates the same jobs as Figure 23, those indirect workers delivering on power technology investment, but instead visualises the sector in which the indirect workers are employed. Investment by the power generation sectors indirectly leads to employment mainly in the following sectors: electrical goods, other equipment goods, construction, market services, and land transport. For investment by the power sectors, construction and other equipment goods are the largest sectors delivering on investment needs. By 2050 in the 1.5°C scenario, there is a total of 590 thousand jobs worldwide in construction for the power generation sector. Moreover, there is a total of over 800 thousand jobs in the 'other equipment goods' sector to produce power generation equipment.

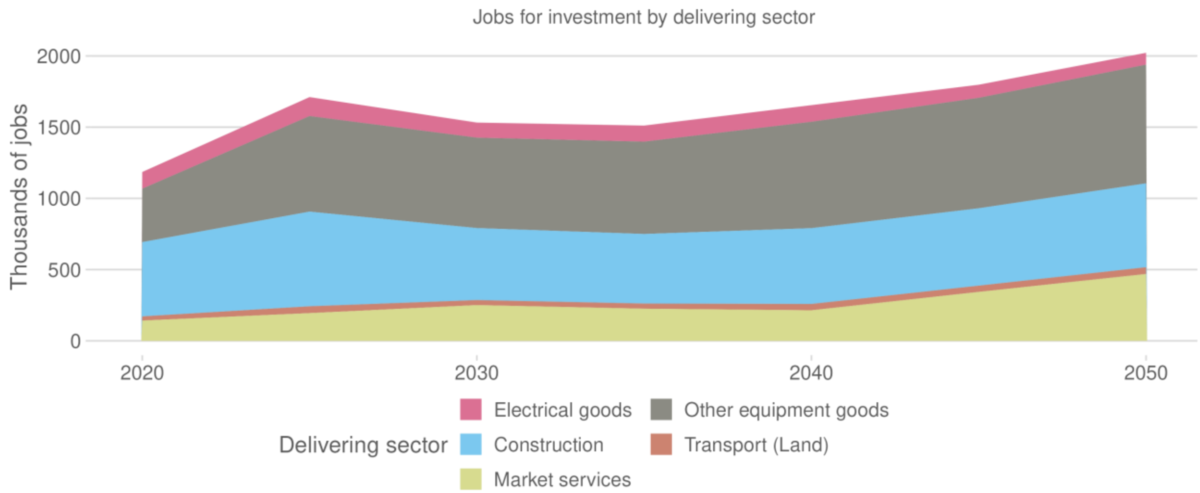
Employment in the electrical goods sector related to investment for power generation fluctuates over time, mainly in line with investments by the solar PV sector. As visualised in Figure 20, the solar PV sector relies to a fair extent on deliveries of electrical equipment. Hence, investments by solar PV are a driver of jobs in the electrical equipment sector.

Figure 23: Absolute worldwide employment over time resulting from investment by the power generation sectors in the 1.5°C scenario, by power sector



Source: JRC-GEM-E3

Figure 24: Absolute worldwide employment over time resulting from investment by the power generation sectors in the 1.5°C scenario, by delivering sector

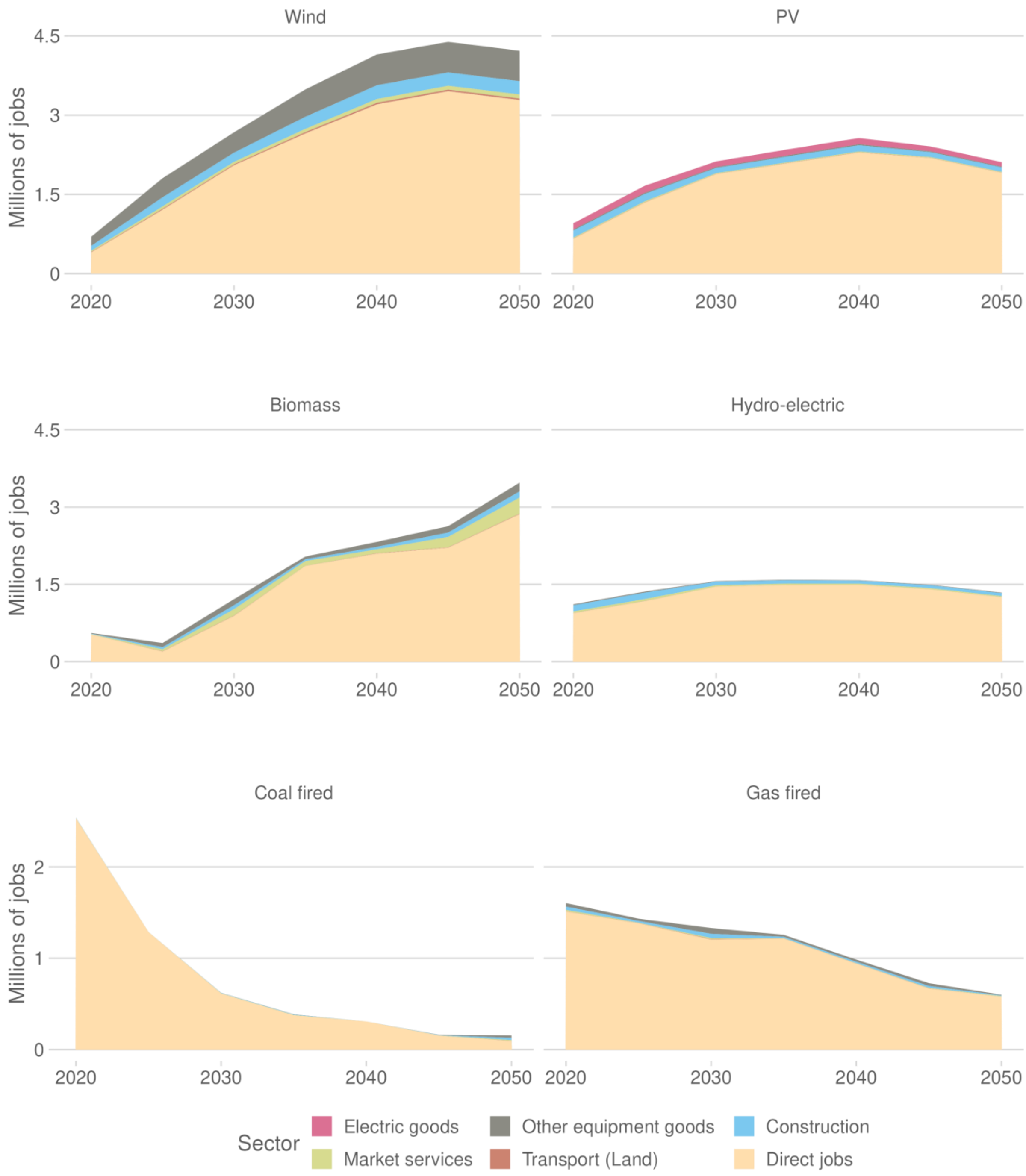


Source: JRC-GEM-E3

Figure 25 shows the projected number of jobs in power generation technologies in the 1.5°C scenario. Energy investments shift direct jobs away from coal and gas fired generation towards wind, solar PV and biomass generation. When compared to the Reference scenario, 4.7 million additional direct jobs in renewables are created by 2050 under the 1.5°C scenario. In line with previous work (Garaffa et al., 2023; Vandyck et al., 2016), fossil fuel sectors face a substantial decrease in the number of jobs by 2050, but because these sectors do not represent a big share of the overall labour market, the deployment of renewables and greater electrification help absorbing and offsetting jobs losses. To a greater extent, this comes from the increase in the direct jobs, but the investment in renewables also promote jobs in other sectors, particularly in construction and manufacturing of electrical and other equipment goods, which demand more workers in different occupations (see Box 3).

Among the different renewable energy technologies, wind energy is the one that induces the largest share of indirect workers. Over time, around 20% of the total jobs related to wind energy are induced indirect jobs as a result of investment by the wind energy sector. Most of these indirect workers are employed in the construction or 'other equipment goods' sectors. For solar PV, around 10% of the total employment related to the sector consists of indirect jobs to deliver on the sector's investment needs. These indirect workers are mainly employed in the construction or the electrical goods sectors. As there is less investment by the fossil fuel sectors, there is less demand for deliveries of investment goods and hence less demand for indirect workers. This is visible in Figure 25 where, especially for coal-fired generation, there are few indirect jobs.

Figure 25. Absolute employment over time resulting from investment by the power generation sectors in the 1.5°C scenario, by power technology



Source: JRC-GEM-E3

5 Conclusions

This report takes stock on the state of countries' adopted energy-emissions policies and announced emissions mitigation objectives, and what collective effect these have on the energy mix, on GHG emissions and on temperature change throughout the century. This report quantifies both the progress that is being made to reduce emissions, and the significant work left to do.

Global emissions are set to peak this decade even without additional policy intervention. However, even taking into account announced pledges for 2030, 2050 and beyond, the world is not on a pathway that is compatible with the Paris Agreement target of 1.5°C temperature change. Significant implementation gaps and ambition gaps remain.

The emission reductions in the current decade in the 1.5°C scenario are particularly steep, requiring a considerable increase in the deployment of low-emissions equipment, which is reflected in the increased investment needs in the energy sector in this scenario.

Efficiently directing investments towards low- and zero-emissions equipment is key to achieving emissions reduction goals. This report outlines which sectors and technologies policymakers and investors should focus on. The current decade is critical; many clean technologies are experiencing rapid growth and deployment already, and this trend needs to be nurtured in order to keep the window open for the 1.5°C objective.

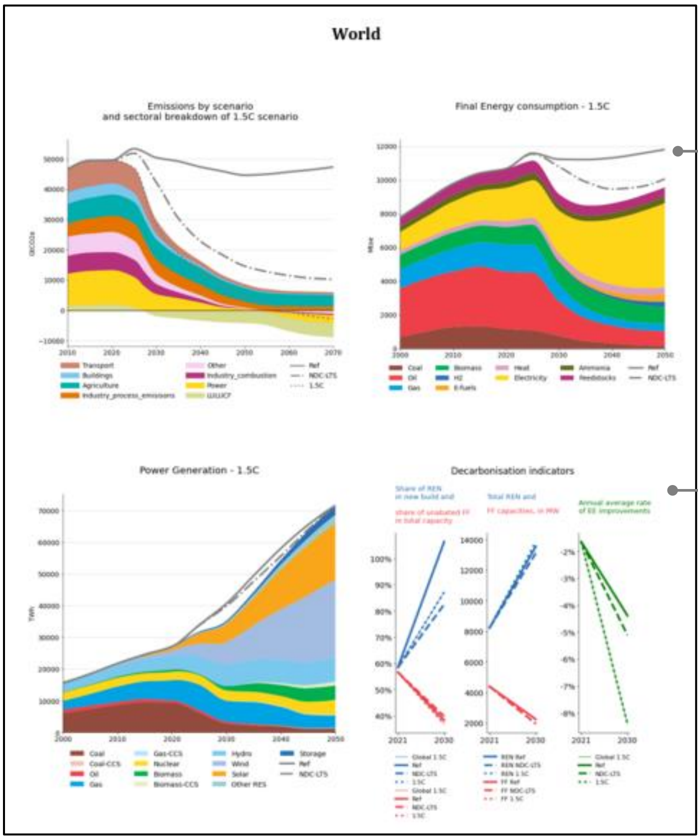
Investing in low-emission technologies stimulates output, and promotes investment and employment in adjacent sectors that supply equipment and services to the energy sector. Decarbonising creates jobs opportunities both in the energy sector and in adjacent sectors.

While decarbonisation leads to an increase in investments in the energy sector, the share of spending in global GDP in the future remains broadly the same as today, indicating that the global economy can manage the burden of decarbonisation. Care must be taken, by both policymakers and investors, to ensure that energy sector investments are 1.5°C-aligned, in order to minimise the risk of misallocated capital slowing down the energy transition.

6 Major economies and World fact sheets

This section presents fact sheets with key metrics for major economies (G20 and the EU) as well as the world aggregate.

How to read the country sheets



Left: GHG emission projections by scenario and sectoral breakdown in the 1.5°C scenario

Right: Final energy consumption by scenario and fuel breakdown in the 1.5°C scenario

Left: Power generation by scenario and by source.

Right: Change in key decarbonisation indicators from 2021 to 2030 under 3 different scenarios for each country (which shows progress from today to 2030 based on policy settings), and in comparison to the global average, indicating if a country is a leader or a laggard:

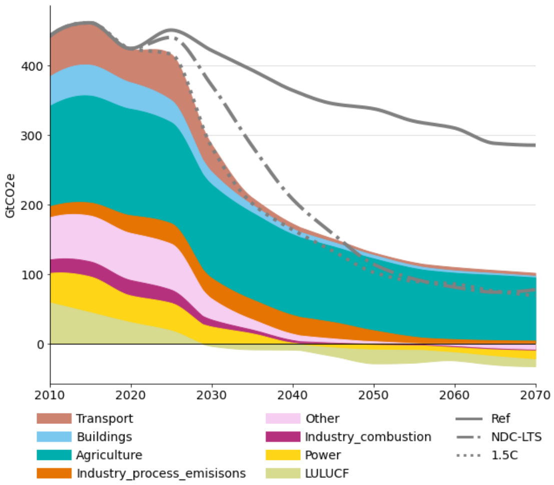
The **first panel** shows the share of renewables and unabated fossil fuels in total new build capacity, indicating how quickly it is installing renewables and retiring fossil fuels.

The **second panel** shows to total installed capacity of renewables and fossil fuels, indicating how far to go to reach a renewables-dominated power mix.

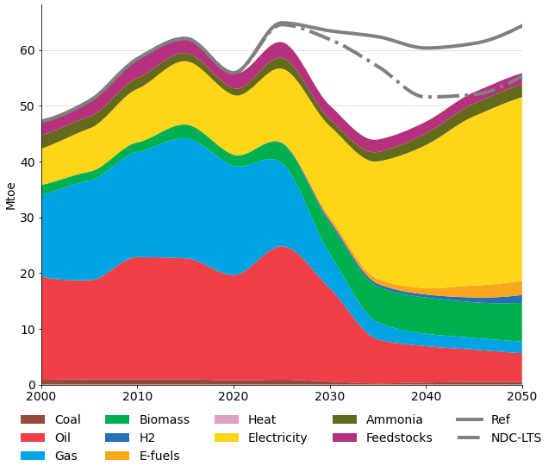
The **third panel** shows the rate of energy efficiency improvements, indicating the country's progress in relation to the doubling of energy efficiency target.

Argentina

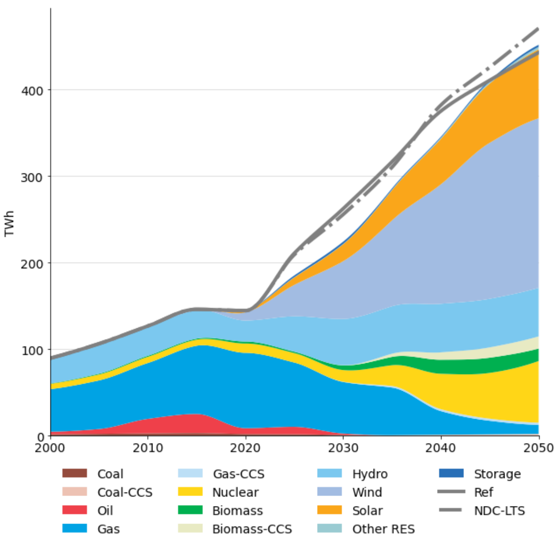
Emissions by scenario
and sectoral breakdown of 1.5C scenario



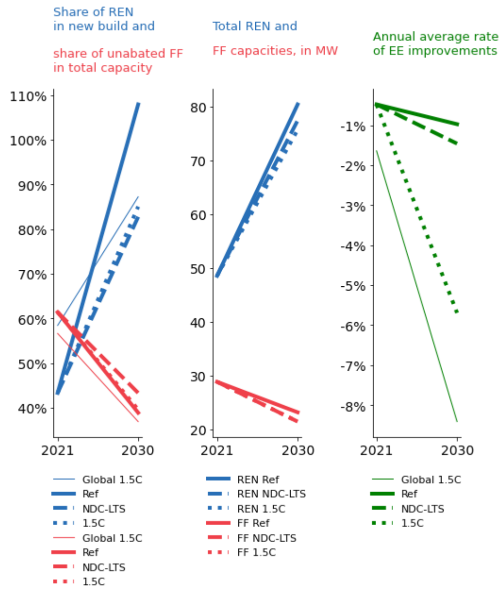
Final Energy consumption - 1.5C



Power Generation - 1.5C

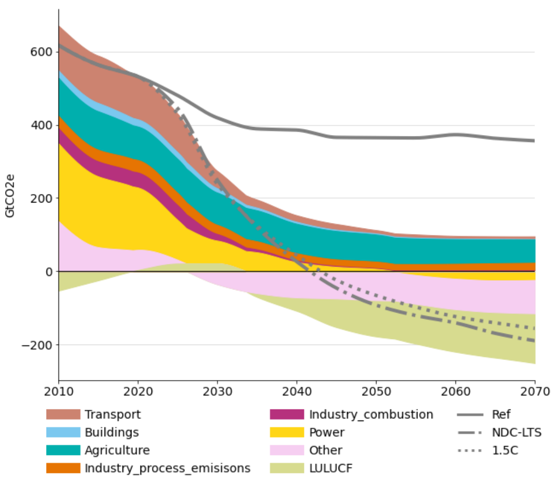


Decarbonisation indicators

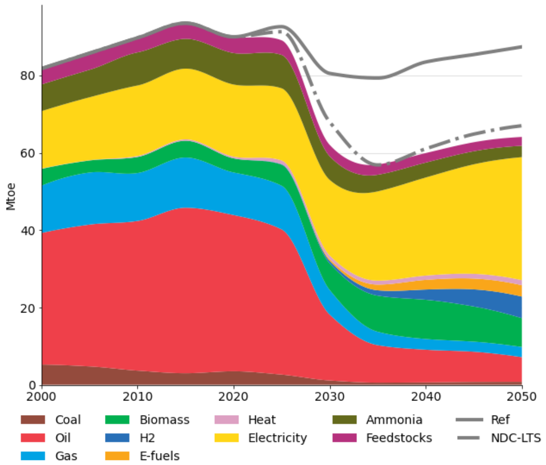


Australia

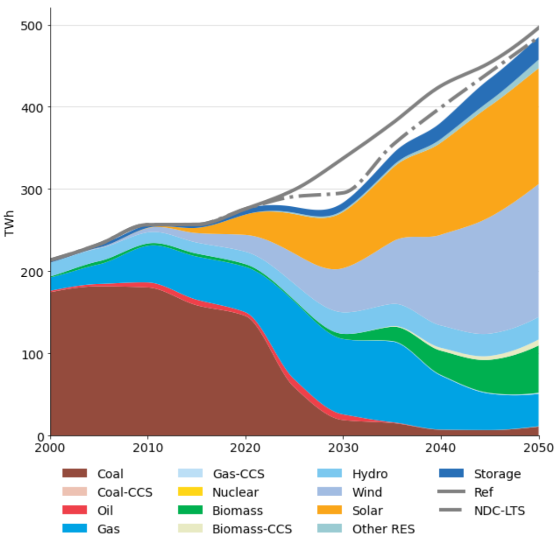
Emissions by scenario
and sectoral breakdown of 1.5C scenario



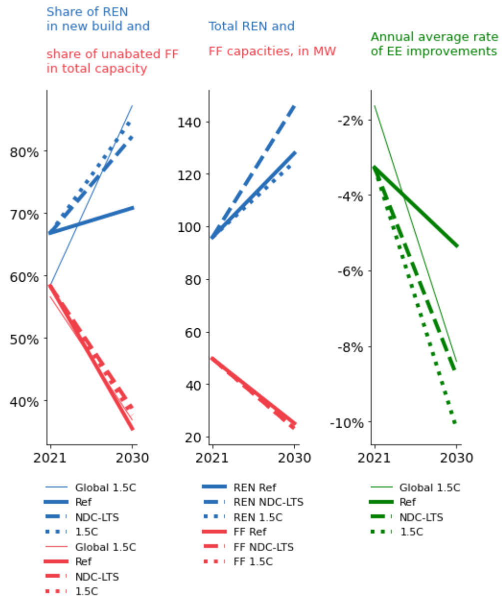
Final Energy consumption - 1.5C



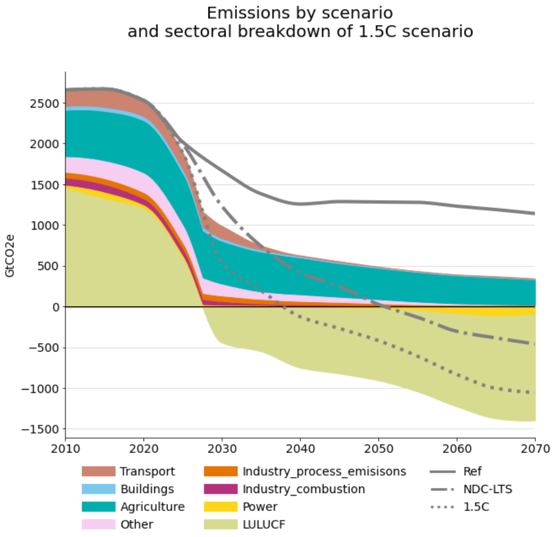
Power Generation - 1.5C

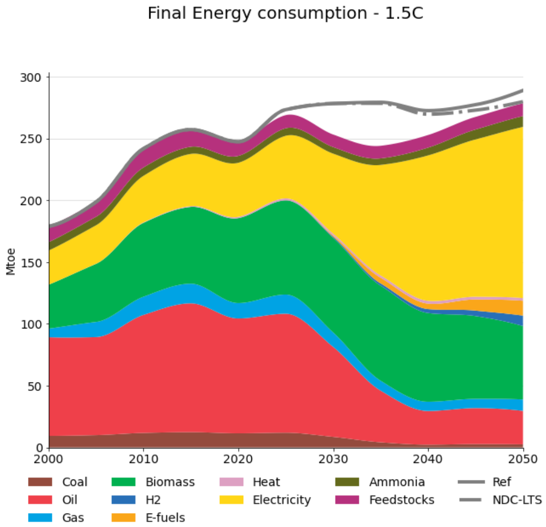


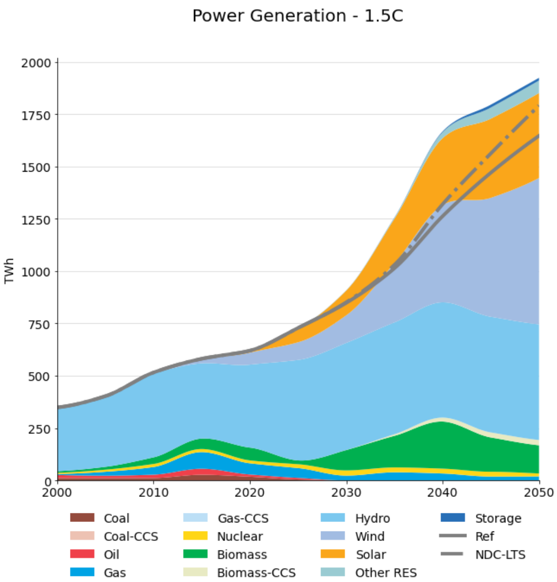
Decarbonisation indicators

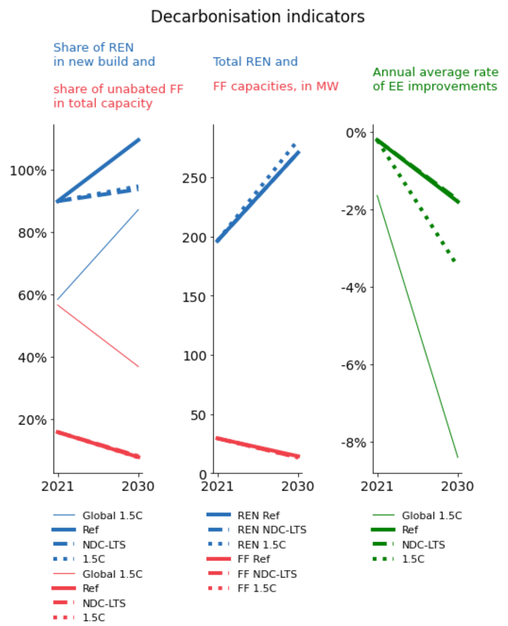


Brazil


Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
2500
2000
1500
1000
500
0
−500
−1000
−1500
2010
2020
2030
2040
2050
2060
2070
Transport
Buildings
Agriculture
Other
Industry_process_emisisons
Industry_combustion
Power
LULUCF
Ref
NDC-LTS
1.5C

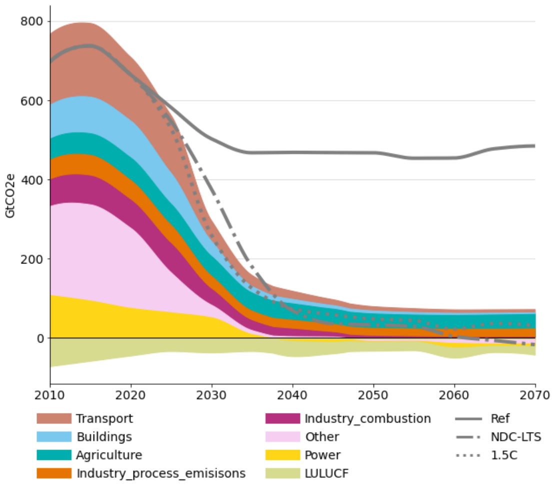

Final Energy consumption - 1.5C
Mtoe
300
250
200
150
100
50
0
2000
2010
2020
2030
2040
2050
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS


Power Generation - 1.5C
TWh
2000
1750
1500
1250
1000
750
500
250
0
2000
2010
2020
2030
2040
2050
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS

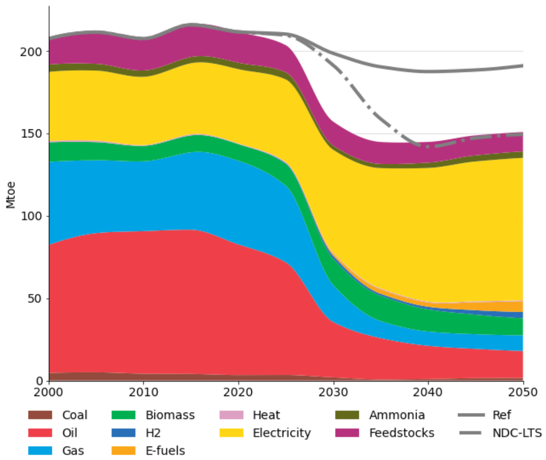

Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
100%
80%
60%
40%
20%
250
200
150
100
50
0
0%
-2%
-4%
-6%
-8%
2021
2030
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C

Canada

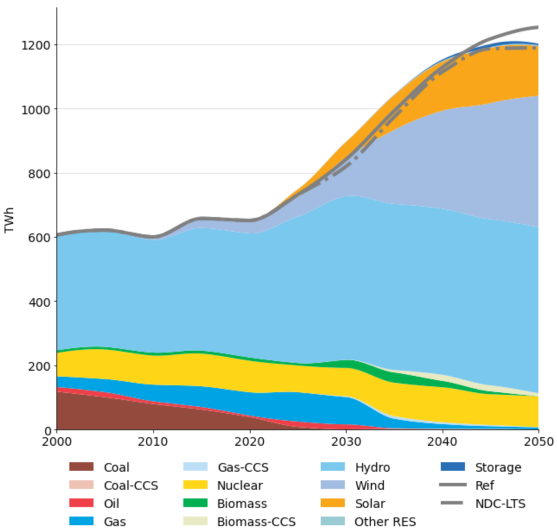
Emissions by scenario
and sectoral breakdown of 1.5C scenario



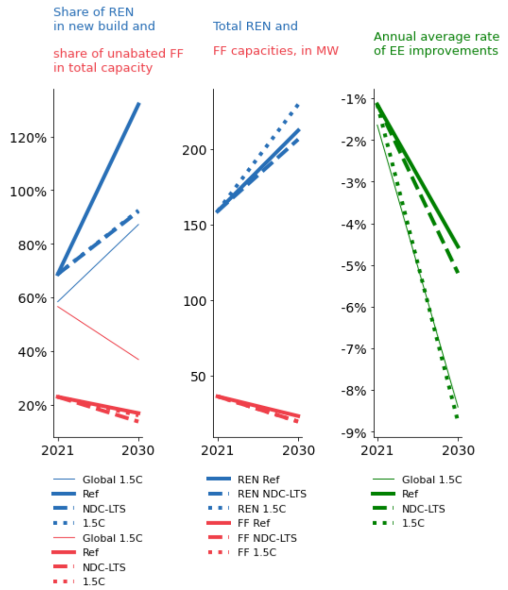
Final Energy consumption - 1.5C



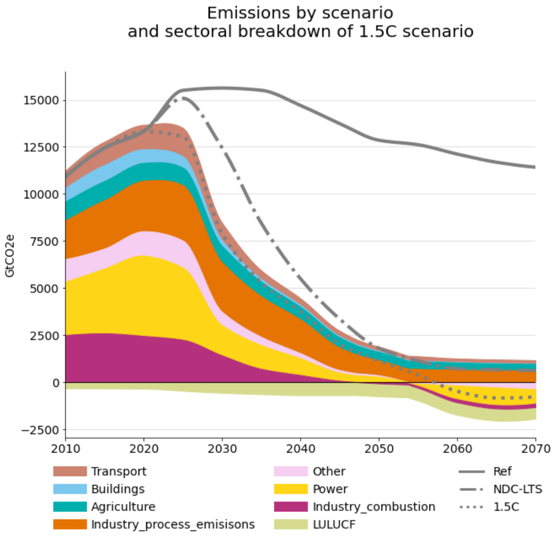
Power Generation - 1.5C

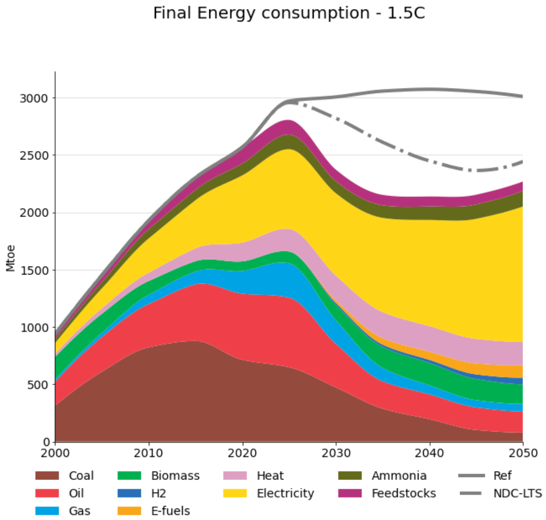


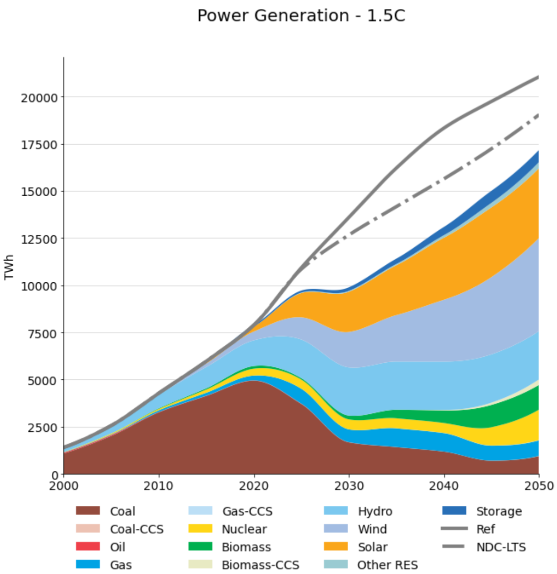
Decarbonisation indicators

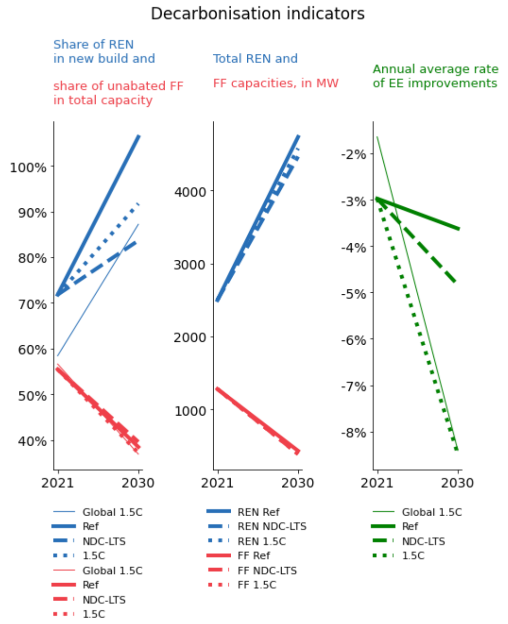


China

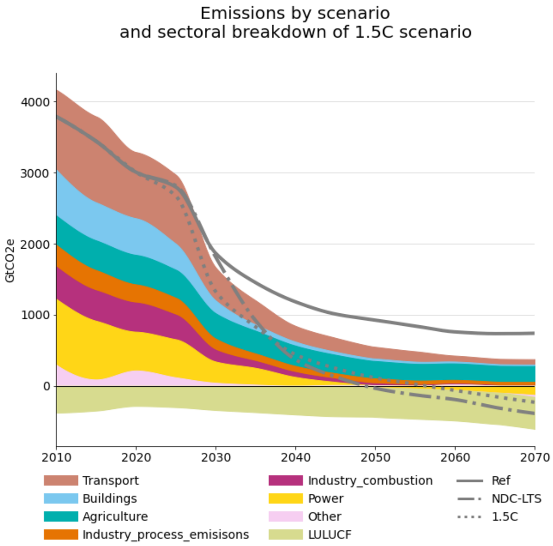

Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
Transport
Buildings
Agriculture
Industry_process_emisisons
Other
Power
Industry_combustion
LULUCF
Ref
NDC-LTS
1.5C

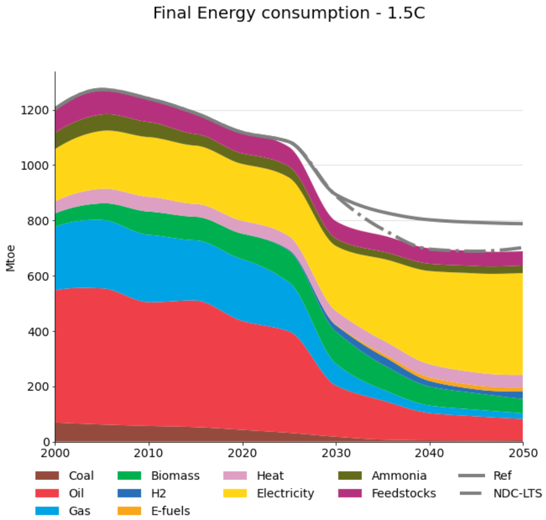

Final Energy consumption - 1.5C
Mtoe
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS

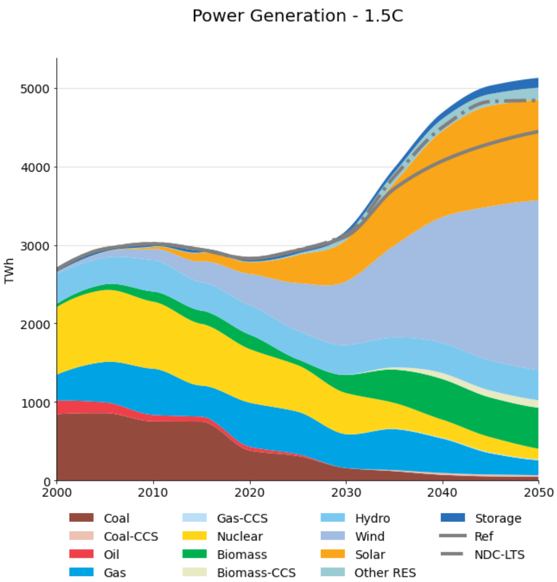

Power Generation - 1.5C
TWh
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS

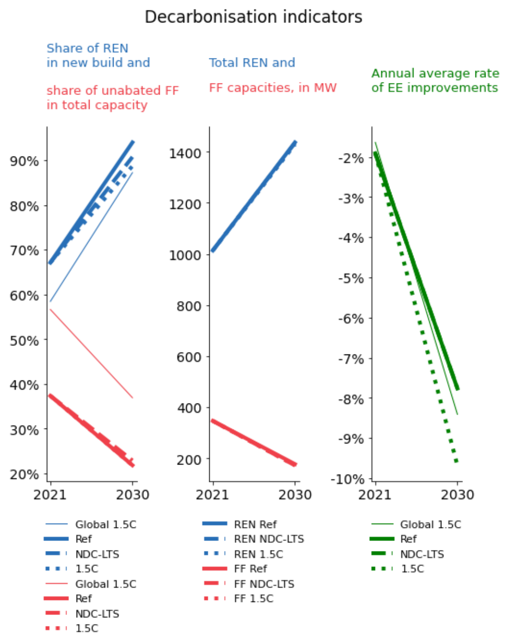

Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C

European Union



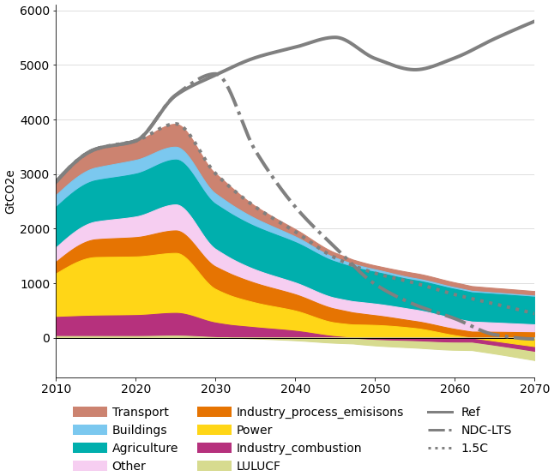




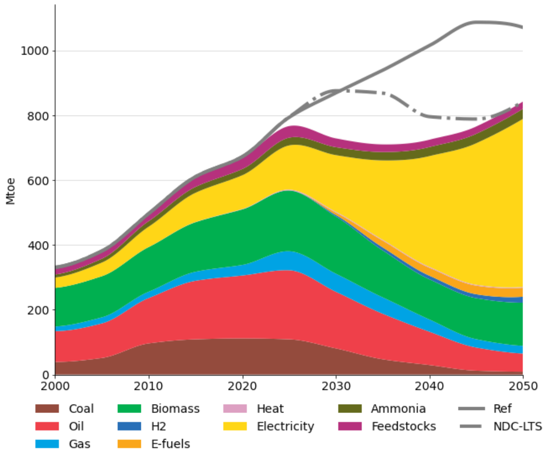


India

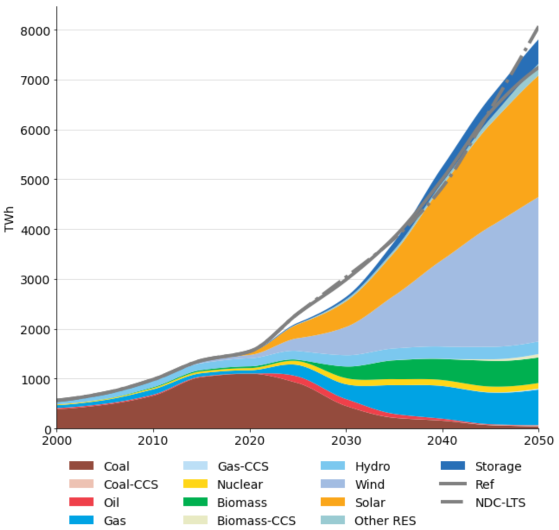
Emissions by scenario
and sectoral breakdown of 1.5C scenario



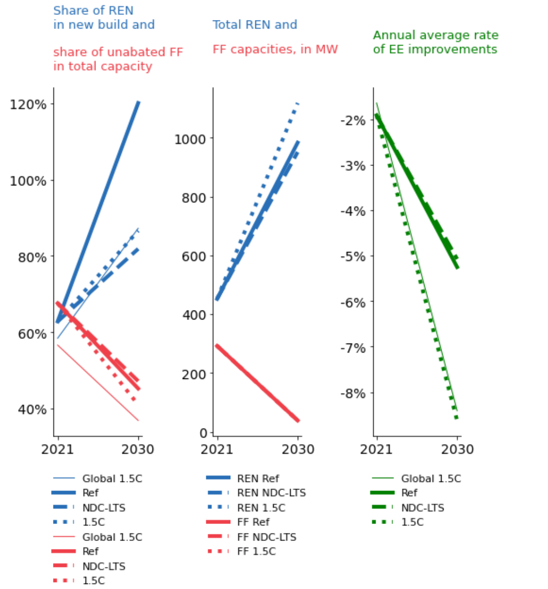
Final Energy consumption - 1.5C



Power Generation - 1.5C

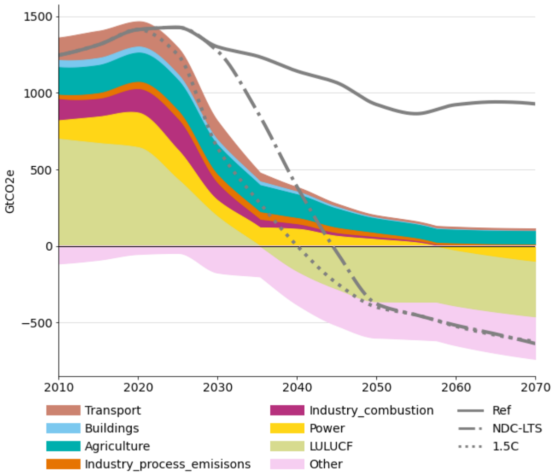


Decarbonisation indicators

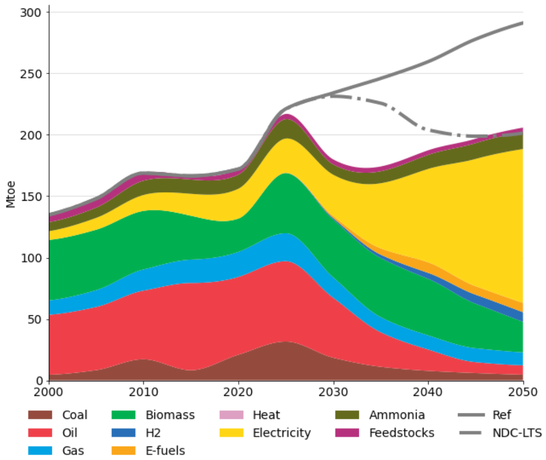


Indonesia

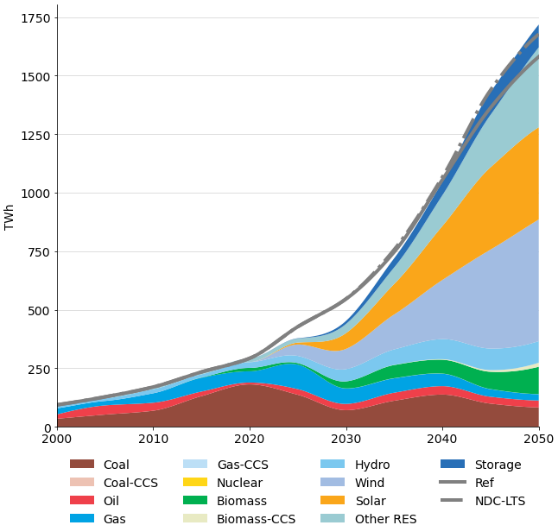
Emissions by scenario
and sectoral breakdown of 1.5C scenario



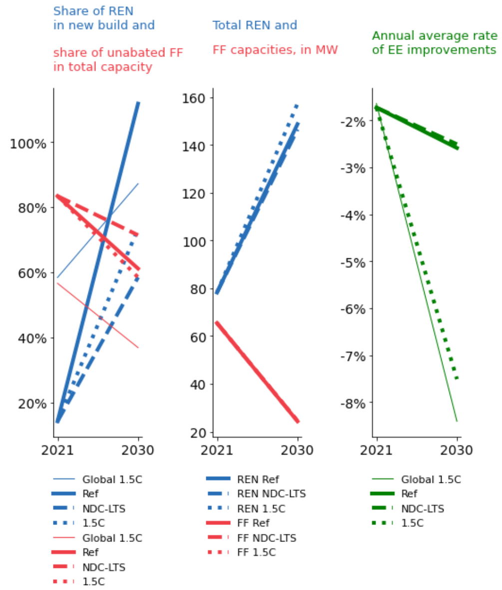
Final Energy consumption - 1.5C



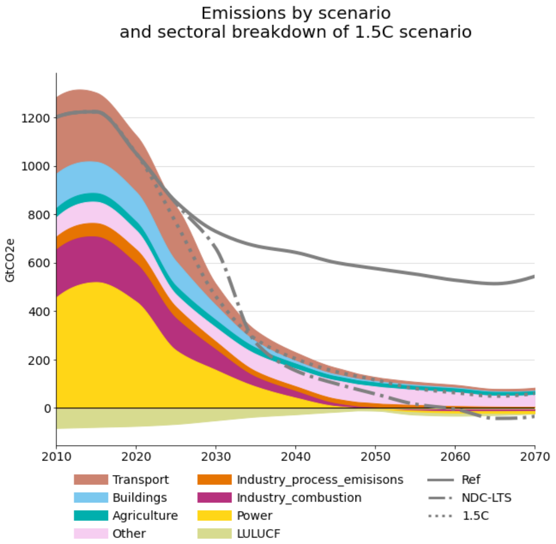
Power Generation - 1.5C

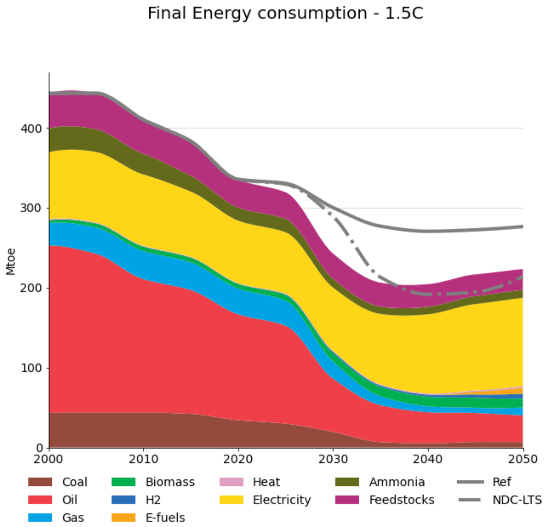


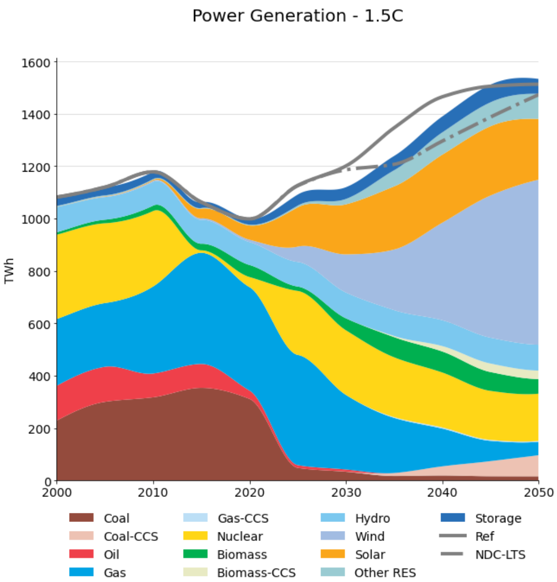
Decarbonisation indicators

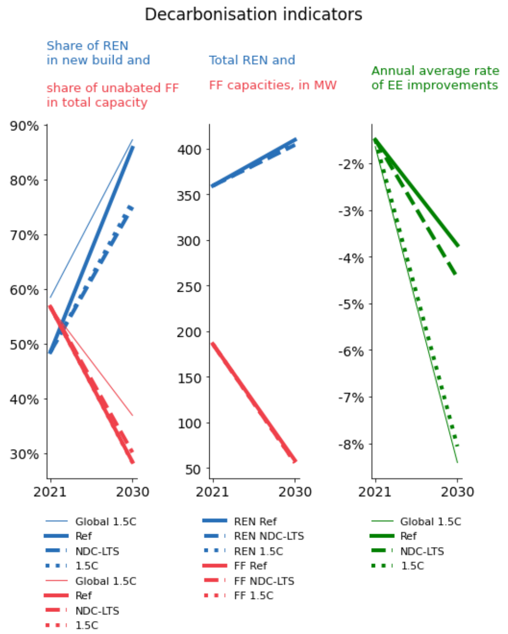


Japan


Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
Transport
Buildings
Agriculture
Other
Industry_process_emisisons
Industry_combustion
Power
LULUCF
Ref
NDC-LTS
1.5C

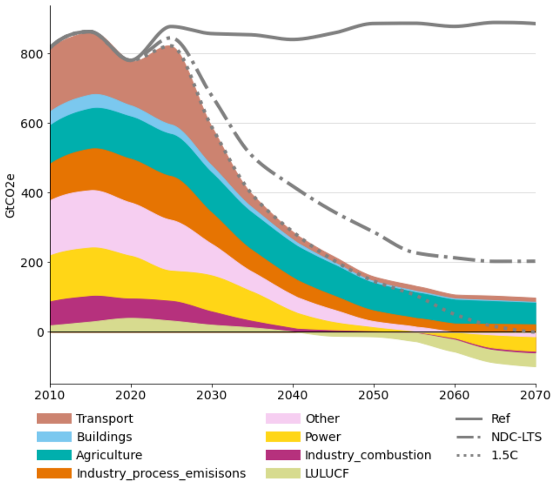

Final Energy consumption - 1.5C
Mtoe
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS


Power Generation - 1.5C
TWh
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS

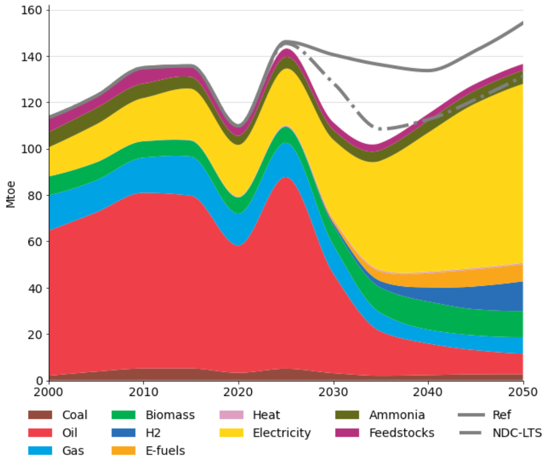

Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C

Mexico

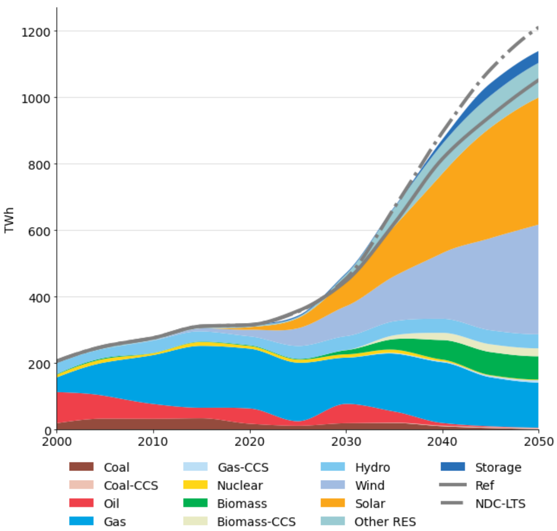
Emissions by scenario
and sectoral breakdown of 1.5C scenario



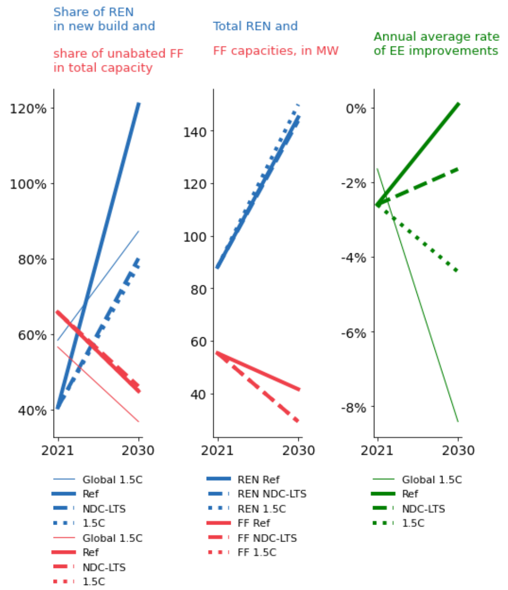
Final Energy consumption - 1.5C



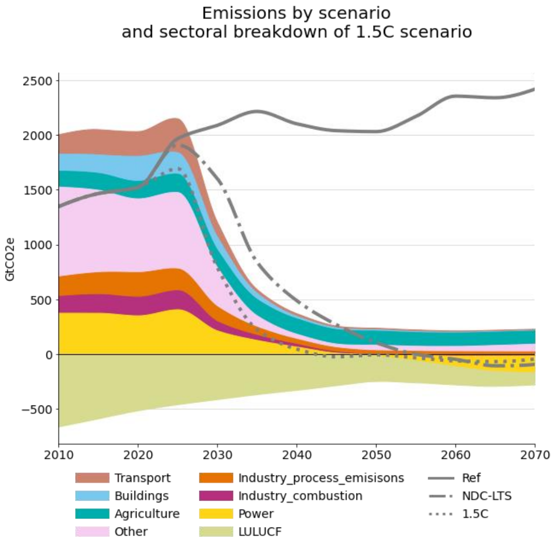
Power Generation - 1.5C



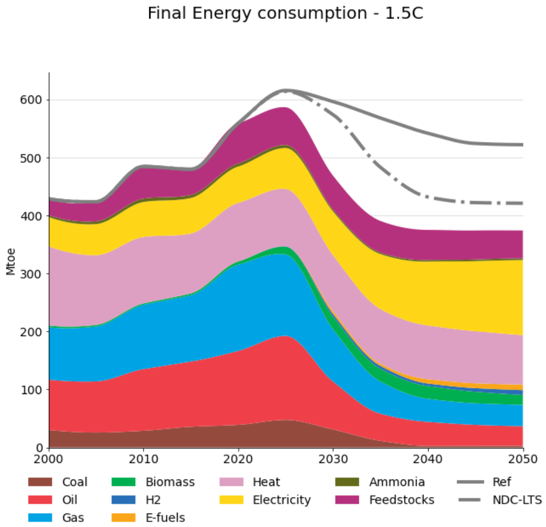
Decarbonisation indicators



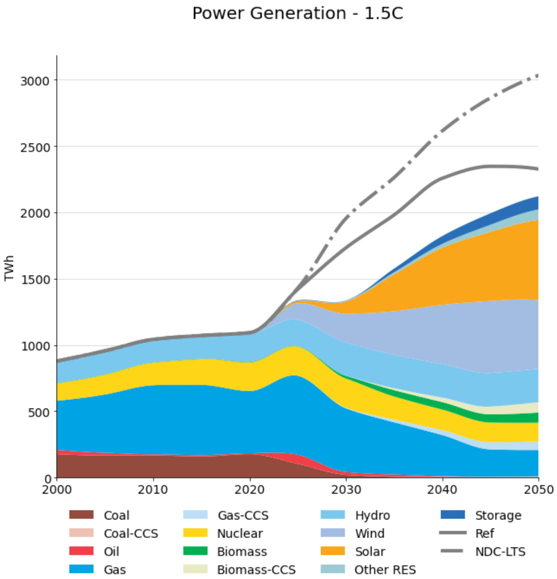
Russia



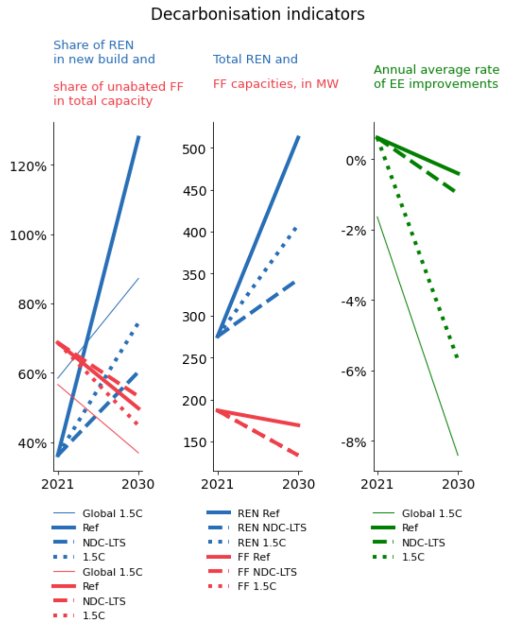
Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
2500
2000
1500
1000
500
0
−500
2010
2020
2030
2040
2050
2060
2070
Transport
Buildings
Agriculture
Other
Industry_process_emisisons
Industry_combustion
Power
LULUCF
Ref
NDC-LTS
1.5C



Final Energy consumption - 1.5C
Mtoe
600
500
400
300
200
100
0
2000
2010
2020
2030
2040
2050
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS



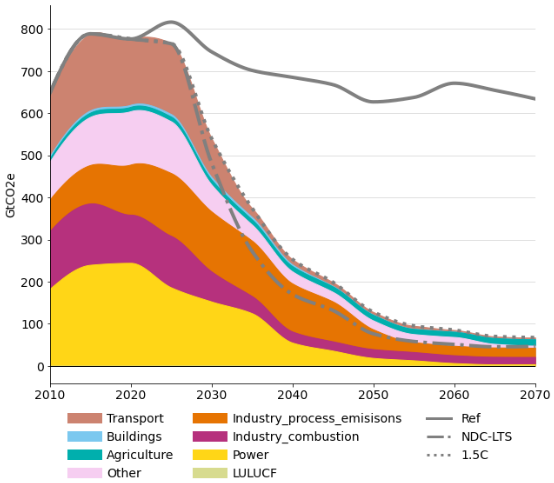
Power Generation - 1.5C
TWh
3000
2500
2000
1500
1000
500
0
2000
2010
2020
2030
2040
2050
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS



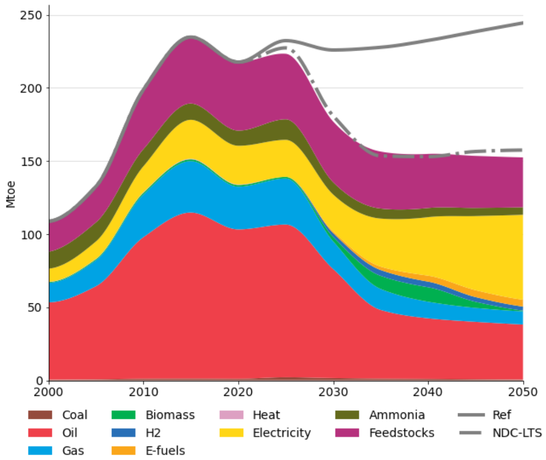
Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
120%
100%
80%
60%
40%
2021
2030
500
450
400
350
300
250
200
150
2021
2030
0%
-2%
-4%
-6%
-8%
2021
2030
Global 1.5C
Ref
NDC-LTS
1.5C
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C
Global 1.5C
Ref
NDC-LTS
1.5C

Saudi Arabia

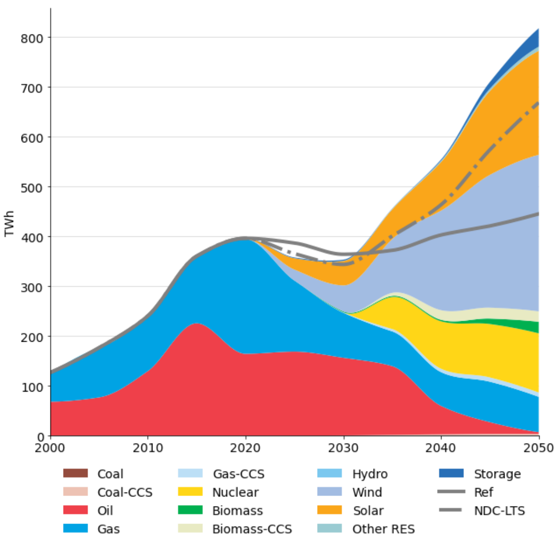
Emissions by scenario
and sectoral breakdown of 1.5C scenario



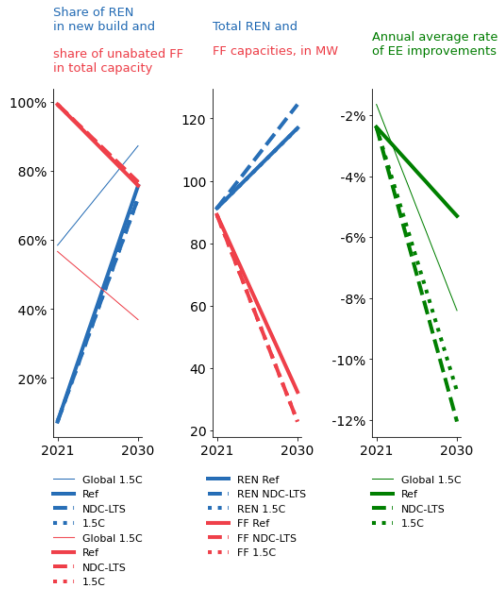
Final Energy consumption - 1.5C



Power Generation - 1.5C

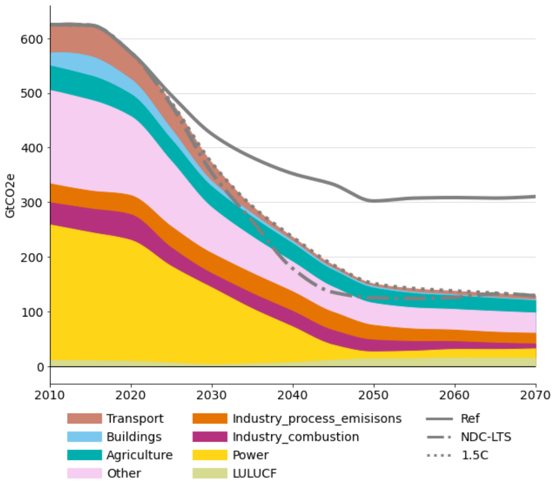


Decarbonisation indicators

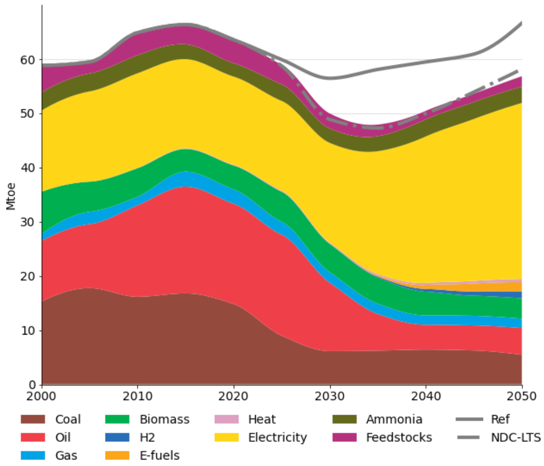


South Africa

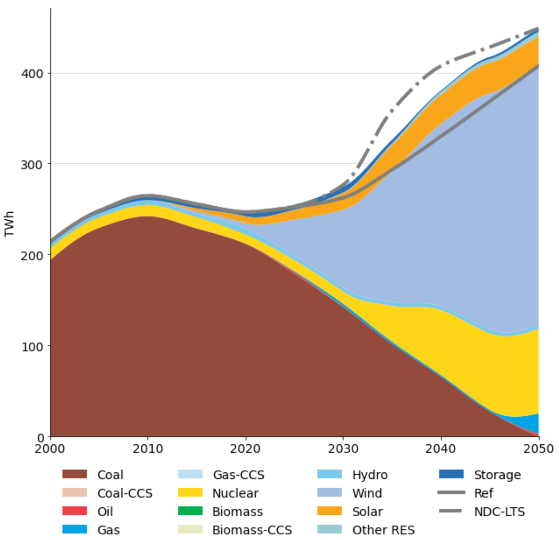
Emissions by scenario
and sectoral breakdown of 1.5C scenario



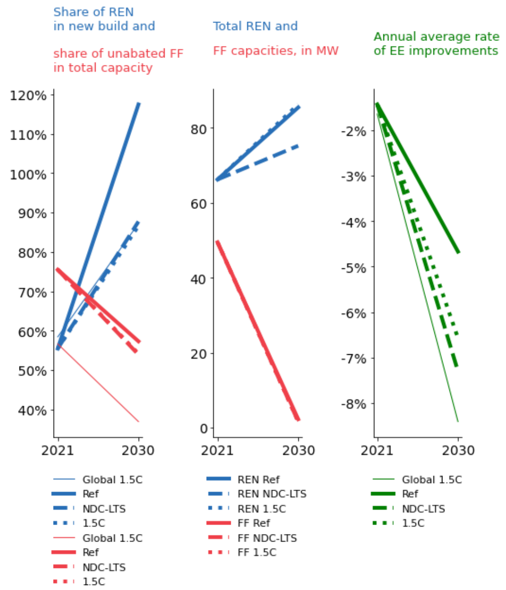
Final Energy consumption - 1.5C



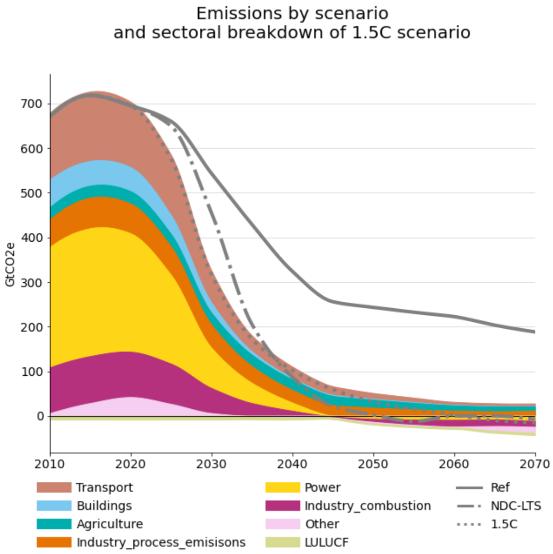
Power Generation - 1.5C



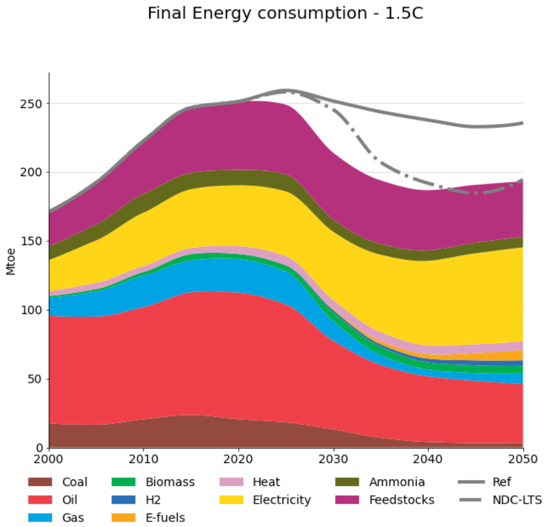
Decarbonisation indicators



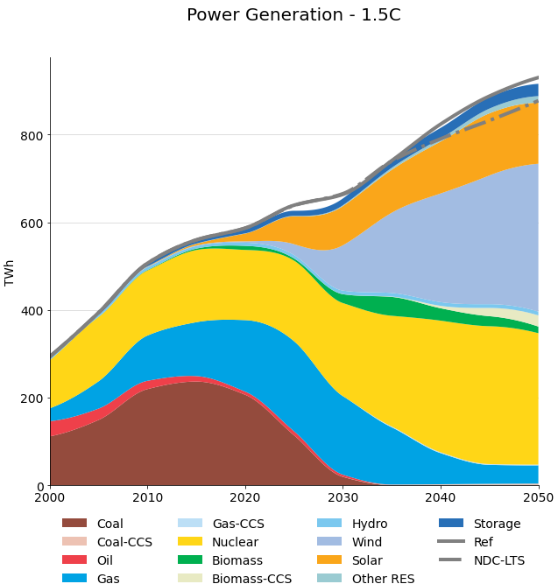
South Korea



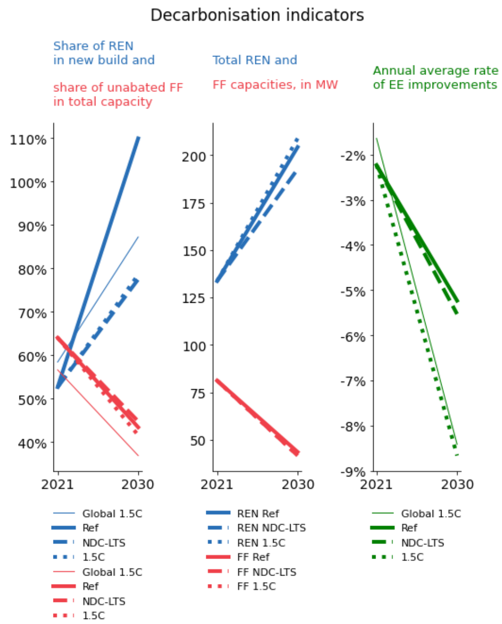
Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
Transport
Buildings
Agriculture
Industry_process_emisisons
Power
Industry_combustion
Other
LULUCF
Ref
NDC-LTS
1.5C



Final Energy consumption - 1.5C
Mtoe
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS

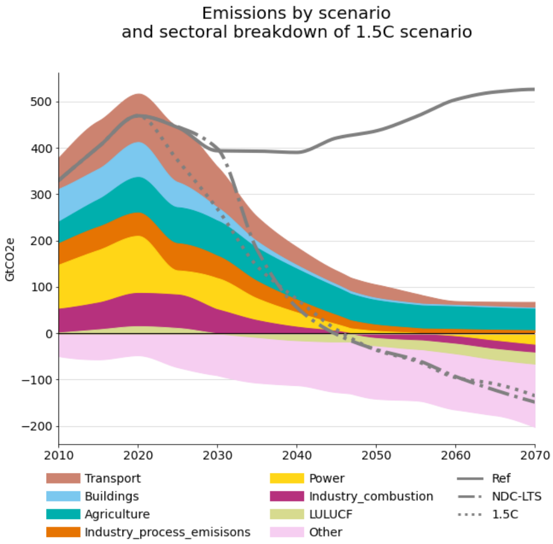


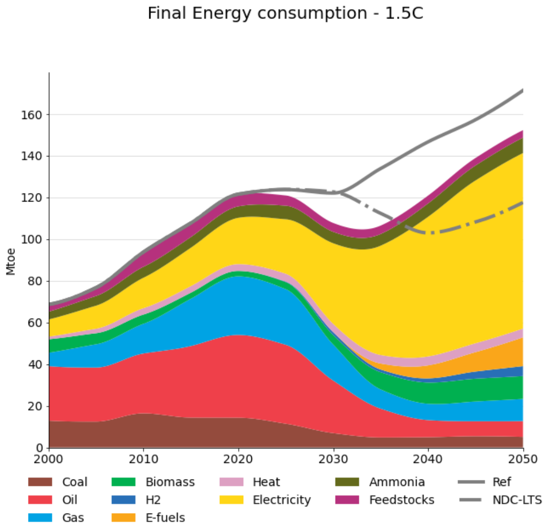
Power Generation - 1.5C
TWh
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS

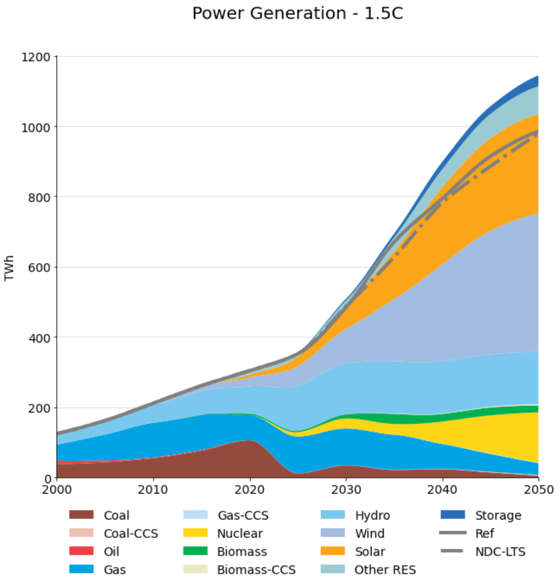


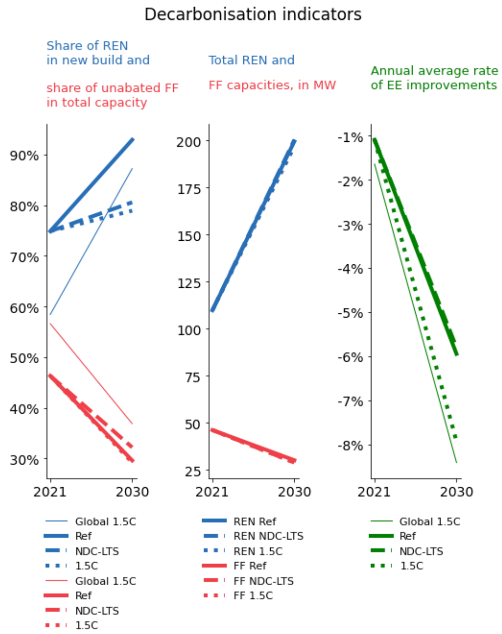
Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
Global 1.5C
Ref
NDC-LTS
1.5C
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C
Global 1.5C
Ref
NDC-LTS
1.5C

Turkey


Emissions by scenario
and sectoral breakdown of 1.5C scenario
GtCO2e
Transport
Buildings
Agriculture
Industry_process_emisisons
Power
Industry_combustion
LULUCF
Other
Ref
NDC-LTS
1.5C

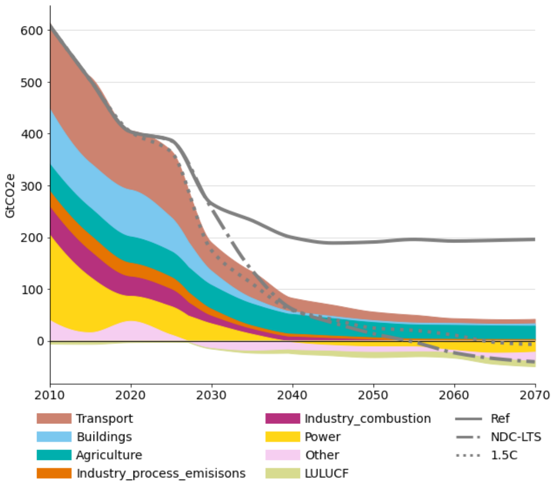

Final Energy consumption - 1.5C
Mtoe
Coal
Oil
Gas
Biomass
H2
E-fuels
Heat
Electricity
Ammonia
Feedstocks
Ref
NDC-LTS


Power Generation - 1.5C
TWh
Coal
Coal-CCS
Oil
Gas
Gas-CCS
Nuclear
Biomass
Biomass-CCS
Hydro
Wind
Solar
Other RES
Storage
Ref
NDC-LTS

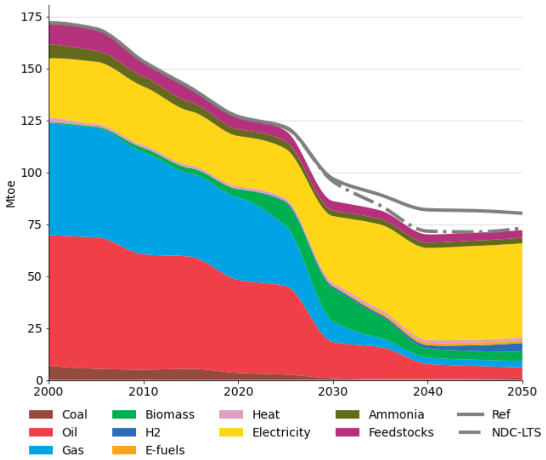

Decarbonisation indicators
Share of REN
in new build and
share of unabated FF
in total capacity
Total REN and
FF capacities, in MW
Annual average rate
of EE improvements
Global 1.5C
Ref
NDC-LTS
1.5C
REN Ref
REN NDC-LTS
REN 1.5C
FF Ref
FF NDC-LTS
FF 1.5C

United Kingdom

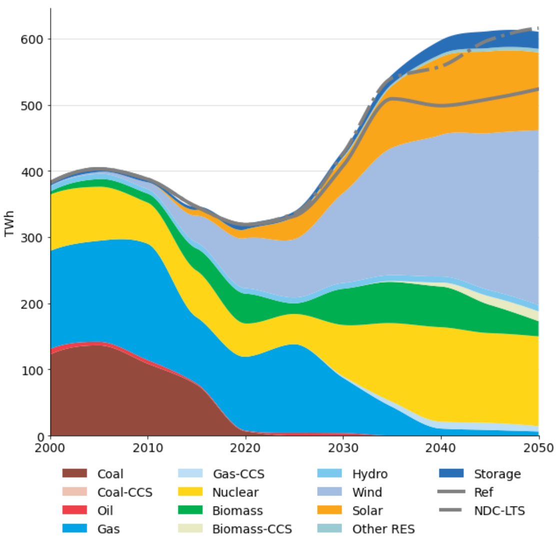
Emissions by scenario
and sectoral breakdown of 1.5C scenario



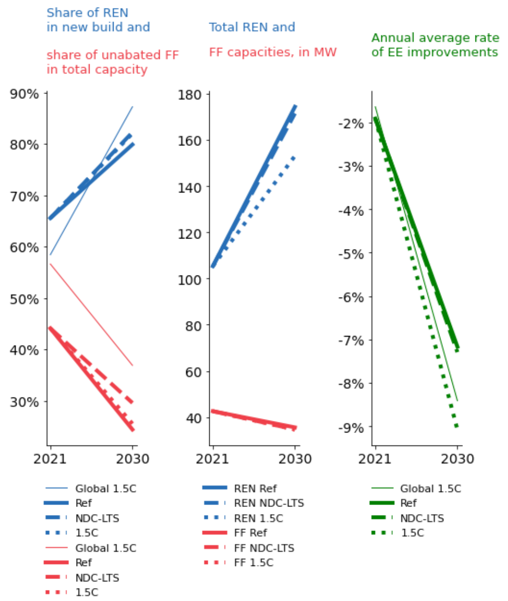
Final Energy consumption - 1.5C



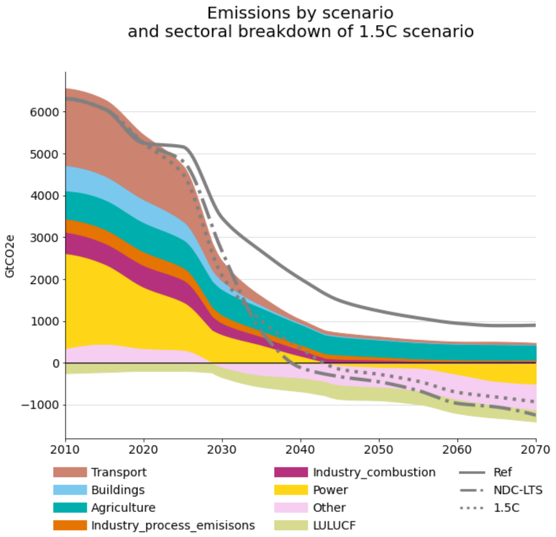
Power Generation - 1.5C

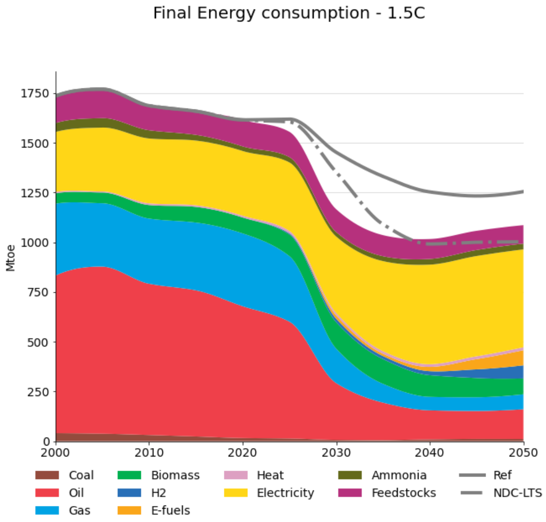


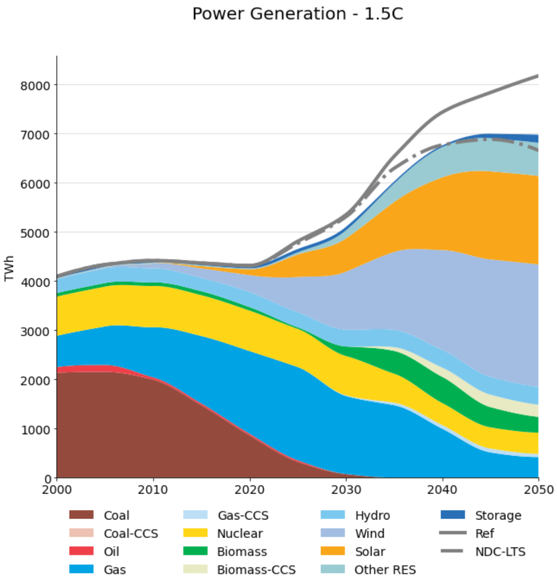
Decarbonisation indicators

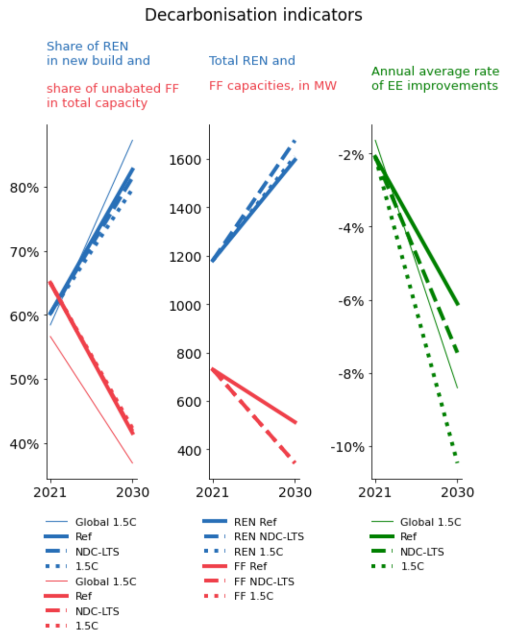


United States



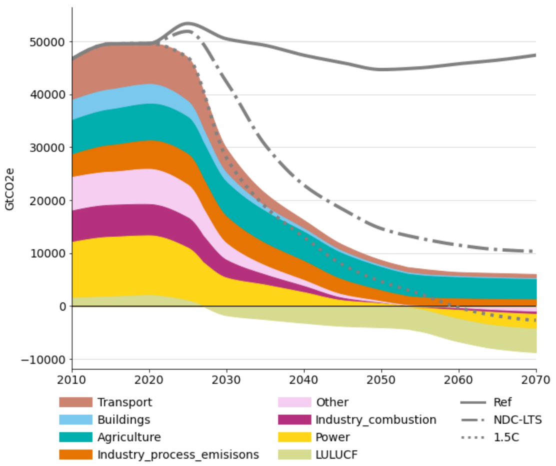




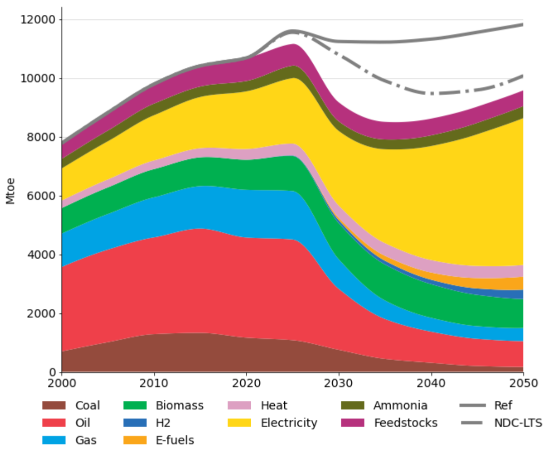


World

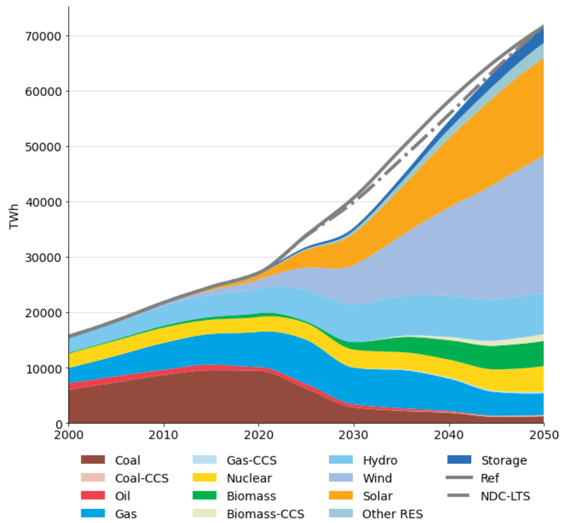
Emissions by scenario
and sectoral breakdown of 1.5C scenario



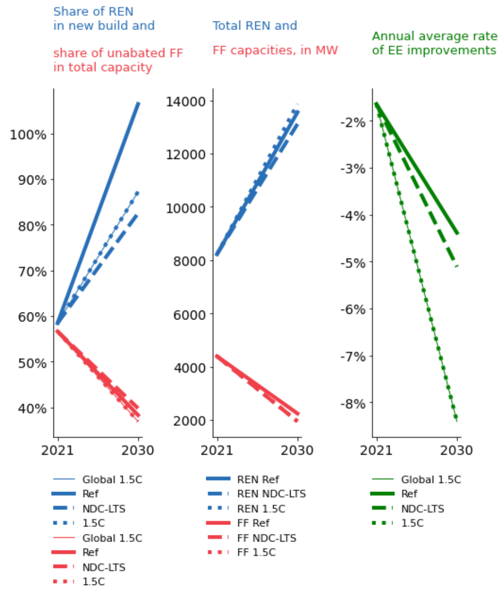
Final Energy consumption - 1.5C



Power Generation - 1.5C



Decarbonisation indicators



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List of abbreviations and definitions

AFOLU	Agriculture, forestry and land-use
BAU	Business as usual
BECCS	Bio-Energy combined with Carbon Capture and Sequestration
BEV	Battery electric vehicle
CCS	Carbon Capture and Sequestration
CDD	Cooling Degree-Days
CETO	Clean Energy Technology Observatory
CGE	Computable General Equilibrium model
CH_4	Methane
CO_2	Carbon dioxide
COM	Communication from the European Commission
COP	Conference of the Parties
DACCS	Direct Air CO_2 Capture and Sequestration
EC	European Commission
ETS	Emission Trading Scheme
EU	European Union as of date of publication (27 Member States)
EV	Electric Vehicle
GDP	Gross Domestic Product
GECO	Global Energy & Climate Outlook
GHG	Greenhouse Gases
GLOBIOM	The Global Biosphere Management Model
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
H2	Hydrogen
HFCs	Hydrofluorocarbons
IATA	International air transport association
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IFC	International Finance Corporation, World Bank Group
ILO	International Labour Organisation
IMF	International Monetary Fund
IMO	International Maritime Organisation
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre of the European Commission

LNG	Liquefied Natural Gas
LTS	Long Term Strategy
LULUCF	Land Use, Land Use Change and Forestry
MER	Market Exchange Rate
MRIO	Multi-regional input-output (table)
N_2O	Nitrous oxide
NDC	Nationally Determined Contribution
NCSC	National Centre for Climate Change Strategy and International Cooperation
NREL	US National Renewables Energy Laboratory
OECD	Organisation of Economic Co-operation and Development
O&G	Oil and Gas
PFCs	Perfluorocarbons
PIRAMID	Platform to Integrate, Reconcile and Align Model-based Input-output Data
POP	Population
PPP	Purchasing Power Parity
POLES-JRC	Prospective Outlook on Long-term Energy Systems, model version used in the JRC
ppm	part per millions
R/P	Ratio Reserves by Production
RES	Renewable Energy
SDS	Sustainable development scenario from IEA
SF_6	Sulphur hexafluoride
TC	Transport changes
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	US Geological Survey
WEC	World Energy Council
WMO	World Meteorological Organisation

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Annexes

Annex 1: Description of POLES-JRC

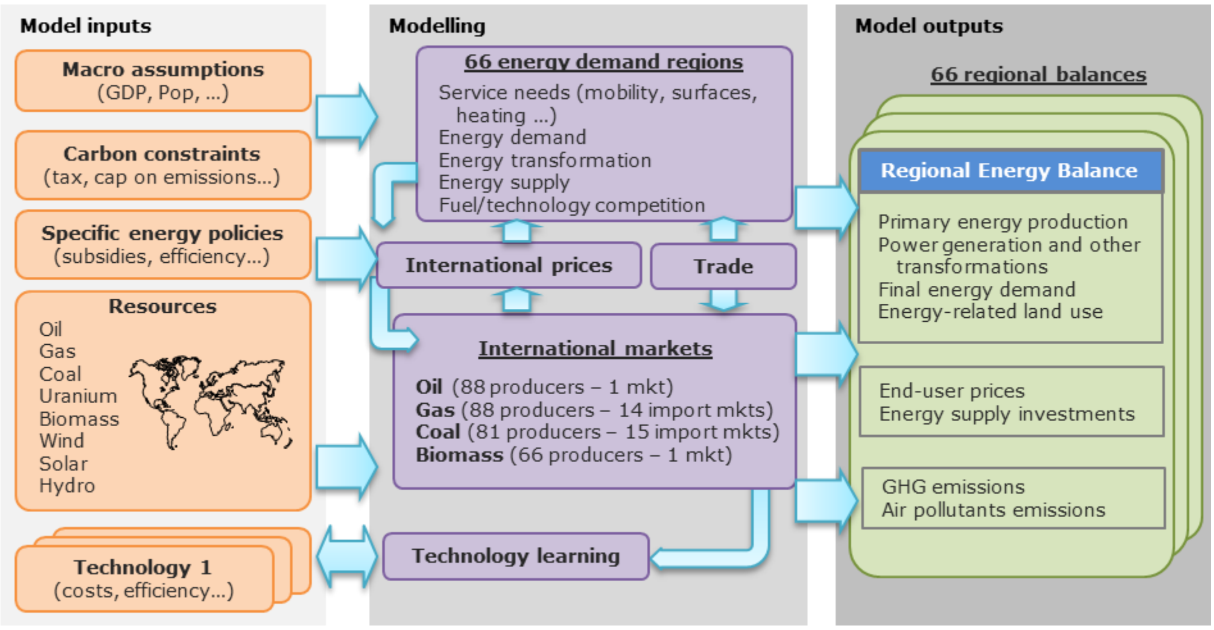
For a more comprehensive description of the model, see (Després et al., 2018).

POLES-JRC is a world energy-economy partial equilibrium simulation model of the energy sector, with complete modelling from upstream production through to final user demand. It follows a year-by-year recursive modelling, with endogenous international energy prices and lagged adjustments of supply and demand by world region, which allows for describing full development pathways to 2050 (see general scheme in Figure 26:).

The model provides full energy and emission balances for 66 countries or regions worldwide (including an explicit representation of OECD and G20 countries), 14 fuel supply branches and 15 final demand sectors.

This exercise used the POLES-JRC 2019 version as a starting point. Differences with other exercises done with the POLES-JRC model, or with exercises by other entities using the POLES model.

Figure 26: POLES-JRC model general scheme



Source: POLES-JRC model.

Final demand

The final demand evolves with activity drivers, energy prices and technological progress. The following sectors are represented:

- industry: chemicals (energy uses and non-energy uses are differentiated), non-metallic minerals, steel, other industry;
- buildings: residential, services (detailed per end-uses: space heating, space cooling, water heating, cooking, lighting, appliances);
- transport (goods and passengers are differentiated): road (motorcycles, cars, light and heavy trucks; different engine types are considered), rail, inland water, international maritime, air (domestic and international);
- agriculture.

Power system

The power system describes the capacity planning of new plants and the operation of existing plants.

The electricity demand curve is built from the sectoral distribution.

The load, wind supply and solar supply are clustered into a number of representative days.

The planning considers the existing structure of the power mix (vintage per technology type), the expected evolution of the load demand, the production cost of new technologies and the resource potential for renewables.

The operation matches electricity demand considering the installed capacities, the variable production costs per technology type, the resource availability for renewables and the contribution of flexible means (stationary storage, vehicle-to-grid, demand-side management).

The electricity price by sector depends on the evolution of the power mix, of the load curve and of energy taxes.

Other transformation

The model also describes other energy transformations sectors: liquid biofuels, coal-to-liquids, gas-to-liquids, hydrogen, centralised heat production.

Oil supply

Oil discoveries, reserves and production are simulated for producing countries and different resource types.

Investments in new capacities are influenced by production costs, which include direct energy inputs in the production process.

The international oil price depends on the evolution of the oil stocks in the short term, and on the marginal production cost and ratio of the Reserves by Production (R/P) ratio in the longer run.

Gas supply

Gas discoveries, reserves and production are simulated for individual producers and different resource types. Investments in new capacities are influenced by production costs, which include direct energy inputs in the production process.

They supply regional markets through inland pipeline, offshore pipelines or LNG.

The gas prices depend on the transport cost, the regional R/P ratio, the evolution of oil price and the development of LNG (integration of the different regional markets).

Coal supply

Coal production is simulated for individual producers. Production cost is influenced by short-term utilisation of existing capacities and a longer-term evolution for the development of new resources. They supply regional markets through inland transport (rail) or by maritime freight. Coal delivery price for each route depends on the production cost and the transport cost.

Biomass supply

The model differentiates various types of primary biomass: energy crops, short rotation crop (lignocellulosic) and wood (lignocellulosic). They are described through a potential and a production cost curve – information on lignocellulosic biomass (short rotation coppices, wood) is derived from look-up tables provided by the specialised model GLOBIOM-G4M (Global Biosphere Management Model). Biomass can be traded, either in solid form or as liquid biofuel.

Wind, solar and other renewables

They are associated with potentials and supply curves per country.

GHG emissions

CO_2 emissions from fossil fuel combustion are derived directly from the projected energy balance. Other GHGs from energy and industry are simulated using activity drivers identified in the model (e.g. sectoral value added, mobility per type of vehicles, fuel production, fuel consumption) and abatement cost curves. GHG from agriculture and LULUCF are derived from GLOBIOM-G4M lookup tables.

Definitions

In this report, hydrogen demand refers to hydrogen used as a fuel for energy use and non-energy applications, such as hydrogen used as feedstock for ammonia production.

E-fuels refers to fuels obtained from power-to-gas and power-to-liquid processes, in which hydrogen and CO_2 are converted to gaseous or liquid hydrocarbon fuels through methanation or the Fischer-Tropsch process. In both cases the CO_2 is sourced from direct air capture powered by renewables. E-fuels are renewable fuels of non-biological origin (RFNBO).

Hydrogen demand as feedstock (pure hydrogen for the production of ammonia and other industrial applications) appears in "Non-energy uses" in the balances, except for hydrogen demand in steelmaking which appears in industry energy demand. Hydrogen uses mixed with other gases (such as methanol) are not considered. Energy inputs for the production of hydrogen, for both energy and non-energy uses, appear in "Other energy transformation and losses" in the balances.

Hydrogen demand as industrial feedstock is included in total hydrogen demand (section 4.1).

Ammonia demand as an energy fuel is only included in international maritime bunkers grouped together with e-fuels.

Domestic e-fuel production can be both gaseous and liquid fuels; however the international trade of e-fuels is exclusively liquid fuels.

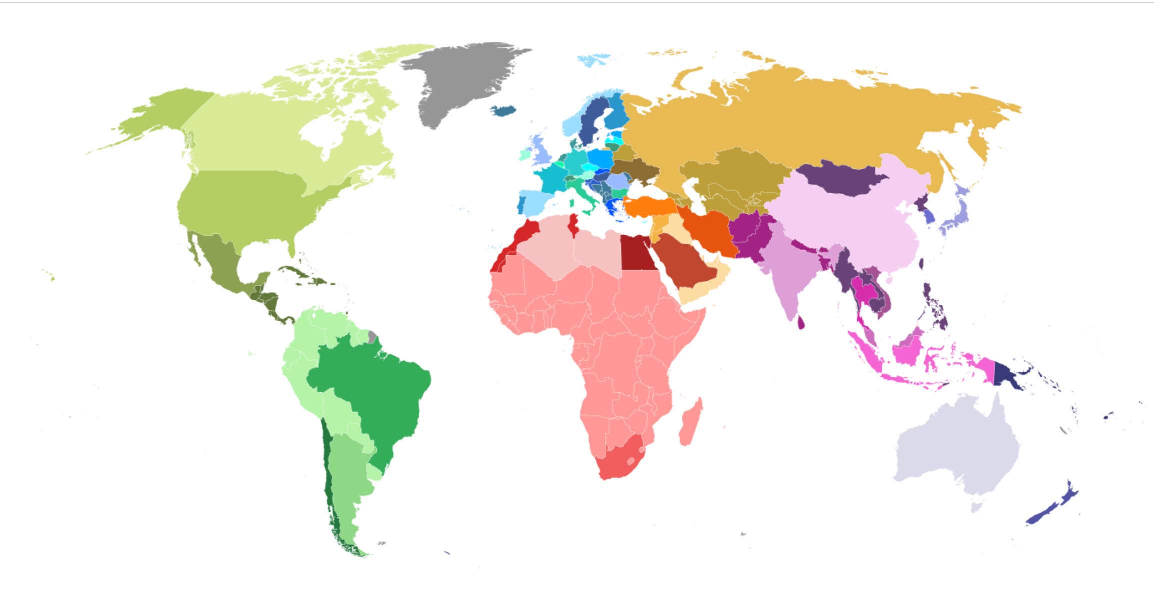
Internationally traded e-fuels can only be produced from renewables ("green hydrogen").

Biomethane is produced from biomass and agricultural wastes, and the inputs of which are accounted for in primary energy as biomass. Biomethane is then mixed together with fossil gas for final users and appears as gas in final energy demand.

Countries and regions

The model decomposes the world energy system into 66 regional entities: 54 individual countries and 12 residual regions see Figure 27:, to which international bunkers (air and maritime) are added.

Figure 27: POLES-JRC model regional detail map (for energy balances)



Source: POLES-JRC model

Table 2: List of 54 individual countries represented in POLES-JRC (for energy balances)

Non-EU individual countries	EU Member States
Argentina	Austria

Australia	Belgium
Brazil	Bulgaria
Canada	Croatia
Chile	Cyprus
China	Czech Republic
Egypt	Denmark
Iceland	Estonia
India	Finland
Indonesia	France
Iran	Germany
Japan	Greece
Malaysia	Hungary
Mexico	Ireland
New Zealand	Italy
Norway	Latvia
Russia	Lithuania
Saudi Arabia	Luxembourg
South Africa	Malta
South Korea	Netherlands
Switzerland	Poland
Thailand	Portugal
Turkey	Romania
Ukraine	Slovak Republic
United Kingdom	Slovenia
United States	Spain
Vietnam	Sweden

Source: POLES-JRC model. Note: Hong-Kong and Macau are included in China.

Table 3: Country mapping for the 12 regions in POLES-JRC (for energy balances)

Rest Central America	Rest Balkans	Rest Sub-Saharan Africa (continued)	Rest South Asia
Bahamas	Albania	Burkina Faso	Afghanistan

Barbados	Bosnia-Herzegovina	Burundi	Bangladesh
Belize	Kosovo	Cameroon	Bhutan
Bermuda	Macedonia	Cape Verde	Maldives
Costa Rica	Moldova	Central African Republic	Nepal
Cuba	Montenegro	Chad	Pakistan
Dominica	Serbia	Comoros	Seychelles
Dominican Republic	Rest of Commonwealth of Independent States	Congo	Sri Lanka
El Salvador	Armenia	Congo DR	Rest South East Asia
Grenada	Azerbaijan	Cote d’Ivoire	Brunei
Guatemala	Belarus	Djibouti	Cambodia
Haiti	Georgia	Equatorial Guinea	Lao PDR
Honduras	Kazakhstan	Eritrea	Mongolia
Jamaica	Kyrgyz Rep.	Ethiopia	Myanmar
Nicaragua	Tajikistan	Gabon	North Korea
NL Antilles and Aruba	Turkmenistan	Gambia	Philippines
Panama	Uzbekistan	Ghana	Singapore
Sao Tome and Principe	Mediterranean Middle East	Guinea	Taiwan
St Lucia	Israel	Guinea-Bissau	Rest Pacific
St Vincent & Grenadines	Jordan	Kenya	Fiji Islands
Trinidad and Tobago	Lebanon	Lesotho	Kiribati
Rest South America	Syria	Liberia	Papua New Guinea
Bolivia	Rest of Persian Gulf	Madagascar	Samoa (Western)
Colombia	Bahrain	Malawi	Solomon Islands
Ecuador	Iraq	Mali	Tonga
Guyana	Kuwait	Mauritania	Vanuatu
Paraguay	Oman	Mauritius	
Peru	Qatar	Mozambique	
Suriname	United Arab Emirates	Namibia	
Uruguay	Yemen	Niger	

Venezuela	**Morocco & Tunisia**	Nigeria
	Morocco	Rwanda
	Tunisia	Senegal
	Algeria & Libya	Sierra Leone
	Algeria	Somalia
	Libya	Sudan
	Rest Sub-Saharan Africa	Swaziland
	Angola	Tanzania
	Benin	Togo
	Botswana	Uganda
		Zambia

Source: POLES-JRC model.

Table 4: POLES-JRC model historical data and projections

Series		Historical data	GECO Projections
Population		(European Commission, 2021; Eurostat., 2023; Lutz et al., 2018)	
GDP, growth		(World Bank, 2023); (IMF, 2023b, 2023c; World Bank, 2023)	(IMF, 2023b, 2023c; OECD, 2021)
Other activity drivers	Value added	World Bank	POLES-JRC model
	Mobility, vehicles, households, tons of steel, …	Sectoral databases	
Energy resources	Oil, gas, coal	BGR, USGS, WEC, Rystad, sectoral information	
	Uranium	NEA	
	Biomass	GLOBIOM-G4M model	
	Hydro	Enerdata	
	Wind, solar	NREL, DLR	
Energy balances	Reserves, production	BP, Enerdata	
	Demand by sector and fuel, transformation (including. power), losses	Enerdata, IEA	
	Power plants	Platts	
Energy prices	International prices, prices to consumer	Enerdata, IEA	POLES-JRC model
GHG emissions	Energy CO_2	Derived from POLES-JRC energy balances	POLES-JRC model
	Other GHG Annex 1 (excl. LULUCF)	UNFCCC	POLES-JRC model, GLOBIOM-G4M model
	Other GHG Non-Annex 1 (excl. LULUCF)	EDGAR	POLES-JRC model, GLOBIOM-G4M model
	LULUCF	(Gidden et al., 2023)	POLES-JRC model, GLOBIOM-G4M model
Air pollutants emissions		GAINS model, EDGAR, IPCC, national sources	GAINS model, national sources
Technology costs		POLES-JRC learning curves based on literature, including but not limited to: EC JRC, WEC, IEA, TECHPOL database	

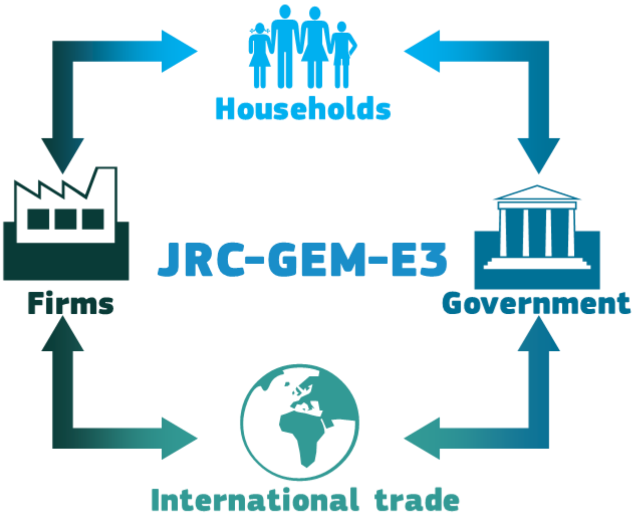
Source: Own elaboration

Annex 2: Description of JRC-GEM-E3

Brief description of main features

The JRC-GEM-E3 model is a global, multi-region, multi-sector, dynamic-recursive computable general equilibrium (CGE) model designed to analyse energy, climate and environmental policies (Capros, et al., 2013) and has been used extensively to analyse EU and global level to inform policy making.[14] The agents in the model are households, firms and governments (Figure 28:). Households that are endowed with production factors and spend their income on consumption and savings. Firms produce goods and services using production factors and intermediate inputs. Different regions in the model are connected by international trade. Governments collect taxes, pay subsidies and undertake government consumption.

Figure 28: Schematic overview of the JRC-GEM-E3 model



Source: Own elaboration

The model version used in GECO 2023 is aggregated into 31 sectors (see **Table 5**), including crude oil, refined oil, gas, coal and electricity generation, with the latter further disaggregated into 8 generation technologies. The generation technologies are modelled using a Leontief production function, while production in other sectors are described by nested constant elasticity of substitution (CES) production functions. We represent 22 regions and the 27 EU member states (see

[14] See also https://ec.europa.eu/jrc/en/gem-e3.

Table 6). Bilateral international trade flows between these regions are modelled following the Armington formulation (Armington, 1969) and linkages between sectors are included based on the GTAP10a power data (Aguiar et al., 2019)

Labour and capital are assumed to be mobile between sectors, but not across regions. Baseline labour supply and unemployment rates are calibrated to the 2021 Ageing Report (European Commission, 2021) for the EU, and to projections by the International Labour Organisation (ILO, 2017) for non-EU regions. The analyses done for this report build on the assumption of flexible wages, abstracting from short-term rigidities. Investments are determined by the rental price of capital and the cost of the investment good. Holding the real interest rate fixed allows for a variation of the balance of payments.

A consumption matrix (Cai & Vandyck, 2020) translates final consumption of production sectors into consumption by purpose. Purchases of durables (vehicles and appliances) are determined by the price of the durable goods and the price of the cost of operation, while purchases linked to the operation of these durables (operation of vehicles and household energy, respectively) are determined by the stock of durables and the cost of operation (Capros, et al., 2013). Household's purchases of the different consumption categories are governed by a Stone-Geary utility function.

Table 5: Sectors in the JRC-GEM-E3 model

Sector name	#	Sector name	#	Sector name	#
Crops	01	Non-metallic Minerals	11	Non-market Services	21
Coal	02	Electric Goods	12	Coal-fired Electricity	22
Crude Oil	03	Transport Equipment	13	Oil-fired Electricity	23
Oil	04	Other Equipment Goods	14	Gas-fired Electricity	24
Gas	05	Consumer Goods Industries	15	Nuclear Electricity	25
Electricity Supply	06	Construction	16	Biomass Electricity	26
Ferrous Metals	07	Transport (Air)	17	Hydro Electricity	27
Non-ferrous Metals	08	Transport (Land)	18	Wind Electricity	28
Chemical Products	09	Transport (Water)	19	Solar Electricity	29
Paper Products	10	Market Services	20	Livestock	30
				Forestry	31

Source: Own elaboration

Regarding GHG emissions, all gases other than CO_2 from land use (and land use change) and forestry are covered in the model. Besides CO_2 emitted from fossil fuel combustion and industrial processes, all non-CO_2 Kyoto GHGs are modelled explicitly in JRC-GEM-E3: methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulphur hexafluoride (SF_6). Abatement of non-CO_2 emissions, industrial process emissions and through CCS is implemented by preserving various bottom up technologies in JRC-GEM-E3 (Weitzel, Saveyn, & Vandyck, 2019).

The reference year is constructed by generating input-output tables based on GTAP's initial base year. Projections for economic activities, energy use and emissions are harmonized with POLES-JRC, so that the economic starting point for the analysis closely resembles that of Reference scenario of the energy model, as described in more detail in the next section. In addition, we also use several inputs from the energy models in the construction of the scenarios (see following section).

Table 6: Regional aggregation of the JRC-GEM-E3 model

Regions in the JRC-GEM-E3 model	Abbreviation
European Union	EU27
United Kingdom	GBR
United States	USA
Japan	JPN
Canada	CAN
Australia	AUS
Russian Federation	RUS
Brazil	BRA
China	CHN
India	IND
South Korea	KOR
Saudi Arabia	SAU
Türkiye	TUR
South Africa	SAF
Mexico	MEX
Argentina	ARG
Indonesia	IDN
EFTA	EFA
Middle East	MEA
Africa	AFR
Other Americas	OAM
Other Asia	OAS
Rest of Eurasia	REA

Source Own elaboration

Reference scenario construction

The macroeconomic balances for a Reference scenario are constructed on the basis of a variety of data sources, in particular achieving an integration of macroeconomic forecasts with energy balances from the POLES-JRC model, see (Rey Los Santos et al., 2018; Wojtowicz et al., 2019). In simple terms, our integration approach uses the Platform to Integrate, Reconcile and Align Model-based Input-output Data (PIRAMID) to construct input-output tables for future years in 5-year-steps, using a balancing procedure that ensures consistency of the various data sources within a National Accounting framework. We extend the procedure, commonly known as RAS procedure, to include data from various sources in a multi-regional context (hence, multi-regional generalised RAS, or MRGRAS) (Temursho et al., 2021).

The main data sources for the version used in GECO 2022 include:

- The input-output tables and the data on bilateral trade flows are derived from the Global Trade Analysis Project (GTAP) 10a power database (Aguiar, Chepeliev, Corong, MacDougall, & Van der Mensbrugghe, 2019). We aggregate the GTAP data to 31 commodities and the regions listed in

Table 6.

- GDP growth rates are assumed to be the same as in the POLES-JRC model. The GDP assumptions are described in Annex 3.
- The International Labour Organisation (ILO) database was used to project population and labour statistics such as labour force, unemployment rate and the share of skilled and unskilled workers. Short term unemployment projections were taken from IMF as the ILO projections do not include the effects of Covid-19, implying the implicit assumption that Covid-19 will not have an effect on long-term unemployment. For the EU27, data from the 2021 Ageing report (European Commission, 2021) was used.
- Energy and emission data using energy balances from POLES-JRC. The alignment with energy balances implies that the emission levels of greenhouse gases (totals and by sector) and the shares of electricity generation technologies are harmonised with the Reference scenario between the POLES-JRC and JRC-GEM-E3 models.

Scenario implementation

In the policy scenarios, we are implementing a constraint on which is achieved by implementing a carbon tax. In harmonizing the emissions between models, carbon prices (e.g. in the 1.5°C Scenario) may differ between regions that would have the same carbon prices in POLES-JRC. In reaction to the emission prices, the model is adjusting endogenously the inputs to the production process, switching between different fuels of varying emission intensity, decreasing the input of energy at the expense of additional capital and labour inputs, reducing the use of emission intensive products and applying end of pipe abatement (CCS and non-CO_2 emissions).

In addition to carbon taxes, decarbonisation options for some sectors are implemented by adjusting model parameters in JRC-GEM-E3 based on changes in POLES-JRC. This “soft-link” can help to better align both models and better capture mitigation responses in complex sectors that are represented in more detail in energy models (Weitzel, et al., 2023). Specifically, information is used to adjusting input shares in production functions of JRC-GEM-E3 via a one-way soft-link (Delzeit, et al., 2020), without feeding information (e.g. on activity levels back to POLES-JRC). In order to not only capture the changes in the energy mix in particular sectors, information on costs are also added. There are three main sectors where we make use of this approach: electricity generation, commercial transport sectors, and household energy use (transport and other use, including heating).

For electricity generation, we replace the JRC-GEM-E3 production function that aggregates electricity from the different generation technologies into a single supply sector through a Leontief function and adjust the share parameters based on electricity generation as projected by POLES-JRC.

In commercial transport sectors (aviation, land transport, water transport), fuel use of different energy carriers is imposed exogenously by collapsing the energy nest of the CES production function into a Leontief aggregation and adjusting the share parameters to reflect changes in the fuel mix and efficiency improvements. We account for a more expensive vehicle fleet by adjusting the non-fuel part of the production function of the transport sectors.

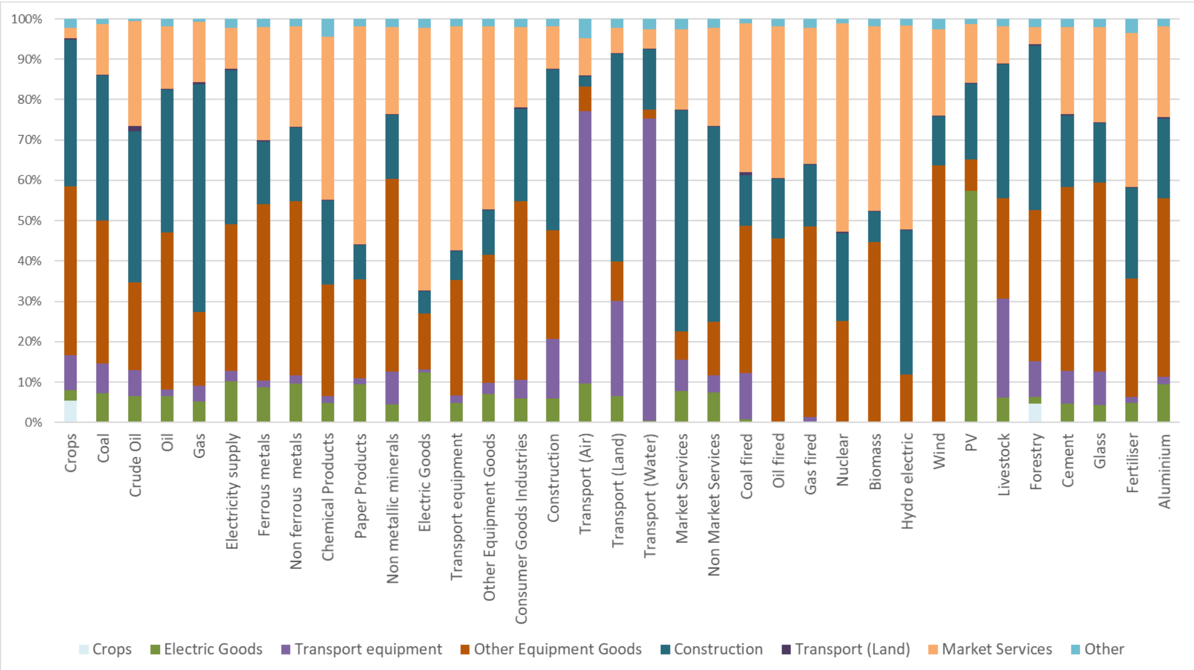
For energy use by private households, a similar approach is used for energy used for private transportation and for other energy use, including heating. For private transportation, the shares of different fuels are adjusted in the consumption matrix based on energy modelling results, reflecting a shift towards cleaner transportation. Any additional cost to change the existing fleet by introducing a higher share of more efficient or electric vehicles is introduced by adjusting the efficiency of consumption of the non-durable vehicles consumption category in the consumption matrix. For household heating and electricity use, the share and the efficiency of fuel use is translated into changes of parameters in the consumption matrix to replicate energy use. Additional costs are modelled as increases in the required (or subsistence) consumption in the Stone Geary consumption function and through an efficiency parameter in the purchase in the “housing” consumption categories, resulting in additional expenditure on the housing consumption category.

Investment Matrix

We use an investment matrix in the JRC-GEM-E3 to represent more accurately the investment flows across sectors, providing an insightful perspective about investment trends both in the Reference and in the scenarios. The sectoral demand of investment in the JRC-GEM-E3 model is determined by changes in the output of this sector and the cost of capital goods over time. On the investment supply, we refer to the sectors that deliver goods and services to build additional capital stock as “delivering sectors”. We use an updated investment matrix for the Computable General Equilibrium (CGE) model JRC-GEM-E3 based on (Norman et al., 2023), which describes the data collection and the steps used to build the investment matrix for the EU countries. In the absence of specific data for the non-EU countries, we assume the EU27 average to link the supply and the demand of investment across sectors. A RAS-balancing procedure brings (aggregate) sectoral investment supply of the investment matrix in line with the investment supply reported in GTAP database.

Previous versions of the JRC-GEM-E3 model used only a single vector of delivering sector regardless of the delivering sector. However, in reality the investment structure differs by investing sector. For example, the solar PV sector requires more electric goods for the formation of capital stock, while the air transport sector demands more on the transport equipment sector as a share of total investment. In the GECO 2023 edition we rely on the updated investment matrix to capture the heterogeneity on the delivery of investments across sectors. Figure 2 shows the shares of delivering sectors contributing to the investment of the JRC-GEM-E3 sectors using the updated investment matrix.

Figure 29: Investment shares by sector in JRC-GEM-E3 based on the investment matrix data



Source: JRC-GEM-E3 based on Norman-López et al. (2023). This includes the rebalancing with GTAP data.

Direct and Indirect jobs

In the JRC-GEM-E3 model, we account for economy-wide job impacts across sectors, including both direct and indirect jobs induced by investment activities. For the reference scenario, we use long term projections for the labour force, unemployment rate, and share of skilled and unskilled workers from the International Labor Organization (ILO) database. In JRC-GEM-E3, we project the number of workers in the energy sectors (including power generation technologies) based on the employment factors (number of direct jobs/energy unit produced) from Pai et al. (2021) and Czako (2020). We multiply the total output of the energy sectors to calculate and project the total number of direct jobs in those sectors..

The indirect jobs are those jobs that are created in the sectors that deliver goods and services for the investment needs of other sectors, also called the 'delivering sectors'. Based on the JRC-GEM-E3 investment matrix, we calculate the investment needs of individual sectors to various delivering sectors, which we convert to the number of jobs using the delivering sector's wages and the sector's overall share of labour value added.

Importantly, in our calculations, we capture only the first round effects of this investment when creating indirect jobs. Purchases of intermediate inputs by the delivering sectors would also create economic activity and require additional workforce to produce, but are not accounted for.

Annex 3: Socio-economic assumptions and fossil fuel prices

The population assumptions follow Europop (European Commission, 2021) for EU and JRC-IIASA projections (Lutz et al., 2018) for the rest of the world.

The GDP projections for the EU are based on the 2022 summer forecast (European Commission, 2022). The GDP projections follow numbers of the 2021 Ageing Report for the EU (European Commission, 2021) for the rest of the world, the sources are IMF World Economic Outlook (IMF, 2023b, 2023c) and the OECD long-tern baseline projections (OECD, 2021). Historical GDP levels are taken from the World Bank (World Bank, 2023).

Table 7: World population and GDP

Time	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Population (billion)	6.1	7.0	7.8	8.5	9.0	9.4	9.7	9.8	9.8	9.7	9.5
GDP (trillion $2015 ppa)	65.2	92.3	120.7	167.1	214.0	264.0	323.0	392.7	471.6	560.2	657.7

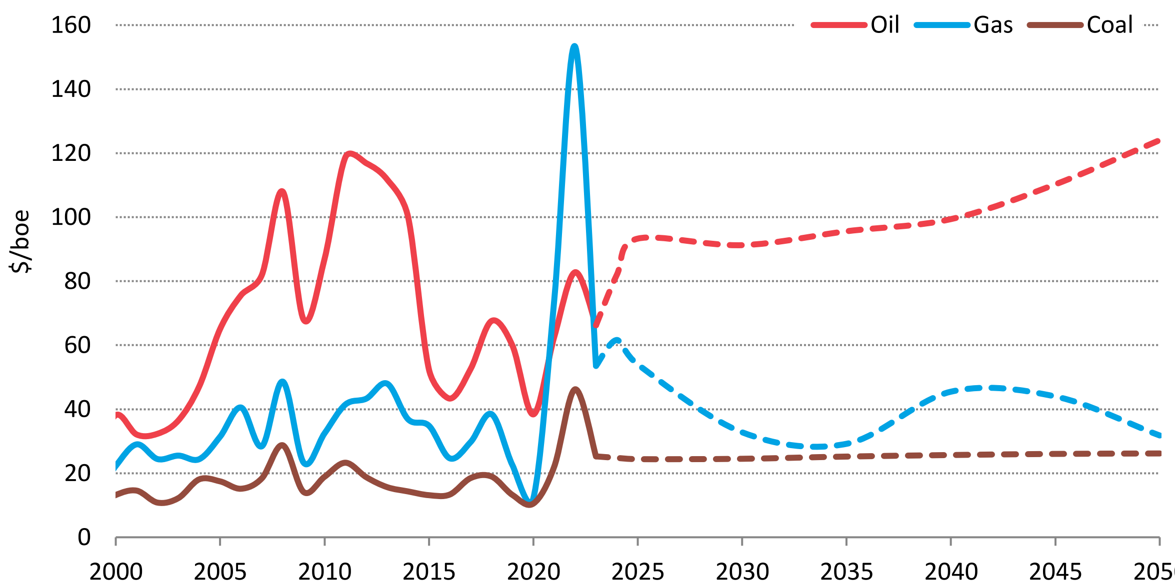
Table 8: GDP assumptions

<table>
<tr><th>Group</th><th>Historical (to 2021)</th><th>2021-2028</th><th>2028-2030</th><th>2031-2050</th><th>2051-2060</th><th>2061-2070</th><th>2071-2100</th></tr>
<tr><td>EU</td><td>WB Apr-2023</td><td colspan="3">Jul-2022 DG ECFIN and 2021 Ageing Report</td><td>intrapolation</td><td colspan="2">GDP/cap as SSP x Europop</td></tr>
<tr><td>Large non-EU</td><td>WB Apr-2023</td><td>IMF Apr/July-2023</td><td>intrapolation</td><td colspan="2">GDP OECD 2021 / Pop IIASA-JRC</td><td colspan="2">GDP/cap as SSP x Pop IIASA-JRC</td></tr>
<tr><td>Rest of World</td><td>WB Apr-2023</td><td>IMF Apr/July-2023</td><td>intrapolation</td><td colspan="4">GDP/cap as SSP x Pop IIASA-JRC</td></tr>
</table>

Source: Own elaboration. Large non-EU: OECD (Australia, Canada, Chile, Iceland, Japan, Republic of Korea, Mexico, New Zealand, Norway, Switzerland, Turkey, United Kingdom, United States); non-OECD (Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia, South Africa).

The international fossil fuel prices in the Reference scenario are shown in Figure 30:.

Figure 30: International fossil fuel prices in the Reference Scenario



Source: POLES-JRC model. Note: Oil prices refer to Brent; gas and coal prices refer to the average imports to the European market.

Annex 4: Policies considered

The scenarios presented in this report build on past work: GECO 2020 (Keramidas et al., 2021a) and GECO 2021 (Keramidas et al., 2021b) The Reference scenario builds from the GECO 2022 (Keramidas et al., 2022) Current Policies scenario.

The Reference scenario considers multiple policies on the energy mix and emissions.

The NDC-LTS scenario includes the policies of the Reference scenario as well as additional policies for 2030 and beyond.

The 1.5°C scenario has the Reference scenario as a starting point; the country-level GHG policies of the NDC-LTS were removed from the 1.5°C scenario, in order to subject all countries to a homogeneous policy driver. This allows to compare country-level pathways that include national policies with the "economically-efficient" pathways of the single carbon price scenario. The 1.5°C scenario subjects all regions and all sectors of the economy to the same carbon price starting from 2024; this price follows a sigmoid curve with an inflection point in 2026.

For land sectors (agriculture and emissions related to land use, land use change and forestry): the carbon price is capped (where necessary) to the maximum carbon price point provided by the soft-linking with a specialized sectoral model.[15]

The following tables summarize all the policies considered to build the emissions pathways in the Reference and NDC-LTS scenarios. We assume that all the major policies are implemented, however some country-related policies may be missing or only partially represented because of several causes:

- They may be announced but not be ratified: e.g. Argentina and South Africa carbon neutrality objectives.
- The policy might lack sufficient information to be represented: e.g. certain mitigation measures in NDCs where emissions without measures are not informed or where the effect is not quantified.
- The POLES-JRC model is not able to take them into account for different reasons: e.g. specific land-related or agriculture-related measures.

For POLES-JRC regions that are country aggregates, the Reference pathway is derived purely from the modelling without additional policies. The NDC-LTS pathway necessitated aggregation work. First, the component countries' NDCs were accounted as volumes of emissions; then, the sum of emissions was converted into a growth (or decrease) target compared to a historical base year (UNFCCC inventories and WRI (World Resources Institute, 2021) were used to translate countries' base years into a single base year); this growth target was used to calibrate POLES-JRC model results for that region.

Table 9: Reference scenario – Energy-related policies

[15] The projections for agriculture and land use metrics in this report were done by soft-linking the specialised model GLOBIOM-G4M (Frank et al., 2021) with the energy system model POLES-JRC.

Region	Sector	Subsector	Target	Base year	Target year	Objective	Source
EU	Transport	New passenger vehicles	Emissions reduction	2021	2025	-15.0%	European Commission, DG Energy
EU	Transport	New passenger vehicles	Emissions reduction	2021	2030	-37.5%	European Commission, DG Energy
EU	Transport	New heavy vehicles	Emissions reduction	2019-2020	2025	-15%	European Commission, DG Energy
EU	Transport	New heavy vehicles	Emissions reduction	2019-2020	2030	-30%	European Commission, DG Energy
EU	Energy	Gross final demand	Share of renewables		2030	45%	European Commission, DG Energy
EU	Energy	Biomethane	Biomethane production (bcm)		2030	35.0	European Commission, DG Energy
EU	Energy	Hydrogen	Hydrogen demand (Mt)		2030	16.2 (not reached)	European Commission, DG Energy
EU	Power	Final energy demand	Final energy (Mtoe)		2030	763.0	European Commission, DG Energy
EU	Power	Power production	Nuclear phase-out for some countries				Countries commitment
EU	Power	Power production	No more construction of nuclear plants				Countries commitment
EU	Power	Power production	Coal phase-out (does not apply to IGCC, CCS)				Countries commitment
EU	Power	Power capacity	Solar (GW)		2030	600.0	European Commission, DG Energy
EU	Transport	Transport demand	Share of renewable fuels		2030	29%	European Commission, DG Energy
EU	Transport	Industry demand	Share of renewable fuels		2030	15%	European Commission, DG Energy
EU	Transport	Buildings demand	Share of renewable fuels		2030	49%	European Commission, DG Energy
United Kingdom	Power	Power production	Coal phase-out (does not apply to IGCC, CCS)				Countries commitment
United Kingdom	Power	Power capacity	Offshore wind (GW)		2030	40.0	The Ten Point Plan for a Green Industrial Revolution
Norway	Transport	New passenger vehicles	Share of BEV Vehicles in sales		2035	100%	National Transport Plan 2022–2033
Switzerland	Power	Power production	Share of renewables (TWh)		2035	11.4	Energy Strategy 2050
Switzerland	Power	Power production	Share of hydro (TWh)		2035	37.4	Energy Strategy 2050
Canada	Power	Power production	Traditional coal-fired plants		2030	30%	Pan-Canadian Framework on Clean Growth and Climate Change (2017)
Canada	Transport	Transport demand	Share of renewable fuels	2012	2030	7%	Canadian Environmental Protection Act (2008)
Canada	Transport	New passenger vehicles	Emissions reduction	2017	2025	-34%	Adapted from Canadian Environmental Protection Act

							(2008)
Canada	Transport	New passenger vehicles	Zero emissions vehicles share		2025	20%	Zero emissions vehicle infrastructure program (2019)
Canada	Transport	New passenger vehicles	Zero emissions vehicles share		2030	60%	Zero emissions vehicle infrastructure program (2019)
Canada	Transport	New passenger vehicles	Zero emissions vehicles share		2035	100%	Zero emissions vehicle infrastructure program (2019)
Mexico	Power	Power production	Share of renewables (including large hydro and nuclear)		2024	35%	Energy Transition Law (2015)
United States	Transport	New passenger vehicles	Emissions reduction	2017	2025	-21.9%	Adapted from EPA GHG standard (2012)
Argentina	Power	Power production	Share of renewables (including large hydro)		2023	18%	RenovAr (2016)
Argentina	Power	Power production	Share of renewables (including large hydro)		2025	20%	RenovAr (2016)
Brazil	Energy	Primary energy demand	Share of renewables (including biofuels)		2031	48%	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power production	Share of renewables (including biofuels)		2031	85%	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Hydro (GW)		2031	107.1	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Small hydro (GW)		2031	10.2	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Nuclear (GW)		2031	4.4	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Biomass (GW)		2031	16.4	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Wind (GW)		2031	30.3	Decenal Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Solar (GW)		2031	10.4	Decenal Energy Expansion Plan (2031)
Brazil	Transport	Transport demand	Share of biodiesel		from 2020	15%	National Biodiesel Programme (2005)
Brazil	Transport	Transport demand	Share of bioethanol		from 2020	27%	Ethanol Blending Mandate (1993)
Chile	Energy	Final energy demand	Energy efficiency	2019	2030	-10%	Ley de Eficiencia Energética (2021)
Chile	Energy	Final energy demand	Energy efficiency	2019	2050	-35%	Ley de Eficiencia Energética (2021)
Chile	Power	Power production	Share of renewables (including large hydro)		2035	60%	Energy Plan 2050 (2016)
Chile	Power	Power production	Share of renewables (including large hydro)		2050	70%	Energy Plan 2050 (2016)
Chile	Power	Power capacity	Coal capacities reduction	2021	2025	-65%	Just Transition Strategy for the Energy Sector (2021)
Chile	Power	Power capacity	Coal phase-out		2040		Just Transition Strategy for the Energy Sector (2021)

Chile	Transport	New passenger vehicles	Electric vehicles share		2040	100%	National Electromobility Strategy (2021)
Australia	Economy	Energy productivity of the economy	Productivity increase	2015	2030	40%	National Energy Productivity Plan 2015-2030 (2015)
Australia	Power	Power production	Share of renewables		2030	50%	States legislation aggregation
Australia	Transport	New passenger vehicles	Electric vehicles share		2030	84%	States legislation aggregation
Japan	Power	Power production	Share of renewables		2030	36-38%	6th Strategic Energy Plan (2021)
Japan	Power	Power production	Share of nuclear		2030	20-22%	6th Strategic Energy Plan (2021)
Japan	Power	Power production	Share of gas		2030	20%	6th Strategic Energy Plan (2021)
Japan	Power	Power production	Share of coal		2030	19%	6th Strategic Energy Plan (2021)
Japan	Transport	Passenger vehicles	Fleet consumption (km/L)	2016	2030	-32.4%	Adapted from fuel economy standards (2019)
Japan	Transport	Heavy vehicles	Fleet consumption (km/L)	2015	2025	-13-14%	Adapted from fuel economy standards (2019)
New Zealand	Power	Power production	Share of renewables		2025	90%	New Zealand Energy Efficiency and Conservation Strategy 2011-2016
New Zealand	Power	Final energy consumption	Share of renewables		2035	50%	Government of New Zealand (2016)
South Korea	Energy	Electricity demand	Reduction vs BAU	BAU	2030	-11.0%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Renewables (TWh)		2030	134.1	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of renewables		2030	21.6%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of renewables		2040	30-35%	Third Energy Master Plan (2019)
South Korea	Power	Power production	Share of LNG		2030	23.3%	Ninth Electricity Plan
South Korea	Power	Power production	Share of coal		2030	25.0%	Ninth Electricity Plan
South Korea	Power	Power production	Share of nuclear		2030	29.9%	Ninth Electricity Plan
South Korea	Power	Power capacity	Renewables (GW)		2030	72.7	10th Basic Energy Plan (2023)
South Korea	Transport	Electric vehicles	Number in cars fleet (Mveh)		2025	1.13	Green New Deal (2020)
South Korea	Transport	Electric vehicles	Number in cars fleet (Mveh)		2030	8.5	3rd Energy Master Plan (2019)
South Korea	Transport	H2 vehicles	Number in cars fleet (Mveh)		2025	0.2	Green New Deal (2020)
South Korea	Transport	H2 vehicles	Number in cars fleet (Mveh)		2030	2.9	3rd Energy Master Plan (2019)
Indonesia	Energy	Primary energy demand	Share of renewables		2025	23%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of renewables		2050	31%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of oil		2025	25%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)

Indonesia	Energy	Primary energy demand	Share of oil		2050	20%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of coal		2025	30%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of coal		2050	25%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of gas		2025	22%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of gas		2050	24%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Power	Power production	Share of low-carbon		2025	23%	National Electricity Plan (2018)
Indonesia	Power	Power capacity	Coal (GW)		2030	54.0	RUPTL 2021-2030
Indonesia	Power	Power capacity	Solar PV (GW)		2030	4.8	RUPTL 2021-2030
Indonesia	Power	Power capacity	Geothermal (GW)		2030	5.7	RUPTL 2021-2030
Indonesia	Power	Power capacity	Hydro (GW)		2030	12.5	RUPTL 2021-2030
Indonesia	Power	Power capacity	CCGT (GW)		2030	18.0	RUPTL 2021-2030
Indonesia	Power	Power capacity	OCGT (GW)		2030	10.0	RUPTL 2021-2030
Indonesia	Transport	Electric vehicles	Number in cars fleet ('000)		2030	2,000	6th ASEAN Energy Outlook - Presidential Regulation 55/2019
China	Energy	Primary energy demand	Share of non-fossil		2025	20%	Energy Development Strategy Action Plan (2014-2020) (2014)
China	Energy	Primary energy demand	Energy intensity reduction	2020	2025	-13.5%	Energy Development Strategy Action Plan (2014-2020) (2014)
China	Power	Final energy demand	Share of electricity		2025	30%	14th Five-Year Plan (2022)
China	Power	Electricity consumption	Share of renewables (including hydro)		2025	33%	14th Five-Year Plan (2022)
China	Power	Electricity consumption	Share of renewables (excluding hydro)		2025	18%	14th Five-Year Plan (2022)
China	Power	Power production	Renewables (TWh)		2025	3,300	14th Five-Year Plan (2022)
China	Power	Power production	Share of non-fossil		2025	39%	14th Five-Year Plan (2022)
China	Power	Power capacity	Nuclear (GW)		2025	70.0	Energy Development Strategy Action Plan (2014-2020) (2014)
China	Transport	New passenger vehicles	Fuel consumption reduction	2020	2025	-20%	Phase V standards (2019)
China	Transport	New passenger vehicles	Share of BEV, PHEV and Fuel Cells Vehicles in sales		2025	25%	New Energy Vehicle development plan (2020)
India	Power	Power capacity	Renewables (GW)		2030	450.0	Optimal mix report (2023)
India	Power	Power capacity	Solar (GW)		2030	300.0	Optimal mix report (2023)
India	Power	Power capacity	Wind (GW)		2030	140.0	Optimal mix report (2023)
India	Power	Power capacity	Coal (GW)		2032	270.0	Optimal mix report

							(2023)
India	Power	Power capacity	Gas (GW)		2032	25.0	Optimal mix report (2023)
India	Power	Power capacity	Nuclear (GW)		2032	20.0	Optimal mix report (2023)
India	Power	Power capacity	Biomass (GW)		2032	16.0	Optimal mix report (2023)
India	Power	Power capacity	Hydro (GW)		2032	68.0	Optimal mix report (2023)
India	Power	Power capacity	Solar (GW)		2032	365.0	Optimal mix report (2023)
India	Power	Power capacity	Wind (GW)		2032	122.0	Optimal mix report (2023)
India	Power	Power capacity	Share of non-fossil		2030	40%	NDC (2016)
Thailand	Energy	Final energy demand	Demand reduction	2018	2036	-6%	Alternative Energy and Power Development Plan (2018)
Thailand	Energy	Final energy demand	Share of renewables		2036	30%	Alternative Energy and Power Development Plan (2018)
Thailand	Energy	Heat generation	Share of renewables		2036	35%	Alternative Energy and Power Development Plan (2018)
Thailand	Power	Power production	Share of renewables (including hydro)		2036	35%	Power Development Plan (2015)
Thailand	Power	Power production	Share of renewables (excluding hydro)		2036	20%	Power Development Plan (2015)
Thailand	Power	Power production	Share of coal		2036	12%	Alternative Energy and Power Development Plan (2018)
Thailand	Power	Power production	Share of gas		2036	53%	Alternative Energy and Power Development Plan (2018)
Thailand	Transport	Transport demand	Share of renewables		2036	35%	Alternative Energy and Power Development Plan (2018)
Malaysia	Power	Power capacity	Share of renewables		2025	20%	National Renewable Energy Policy (2009)
Vietnam	Power	Power production	Share of renewables		2030	15-20%	National Energy Development Strategy (2021)
Vietnam	Power	Power production	Share of renewables		2045	25-30%	National Energy Development Strategy (2021)
Vietnam	Power	Power capacity	Coal (GW)		2030	30.0	Draft Power Development Plan 8 (2023)
Russia	Power	Power production	Share of renewables (including hydro)		2024	20%	Resolution of the Government No. 1-r of 8 January 2009
Russia	Power	Power production	Share of renewables (excluding hydro)		2024	4.5%	Resolution of the Government No. 1-r of 8 January 2009
Russia	Power	Power capacity	Renewables (excluding hydro) (GW)		2025	5.4	Capacity Supply Agreement for Renewable Energy Sources (CSA-RES) 1.0
Russia	Power	Power capacity	Additional solar (GW)	2025	2035	2.2	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)

Russia	Power	Power capacity	Additional wind (GW)	2025	2035	3.0	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)
Russia	Power	Power capacity	Additional small Hydro (GW)	2025	2035	0.17 (not reached)	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)
Ukraine	Power	Power production	Share of renewables (including hydro)		2035	25%	Energy Strategy (2017)
Ukraine	Power	Power production	Share of nuclear		2035	50%	Energy Strategy (2017)
Turkey	Energy	Primary energy demand	Share of renewables		2035	23.7%	National Energy Plan for 2035 (2023)
Turkey	Power	Power capacity	Nuclear (GW)		2024	1.2	Planned capacity
Turkey	Power	Power capacity	Nuclear (GW)		2028	2.8	Planned capacity
Turkey	Power	Power capacity	Solar (GW)		2035	53.0	National Energy Plan for 2035 (2023)
Turkey	Transport	New passenger vehicles	Electric vehicles share		2040	100%	National Energy Plan for 2035 (2023)
Saudi Arabia	Energy	Primary energy demand	Share of renewables		2030	10% (not reached)	Energy markets mechanism (2012)
Saudi Arabia	Energy	Electricity	Electricity intensity reduction	2005	2030	-30%	Vision 2030 (2016)
Saudi Arabia	Energy	Electricity	Energy efficiency increase	2005	2030	30%	National Energy Efficiency program (2013)
Saudi Arabia	Power	Power capacity	Renewables (GW)		2030	58.7	Vision 2030 (2016)
Saudi Arabia	Power	Power capacity	Wind (GW)		2030	16.0	Vision 2030 (2016)
Saudi Arabia	Power	Power capacity	PV (GW)		2030	40.0	Vision 2030 (2016)
Saudi Arabia	Power	Power capacity	CSP (GW)		2030	2.7	Vision 2030 (2016)
Saudi Arabia	Power	Power capacity	Nuclear (GW)		2030	2.8	Vision 2030 (2016)
South Africa	Power	Power capacity	Coal (GW)		2030	33.3	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Gas (GW)		2030	6.3	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Nuclear (GW)		2030	1.8	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Wind (GW)		2030	17.7	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Solar PV (GW)		2030	8.2	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	CSP (GW)		2030	0.6	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Hydro (GW)		2030	4.6	Integrated Resource Plan (2019)
South Africa	Power	Power capacity	Coal remaining (GW)		2030	27.3	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	Power capacity	Coal remaining (GW)		2050	2.8	Integrated Resource Plan (2010, updated 2013)
South Africa	Buildings	Final energy demand	Consumption reduction	2015	2030	-33% (not reached)	Post-2015 National Energy Efficiency Strategy
Maritime	Maritime	Carbon intensity reduction	% reduction of tCO2 per tkm	2000-2010	2025	-30%	IMO (2018)
Maritime	Maritime	Carbon intensity reduction	% reduction of tCO2 per tkm	2000-2010	2030	-40%	IMO (2018)

Table 10: Reference scenario – GHG-related policies

Region	Sector	Gases	Subsector	Target	Base year	Target year	Objective	Source
Europe								
EU	Transport	All GHG	Transport	% reduction in 2050 vs 1990	1990	2050	-60%	European Strategy for low-emission mobility
EU	Transport	CO2	Road transport	% reduction in 2030 vs 2005	2005	2030	-23%	European Commission, DG Energy
EU	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	Fit For 55 (2021)
EU	ETS sectors	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-61%	European Commission, DG Energy
EU	ETS sectors	All GHG	Emissions reduction	% reduction in 2050 vs 2005	2005	2050	-73%	European Commission, DG Energy
EU	ETS sectors 2	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	European Commission, DG Energy
EU	Non-ETS sectors	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-40%	European Commission, DG Energy
EU	Transport	All GHG	GHG intensity reduction	% reduction in 2030 vs 2022	2022	2030	-13%	European Commission, DG Energy
EU	LULUCF	All GHG	LULUCF	Emissions budget (MtCO2eq)		2030	310	European Commission, DG Energy
North America								
Canada	Oil & Gas	CH4	Oil & gas production	% reduction in 2025 vs 2012	2012	2030	-75%	Global Methane Pledge (2021)
United States	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-40%	Rhodium Group (2022)
United States	Power	All GHG	Power production	% reduction in 2030 vs 2005	2005	2030	-70%	Resources For the Future (2022)
United States	Oil & Gas	CH4	Oil & gas production	% reduction in 2025 vs 2012	2012	2025	-45%	Environmental Protection Agency (EPA) (2016)
Central & South America								
Pacific								
Japan	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-26%	NDC (2015)
Japan	All incl LULUCF	F-gases	Emissions reduction	% reduction in 2030 vs 2013 (HFC, PFC, SF6, NF3)	2013	2030	-25.1% (not reached)	NDC (2015)
Asia								
China	Industry	CO2	CO2 emissions per unit of industrial added value	Carbon intensity reduction	2015	2025	-40%	14th Five-Year Plan (2021)
CIS								
Ukraine	Energy	CO2	Fuel use	Carbon intensity reduction	2010	2025	-10%	National Renewable Energy Action Plan 2020 (2014)
Ukraine	Energy	CO2	Fuel use	Carbon intensity reduction	2010	2030	-15%	National Renewable Energy Action Plan 2020 (2014)
Ukraine	Energy	CO2	Fuel use	Carbon intensity reduction	2010	2035	-20%	National Renewable Energy Action Plan 2020 (2014)
Africa								
South Africa	Power	CO2	Power production	Emissions budget (MtCO2eq)		2025	275	Integrated Resource Plan (2019)

Table 11: NDC-LTS scenario – Energy-related policies

Region	Sector	Subsector	Target	Base year	Target year	Objective	Source
Canada	Power	Power production	Share of renewables		2030	80-90%	Sustainable Development Goal 7 (2022)
Brazil	Energy	Primary energy demand	Share of renewables (including large hydro)		2030	45%	NDC (2016)
Brazil	Energy	Primary energy demand	Share of renewables (excluding large hydro)		2030	33%	NDC (2016)
Brazil	Energy	Primary energy demand	Share of biomass		2030	18%	NDC (2016)
Brazil	Power	Power production	Share of renewables (excluding large hydro)		2030	23%	NDC (2016)
Brazil	Transport	Transport demand	Share of biodiesel		2023	15%	Government announcement (2022)
Japan	Power	Power production	Nuclear: no further extensions, no new reactors		2050	0	Third Energy Master Plan (2019)
South Korea	Power	Power production	Nuclear: no further extensions, no new reactors		2050	0	Third Energy Master Plan (2019)
South Korea	Power	Power production	Coal: drastically reduced		2050	0	Third Energy Master Plan (2019)
China	Energy	Primary energy demand	Share of non-fossil		2030	25%	NDC (2021)
China	Power	Power capacity	Wind and solar (TW)		2030	1.2	NDC (2021)
Thailand	Power	Power capacity	Share of renewables		2050	50%	LTS (2021)
Thailand	Transport	Electric vehicles	Share in cars sales		2035	69%	LTS (2021)
Vietnam	Power	Power capacity	Share of renewables		2030	50%	Just Energy Transition Partnership (2022)
Vietnam	Power	Power capacity	No coal new plants after 2030		2030		National Climate Change Strategy (2022)
Vietnam	Power	Power capacity	Reduction of coal fleet after 2035		2035		National Climate Change Strategy (2022)
Russia	Energy	Hydrogen	Hydrogen production for export		2024	0.2	Energy Strategy to 2035 (2020)
Russia	Energy	Hydrogen	Hydrogen production for export		2035	2.0	Energy Strategy to 2035 (2020)
Saudi Arabia	Energy	Hydrogen	Hydrogen production (green and blue)		2030	4	NDC (2021)
Saudi Arabia	Energy	Hydrogen	Hydrogen production (green)		2025	0.237	Neom Helios project
Saudi Arabia	Power	Power production	Share of renewables		2030	50%	NDC (2021)
Turkey	Energy	Primary energy demand	Share of renewables (excluding large hydro)		2030	20%	NDC (2023)
Turkey	Power	Power capacity	Nuclear (GW)		2030	4.8	NDC (2023)
Turkey	Power	Power capacity	Solar (GW)		2030	33.0	NDC (2023)
Turkey	Power	Power capacity	Wind (GW)		2030	18.0	NDC (2023)
Turkey	Power	Power capacity	Hydro (GW)		2030	35.0	NDC (2023)
Turkey	Power	Power capacity	Battery (GW)		2030	2.1	NDC (2023)
Turkey	Power	Power capacity	Electrolysers (GW)		2030	1.9	NDC (2023)
South Africa	Power	Power capacity	Added renewables in 2025 from 2012 (GW)	2012	2025	12	NDC (2016)

South Africa	Transport	Electric vehicles	Number in cars fleet (kveh)	2016	2050	15	NDC (2016)
Aviation	Aviation	Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2030	-40%	ICAO (2019)
Aviation	Aviation	Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2040	-51% (not reached)	ICAO (2019)
Aviation	Aviation	Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2050	-60% (not reached)	ICAO (2019)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2025	2%	IATA (2021)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2030	5.2%	IATA (2021)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2035	17% (not reached)	IATA (2021)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2040	39% (not reached)	IATA (2021)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2045	54% (not reached)	IATA (2021)
Aviation	Aviation	Fuel consumption	Share of biofuels and e-fuels		2050	65% (not reached)	IATA (2021)
Aviation	Aviation	Fleet	Electric and H2 aircrafts market entry		2035		IATA (2021)
Aviation	Aviation	Activity (passenger and freight)	Share of H2 and electric		2050	13%	IATA (2021)
Maritime	Maritime	Carbon intensity reduction	% reduction of tCO2 per tkm	2008	2050	-70%	IMO (2018)

Table 12: NDC-LTS scenario – GHG-related policies

Region	Sector	GHG	Subsector	Target	Base year	Target year	Objective	Source
Europe								
EU	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	LTS (2020)
EU	Transport	All GHG	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-90%	European Green Deal (2019)
United Kingdom	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-68%	NDC (2020)
United Kingdom	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Switzerland	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-50%	NDC (2020)
Switzerland	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Norway	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	NDC (2020)
Norway	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-95%	LTS (2019)
North America								
Canada	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	NDC (2021)
Canada	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions reduction vs BAU	% reduction in 2030 vs BAU		BAU 2030	-36%	NDC (2020)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions peak year	Peak before		2026		NDC (2020)
Mexico	All incl LULUCF excl	All GHG	Emissions intensity per GDP	% reduction in 2030 vs 2013	2013	2030	-40%	NDC (2020)

	absorption							
Mexico	All incl LULUCF excl absorption	All GHG	Emissions reduction	% reduction in 2050 vs 2000	2000	2050	-50%	NDC (2015)
United States	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2025 vs 2005	2005	2025	-28%	NDC (2021)
United States	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-52%	NDC (2021)
United States	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Central & South America								
Argentina	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2007	2007	2030	-19%	NDC (2020)
Argentina	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-2%	NDC (2020)
Argentina	All incl LULUCF	CO2	Net-zero emissions	Emissions 2050	1990	2050	0	NDC (2021)
Brazil	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2025 vs 2005	2005	2025	-37%	NDC (2020)
Brazil	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-50%	NDC (2021)
Brazil	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	Brazilian Administration (2021)
Chile	All excl LULUCF	All GHG	Emissions budget	Emissions budget (MtCO2eq)		2030	95	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions budget	Budget over 2020-2030 (MtCO2eq)	2020	2030	1,100	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2016	2016	2030	-45%	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions peak year	Peak before		2025		NDC (2020)
Chile	All incl LULUCF	All GHG	Black carbon emissions	% reduction in 2030 vs 2016	2016	2030	-25%	NDC (2020)
Chile	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	NDC (2020)
Chile	AFOLU	All GHG	Emissions reduction	% reduction in 2030 vs average 2001-2013	av. 2001-2013	2030	-25%	NDC (2020)
Rest of Central America	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	9%	NDC (2017-2021)
Rest of South America	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	8%	NDC (2017-2021)
Pacific								
Australia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-28%	NDC (2022)
Australia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	1990	2050	0	LTS (2021)
New-Zealand	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-50%	NDC (2021)
New-Zealand	All incl LULUCF	All GHG, exc CH4	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
New-Zealand	All incl LULUCF	CH4	Emissions reduction	% reduction in 2050 vs 2017	2017	2050	-47%	NDC (2021)
Japan	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-46%	NDC (2021)
Japan	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
Japan	Energy	CO2	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-45.2%	NDC (2021)
Japan	Non-energy	CO2	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-14.9%	NDC (2021)
Japan	All incl LULUCF	CH4	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-11%	NDC (2021)
Japan	All incl	N2O	Emissions	% reduction in 2030	2013	2030	-16.8%	NDC (2021)

	LULUCF		reduction	vs 2013				
Japan	All incl LULUCF	F-gases	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-27%	NDC (2021)
South Korea	All incl LULUCF	All GHG exc NF3	Emissions reduction	% reduction in 2030 vs 2018	2018	2030	-40%	NDC (2021)
South Korea	All incl LULUCF	All GHG exc NF3	Net-zero emissions	Emissions 2050		2050	0	LTS (2020)
Indonesia	All incl LULUCF	All GHG	Emissions budget	Emissions budget (MtCO2eq)		2030	1,683	NDC (2021)
Indonesia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU	BAU	2030	-41%	NDC (2021)
Indonesia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060		2060	0	LTS (2021)
Indonesia	Power	All GHG	Emissions peak year	Peak before, with budget (MtCO2eq)		2030	290	Just Energy Transition Partnership (2022)
Rest of Pacific	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	130%	NDC (2020)
Asia								
China	All excl non-CO2 sectors	CO2	Emissions per unit of GDP reduction	% reduction in 2030 vs 2005	2005	2030	-65%	NDC (2020)
China	All excl non-CO2 sectors	CO2	Emissions peak	Peak before		2030		NDC (2020)
China	All incl LULUCF	CO2	Net-zero emissions	Emissions 2060		2060	0	LTS (2021)
India	All incl LULUCF	All GHG	Emissions per unit of GDP reduction	% reduction in 2030 vs 2005	2005	2030	-45%	NDC (2022)
India	All incl LULUCF	All GHG	Carbon neutrality	Emissions 2070		2070	0	NDC (2022)
India	Absorption	All GHG, exc CH4	Emissions budget	Over 2020-2030 (GtCO2eq)	2020	2030	2.5-3	NDC (2016)
Vietnam	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU	BAU	2030	-27%	NDC (2020)
Vietnam	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU		2030	-43.5%	NDC (2022)
Vietnam	All incl LULUCF	All GHG	Emissions peak year	Peak before		2035		National Climate Change Strategy to 2050 (2022)
Vietnam	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050		2050	0	National Climate Change Strategy to 2050 (2022)
Vietnam	Energy	All GHG	Emissions reduction	% reduction in 2030 vs BAU		2030	-24.4%	NDC (2022)
Vietnam	Power	All GHG	Emissions peak year	Peak before, with budget (MtCO2eq)		2030	170	NDC (2022)
Thailand	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU		2030	-20%	NDC (2020)
Thailand	All incl LULUCF	All GHG	Emissions peak year	Peak before, with budget (MtCO2eq)		2030	370	LTS (2021)
Thailand	All incl LULUCF	All GHG	Emissions budget	Emissions budget (MtCO2eq)		2050	200	LTS (2021)
Thailand	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2065		2065	0	LTS (2021)
Malaysia	All incl LULUCF	All GHG	Emissions intensity reduction	% reduction vs GDP	2005	2030	-45%	NDC (2021)
Rest of South Asia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	97%	NDC (2016-2021)
Rest of South-East Asia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-11%	NDC (2015-2021)
CIS								
Russia	All incl	All	Emissions	% reduction in 2030	1990	2030	-30%	NDC (2020)

	LULUCF	GHG	reduction	vs 1990				
Russia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-80%	NDC (2021)
Russia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060		2060	0	NDC (2021)
Ukraine	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-65%	NDC (2021)
Ukraine	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060		2060	0	NDC (2021)
Rest of Central Europe	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	31%	NDC (2016-2021)
Rest of CIS	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	12%	NDC (2016-2021)
Middle East								
Saudi Arabia	All excl LULUCF	All GHG	Emissions reduction	Reduction vs BAU (MtCO2eq)	2019	2030	-278	NDC (2021)
Saudi Arabia	All incl LULUCF	All GHG, exc CH4	Net-zero emissions	Emissions 2060	1990	2060	0	NDC (2021)
Saudi Arabia	All excl LULUCF	CO2	CCS	CO2 captured (MtCO2eq)		2030	44 (not reached)	NDC (2021)
Saudi Arabia	All incl LULUCF	CH4	Emissions reduction	% reduction in 2030 vs 2020	2020	2030	-30%	NDC (2021)
Turkey	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU	BAU	2030	-41%	NDC (2023)
Turkey	All incl LULUCF	All GHG, exc CH4	Net-zero emissions	Emissions 2053	1990	2053	0	NDC (2021)
Egypt	Power	All GHG	Power	Emissions budget (MtCO2eq)		2030	144.8	NDC (2022)
Egypt	Transport	All GHG	Transport	Emissions budget (MtCO2eq)		2030	115.4	NDC (2022)
Egypt	Oil & Gas	All GHG	Oil & Gas	Emissions budget (MtCO2eq)		2030	0.89	NDC (2022)
Mediterranean Middle East	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	0%	NDC (2016-2021)
Rest of Persian Gulf	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	44%	NDC (2015-2021)
Africa								
South Africa	All incl LULUCF	All GHG	Emissions budget	Emissions budget (MtCO2eq)		2030	350	NDC (2021)
South Africa	All incl LULUCF	All GHG (exc. SF6 and NF3)	Net-zero emissions	Emissions 2050		2050	0 (not reached)	NDC (2021)
South Africa	Power	CO2	Net-zero emissions	Emissions 2050		2050	0 (not reached)	NDC (2021)
South Africa	Coal to liquids	CO2	CCS from coal-to-liquid plant	CO2 captured (MtCO2eq)		2030	23 (not reached)	NDC (2021)
Algeria and Libya	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-19%	NDC (2016)
Morocco and Tunisia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-3%	NDC (2021)
Rest of Sub-Saharan Africa	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	4%	NDC (2021)
Bunkers								
Aviation	Aviation	CO2	Emissions reduction	Emissions 2050		2050	0 (not reached)	ICAO (2021)
Maritime	Maritime	All GHG	Emissions reduction	% reduction in 2050 vs 2008	2008	2030	-20%	IMO (2023)
Maritime	Maritime	All GHG	Emissions reduction	% reduction in 2050 vs 2008	2008	2040	-70%	IMO (2023)
Maritime	Maritime	All	Emissions	% reduction in 2050	2008	2050	-100%	IMO (2023)

	GHG	reduction	vs 2008

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