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Global Energy and Climate Outlook 2024

Updating NDCs and closing the ambition gap – indicators for 1.5°C alignment

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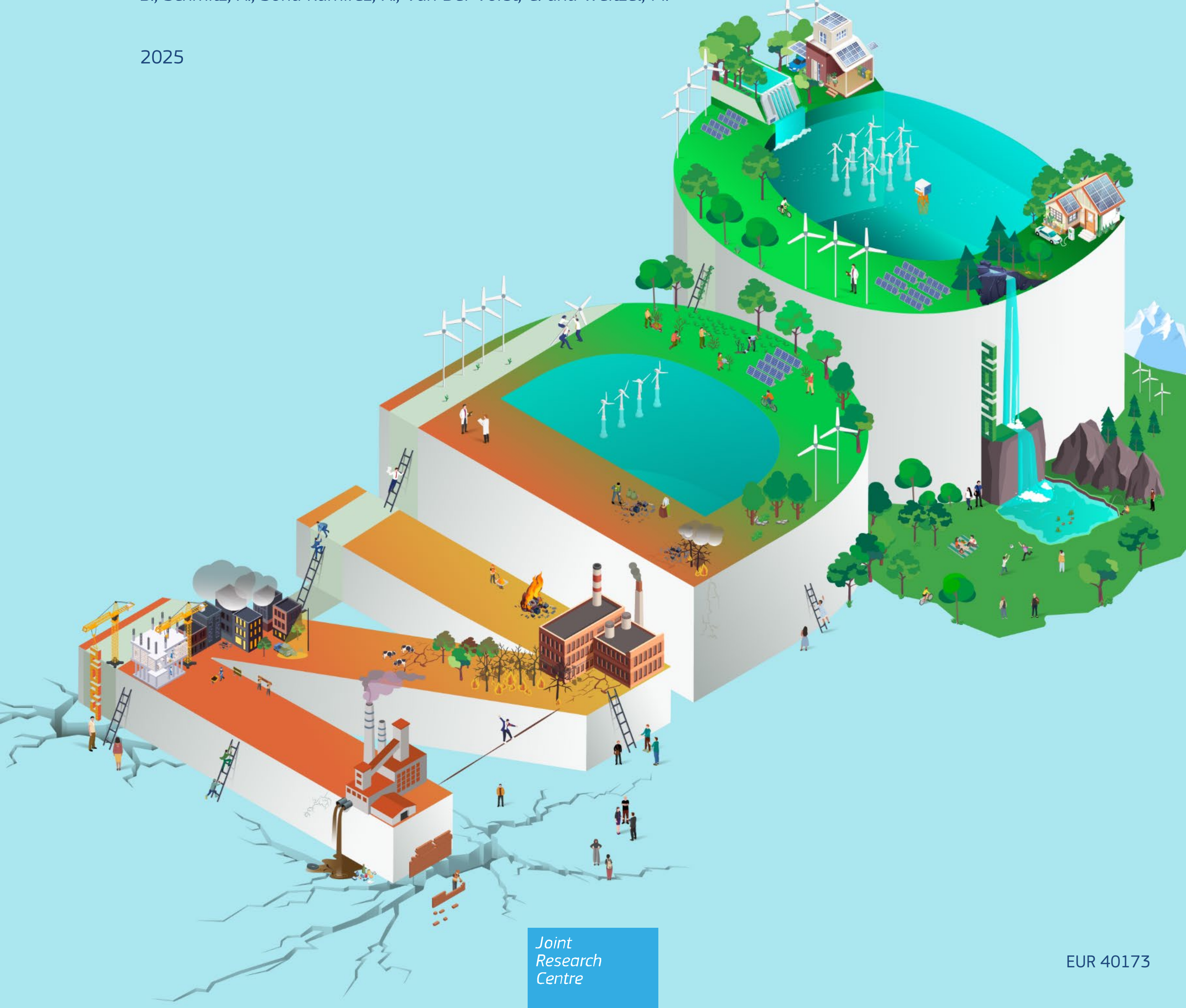

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Contents

Abstract

This edition of the Global Energy and Climate Outlook (GECO 2024), in its 10th year of publication, presents an updated view of the implications of energy and climate policies worldwide, finding that the world is still not on track to achieve its climate targets, as both implementation gaps (between current policies and pledges) and ambition gaps (between current pledges and a 1.5°C trajectory) remain. Whilst emissions peak in the coming years in all scenarios, the world is currently, in the absence of additional action, on track for 2.6°C of warming by the end of the century.

Updated NDCs are due in 2025, to support the UNFCCC NDC update cycle. GECO 2024 presents a set of 1.5°C-aligned indicators, focussing on the year 2035, along four main decarbonisation strategies:

i) producing clean electricity
ii) electrifying end-uses and improving energy efficiency
iii) decarbonisation of hard-to-abate sectors
iv) scaling-up negative emissions.

The current decade is key for keeping the 1.5°C target possible, and aligning NDC targets with a Paris Agreement compatible trajectory represents an indispensable step in this direction. Accelerating the power sector transition towards renewable energy sources is crucial to decarbonise the whole energy sector via simultaneous electrification of end uses. Decarbonising remaining sectors that are more costly to electrify requires ramping up the production of low-carbon fuels such as biomass, hydrogen and e-fuels, alongside deploying more mature technologies such as carbon capture and sequestration. Despite ambitious efforts to mitigate emissions, it is increasingly clear that the world's 1.5°C pathway is likely to result in global temperature overshoot, and therefore negative emissions from both land-use sinks and the energy sector are required to limit the global temperature increase. The indicators presented in GECO 2024's Country Sheets follow these main decarbonisation strategies, with the aim to guide negotiators during the forthcoming NDC update cycle.

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

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Jose Ordonez is main author to Chapter 5 of this report, with contributions from Paul Dowling and Kimon Keramidas.

Rafael Garaffa and Camille van der Vorst are main authors to Chapter 6 of this report, with contributions from Jose Ordonez and Matthias Weitzel.

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Foreword

The release of the 10th edition of the Global Energy and Climate Outlook (GECO) is a good occasion to reflect on the history of the GECO, and its importance for ambitious EU and global climate action.

The 2015 Paris Agreement compels nearly 200 countries to prepare, update and implement ambitious national climate mitigation commitments. This includes the publication and implementation of Nationally Determined Contributions (NDCs), in line with long-term low greenhouse gas emission development strategies (LT-LEDS). NDCs and strategies must be consistent with the Paris Agreement mitigation goal of holding global average temperature increase to well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C. That is how the global community can jointly realise the Paris Agreement's goals and keep our planet liveable.

The first global stocktake agreed at COP28 in Dubai last year provides us with an actionable compass for global, collective action towards the implementation of the Paris Agreement. For the first time, a COP decision singled out the main and indispensable solution to meet the goals of the Paris Agreement, namely, to transition away from fossil fuels. It highlights how to get there through transforming our energy systems, starting in this critical decade by the tripling of renewables and the doubling of energy efficiency.

The GECO and the dedicated team behind it have, for years, facilitated the achievement of ambitious global commitments, such as those taken at COP28. The robust analysis that the GECO provides us with, fosters greater understanding of the global climate ambition and action. One of the GECO's core aims is to support the stocktaking of the aggregate effect of national climate pledges made under the Paris Agreement, the policies that go with them and their implications for global energy markets and climate change.

The first GECO edition already set the direction for the publication series by taking stock of policies in place (at that time, "current pre-2020 pledges and policies") and how this would shape global energy and climate trajectories. Back then, the report found that the world was at risk of a temperature increase of around 4°C by the end of the century. Fast forward to 2021, the GECO addressed in detail the updated NDCs and long-term net-zero pledges put forward by many countries ahead of COP26 in Glasgow.

Following this tradition, the GECO 2024 quantification of 1.5°C-aligned contribution levels for the next round of NDCs will be a crucial asset in international negotiations. The evidence-based significant and immediate global reduction of greenhouse gases that the GECO 2024 demonstrates is needed to keep 1.5°C in reach is a stark reminder of the global, collective action ahead of us in this critical decade.

The GECO reports have been an invaluable reference for the Commission's work, the EU's decision-making and its international climate diplomacy. It is an authoritative, useful, and timely source of information at successive COPs. The detailed analytical assessments, the annual deep dives into the most topical questions for the energy transition along with the estimation of temperature impacts of current policies and climate pledges is shaping reflection and action in international climate negotiations.

GECO scenarios have fed into the world's most important scientific publications on decarbonisation, including the UNEP Emissions Gap reports and IPCC Assessment Reports. Beyond reports and publications, the GECO team have been close and trusted partners for DG Climate Action, regularly providing outputs and analysis, and accompanying DG CLIMA in meetings with counterparts around the world to inform discussions of the latest decarbonisation and mitigation science.

DG Climate Action has been a proud supporter of the GECO publication over the last decade and looks forward to continuing the collaboration for future GECO editions.

Kurt Vandenberghe
Director-General
Directorate-General for Climate Action (DG CLIMA)
European Commission

Executive summary

As parties to the UNFCCC prepare their next round of Nationally Determined Contributions (NDCs) under the Paris Agreement, this edition of the Global Energy and Climate Outlook (GECO) is designed to support these efforts. Offering a benchmark of emissions and energy system pathways aligned with a 1.5°C-compatible trajectory, the report serves as a valuable reference for policymakers and modelling teams. The report offers a global perspective to complement each country's national approach to NDC updates and progress toward the Paris Agreement's most ambitious targets.

Key conclusions

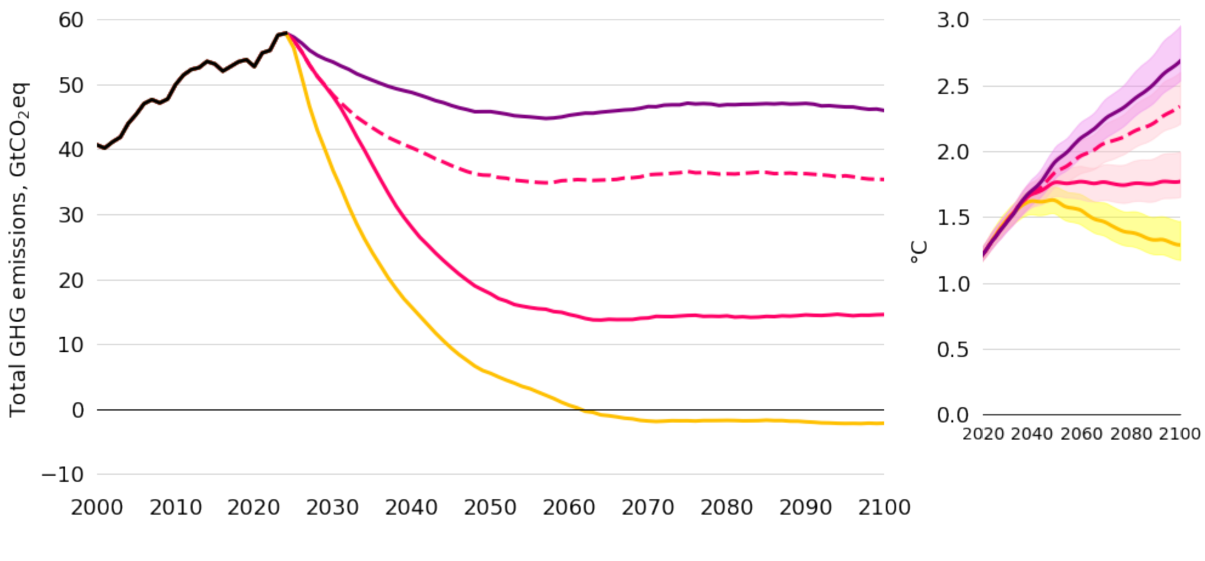
The current decade is crucial for aligning world emissions to a pathway compatible with the 1.5°C temperature change target set out in the Paris Agreement. Current G20 climate policies and pledges fall short of the 1.5°C pathway. The upcoming 2035 NDC updates are critical to keep the 1.5°C target within reach. To meet ambitious decarbonisation goals, GECO 2024 highlights four universal strategies, which together provide a comprehensive roadmap for global decarbonisation: i) producing clean electricity, i) electrifying end-uses and improving energy efficiency, iii) decarbonising hard-to-abate sectors, and iv) scaling-up negative emissions.

Main findings

Limiting global warming to 1.5°C by the end of the century requires an immediate reduction of emissions across all sectors, and milestones in key years guide the way: by 2030, reaching COP28's objectives to triple global renewable energy capacity and double energy efficiency compared to 2022; by 2035, achieving a 56% reduction in emissions from 2022 levels; and by 2050, achieving a 90% reduction from 2022. Substantial progress during this decade is crucial to keep a 1.5°C global warming target within reach**.** Delays in achieving the COP28 global targets, or weaker ambition during the next round of NDCs, pose a risk of an even higher temperature overshoot, increasing climate impacts on natural and human systems and triggering potential irreversible tipping points in the earth's climate system.

The climate ambition of G20 economies still falls short of aligning with the 1.5°C trajectory (*Figure ES1*). Taking stock of existing NDC targets as of June 2024, as well as mid-century Long Term Strategy decarbonisation pledges, large ambition and implementation gaps remain. Projections including currently legislated energy-climate policies point to global emissions peaking within the current decade, which is an important shift in expectations compared to earlier years. Yet, following these legislated energy-climate policies, the world is on a trajectory to reach a 2.6°C increase by the end of the century. Full implementation of existing NDC targets and mid-century decarbonisation pledges lowers this increase to 1.8°C.

Figure ES1. Global emissions and global mean temperature change, by scenario.



Source: POLES-JRC model

Updating 2035 ambition means updating the emission pathway between now and 2035, immediately increasing ambition. The 2035 indicators presented in GECO 2024 could be used by countries as input for the creation of *updated NDC pathways* that would trigger additional mitigation immediately, with higher ambition in 2030 than current 2030 NDCs targets as well.

To close these gaps, GECO 2024 presents 2035 economy-wide emissions levels for selected G20 economies that align with a global 1.5°C pathway, summarised in Table ES1. Achieving these levels requires action along four key global strategies, which are independently and collectively essential for decarbonising the economy. In addition, GECO 2024 establishes global benchmarks for these strategies, providing a useful reference for upcoming NDC updates. Specifically, by 2035:

Strategy 1 – producing clean electricity*: no G20 country has a share of non-fossil electricity generation lower than 50%.*
Strategy 2 – electrifying end-uses and improving energy efficiency*: no G20 country has a share of electricity in total final energy lower than 35%.*
Strategy 3 – decarbonising hard-to-abate sectors*: most G20 countries capture between 5-20% of total industrial emissions with CCS.*
Strategy 4 – scaling-up negative emissions*: stop deforestation and reverse it with afforestation, while ramping up technology-based negative emissions.*

While the four strategies are universally applicable, their relevance in delivering emission reductions is highly context dependent. Countries with a comparably carbon-intensive power sector achieve relatively larger emission reductions from strategy 1. Countries with many electrifiable end-uses or large hard to abate sectors see more reductions from strategy 2 or 3, and countries with large carbon sink potential in the land sector see a large role from strategy 4.

Analysis of the macroeconomic impacts indicates that achieving the Paris Agreement's most ambitious goals incurs only minor global aggregated costs. The 1.5°C scenario shows sustained and substantial growth in global GDP, employment, output, and investment across the projection period. Fossil-fuel sectors shrink, while sectors and value chains of low-carbon technologies expand. Given the comparably small share of fossil-fuel sectors in the overall economy, the global aggregated costs of decarbonising are minor, especially when weighed against the potentially much higher costs of inaction, which include the cost of severe climate impacts and higher adaptation costs.

This report is supplemented with detailed country-level material. The first Annex presents country sheets for selected the G20 economies, presenting economy-wide and sectoral energy and emission trajectories, and the development of key-indicators across the 4 main decarbonisation strategies, as well as employment impacts over time. Additionally, detailed energy and emission balances for all scenarios, as well as the Multi-Regional Input-Output tables of the world economy serving as macro-economic baseline are available for download.

Table ES1. 1.5°C-aligned 2035 emission levels for selected G20 economies.

	1.5°C scenario economy-wide 2035 emission levels	
	2035 emissions in Mt CO_2eq	**Reduction from 2022 in %**
Argentina	221	-51%
Australia	185	-65%
Brazil*	-340	-121%
Canada	194	-72%
China	4834	-66%
EU	1023	-67%
India	2634	-30%
Indonesia	627	-70%
Japan	422	-60%
Mexico	243	-62%
Russia	602	-65%
Saudi Arabia	289	-65%

South Africa	164	-69%
South Korea	175	-73%
Turkey	183	-62%
United Kingdom	121	-71%
United States	1348	-76%

*Source: POLES-JRC model. * The 1.5°C scenario presented in GECO24 represents a global least-cost energy-emissions pathway to reaching the most ambitious goal of the Paris Agreement (see chapter 2). Countries with large and low cost negative emissions potentials, such as LULUCF sinks in Brazil, see emission reduction levels that exceed their domestic emissions levels (see section 5.6).*

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. Previous editions, accompanying energy and emission balances and multi-regional Input-Output tables serving as macro-economic baseline are available at the GECO repository of JRC (GECO, 2023).

Quick guide

After an introduction describing the motivation and scope of this year's GECO, Chapter 2 provides details on the climate policy scenarios. Chapter 3 presents key results for emissions and energy systems on the global level. Chapter 4 explores the role of the global renewables and energy efficiency targets in aligning global decarbonisation efforts to a 1.5°C trajectory and in limiting temperature overshoot. Chapter 5 outlines the four decarbonisation strategies at the global level and quantifies the ambition gaps to be closed in order for the combined NDCs to be 1.5°C-aligned. Chapter 6 examines the impact of decarbonisation on the global economy and on energy-related jobs in the 1.5°C scenario. Finally, Annex 1 presents a series of country sheets for selected G20 countries and regions, comprising of detailed sectoral indicators outlining the transformation of the energy sector in the 1.5°C scenario.

1 Introduction

This edition of the Global Energy and Climate Outlook (*GECO 2024*) comes at an important moment, as the world prepares for the next round of Nationally Determined Contributions (NDCs) updates due in 2025, following the 5-year cycle established by Article 4 of the Paris Agreement. In addition, the Global Stocktake agreed at COP 28 (UNFCCC, 2024a) encourages countries to widen and deepen the details of emissions reduction commitments, to include sectoral targets and other greenhouse gases. This edition of GECO aims to provide a comprehensive global benchmark for these upcoming NDC updates, supporting their alignment with the most ambitious targets of the Paris Agreement. Utilising the modelling toolbox of the global energy model POLES-JRC and the macroeconomic model JRC-GEM-E3, GECO 2024 offers a detailed analysis of a globally cost-efficient 1.5°C pathway, to support countries in aligning their national ambition with a global 1.5°C pathway.

The timeframe to achieve the most ambitious targets of the Paris Agreement is narrowing. Limiting global warming to 1.5°C requires achieving global carbon neutrality by mid-century, a goal to which most major emitters have committed in their long-term decarbonisation pledges. To reach mid-century decarbonisation targets, immediate progress in emission reductions is necessary, with the aim of more than halving (-56%) global emissions by 2035 compared to 2022 levels. This has concrete implications for emission levels across all countries and all emitting sectors by 2035. The coming decade, and the updated NDC targets that will define this decade's emissions pathway, are critical for limiting temperature overshoot and minimising climate damages.

Achieving carbon neutrality in line with the Paris Agreement's most ambitious goals requires all major emitters to undertake rapid and substantial decarbonisation efforts. Given the very narrow window available to achieve a 1.5°C global temperature stabilisation, high ambition levels across all G20 countries are essential as the group is responsible for approximately 80% of global emissions. Ambitious 2035 NDC updates are required by all major emitters to set the world on a 1.5°C-aligned pathway.

Updating 2035 ambition means updating the emission pathway between now and 2035, immediately increasing ambition. The 2035 indicators presented in GECO 2024 can be considered as main elements for the creation of *updated NDC pathways* that would trigger additional mitigation immediately, with higher ambition in 2030 than current 2030 NDCs targets as well.

GECO 2024 provides a detailed analysis of the strategies required to align the 2035 NDC updates with the 1.5°C global temperature stabilisation goal. It presents 1.5°C-aligned economy-wide emission levels for selected G20 emitters as benchmarks for 2035 NDC targets. It also presents a set of 1.5°C-aligned indicators for the NDC update target year 2035 alongside the 4 main global strategies to transition to a low-emissions economy:

i) Producing clean electricity
ii) Electrify end-uses and improve energy efficiency
iii) Decarbonising hard-to abate sectors
iv) Scaling-up negative emissions.

The four strategies are needed in all major emitters to reach their economy-wide targets in a cost-efficient manner. The importance in each country of these strategies is highly dependent on the heterogeneity of energy mixes and decarbonisation options across countries.

GECO 2024 is structured as follows:

- Chapter 2 introduces the three main scenarios considered in this report: a Reference scenario which considers existing policies; an NDC-LTS scenario, reaching announced targets; and a globally cost-efficient 1.5°C scenario.
- Chapter 3 explores global emissions trajectories and temperatures, followed by the global energy system transformation in a 1.5°C world, detailing the evolution of energy demand and supply towards mid-century.
- Chapter 4 examines the role of the global renewables and energy efficiency targets announced at COP28, and the effort required to limit global temperature overshoot.
- Chapter 5 presents set of 1.5°C-aligned indicators for 2035 and 2050 as benchmark for NDC-updates, alongside the main strategies to decarbonise the global economy in line with a 1.5°C pathway.

- Chapter 6 examines the impact of decarbonisation on the global economy and on energy-related jobs in the 1.5°C scenario.
- In addition, Annex 1 presents country-specific fact sheets for major economies, offering a detailed roadmap for policymakers to align emission reduction ambitions during the forthcoming update of NDCs.

2 Scenarios and definitions

This chapter provides a detailed description of the scenarios and assumptions made for the projections presented in this report.

GECO 2024 presents three main scenarios, a reference, an NDC-LTS, and a 1.5°C scenario (Table 1). These scenarios are produced based on results from the partial equilibrium global energy model POLES-JRC and the general equilibrium model JRC-GEM-E3, covering the interactions between the global economy, the energy system and the environment[1].

Table 1. GECO 2024 scenario overview

Scenarios	Rationale, main goals and policy drivers
Reference	Represents the energy-emissions trajectory under policies legislated as of June 2024.
NDC-LTS	Portrays energy-emissions pathways fully achieving existing NDCs, with the NDC-LTS scenario adding long-term carbon neutrality pledges. This scenario employs country-specific carbon values to achieve economy-wide emission targets.
1.5°C scenario	Portrays a cost-effective global energy-emissions trajectory to limit warming to 1.5°C by 2100. Mitigation efforts across countries and the sectoral breakdown of emission reduction follows a global least-cost rationale based on a globally uniform carbon value. This scenario serves as a benchmark to evaluate ambition gap (between existing targets and a 1.5°C pathway) and implementation gap (between legislated policies and a 1.5°C pathway), as well as 1.5°C-aligned 2035 NDC levels.

Source: JRC.

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 backed by concrete supporting energy-sector policies, are enacted. Only policies that have been legislated up until June 2024 are considered. This scenario does not aim to reach stated policies or targets, whether legislated or not, that have not been accompanied by concrete action plans.

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 5 for the list of policies considered in the Reference scenario.

NDC-LTS scenario: considers the targets of NDCs in the medium term and the LTSs (long-term strategies) 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' LTSs, 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 prices, if they exist, are kept constant at their 2030 level. This scenario includes the net-zero emissions targets announced by many countries. The NDC-LTS scenario also considers decarbonisation proposals related to international aviation and maritime transportation sectors. See Annex 5 for a list of NDC and LTS objectives included in this scenario.

This report's projections differ from national modelling exercises in the NDC documents. This can be due to different key macroeconomic assumptions and consequently energy demand growth, to operating patterns of the power sector or to other assumptions or modelling representations. This can lead to certain sectoral targets

[1] A detailed description of the POLES-JRC and JRC-GEM-E3 models can be found in Annex 2 and Annex 3. In addition, details on socio-economic assumptions and internationally traded fossil fuel prices can be found in Annex 4.

in an NDC document not being reached in our 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 and only NDC targets were kept, 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. It results in an approximately 75% probability of not exceeding the 1.5°C temperature limit in 2100[2]. A single global carbon price for all regions is used in this scenario, starting immediately (2025) and strongly increasing over time. Bottom-up policy drivers (such as renewables targets) from the NDC-LTS scenario are not included 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 representation of an economically-efficient pathway to the temperature target, 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 land use sinks, is considerable (22 $GtCO_2$/year in 2100, including CO_2 captured for the production of synthetic fuels). CO_2 capture from combustion, industrial processes and CO_2 direct air capture technologies are made available progressively beyond 2030 (about 10 $GtCO_2$/year in 2050). The mobilisation of biomass as an energy resource is relatively limited (remaining below 180 EJ/year for all years), in order to reflect the use of only sustainably-grown biomass[3]. Within the above economic and technological constraints, the overshoot of the temperature target is kept low (with a peak temperature at 1.6°C around mid-century, at median probability).

Box 1. Differences with GECO 2023

Several upgrades of the POLES-JRC model were conducted, both for input data and for modelling code. The model has been updated with the latest historical data for recent years. Supply-side and demand-side technology costs as well as learning rates were further updated with recent literature (notably for direct air capture of CO_2, biofuels production and heat pumps) (CETO B2, 2024). Fuel/technology preference parameters were revised in the model to reflect recent investment patterns in the updated historical statistics. The regional gas markets price formation equation was revised. A long-term electricity storage technology was added to the power sector. The economics of hydrogen production with grid-based electrolysis were revised to reflect the use of power oversupply. The techno-economic parameters of direct air capture of CO_2 were revised with the specification of dedicated renewables capacities and battery capacities. Historical industrial energy consuming stock turnover was revised. Road vehicles stock turnover mechanism and annual sales calculation were revised; road transport vehicles efficiencies were revised. Historical international maritime energy consumption was re-estimated for the entire historical period and revised downwards, to better reflect statistics. More information about the sources and the input data used in POLES-JRC can be found in Annex 2.

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.

As in GECO 2023, 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 (Frank et al., 2021). For the reporting at the global level, CO2 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.

The JRC-GEM-E3 model has been updated to the latest GTAP 11 database (Aguiar et al., 2023), which includes up-to-date Input-Output tables for key economies (e.g., Australia, Brazil, Canada, China, India, Russia, United Kingdom, USA). Employment factors were also updated with recent literature.

[2] Global mean surface temperatures obtained with the online tool liveMAGICC, based on GHG and air pollutant emissions projections from POLES-JRC: http://live.magicc.org/. 75% probability derived as a linear interpolation between the provided probabilities of 67% and 83%.

[3] 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).

The investment matrix in JRC-GEM-E3, which links investing sectors and sectors supplying the purchased investment goods (Norman et al., 2023), was updated to include OECD data for non-EU27 countries (Alsamawi et al., 2020).

Unless noted otherwise, monetary values ($) are constant US dollars of 2022.

3 Global energy and emissions projections: current ambition is not enough

This chapter presents global GHG emissions and temperature trajectories in GECO's main scenarios, highlighting the prevailing ambition and implementation gaps in alignment with a 1.5°C target. In the 10th year of publication of this report, the chapter then provides a retrospective on end-of-century temperature projections across past editions, illustrating progress toward decarbonisation. The chapter provides an overview of the energy system transformation in the 1.5°C scenario, detailing the development of sectoral emissions, primary and final energy by sectors, and the power sector, between 2000 and 2050.

3.1 Global emission and temperature trajectories

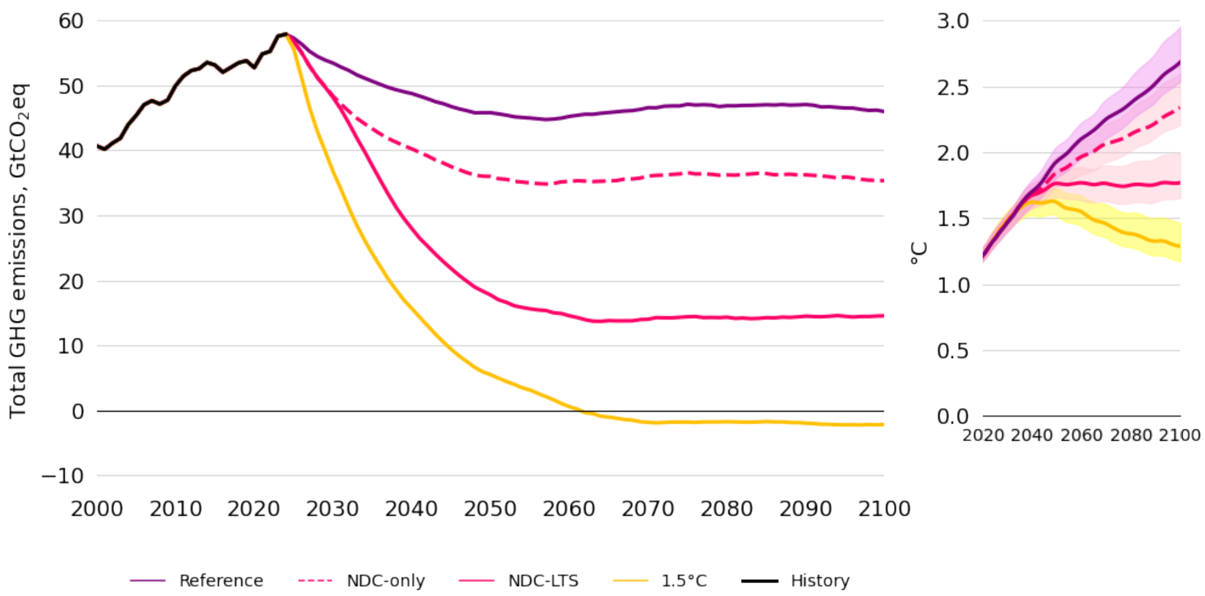
GECO 2024 analyses global emissions trajectories, and the gaps between what is required, what has been pledged, and what is actually happening. The global emissions trajectory of the Reference scenario sees an imminent peak in global emissions in the coming years, after which, based on current policies in place, global emissions are projected to decrease through to 2050, before broadly stabilising at a level equivalent to global emissions in the 2000s.

The NDC-only case shows the effect of the world's Nationally Determined Contributions, where global emission reductions between today and 2050 are steeper, before again stabilising around mid-century at levels similar to those seen in the 1980s.

The NDC-LTS scenario, which includes both 2030 NDC proposals and long-term decarbonisation pledges, sees continued decarbonisation, before stabilising around 15MtCO_2eq through the second half of the century. This represents a significant *implementation gap,* beginning this decade, between what's been pledged and the policies that have been enacted to realise these pledges.

The 1.5°C scenario sees very rapid emissions reductions, starting immediately and continuing through the next 3 decades, at average rates of global emissions reduction between 8-10% per annum. The 1.5°C scenario reaches net zero around 2060, after which negative emissions are required to stabilise and reduce global temperatures to remain at the 1.5°C temperature threshold. Likewise, there is a large *ambition gap* remaining between the pledged emission reductions and those required to align to world to a 1.5°C trajectory.

Figure 1. Global GHG emissions and global mean temperate change, by scenario



Source: POLES-JRC model, liveMAGICC (probabilistic setting).

The persistent high annual global emissions over the century in the Reference scenario result in a global surface temperature of 2.6°C of warming by the end of the century. Accounting for all current NDC pledges in the NDC-only case sees temperatures reach 2.3°C, and the addition of the long term net zero goals leads to a stabilisation of global temperatures through the second half of the century at around 1.8°C, representing a decrease of

0.8°C compared to the Reference scenario. The 1.5°C scenario results in a peak temperature of 1.6°C around mid-century, and then a steady decrease to reach 1.3°C of warming by end of the century.

3.1.1 Ten years of GECOs highlights climate policy progress

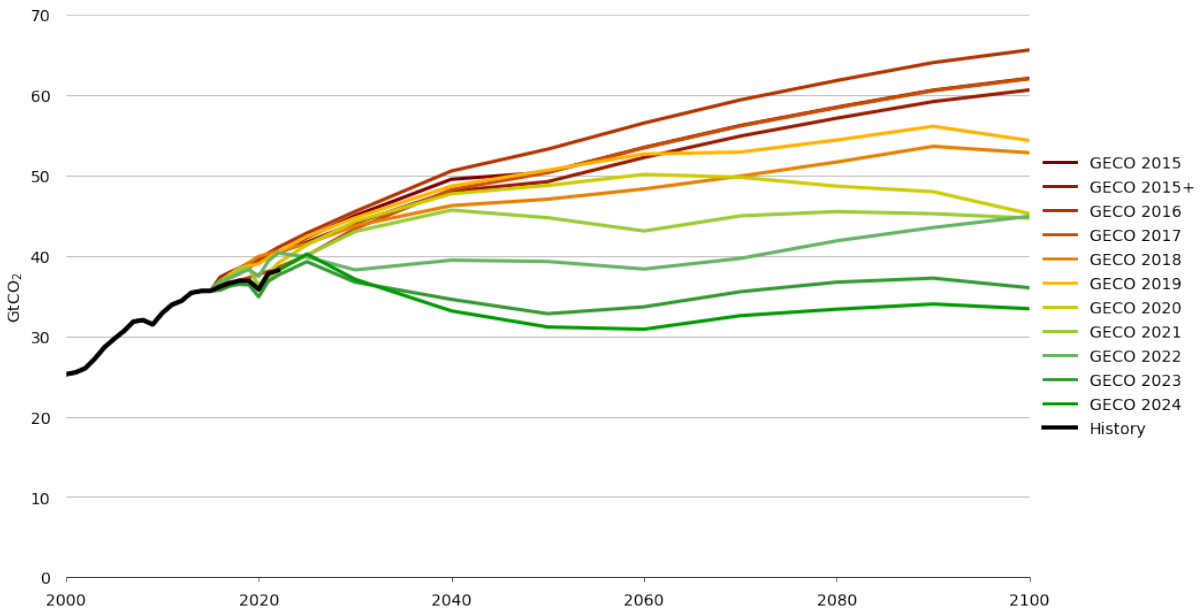
GECO 2024 marks the 10th anniversary of the GECO publication series. This is an opportune moment to explore how GECO projections have evolved over the past decade, and what the implications are for our expectations of global warming over the 21st century.

The first GECO report published in 2015 projected a steady emissions growth over the coming decades. As the years went by, two main drivers combined to change these projections: more emissions reduction policies were adopted globally; and cost reductions in low-emission technologies were achieved;. When these updates were included in the "baseline" scenario of each GECO's global energy and emissions modelling, we saw lower emissions in our projections.

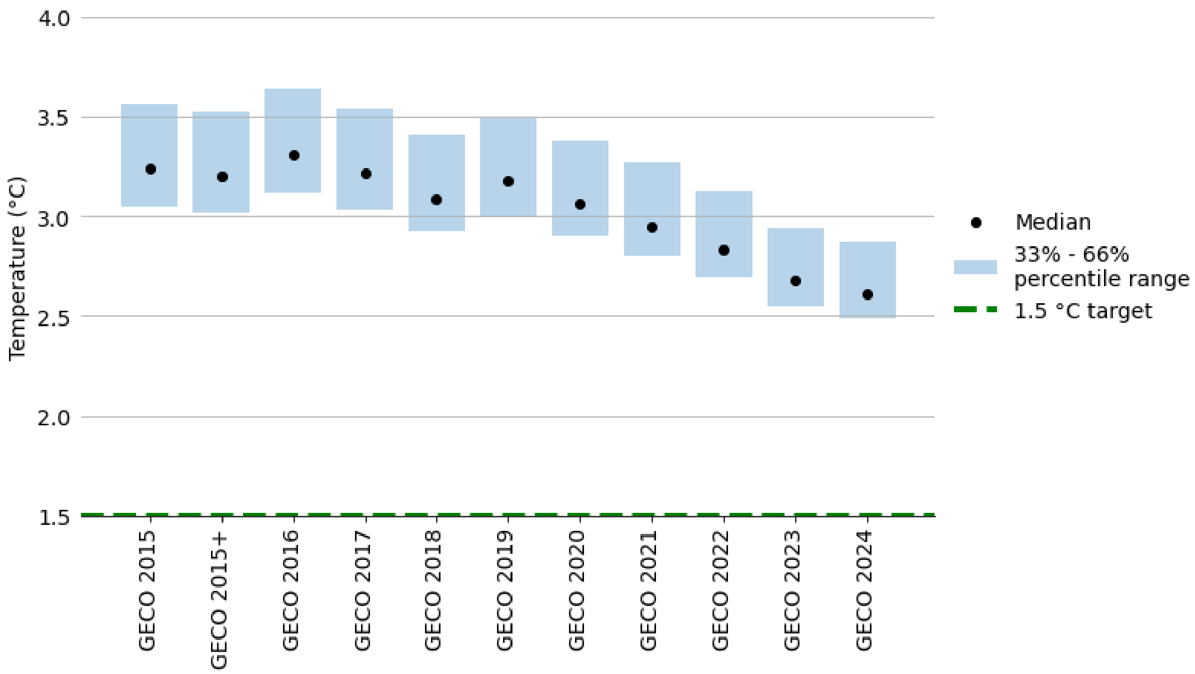
Over a decade of projections, there is a remarkable decrease in global emissions. Figure 2 (top) shows a comparison of global CO_2 emissions from 11 GECO baselines, starting with GECO 2015 all the way to this year's GECO 2024[4]. As explained in Box 2, we compare CO_2 emissions from energy (fossil) and industry, which capture the large majority of GHG emissions (69% as of 2022), and also where the bulk of global decarbonisation efforts have been focussed over the past decade.)

GECO 2015 saw steadily increasing energy and industry CO_2 emissions over the century, reaching an increase of around +88% by 2100 compared to 2010. By contrast, GECO 2024 sees energy and industry CO_2 emissions peak in the coming years, before stabilising at a level below today's emissions (-10% in 2100 vs 2010). The difference between these two scenarios, in end of century emissions, is 32 $GtCO_2$, indicating that the past 10 years of progress reduces annual global emissions equivalent to today's level, i.e. the world has gone from a doubling of emissions to a stabilisation.

Figure 2. Global energy and industry CO_2 emissions of previous GECOs (top) and global end-of-century temperature of previous GECOs (bottom), baseline scenarios



[4] GECO 2015+ refers to an updated scenario for an analysis that was conducted before the Paris COP21 (Kitous & Keramidas, 2015).



Source: POLES-JRC model, liveMAGICC (probabilistic setting).

As global energy and industry CO_2 emissions reduced over the years, so too the projected end-of-century global temperature increase has reduced. In Figure 2 (bottom), temperature change in 2100 is plotted over the successive projections. GECO 2015 sees the end-of-century temperature reaching 3.2°C, while GECO 2024 sees the end-of-century temperature increase reach 2.6°C (median probability).

The past 10 years have witnessed a virtuous cycle of increasing decarbonisation policy ambition, creating more favourable market conditions. This has led to deployments of low-emission technologies, which have resulted in cost reductions of these technologies, and which in turn have lowered the costs of each subsequent climate policy intervention. A decade of GECO global projections portrays a shift from a pathway towards 3.2°C of warming by the end of the century to one of 2.6°C in this year's GECO. This represents a reduction of 0.6°C in 10 years, bringing the world significantly closer to the Paris Agreement climate target of limiting warming to 1.5°C.

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However, it is important to note that, while the emissions and temperature reductions indicate, actually reaching the 1.5°C target requires significant additional emission reduction effort. Lower emissions trajectories and lower temperatures do not happen automatically with the passage of time, as if there were a sort of natural momentum whereby an extrapolation of this progress would deliver the global climate targets. Without ambitious new policy, investments and technological progress, emissions reductions would broadly stagnate, and future projections would see emissions and temperatures largely unchanged.

Box 2. Methodology for historical GECO comparisons

Over the years, each new GECO has benefitted from continuous model development and updates to the POLES-JRC model, and changes to key external inputs, as well as updates to the tools used to calculate global temperature change (MAGICC input parametrisation and model). As a result, a robust comparison of emissions and temperature projections across GECO editions is difficult. As such, the following steps were taken to ensure maximum comparability.

The online MAGICC tool (https://live.magicc.org/) has been used in previous GECOs to project the global temperature change (systematically since 2017). It has been progressively updated over the years and this analysis uses the latest MAGICC7 online tool to calculate the temperature change of all historical GECO baselines. MAGICC uses emissions time series from POLES-JRC and the following inputs were used in this analysis.

For each historical "baseline" projection, we extracted the series for global energy and industrial CO_2 emissions, including international bunkers and industrial process emissions, which is the major driver of emissions and temperature change.

Some of the original scenarios only contained projected values until 2050. To create a time series to 2100 the missing years have been projected based on the trend from the most similar GECO scenarios for which we had available data until the end of the century.

The remaining components of emissions and temperature change (i.e. LULUCF emissions, non-CO_2 GHG emissions, emissions of other forcing species such as air pollutants) were set to their most recent update, i.e. the values in the GECO 2024 Reference scenario. This is done to isolate the effect of the actual changes in the energy system fundamentals from the effect ('noise') of the changes introduced by the progressive updating and modification of our modelling tools and assumptions over the years.

While the names of the scenarios have changed over the years (e.g., from *Current Policies* to *Reference*), the scenarios used in this analysis are based on the policies enacted at the time of modelling.

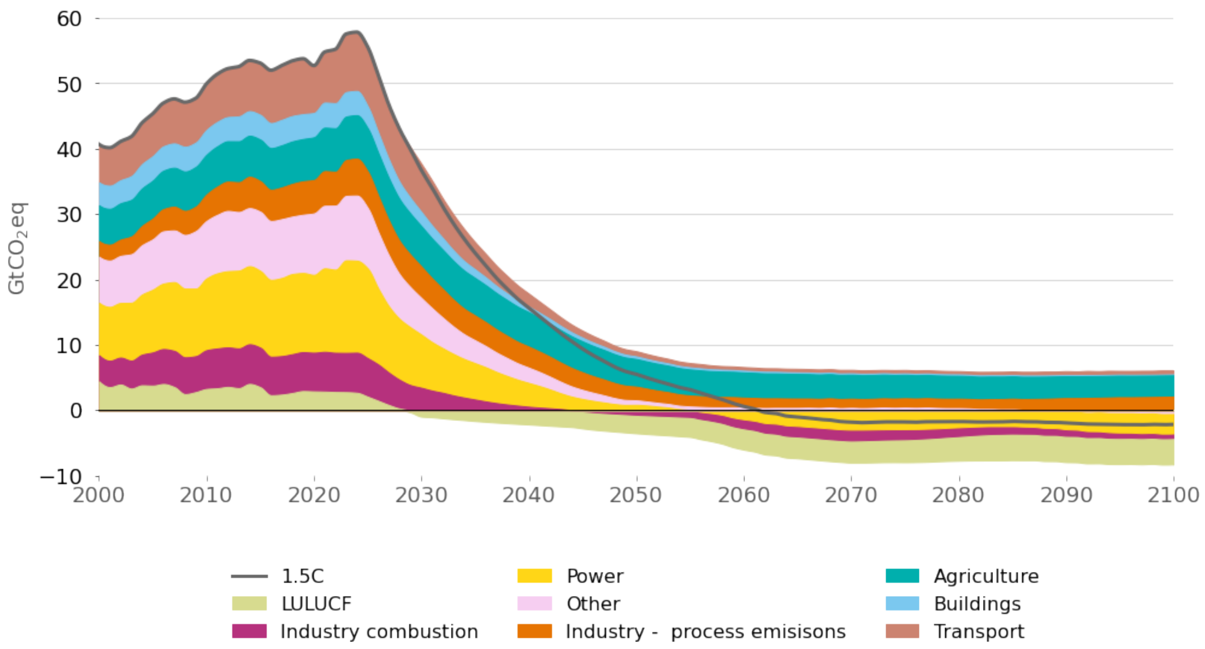
Some caveats remain: the results for both emissions and temperatures in this analysis are not directly comparable to those presented in the original GECO reports. There have been certain definition changes and policy and technological developments in non-CO_2 emissions reductions over the years which are excluded from this analysis; whilst they are small, the analysis likely underestimates the reductions over time of total global emission projections.

Changes in the modelling code (methodological enhancements, increase of detail of sectoral or technological representation) were a prerequisite towards capturing the evolving future characteristics of the energy system. Modelling enhancements over the years have been introduced across all sectors and technologies, some changes have led to lower emissions, some changes to higher emissions, there is likely significant offsetting and netting out of these modelling impacts. Other important drivers of emissions are GDP and population projections, these too are likely to have played a minor role given the range of GDP in 2050 across the 10 years of GECO is 21% and of population is 3%.

3.2 Energy supply and demand in a 1.5°C trajectory

In the 1.5°C scenario, which models an immediate reduction in emissions in order to limit end-of-century temperature rise to 1.5°C, total global emissions reduce by 5.0% per annum between 2022 and 2030, and by 8.2% per annum from 2030 to 2040. The rapid decarbonisation seen in the 1.5°C scenario results in extremely steep emissions reductions across most sectors in the next two decades. Agriculture and industrial processes see more modest emissions reductions. Emissions in the land sector turn negative before 2030, reinforcing the urgency of the COP26 pledge to end and reverse deforestation by 2030. Emissions in the buildings and transport sectors are greatly reduced by 2040 via electrification, and biomass use coupled with CCS in industry and in power generation generate negative emissions from 2050 onwards.

Figure 3. Global emissions, by sector, 1.5°C scenario

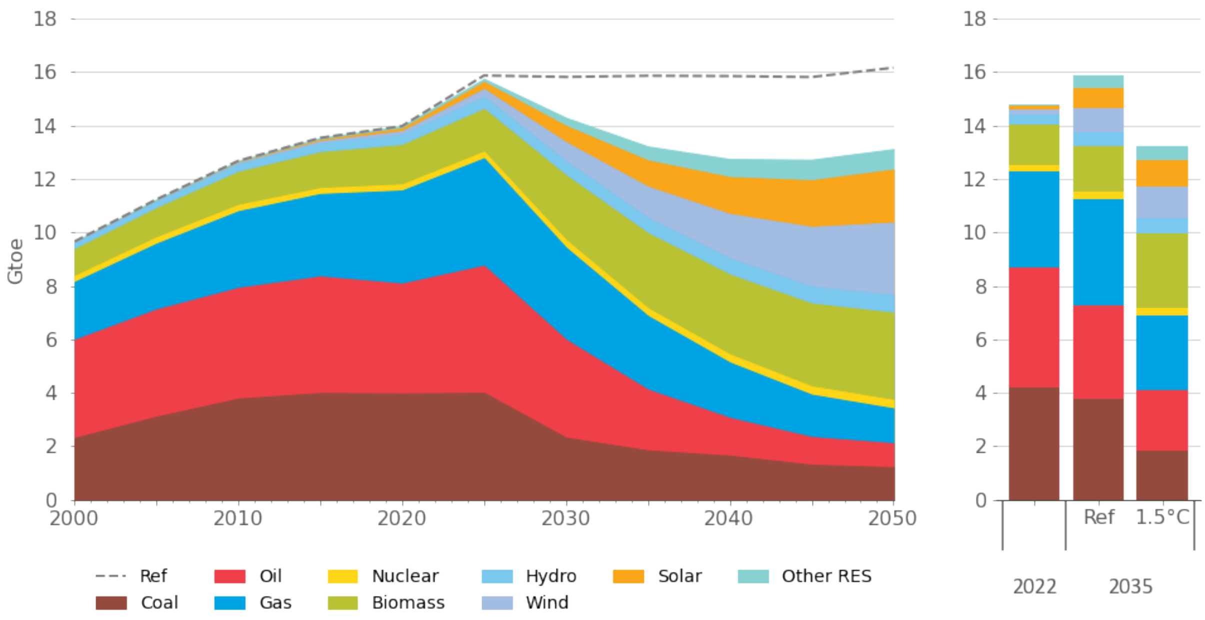


Source: POLES-JRC model. Other includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production) as well as the sink from the direct air capture of CO_2.

The share of fossil fuels in global primary energy supply decreases from 83% in 2022, to 52% in 2035 and 26% in 2050 in the 1.5°C scenario. Coal demand, which remains largely unchanged through the projection period in the Reference scenario, sees the largest decrease in the 1.5°C scenario, suppling only 9% of total demand by 2050. Oil demand sees a similar contraction, led by a decrease in transport. Biomass demand more than doubles by 2050, as its use increases in power generation, industry and transport.

Total global primary energy supply remains broadly flat in the Reference scenario, indicating that the world is close to 'peak' energy consumption, in spite of growing population and economic output, as the superior energy efficiency of increasingly electrified end–uses partially accounts for much of the decline.

Figure 4. Global primary energy supply, by fuel, 1.5°C scenario



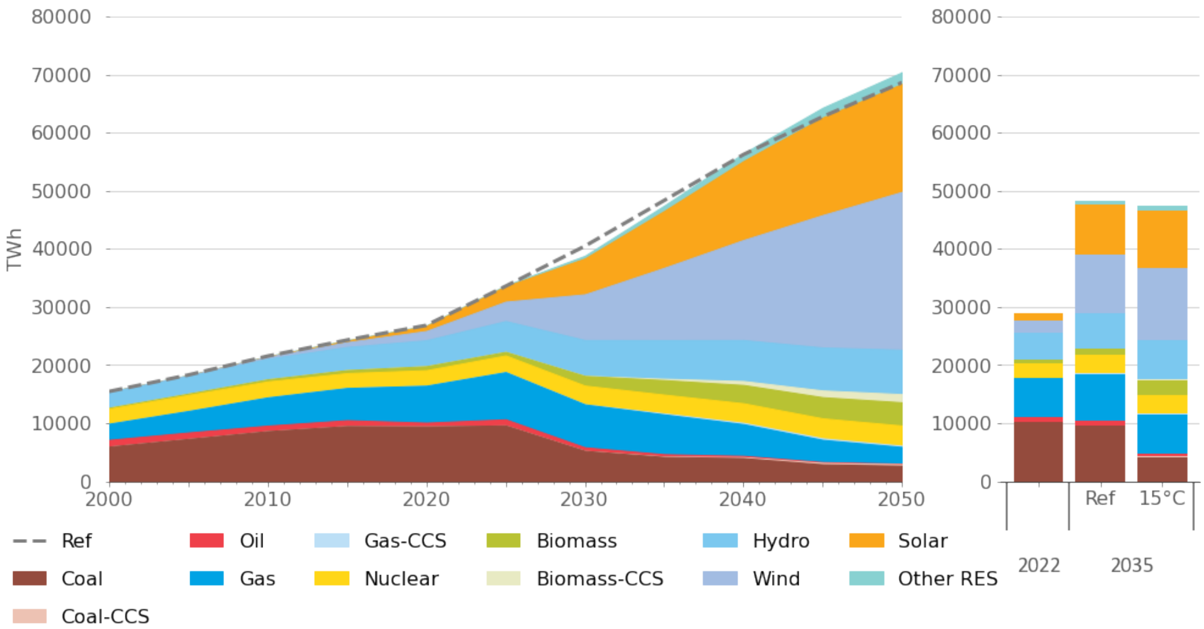
Source: POLES-JRC model. Other RES: geothermal and ocean. Including bunkers.

Focussing again on the 1.5°C scenario, global power generation increases by 64% from 2022 to 2035, and more than doubles (+143%) by 2050 reaching over 70 PWh. Renewable power accounts for the bulk of this expansion: solar generation increases 15-fold, and wind increases 13-fold by 2050 in the 1.5°C scenario. Biomass generation has an increasing contribution in the electricity mix to accounting for 7% of total generation by 2050 and, together with flexibility means like batteries, plays an important role in integrating variable renewables generation. Nuclear electricity generation increases by 30% from 2022 to 2050. Decarbonisation requires the almost complete exit of unabated coal generation, but gas generation maintains a share, again to provide balancing services.

Besides the greatly reduced contribution from coal generation, the global mix of power generation technologies is quite similar in both the 1.5°C scenario and the Reference scenario, as witnessed by the already very high share of renewables in the Reference scenario. There is little uncertainty that solar and wind, as the lowest-cost forms of newly installed electricity generation, account for large shares of the future power generation mix, and the additional effort of scaling up renewables deployments from the Reference to the 1.5°C scenario is relatively minor.

Total global power generation is almost identical in both the Reference and 1.5°C scenarios, as many of the main electrification options in end-use sectors (e.g. electric vehicles, heat pumps in buildings) are the lowest-cost option in both scenarios, and thus enter the market at similar rates, leading to similar overall levels of electricity demand. Deep electrification is not only a characteristic of the 1.5°C scenario, it is also a structural feature noticeable in the Reference scenario.

Figure 5. Global power generation, by technology, 1.5°C scenario

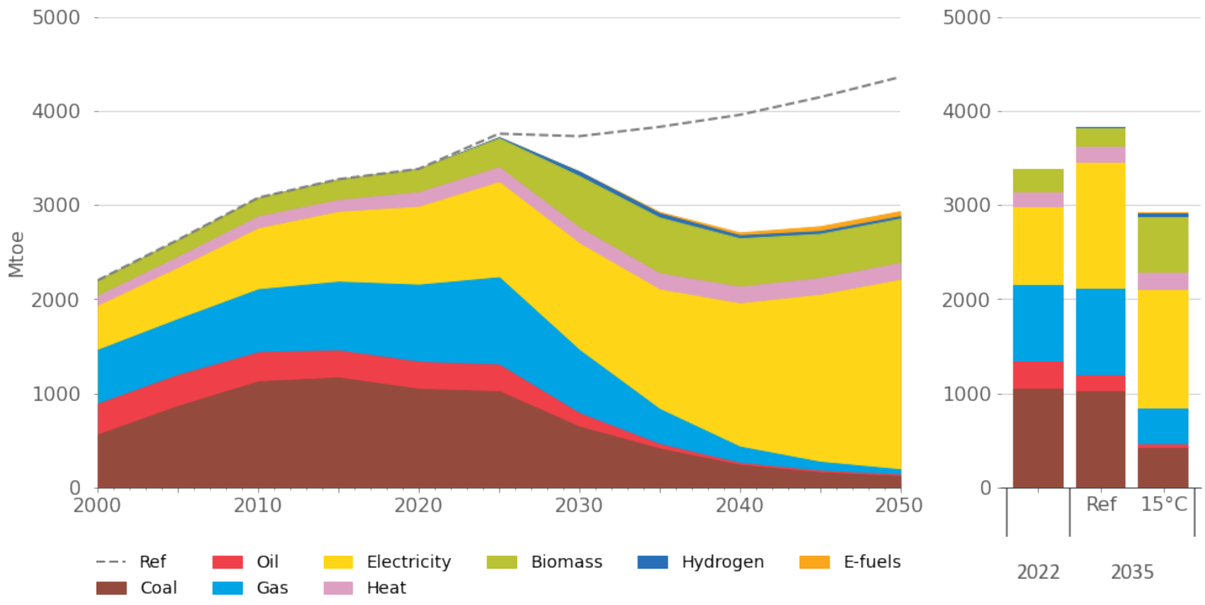


Source: POLES-JRC model.

The projected decarbonisation of the industrial sectors is dominated by the substitution of traditional fuels by electricity and biomass. The 1.5°C scenario sees a rapid decrease in the share of fossil fuels in industry during the current decade, decreasing form 62% in 2022 to 28% in 2035, and continuing towards 2050 where fossil fuels provide only 8% of industry demand. Electricity takes the largest share, driven by the penetration of heat pumps and electric furnaces replacing fossil fuels for heat generation. Hydrogen and e-fuels[5] hardly enter the industry fuel mix, as electrification, fuel switching to biomass, and fossil fuels with CCS carry the bulk of the decarbonisation effort.

[5] E-fuels are 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. The CO_2 is sourced from direct air capture powered by renewables. E-fuels are renewable fuels of non-biological origin (RFNBO).

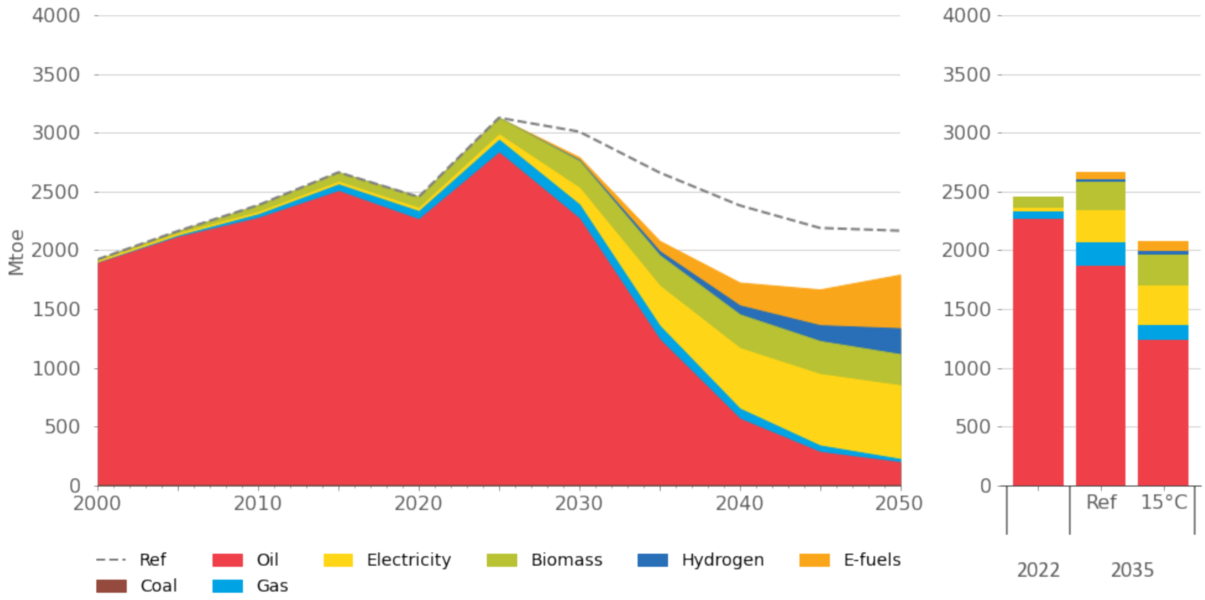
Figure 6. Global industry sector final energy demand, by fuel, 1.5°C scenario



Source: POLES-JRC model.

The transport sector sees a remarkable improvement in energy efficiency, in both the Reference and 1.5°C scenario, as electric vehicles (EVs) quickly become the lowest cost option in both scenarios, replacing less efficient internal combustion engines. EVs account for 21% of the global car fleet in 2035, and 71% in 2050 in the 1.5°C scenario, by which time they are responsible for 11% of final electricity demand (including electric and plug-in hybrid light and heavy duty vehicles). The electrification of transport quickly relegates the role of oil from the major transport fuel to niche fuel by 2050, accounting for 11% of global transport demand, mainly driven by its remaining role in the aviation and maritime sectors. Hydrogen also plays a limited role in both the Reference and 1.5°C scenario, being mostly supported by existing policies, whereas the 1.5°C scenario sees the entrance of e-fuels into the market post-2035, particularly in aviation and maritime transport. Biofuels demand almost doubles between 2022 and 2050.

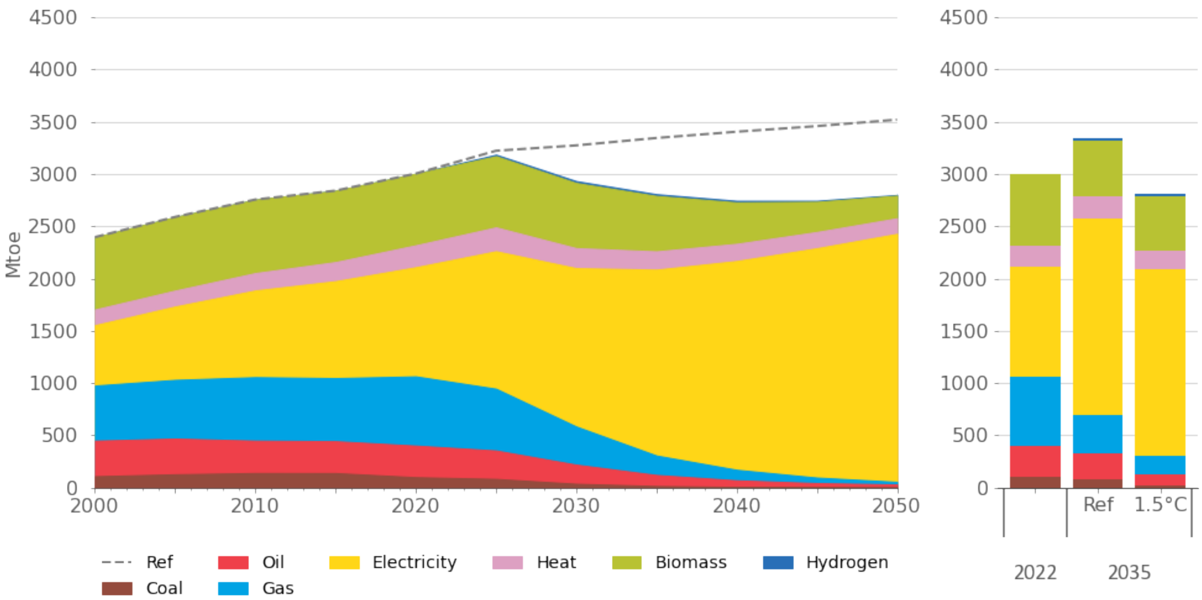
Figure 7. Global transport sector final energy demand, by fuel, 1.5°C scenario



Source: POLES-JRC model. Including bunkers.

Of the main final consumption sectors, the global buildings sector sees the least difference between the Reference and 1.5°C scenarios. This is a consequence of the lowest level of uncertainty in the main drivers of the projections: the increasing share of electricity in the energy mix in both scenarios. In developing regions, the increasing share of electricity is driven by the change from traditional biomass to grid-connected electricity, and the widespread adoption of heat-pumps in more developed regions. Of note is the absence of hydrogen in buildings, as the lower costs of electrification of heating see hydrogen fail to enter the energy mix. The superior efficiency of electrified energy service delivery leads to broadly stable energy demand in buildings globally in the 1.5°C scenario, even as population and per-capita income increases lead to more and larger building floor space throughout the projection period. Electricity from buildings continues to account for around half (46%) of final electricity demand by 2050.

Figure 8. Global buildings sector energy demand, by fuel, 1.5°C scenario



Source: POLES-JRC model.

4 Global targets and temperature overshoot: the coming decade is critical

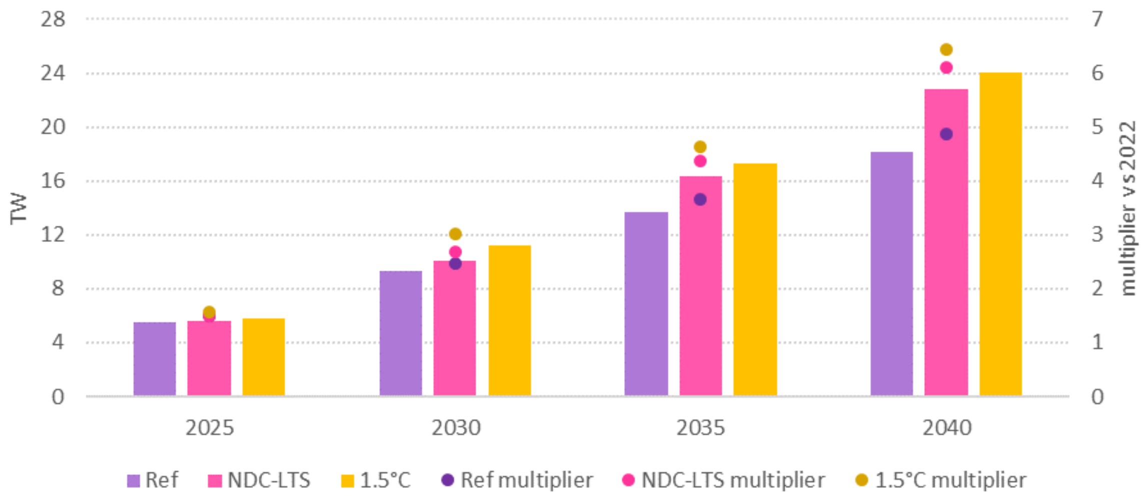
This chapter reviews COP28's global targets to support a 1.5°C pathway, while also examining the development of renewables and energy efficiency toward mid-century. It then presents an overshoot analysis, with four runs that result in different peak warming levels. The chapter underscores the crucial role of immediate action in minimising temperature overshoot and avoiding the increased risk of higher climate damages.

4.1 COP28 2030 Global Renewable and Energy Efficiency targets

COP28 saw the announcement of two global decarbonisation targets, which aimed at accelerating decarbonisation in the current decade to 2030. On the supply side, the targets consist in the tripling of installed capacity of renewable power generation to reach 11 GW globally by 2030, and on the demand side, the doubling of the rate of global energy efficiency improvements by 2030. The 1.5°C scenario sees these targets being achieved by 2030, but as the focus of the upcoming NDC update cycle turns to beyond 2030, the GECO scenarios can explore a longer timeline of these targets.

Figure 9 shows that in the 1.5°C scenario, global installed capacity increases from 11.2 GW in 2030 to 17.1 GW in 2035 (a 52% increase from 2030) and reaching 23.7 GW in 2040 (a 39% increase from 2035), representing a steady continuation in the 2030-2040 decade of the accelerated growth rate that is required to reach the 2030 target.

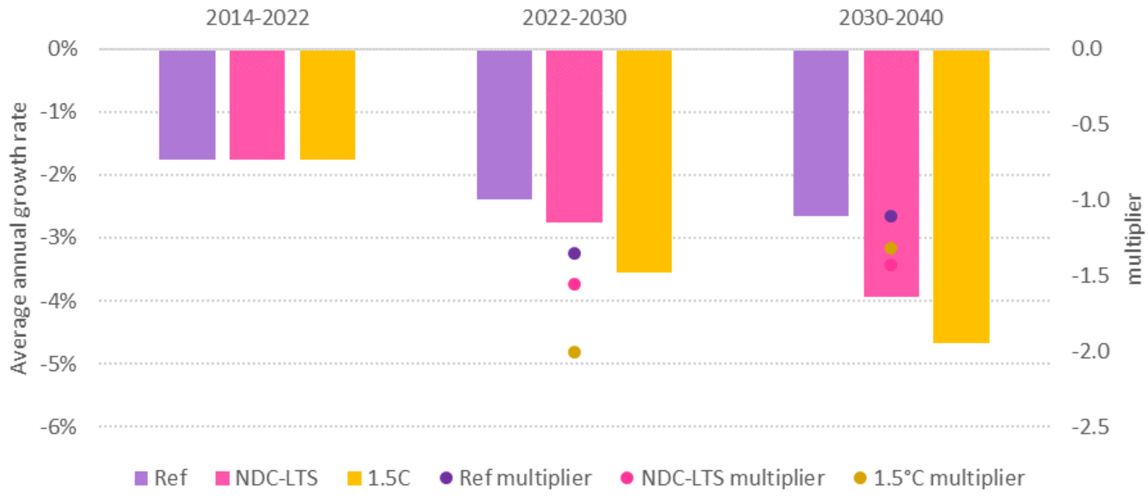
Figure 9. Global installed Renewables capacity, and multiplier from 2022, by scenario



Source: POLES-JRC model. The multipliers refer to the evolution compared to the value in 2022, in the targets referred to as 'tripling' and 'doubling'.

By contrast, the 2030-2040 decade of the energy efficiency improvements shows a marked slowdown compared to the requirements in the current decade to 2030. A doubling of energy efficiency improvements is seen in the 1.5°C scenario by 2030. After this, the rate of improvement slows, to an increase of just 37% over the 2030-2040 decade. This indicates that the "heavy lifting" of energy efficiency improvements in a 1.5°C-aligned trajectory happens this decade, of which one of the main drivers is the substantial electrification of transport via the rapid penetration of electric vehicles.

Figure 10. Average improvement in global energy efficiency, by scenario



Source: POLES-JRC model. The multipliers refer to the change compared to the previous period (i.e., evolution of average annual growth rate of 2022-2030 vs 2014-2022; and of 2030-2040 vs 2022-2030).

Also noteworthy is the relative gap between the Ref and NDC-LTS scenarios and the 1.5°C scenario, for the two indicators. It is clear that both existing policies and targets for renewable deployment, while lagging, are relatively close to what is required to meet a 1.5°C trajectory. Progress on the energy efficiency improvement has a more marked gap, where both the Reference scenario and NDC-LTS scenario lag well behind the 1.5°C scenario, underlining the need for more policy effort on implementation and ambition on energy efficiency improvements.

4.2 NDC updates are a critical determinant for temperature overshoot and climate damages

Many long-term 1.5°C-compatiable scenarios include a transition period during which this temperature limit is exceeded, followed by a period when global temperatures decrease towards the end of the century (Riahi et al., 2021). The level to which global temperatures are exceeded, i.e. the amount and duration of overshoot, determines the level of global climate change-induced damages that occurs (Drouet et al., 2021). Reaching 1.5°C, and above, risks crossing multiple climate tipping points, and crossing these tipping points can generate climate feedbacks that increase the likelihood of crossing other tipping points (Armstrong McKay et al., 2022). With the importance of quantifying temperature overshoot being highlighted by the IPCC classifications of 1.5°C scenarios with “no or limited overshoot” and “high overshoot”[6], each additional 0.1°C increase in overshoot risks approaching and exceeding additional tipping points (Möller et al., 2024).

As shown in Chapter 1.1, the main *1.5°C scenario* in GECO 2024 results in a maximum global temperature of 1.6°C (with median probability) being reached around 2050. Efforts to increase mitigation in the coming decades beyond that of the GECO 2024 1.5°C scenario result in a lower peak warming than 1.6°C, conversely failure to achieve the emissions reductions in the 1.5°C scenario results in a temperature peak exceeding 1.6°C. This analysis explores 2 variants of global temperature overshoot, examining the relative difference between a 0.1°C increase or decrease in peak warming, and the changes in the energy sector and key decarbonisation metrics that result in these peak warming levels.

[6] IPCC Summary for Policymakers AR6 Synthesis Report, Section 3.3.4 (Lee & Romero, 2023)

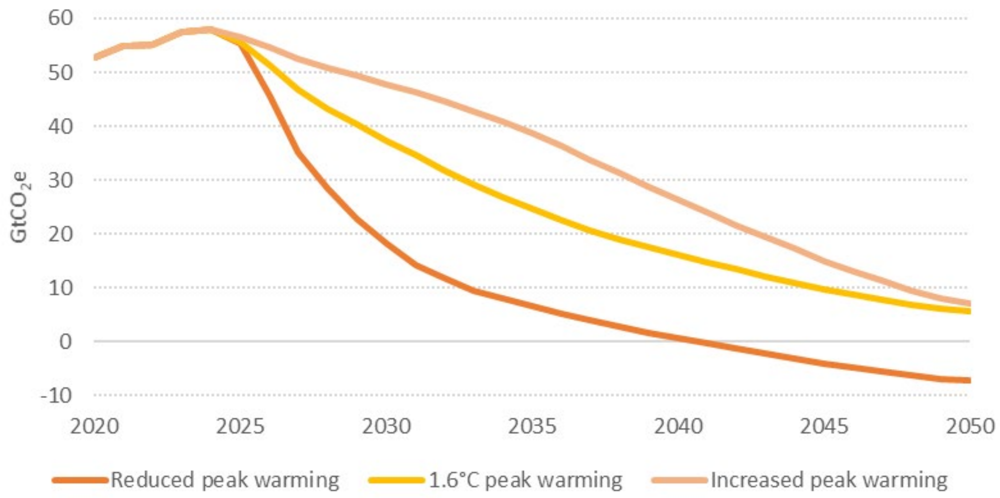
Box 3. Methodology for the peak warming analysis

To represent different levels of decarbonisation ambition and implementation, the global carbon price trajectory is appropriately adjusted in the coming decades in order to achieve the following levels of peak warming:

- **Reduced peak warming**: a reduction in peak warming of 0.1°C compared to the main 1.5°C scenario.
- **1.6°C peak warming**: corresponding to the main GECO 2024 1.5°C scenario.
- **Increased peak warming**: an increase in peak warming of 0.1°C compared to the main 1.5°C scenario.

Warming levels for all scenarios refer to mean probabilities from MAGICC (probabilistic setting).

Figure 11. Global GHG emissions, by peak warming run



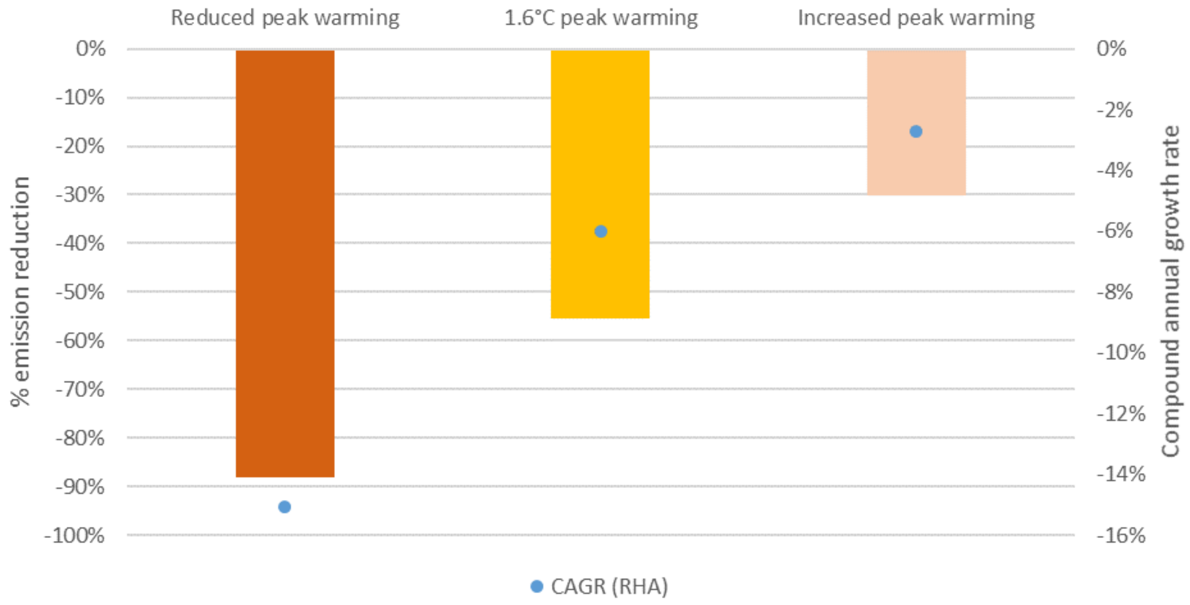
Source: POLES-JRC model.

Figure 11 outlines the global emissions in the three peak warming runs relative to the 1.5°C scenario, over the critical pre-2050 period, differing primarily in the speed of emissions reductions in the 2025-2035 period.

Achieving a reduction in peak warming of 0.1°C compared to the main 1.5°C scenario requires an extremely rapid decrease in emissions the coming decade, in excess of the already rapid decrease in global emissions required to reach the 1.5°C scenario trajectory. In the 1.5°C peak warming run global emissions reach 11.7 $GtCO_2eq$ in 2035, compared to 25.1 $GtCO_2eq$ in the 1.6°C peak warming run, representing an additional halving of global emissions. Figure 12 shows the annual rate of reduction of global emissions in the 1.5°C peak warming run is 15% per annum between 2022 and 2035 (an 88% global emission reduction over the period), compared to 6% per annum in the 1.6°C peak warming run (a 56% global emission reduction over the period). The reduced level of overshoot in the 1.5°C peak warming run requires an annual reduction of emissions every year for the next decade of 3.3$GtCO_2eq$, equivalent to India’s emission today.

In addition, the global emission reduction levels in the key NDC update year of 2035, relative to 2022, are shown in Figure 12 for the four overshoot runs. The slower emissions reduction in the coming decade in the 1.7°C peak warming run compared to the 1.6°C peak warming run, a reduction of 30% by 2035, is similar to the emissions reductions resulting from current NDC-LTS pledges.

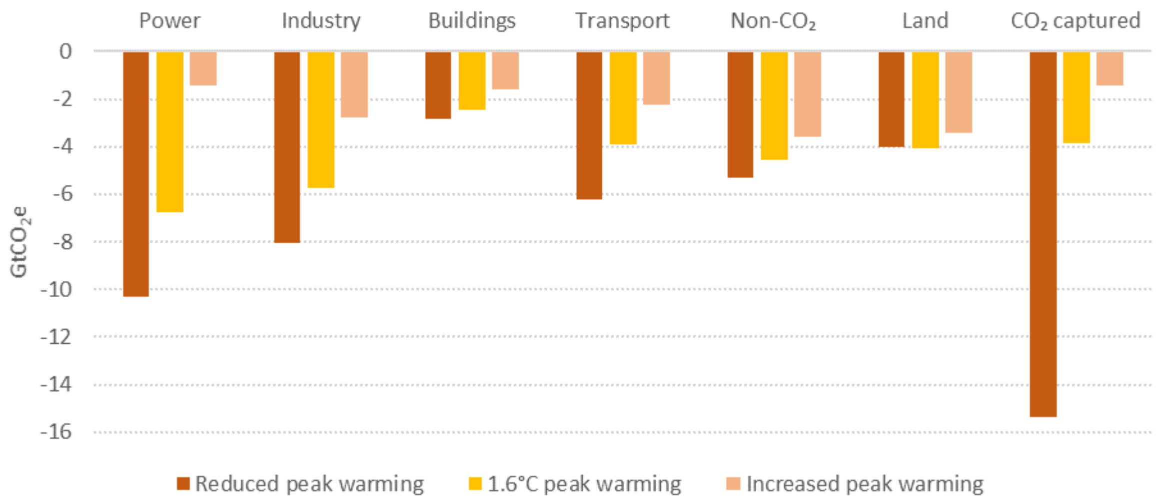
Figure 12. Global emission reductions and emissions CAGR, 2022-2030, by peak warming run



Source: POLES-JRC model. CAGR: compound annual growth rate.

Figure 13 shows the relative increase or decrease in decarbonisation by 2035, across key sectors, in the overshoot runs. The main lever for achieving the accelerated emission reductions in the 1.5°C peak warming run is carbon removal via direct air capture (DAC) and biomass coupled with Carbon Capture and Storage (BECCS), which sees a four-fold increase compared to the level in the 1.6°C peak warming run. Power generation, transport and industry also see large increases in emissions reductions compared to the 1.6°C peak warming run. In the 1.7°C and 1.8°C peak warming runs the underachievement of emission reductions, relative to the 1.6°C peak warming run, occurs mostly in power generation, due to the extended operation of unabated coal plants.

Figure 13. Global emission reductions in key sectors over 2022-2030, by peak warming run



Source: POLES-JRC model.

The success or failure of achieving the global renewable and energy efficiency improvement targets analysed in Chapter 4.1 is likely a key determinant of the amount of peak warming. Table 2 quantifies the impacts on these key targets across the range of peak warming runs. Achieving the tripling of global renewables and doubling of energy efficiency targets, and realising the emissions reductions required in the main 1.5°C scenario pose a significant global challenge, and yet they result in 1.6°C of peak warming.

Table 2. Key decarbonisation metrics, by peak warming run

Peak warming run	Global RE capacity in 2030	Multiple increase in global RE capacity by 2030	Global energy efficiency improvement rate 2022-2030
Reduced peak warming	24.6 TW	6.6	3.7
1.6°C peak warming*	11.2 TW	3.0	2.0
Increased peak warming	9.7 TW	2.6	1.4

*Source: POLES-JRC model. Note: * The main 1.5°C scenario considered in this report.*

Limiting peak warming to 1.5°C requires a rate of global emission reduction in the coming decade that appears to be out of reach. It implies a significant increase in climate policy, going far beyond that required to close the current ambition and implementation gaps to the main GECO 2024 1.5°C scenario.

By contrast, failure to achieve the targets and emissions reductions of the 1.5°C scenario result in increased peak warming. A significant driver of global emission reductions in the coming decade is the next round of NDC updates, which are therefore a critical factor in minimising overshoot and climate damages. In addition, allowing greater overshoot by the middle of the century requires even larger annual negative emissions towards the end of the century to limit end-of-century temperature increase to 1.5°C.

5 Updating 2035 NDC targets in a 1.5°C trajectory

This chapter presents the existing key 2030 NDC targets of selected G20 economies and their ambition gap to 1.5°C emission levels for the same year. It then presents 1.5°C emission levels for 2035 as a benchmark for the upcoming cycle of economy-wide NDC updates due to be submitted to UNFCCC by COP30 in 2025, hereafter referred to as "2035 NDC updates". Following this, it introduces four main strategies for decarbonising the global economy that apply across all countries as an economically efficient roadmap for decarbonisation. Dedicated sections for each strategy examine the indicators necessary to achieve these strategies in a 1.5°C trajectory, and present progress across G20 economies over time, focusing on the years 2035 and 2050.

Box 4. Updating 2035 ambition means updating the emission pathway between now and 2035, immediately increasing ambition

Alignment *only in 2035* with the indicators presented in this Chapter does not necessarily mean that the world is on a 1.5°C-compatible pathway. Rather, the emission pathway between today and 2035 dictates 1.5°C-alignment. If countries continue to pursue their current NDC targets until 2030, and only thereafter increase ambition to the level described by the 2035 indicators, the additional cumulative emissions resulting from that delay would require increased ambition in 2035 beyond the 2035 1.5°C indicators described here. As a result, the 2035 indicators presented in the following sections can be taken as main elements for the creation of *updated NDC pathways* that would trigger immediate additional mitigation, with higher ambition in 2030 than current 2030 NDCs targets as well.

5.1 Updating NDC targets and closing the 1.5°C ambition gap

Table 3 presents an overview of the key economy-wide Nationally Determined Contributions (NDC) targets from selected G20 countries[7] and major emitters. The table ranks countries by their share of global GHG emissions in 2022, and presents key 2030 NDC targets, as well as the type of target. In 2022, the G20 countries together accounted for approximately 80% of global GHG emissions, while the 4 largest emitters, China (30 %), the United States (12%), India (8%) and the EU27 (6%) represented more than half of global emissions.

The definition of economy-wide 2030 targets in NDCs varies by country, with three main types of targets prevailing:

- **Absolute targets**: the most prevalent type of target for the G20 economies (e.g. the EU, USA, UK, Canada, Japan) is an emission reduction target referenced to a historical year, which can be translated into absolute emission values in the target year. Other key emitters such as Brazil, South Africa, Saudi Arabia or Argentina also utilise absolute emission reduction targets. Together, G20 economies with absolute targets represent 34% of global 2022 emissions.
- **Intensity Targets**: China and India, jointly representing 36% of global 2022 emissions, utilise economy-wide emissions' intensity targets (CO_2 per unit of GDP). Emission intensity targets depend on future GDP growth rates, as such, intensity targets are subject to higher uncertainty on the absolute emissions reached in the target year. China's and India's NDC targets also include renewable energy targets.
- **Relative-to-baseline targets**: other major emitters, for example Indonesia and Mexico, as well as other important non-G20 emitters such as Vietnam and Thailand, utilise targets relative to a future baseline emission trajectory. This formulation is also subject to higher uncertainty as the baseline emissions trajectory is dependent on many factors, which means the relative strength of emissions reductions depends as much on the baseline comparison point as on the emissions reductions themselves.

[7] We exclude the African Union from the analysis in this section, which joined the G20 in 2023, as it does not submit a collective NDC under the Paris Agreement.

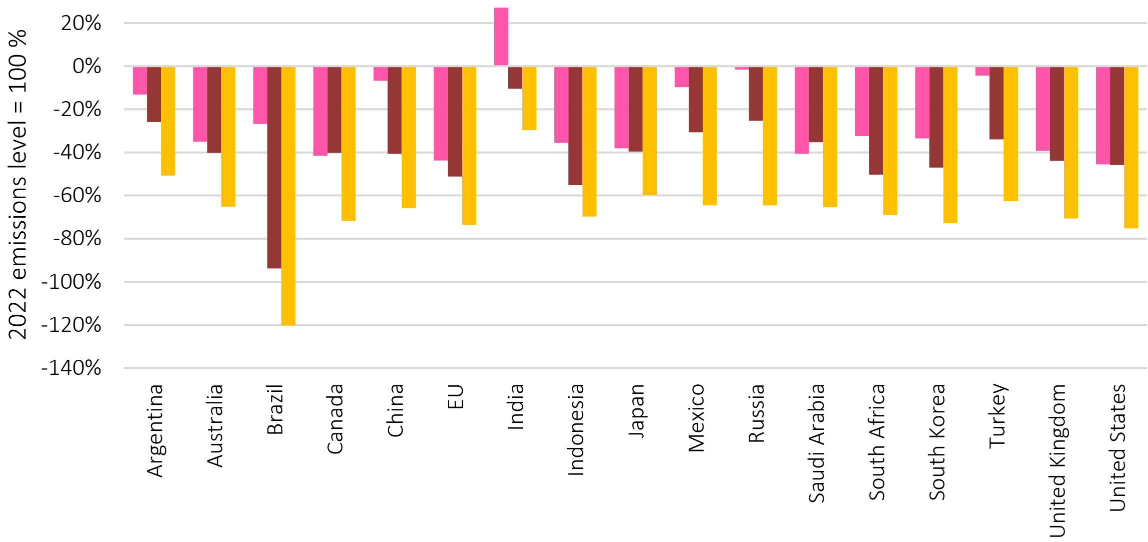
Table 3. Key NDC 2030 targets of selected G20 countries, ranked by size of emissions

Country and % global GHG emissions in 2022 (incl. LULUCF)		Key 2030 NDC targets	Target type
China	29%	Reducing emissions intensity of GDP by over 65% from 2005 level Share of non-fossil in primary energy of 25% Reach over 1200 GW by 2030 of wind and solar power	intensity
United States	11%	Emissions reductions of 50-52% by 2030 compared to 2005 levels	absolute
India	8%	Reducing emissions intensity of GDP 45% by 2030 compared to 2005 levels. 50% cumulative power capacity from non-fossil fuels by 2030	intensity
EU 27	6%	Reduce emissions by at least 55% by 2030 compared to 1990.	absolute
Indonesia	4%	Emission reduction of 43.2% by 2030 compared to BAU.	relative to baseline
Russia	3%	Reduce emissions to 70% by 2030 relative to 1990 level	absolute
Brazil	3%	Emissions reduction of 48.4% by 2025 and 53.1% by 2030 compared to 2005 levels	absolute
Japan	2%	Emission reduction of 46% by 2030 compared to 2013 levels.	absolute
Saudi Arabia	2%	Reduces emissions by 278 $MtCO_2eq$ annually from 2020 to 2030	absolute
Canada	1%	Emission reduction of 40-45% by 2030 below 2005 levels.	absolute
South Korea	1%	Emission reduction of 40% by 2030 compared to 2018 levels	absolute
Mexico	1%	Emission reduction of 35% by 2030 compared to BAU	relative to baseline
Australia	1%	Emission reduction of 43% below 2005 levels by 2030.	absolute
South Africa	1%	Emissions of 350-420 $MtCO_2eq$ by 2030.	absolute
Turkey	<1%	Emission reduction of 41% by 2030 compared to BAU	relative to baseline
Argentina	<1%	Emissions of 349 $MtCO_2eq$ by 2030	absolute
United Kingdom	<1%	Emission reduction of 68% by 2030 compared to 1990 levels	absolute

Source: JRC based on UNFCCC NDC registry (UNFCCC, 2024b).

As illustrated in Figure 1 of chapter 3, 2030 NDC targets at a global level reveal a significant gap between the pledged emission reductions and the levels required to align with a 1.5°C trajectory (*ambition gap*). Figure 14 visualises this gap for the G20 countries. It presents the 2030 NDC emission levels as projected in this outlook, as well as the 2030 emission reduction levels in the 1.5°C-scenario, both relative to emissions in 2022. With the exception of India, the 2030 NDC targets of G20 countries envision lower absolute emission levels than in 2022. At the same time, the ambition gap between existing 2030 NDC targets and a 1.5°C emission level is present for the majority of countries. As a benchmark for 2035 NDC updates, Figure 14 also presents 2035 emission reduction levels aligned with a 1.5°C scenario. These levels illustrate how all G20 countries require substantially more ambitious emission reduction targets by 2035, in order to be 1.5°C-aligned.

Figure 14. Selected G20 economies GHG emission reductions from 2022 by scenario



Source: POLES-JRC model. Note: Emissions are indexed (2022 = 100%) for comparability. Including LULUCF.

To provide a specific benchmark for 2035 NDC targets aligned with a 1.5°C global emission pathway, Table 4 presents economy-wide emission levels in 2035 from the 1.5°C scenario. It shows the 1.5°C-aligned 2035 emission levels by country (left column), and in the right column are 2035 emission reduction targets in the same formulation as each country's 2030 NDC targets, presenting intensity, relative-to-historical year and relative-to-baseline target formulations.

Table 4. NDC 2035 inputs based on emission levels in the 1.5°C scenario of this outlook

	1.5°C scenario economy-wide 2035 emission levels		**1.5°C scenario 2035 emissions levels, in countries' current NDC terms**	
China	4834 Mt CO_2eq	absolute	Reducing emissions intensity of GDP* by over 89% by 2035 compared to 2005 levels	intensity
USA	1348 Mt CO_2eq	absolute	Emissions reductions of 78% by 2035 compared to 2005 levels	absolute
India	2634 Mt CO_2eq	absolute	Reducing emissions intensity of GDP* by over 76% by 2035 compared to 2005 levels	intensity
EU 27	1023 Mt CO_2eq	absolute	Emissions reduction of 82% by 2035 compared to 1990.	absolute
Indonesia	627 Mt CO_2eq	absolute	Emissions reduction of 68% by 2035 compared to GECO24 reference* scenario of 1936 Mt CO_2 by 2035	relative to baseline
Russia	602 Mt CO_2eq	absolute	Emissions reduction of 81% by 2035 compared to 1990.	absolute
Brazil	-340 Mt CO_2eq	absolute	Emissions reduction of 113% by 2035 compared to 2005 levels*	absolute
Japan	422 Mt CO_2eq	absolute	Emissions reduction of 65% by 2035 compared to 2015 levels	absolute
Saudi Arabia	289 Mt CO_2eqq	absolute	Reaching an emissions level of no more than 289 Mt CO_2eq by 2035	absolute
Canada	194 Mt CO_2eq	absolute	Emissions reduction of 73% by 2035 compared to 2005 levels	absolute

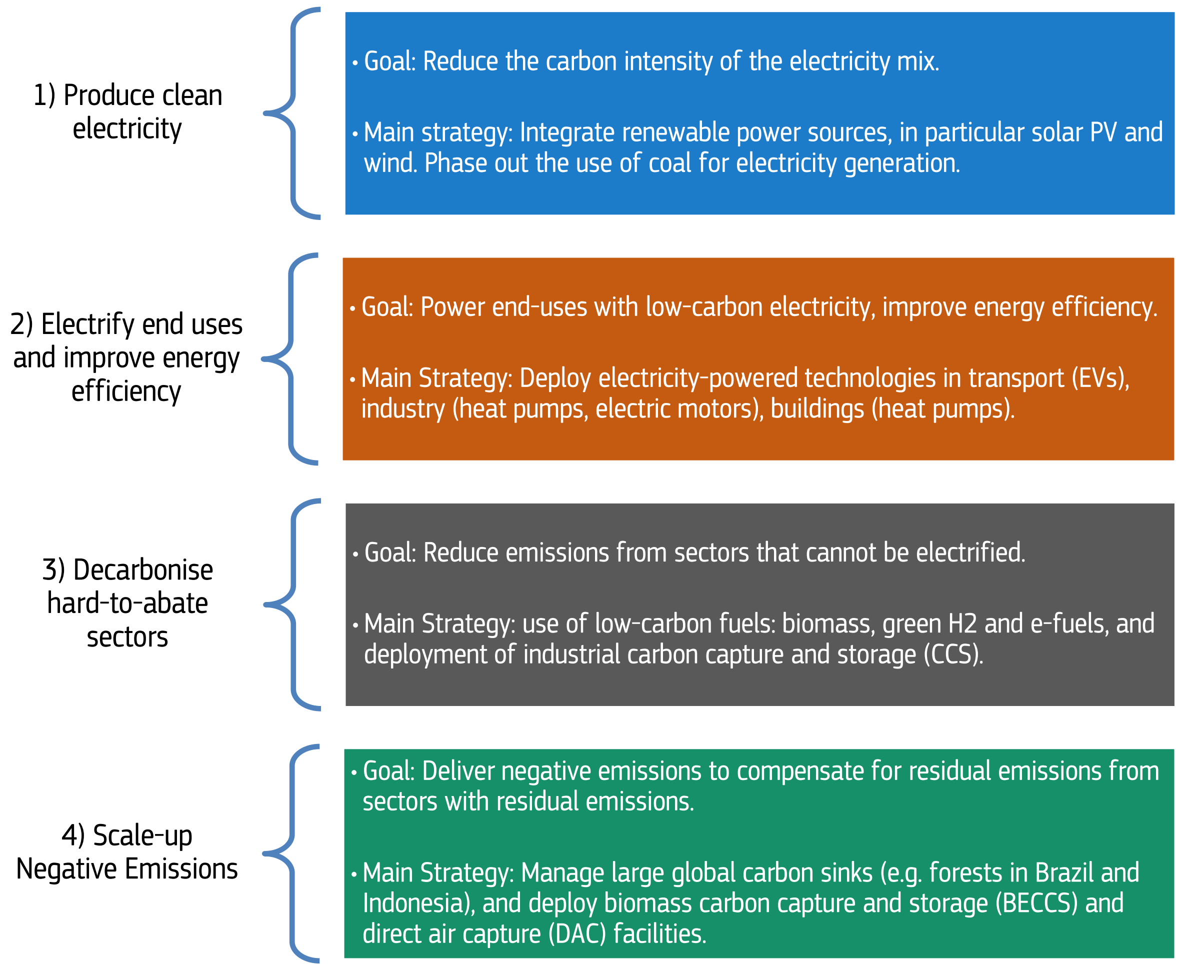
South Korea	175 Mt CO_2eq	absolute	Emissions reduction of 73% by 2035 compared to 2020 levels	absolute
Mexico	243 Mt CO_2eq	absolute	Emissions reduction of 64% by 2035 compared to GECO24 reference* scenario of 642 MtCO_2eq by 2035	relative to baseline
Australia	185 Mt CO_2eq	absolute	Emission reduction of 69% by 2035 compared to 2005 levels	absolute
South Africa	164 Mt CO_2eq	absolute	Reaching an emissions level of no more than 164 Mt CO_2eq by 2035	absolute
Turkey	183 Mt CO_2eq	absolute	Emission reduction of 62% by 2035 compared to GECO24 reference* scenario of 472 Mt CO_2eq by 2035	relative to baseline
Argentina	221 Mt CO_2eq	absolute	Reaching an emissions level of no more than 221 Mt CO_2eq by 2035	absolute
UK	121 Mt CO_2eq	absolute	Emissions reduction of 85% by 2035 compared to 1990.	absolute

*Source: POLES-JRC. *Note: Underlying GDP and reference emissions projections might deviate from official country sources, see supplementary energy and emission balances for detailed values.*

5.2 An Indicators-based approach along the 4 main complementary strategies to decarbonise

Achieving economy-wide emission levels aligned with a 1.5°C emissions trajectory has concrete implications across all emitting sectors in the year 2035. This section presents the development of key global indicators aligned with a 1.5°C trajectory, focusing on four main strategies for decarbonising the global economy: i) producing clean electricity; ii) electrifying end uses and improving energy efficiency, iii) decarbonising hard-to-abate sectors, and; iv) increasing negative emissions while reducing residual emissions (Figure 15). While the four strategies are universally applicable, their relevance in delivering emission reductions is highly context dependent.

Figure 15: The 4 main strategies to decarbonise the global economy.



Source: JRC.

Producing clean electricity is of crucial importance: electricity generation is the second largest emitting sector, and also represents the means for decarbonising end-use sectors through electrification. In the 1.5°C scenario, the average carbon content of electricity decreases from 434 grams of CO_2 per kWh in 2022 by some three-quarters, to reach 116 CO_2/kWh by 2035 and close to zero CO_2/kWh by 2050 (Table 5). To achieve this, the share of non-fossil electricity rises from 39% in 2022 to 75% by 2035 and 91% by 2050. The share of fossil-fuel based electricity decreases, in particular unabated coal-fired electricity which is the largest single source of global CO_2 emissions, drops sharply to one-third of 2022 levels by 2035, and is phased out globally between 2040 and 2050.

Electrification is the cornerstone to reducing emissions across the end-use sectors of industry, transport and buildings. Electrification leads to significant **energy efficiency** gains by replacing less efficient, fossil-fuel based combustion processes with electric technologies such as electric vehicles and heat pumps for electric heating. By 2035, the share of electricity in total final energy consumption in the 1.5°C scenario increases from 22% in 2022 to 43% in 2035, with significant increases in the electrification of road transport and industrial processes. These changes drive a 20% reduction in total final energy consumption (TFEC) compared to the Reference scenario by 2035, highlighting the efficiency gains achievable through electrification. At the same time, delivering emission reductions from electrification is largely dependent on reducing the carbon intensity of the power sector.

Not all sectors can be electrified. So-called **hard-to-abate sectors** present specific characteristics that make electrification and other comparatively low-cost measures to reduce emissions a challenge: high temperature requirements in the production of energy-intensive materials such as cement, steel, base chemicals; emissions inherent to the production process (e.g. cement or primary steel); or weight and space constraints for long-haul transport in the aviation and maritime sectors. The decarbonisation of these sectors requires low-emissions fuels such as biomass, the deployment of industrial carbon capture and storage (CCS) and green hydrogen and e-fuels. In the 1.5°C scenario by 2035, CCS is projected to capture 12% of gross industry emissions, with hydrogen and e-fuels expected to contribute 2% of total final energy consumption (TFEC). By 2050, these shares are anticipated to rise significantly, with CCS capturing 51% of industry emissions (which by 2050 have already reduced by three-quarters compared to 2022, via an ensemble of cheaper abatement options already deployed) and hydrogen and e-fuels accounting for 7% of TFEC.

Finally, even with aggressive decarbonisation efforts across all sectors, **residual emissions** remain. These emissions are offset through **negative emissions** technologies, particularly those involving land use, such as afforestation and reforestation, and technological solutions like biomass coupled with Carbon Capture and Storage (BECCS) and the Direct Air Capture of CO_2 (DAC). By 2035, the volume of CO_2 removed through these methods is projected to reach 5.5 Gt in the 1.5°C scenario, with 4.4 Gt from land-use change and forestry (LULUCF) and 1.0 Gt from DAC and BECCS combined. By 2050, these efforts scale-up dramatically and nearly double, achieving a total removal of 10.4 Gt of CO_2 annually, with 5.6 Gt captured by LULUCF and 4.7 Gt by DAC and BECCS. These negative emissions are essential to achieve net-zero targets and to compensate for the residual emissions that cannot be avoided.

Table 5. Key global indicators for the 4 main decarbonisation strategies in the 1.5°C scenario

		2022	**2035**	**2050**
Clean electricity	Electricity carbon content (grams CO_2/kWh)	434	116	11
	Share of non-fossil electricity in %	39	75	91
Electrify end-uses and energy efficiency	Share of electricity in final energy %	22	43	65
	TFEC savings compared to Reference %	n.a.	20	25
Hard-to-abate sectors	Industry emissions captured by CCS %	0	12	51
	Share of hydrogen and e-fuels in TFEC %	0	2	7
Negative emissions	CO_2 removed from the atmosphere compared to 2022 levels in Gt CO_2	0	5	10

Source: POLES-JRC. Electrification-related figures include bunkers.

To contextualise the relevance of the different strategies and indicators presented in Table 5, Figure 16 presents the contributions of the main emission reduction strategies and their sub-components to delivering the emission reductions between 2022 and 2050 in the 1.5°C scenario. The outer circle outlines the four primary strategies, while the inner circle further breaks these strategies down into key sub-sectoral actions.

The power sector decarbonisation represents the cornerstone of the global energy transition, delivering approximately one-third of direct emission reductions by mid-century, while another third is delivered by the power sector indirectly via the clean electricity used in electrified end-uses. The power sector transformation largely relies on the integration of renewable electricity generation sources, which alone make up 25% of the global emission reductions in a 1.5°C trajectory, while fossil-fuel switching from coal to gas (9%) and CCS in power generation (4%) play a comparably smaller role.

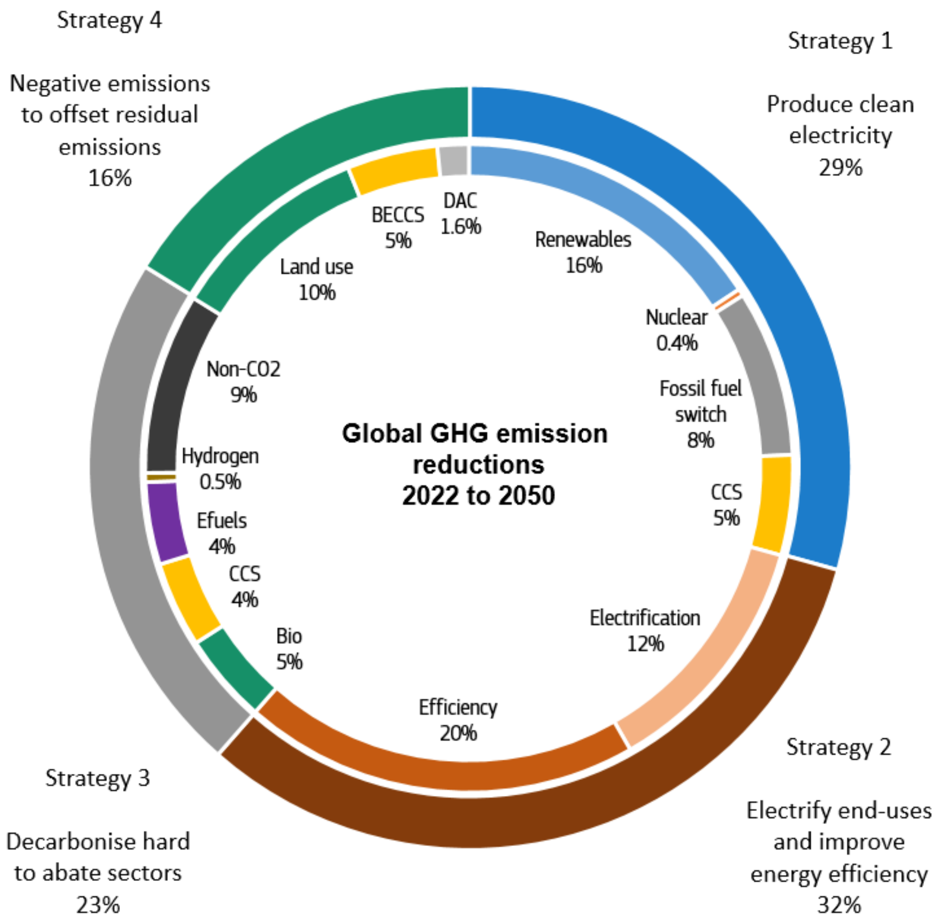
The electrification of end-uses leads to significant improvements in energy efficiency, and these two actions combined account for a third of emissions reductions.

Decarbonising hard-to-abate sectors contributes about a quarter of total emission reductions by mid-century, and primarily relies on the use of biomass (8%), carbon capture and storage (5%), e-fuels and green hydrogen (each 2% of total emission reductions), which play an increasing role towards 2050.

Negative emissions strategies account for 16% of the total emission reductions, from which the bulk is delivered by land use, land-use change, and forestry (LULUCF). Biomass coupled with CCS (5%) and DAC (2%) play a comparably smaller role, with their contribution increasing towards 2050.

The importance of the land sector as an emissions sink cannot be overstated, emissions reductions from land use (10%) are nearly as large as the 12% coming from electrification from the millions of EVs and heat pumps and other electrical technologies that are deployed between today and 2050 in the 1.5°C scenario.

Figure 16. Emission reductions between 2022 and 2050 in the 1.5°C by main strategies to decarbonise.



Source: POLES-JRC

5.3 Strategy 1: Produce clean electricity

Table 6 presents key indicators for the global power sector, illustrating significant changes, by technology, in installed capacity, capacity additions, and the share of main non-fossil and fossil technologies that align with a 1.5°C trajectory.

Solar PV and wind installed capacities grow substantially, positioning these technologies as the backbone of global decarbonisation efforts. Solar PV capacities grow ten-fold from 1073 GW in 2022 to approx**.** 7,200 GW by 2035**,** and close to 13,500 GW by 2050**.** The global annual average net additions of solar PV capacity increase from 400 GW per year in the 2020s to 540 GW per year in the 2030s, while electricity generation increases to 21% by 2035, and further to 26% by 2050**.** Wind energy follows a similar growth path. Despite a similar level of installed wind capacity as compared to solar PV, wind´s higher capacity factor leads to wind-electricity becoming the single largest source of electricity generation by mid-century, with its share growing from 7% in 2022 to 26% by 2035, and further to 39% by 2050, making it the dominant technology in the 1.5°C pathway.

Nuclear electricity, in contrast, is projected to see a marginal increase in globally installed capacity from 403 GW in 2022 to 507 GW by 2050. Nuclear electricity's share in the global generation drops from 9% in 2022 to just 5% by 2050, as its integration is outpaced by the rapidly growing wind and solar PV deployments.

Unabated coal-fired power plants, to date the dominant source of global electricity generation, as well as the single largest source of CO_2 emissions, are rapidly phased-out in the 1.5°C scenario: unabated coal capacities decrease from close to 2200 GW in 2022 to 1850 GW by 2035, while the average capacity factor of the global coal fleet decreases to 30%, or close to 2500 hour per year. This results in coal electricity production in 2035 representing less than half of its 2022 levels. Gas generation capacity also decreases from close to 1850 GW by 2030 to 1500 GW by 2035 and to 1200 GW by 2050.

Table 6. Key global indicators for strategy 1, the power sector decarbonisation in the 1.5°C scenario.

		2022	**2035**	**2050**
Carbon content of electricity in gram CO_2 per kWh		**434**	**116**	**11**
Share of non-fossil generation in total generation		**39%**	**75%**	**91%**
Solar PV	Installed capacity ***in GW***	1 073	7 190	13 380
	Yearly net additions ***in GW***	388	526	352
	Share in power generation ***in %***	4	21	26
Wind	Installed capacity	904	5 688	12 253
	Yearly average net additions	302	398	452
	Share in power generation	3	12	39
Nuclear	Installed capacity	403	475	507
	Yearly average net additions	1	16	21
	Share in power generation	9	7	5
Coal	Installed capacity	2 199	1 843	1 281
	Yearly average net retirements	-25	-6	-57
	Share in power generation	35	9	4
Gas	Installed capacity	1 841	1 500	1 186
	Yearly average net retirements	-29	-1	-31
	Share in power generation	23	15	5
Oil	Installed capacity	363	182	119
	Yearly average net retirements	-14	-6	-4
	Share in power generation	2.6	0.8	0.1

Source: POLES-JRC

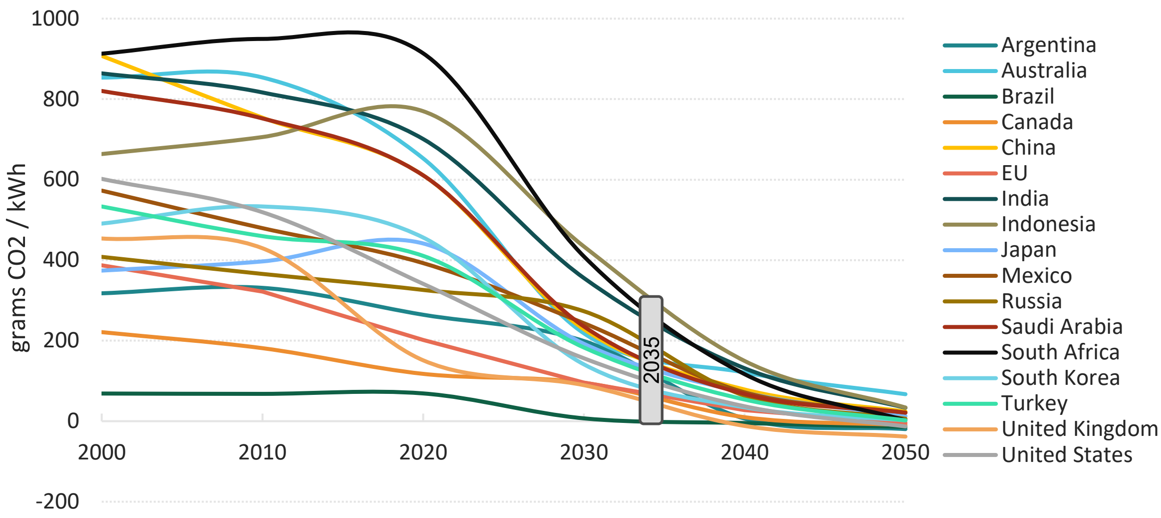
To provide an overview of how the main indicators of the power sector decarbonisation develop, by country, Figure 17 illustrates the development of the carbon intensity of electricity generation among G20 economies, while Figure 18 presents the share of non-fossil electricity generation:

- ***Despite the heterogeneity in the initial power mixes across the G20 countries, in the 1.5°C scenario no G20 country has a carbon intensity exceeding 300 grams of CO_2/kWh by 2035, and no country exceeds 100 grams of CO_2/kWh by 2050.***

- ***In the 1.5°C scenario, no G20 country has a share of non-fossil electricity generation lower than 50% by 2035, and all G20 countries are projected to achieve at least 80% of non-fossil generation by 2050.***

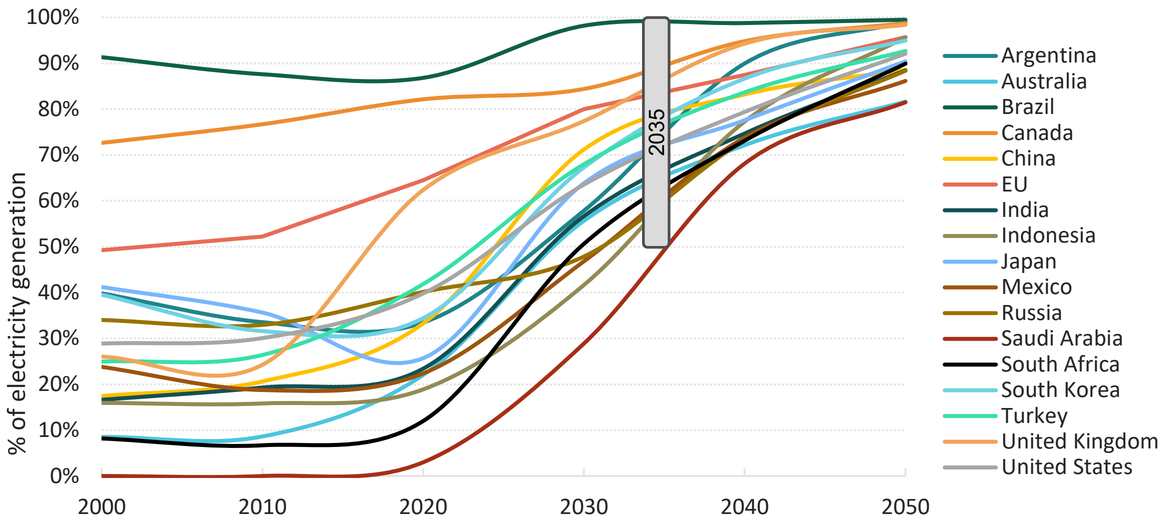
As an indicator of power sector decarbonisation for updated NDCs, Table 7 presents 1.5°C-aligned values for the carbon intensity and the share of non-fossil electricity of electricity generation for G20 countries in the target year 2035 as presented in Figure 17 and 18.

Figure 17. Carbon intensity of electricity generation between among selected G20 countries between 2000 and 2050.



Source: POLES-JRC.

Figure 18. Share of non-fossil electricity generation (right) among selected G20 countries between 2000 and 2050.



Source: POLES-JRC.

Table 7. Carbon intensity and share of non-fossil electricity generation for selected G20 countries, 1.5°C scenario.

	Upper value of carbon intensity ($g\ CO_2/kWh$) by 2035	Minimum share of non-fossil electricity generation (%) by 2035
Argentina	74	77
Australia	192	61
Brazil	2	98
Canada	38	91
China	122	80
EU	60	83
India	222	66
Indonesia	291	58
Japan	130	71
Mexico	119	65
Russia	133	62
Saudi Arabia	128	51

South Africa	208	67
South Korea	70	80
Turkey	117	76
United Kingdom	36	87
United States	88	72

Source: POLES-JRC

5.4 Strategy 2: Electrify end-uses and improve energy efficiency

Table 8 presents key indicators in global electrification across the industry, transport and buildings sectors in the 1.5°C scenario. By 2035, the share of electricity in global total final energy consumption (TFEC) increases from 22% in 2022 to more than 40% by 2035 and close to 70% by 2050. Alongside this growth, energy efficiency gains are set to play a critical role, with energy savings between the Reference and the 1.5° scenario reaching 20% by 2035, and 25% by 2050. These savings underscore the impact of replacing fossil-based combustion with high-efficiency electrified technologies on the one hand, while simultaneously improving efficiency in non-electricity technologies on the other.

Table 8. Key global indicators for strategy 2, electrification and energy efficiency in the 1.5°C scenario.

	2022	**2035**	**2050**
Share of electricity in TFEC %	**22**	**43**	**65**
Energy savings as compared to reference %	**0**	**20**	**25**
Buildings electrification %	**36**	**63**	**85**
Energy savings as compared to reference %	**n.a.**	**16**	**20**
Installed capacity of heat pumps in buildings in GW	978	4 523	5 063
Yearly average heat pump additions in GW	156	266	226
Share of heat pumps in building heating demand %	<1	5	14
Industry electrification %	**26**	**43**	**69**
Energy savings as compared to reference %	**n.a.**	**24**	**33**
Installed capacity of heat pumps in industry in GW	0	586	1537
Yearly average heat pump additions in GW	0	74	122
Share of heat pumps in industry FEC %	0	6	16
Transport electrification %	**1**	**16**	**35**
Energy savings as compared to reference %	**n.a.**	**24**	**18**
Share of EVs in cars fleet %	<1	48	59
Share of EVs in LDV fleet%	<1	44	69

Source: POLES-JRC. Total and transport electrification include bunkers.

In the buildings sector, electrification increases to 36% by 2035 and close to 85% by 2050. In countries with a substantial demand for heating, e.g. mainly in North America, Europe, Central and East Asia, a key contributor to achieve a substantial electrification shift is the adoption of heat pumps for heating, replacing the existing stock of mostly gas- and oil-fuelled boilers in residential and commercial buildings. Accordingly, the share of fossil fuel demand in global buildings final energy demand is reduced from 35% in 2022 to close to 2% by 2050. In the 1.5°C scenario, hydrogen is projected to play virtually no role in the buildings sector, with a share lower than 1% of total final energy demand of buildings over the whole time horizon. Improved electrification and higher efficiency of non-electrified technologies in the buildings sectors lead to a 16% reduction in energy use in 2035 and 20% by 2050 in the 1.5°C scenario as compared to the Reference scenario.

In the industry sector, electrification rises from 26% in 2022 to 43% by 2035 and close to 69% by 2050. Nevertheless, energy savings in the industrial sector, compared to the reference, are projected to reach 24% by 2035 and 33% by 2050. This reflects a substantial improvement in energy efficiency, driving both emissions reductions and cost savings for industrial operators.

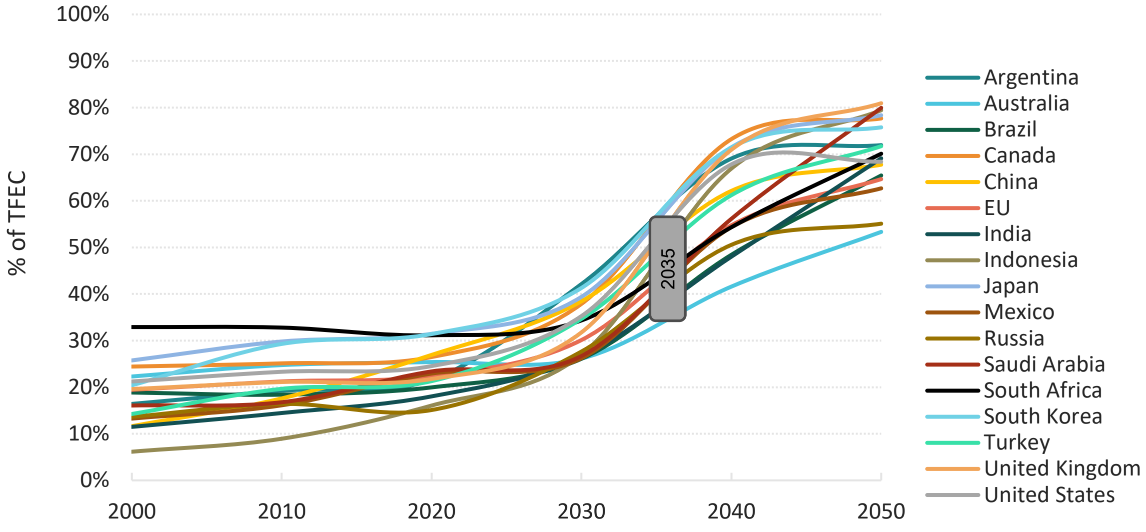
In the transport sector, electrification in the 1.5°C scenario increases to 16% by 2035 and to 35% by 2050 (close to 50% excluding bunkers). The adoption of electric vehicles (EVs) is key to achieving this shift. The share of EVs in the global car fleet is projected to grow from close to 1% in 2022 to 48% by 2035 and 59% by 2050, while the share in light vehicle fleets rises to 44% by 2035 and 69% by 2050.

To provide an overview of the development of electrification across countries, Figure 19 illustrates the electrification share in total final energy use among G20 economies in the 1.5°C scenario.

- ***Despite some countries starting from a very low share of electricity today, in the 1.5°C scenario no G20 country is projected to have a share of electricity in final energy use of less than 35% by 2035 and 55% by 2050.***

As an indicator of electrification levels for updated NDCs, Table 9 presents 1.5°C-aligned values for the share of electrification in total final energy use, as well as in the industry, transport and buildings sector of G20 countries in the target year 2035.

Figure 19. Share of electricity in total final energy demand by selected G20 countries between 2000 and 2050, 1.5°C scenario.



Source: POLES-JRC.

Table 9. Share of electricity in total and sectoral final energy in 2035 for selected G20 countries, 1.5°C scenario.

	Total final energy demand (FEC) electrification by 2035	Industry FEC electrification by 2035	Transport FEC electrification by 2035	Buildings FEC electrification by 2035
Argentina	57%	62%	17%	94%
Australia	36%	32%	21%	59%
Brazil	36%	30%	14%	78%
Canada	57%	60%	26%	74%
China	50%	46%	26%	71%
EU	42%	45%	34%	43%
India	36%	25%	20%	55%
Indonesia	49%	42%	25%	79%
Japan	56%	54%	22%	76%
Mexico	40%	50%	13%	78%
Russia	40%	32%	19%	60%
Saudi Arabia	40%	19%	24%	93%
South Africa	41%	57%	11%	57%
South Korea	57%	50%	28%	77%
Turkey	49%	40%	30%	71%

United Kingdom	52%	52%	42%	57%
United States	53%	49%	18%	81%

Source: POLES-JRC.

5.5 Strategy 3: Decarbonise hard-to-abate sectors

Table 10 presents indicators in key hard-to-abate sectors, in which electrification is challenging. Decarbonising these key sectors relies on an ensemble of mitigation options. These options range from biomass co-firing to significant investments in new capacities and infrastructure, e.g. for carbon capture and storage facilities, or the production and transport of hydrogen, e-fuels and captured CO_2. These investments make the abatement of hard-to-abate sectors comparatively costly and technically challenging:

- In **cement** production, deploying carbon capture and storage (CCS) is crucial to capture process emissions, as approximately two-thirds of cement emissions come from the high-temperature clinker production process. In the 1.5°C scenario, by 2035, 8% of global cement emissions are captured by CCS, and this increases to 55% by 2050. Co-firing biomass and electrification can decarbonise part of the processes (e.g. electric pre-heaters are being deployed at scale, and electric kilns are under research); injecting CO_2 in prefabricated concrete blocks or using different chemistries entirely are both nascent processes (IEA, 2018).
- In **steelmaking**, 72% of current global production is produced by blast furnace-basic oxygen furnaces in 2022, which are gradually replaced by increased electrification via recycling of scrap in the 1.5°C scenario. Increasing the share of electric arc furnaces from current levels (22% of global production) presents the cheapest and most energy-efficient mitigation potential but faces constraints due to the availability of scrap and steel quality requirements. Emissions reductions in primary steel are achieved by retrofitting the existing capacities with CCS, capturing 6% of global steel emissions by 2035 and 37% by 2050, and co-firing biomass, even considering the technical challenges and costs of CO_2 transport infrastructure and the lower calorific value of biomass. Zero-emissions steel is also produced by deploying production capacities that use hydrogen, however green hydrogen supply costs remain high throughout mid-century, resulting in low adoption in the 1.5°C scenario (Keramidas et al., 2024).
- In **international transport** (aviation and maritime), fuel switching to low-emission liquid fuels primarily biofuels, and e-fuels, i.e. synthetic fuels derived from low-carbon hydrogen and captured CO_2, is the main route of decarbonisation in the 1.5°C scenario. Only in these sectors, the use of hydrogen and e-fuels is projected to be significant, reaching a share in final energy use of 4% and 14% by 2035, and as much as 42% and 79% in 2050, for aviation and maritime, respectively (Müller-Casseres et al., 2024).
- **Non-CO_2 emissions in industrial activities**: much of these emissions are an inherent part of production processes. Mitigation options consist of substitution of chemical species: e.g., change of refrigerant species to reduce HFC gases, or change of anodes in aluminium production to reduce PFC gases. Further mitigation can be achieved by properly capturing the gases: e.g., capture and destruction or recycling of N_2O upon production of adipic and nitric acids; or collection and reuse of SF_6 upon the end of the lifetime of the electric equipment (Mainhardt & Kruger, 2000; Winiwarter et al., 2018).
- **Non-CO_2 emissions in agriculture**: these emissions are mainly the result of livestock and rice paddies (CH_4 emissions) and livestock waste management and fertiliser application (N_2O emissions). Mitigation options consist in more targeted use of fertilisers (e.g. with precision farming), manure management and change in livestock feeding. However, these measures can only provide a certain amount of reductions; deeper mitigation could be achieved by changing demand for food (food waste management, meat calorie intake), however these are measures not modelled in this analysis (Höglund-Isaksson et al., 2021).

Table 10. Key global indicators for strategy 3, the decarbonisation of hard-to-abate sectors in the 1.5°C scenario.

	2022	**2035**	**2050**
Sectoral emissions ($MtCO_2eq$)			
Cement	2 451	2 463	709
Steel	2 342	1 345	-15
Chemicals	1 684	471	7
Maritime	1 012	635	351
Aviation	792	802	226
Industry (non-CO_2)	1 498	464	148

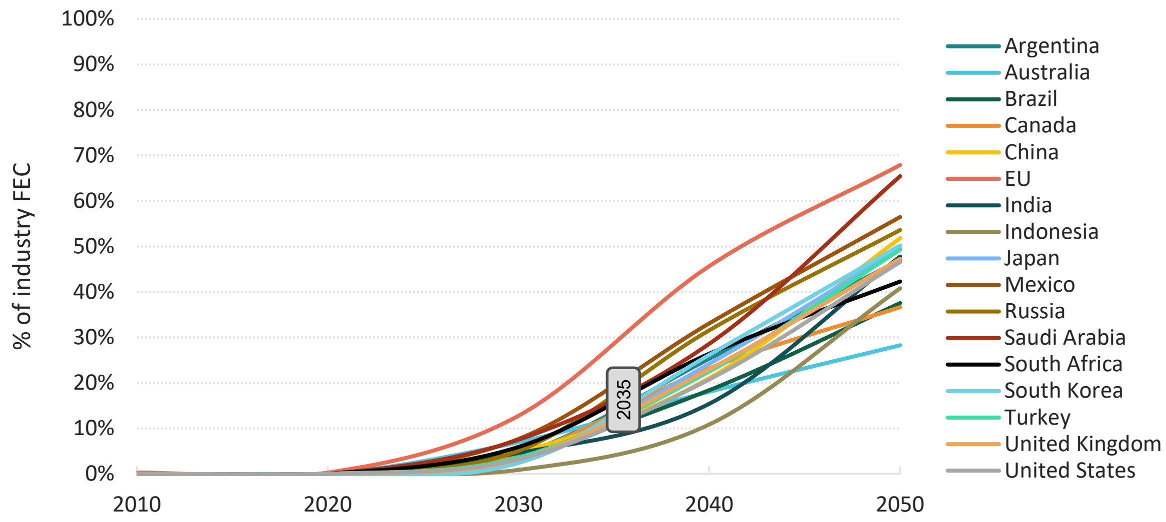
Agriculture (non-CO_2)	6 646	5 743	4 224
Share of emissions captured by CCS in %			
Industry total	0%	9%	49%
Cement	0%	8%	55%
Steel	0%	5%	37%
Share of biomass in sectoral FEC in %			
Industry total	7%	19%	15%
Cement	3%	14%	54%
Steel	1%	9%	25%
Share of H2 and e-fuels in sectoral FEC in %			
Heavy-duty road vehicles	0%	5%	31%
Maritime	0%	15%	79%
Aviation	0%	3%	42%

Source: POLES-JRC.

To provide an overview of the development of two key technologies in hard-to-abate sectors, Figure 20 illustrates the development of CCS and Figure 21 green hydrogen and e-fuels in the 1.5°C scenario for G20 economies. More specifically, Figure 20 portrays the share of gross industrial emissions, including both fuel and process emissions, that are captured by CCS in the 1.5°C scenario, while Figure 21 presents the share of hydrogen and e-fuels in total final energy consumption.

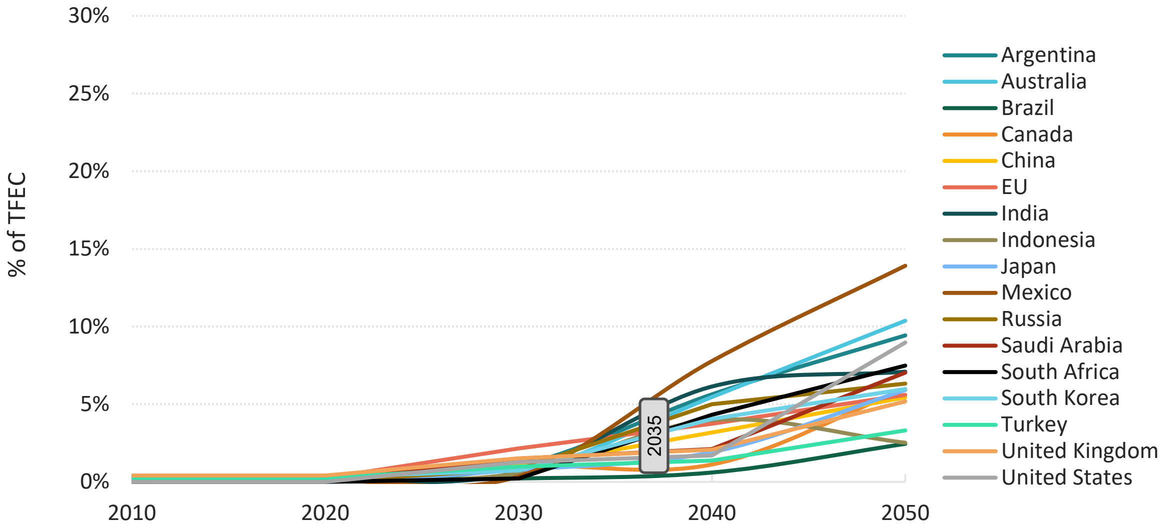
- ***By 2035, in the 1.5°C scenario most G20 countries capture between 5 and 20% of industrial emissions with CCS, a share that increases to 40-60% by 2050***.
- ***By 2035, in the 1.5°C scenario no G20 country is projected to have a share higher than 5% of hydrogen an e-fuels, and by 2050, no country is projected to have a share lower than 3% or higher than 16%, reflecting the higher costs and therefore limited applications of these low-carbon fuels.***

Figure 20. Share of gross industrial emissions (fuel and process emissions) captured by CCS for selected G20 countries, 1.5°C Scenario



Source: POLES-JRC model.

Figure 21. Share of hydrogen and e-fuels in total final energy consumption (right) for selected G20 countries, 1.5°C scenario



Source: POLES-JRC model. Note: total final energy consumption covers energy uses only, excluding international transport.

As an indicator for updated NDCs of key technologies to decarbonise hard-to abate sectors, Table 11 provides the values for 2035.

Table 11. Share of gross industrial emissions captured by CCS and share of e-fuels and hydrogen in TFEC in 2035, 1.5°C scenario.

	Share of industrial emissions captured with carbon capture and storage by 2035	Share of hydrogen and e-fuels in total final energy consumption by 2035
Argentina	13%	3%
Australia	14%	3%
Brazil	11%	0%
Canada	11%	1%
China	12%	2%
EU	22%	3%
India	10%	3%
Indonesia	10%	3%
Japan	9%	1%
Mexico	21%	3%
Russia	13%	3%
Saudi Arabia	19%	2%
South Africa	14%	2%
South Korea	9%	2%
Turkey	13%	2%
United Kingdom	13%	2%
United States	10%	1%

Source: POLES-JRC.

5.6 Strategy 4: Scale-up negative emissions

To achieve net-zero emissions by 2050, ambitious decarbonisation efforts in the energy system are complemented by negative emissions, which offset residual emissions especially from hard-to-abate sectors. In particular, strong land-use, land-use change, and forestry (LULUCF) management, and scaling-up of negative emission technologies such as Direct Air Capture (DAC) and Biomass coupled with Carbon Capture and Storage (BECCS). As shown in Figure 3 in chapter 3.2 of this report, LULUCF emissions, which by 2020 represent approx. 2.8 Gt of CO_2, rapidly decline to become a global emissions sink. Table 12 outlines key indicators for negative emissions in a 1.5°C-aligned trajectory, presenting the necessary reductions compared to 2020 levels. Accordingly, in the 1.5°C scenario LULUCF accounts for the bulk of emission reductions coming from negative emissions strategies by 2035, accounting for around 80% of reductions from 2020 levels,, while BECCS and DAC account for about 10% each. Towards mid-century, an increasing reliance on BECCS and DAC technologies sees their relative contribution to negative emissions grow to 20% each.

Table 12. Key indicators for strategy 4, negative emissions in the 1.5°C scenario.

	2035	**2050**
Emission reductions from 2020 levels (Mt CO_2)	**- 5556**	**- 10455**
of which LULUCF	-4 529	-5 730
of which BECCS	-487	-2 647
of which DAC	-540	-2 078

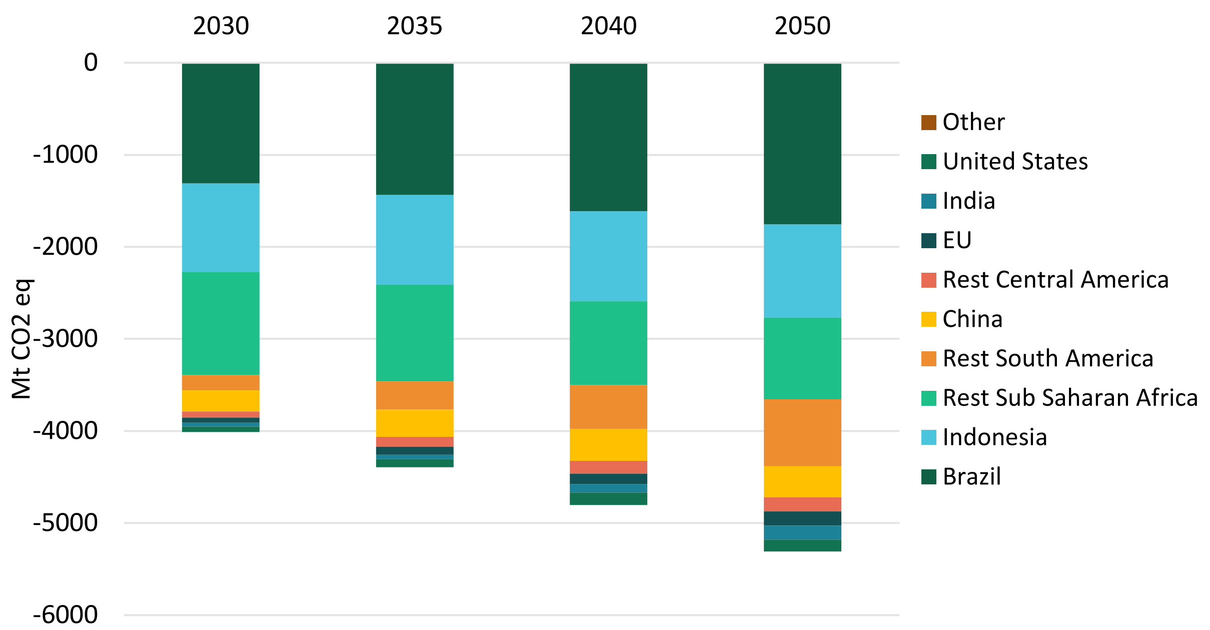
Source: POLES-JRC. 2020 historical emissions after Grassi et al., (2023).

Achieving substantial emission reductions from land-use, land-use change, and forestry is essential in the coming decade for meeting global climate targets, particularly for countries with significant land-use potential.

- ***In the 1.5°C scenario, nations with large forests and potential for improved land management, such as Brazil and other South American countries, Sub-Saharan Africa, and parts of Asia, achieve negative emissions that largely exceed their domestic residual emissions, highlighting the crucial role these regions play in realising global climate goals.***

Figure 22 presents projected LULUCF emission reductions for key regions from 2020 levels in the 1.5°C scenario[8]. Brazil and Sub-Saharan Africa are projected to reduce LULUCF emissions from 2020 to 2035 by -1.3 Gt CO_2 and -1.1 Gt CO_2, respectively. Other major contributors include Indonesia (-0.6 Gt CO_2), and the rest of South America (excluding Brazil, Argentina and Chile) with -0.3 Gt CO_2 by the same year.

Figure 22. Emission reductions from LULUCF from 2020 levels by key regions, 1.5°C.



Source: POLES-JRC. 2020 historical emissions after Grassi et al., (2023).

[8] Projected LULUCF emissions exclude extreme events such as wildfires or large fires from peatland clearing, which can account for substantial LULUCF emissions.

Complementing the large initial role for the land sector as an emissions sink, technological solutions increasingly fill the gap to address residual emissions towards mid-century. In the 1.5°C scenario the use of bioenergy with carbon capture and storage is concentrated in regions with substantial biomass production capacities, allowing for significant carbon capture while generating energy. Direct air capture is also increasingly important, while having the flexibility to be deployed globally. DAC also serves dual purposes: capturing CO_2 either for permanent storage (CCS) or to supply CO_2 for the production of synthetic fuels (e-fuels), which can be traded internationally. This dual role creates a market-driven demand for DAC, as e-fuels can be exported from low-cost production areas to regions with higher energy costs, making DAC a crucial technology for both carbon capture and global fuel markets. As an indicator for updated 1.5°C-aligned NDCs, Table 13 presents the negative emission levels in the 1.5°C scenario by major regions with land-use sinks.

Table 13. Emission reduction levels from LULUCF from 2020 levels by key regions.

	LULUCF emissions ($MtCO_2eq$)	
	2035	2050
Brazil	-1437	-1757
“Indonesia	-973	-1011
Sub Saharan Africa	-1051	-887
Rest of South America	-306	-727
China	-296	-338
Central America	-110	-154
EU	-85	-154
India	-47	-152
United States	-88	-128

Source: POLES-JRC. Note: CO_2 emissions from agriculture, land use, land use change and forestry (AFOLU) are based on the Grassi et al., (2023) approach.

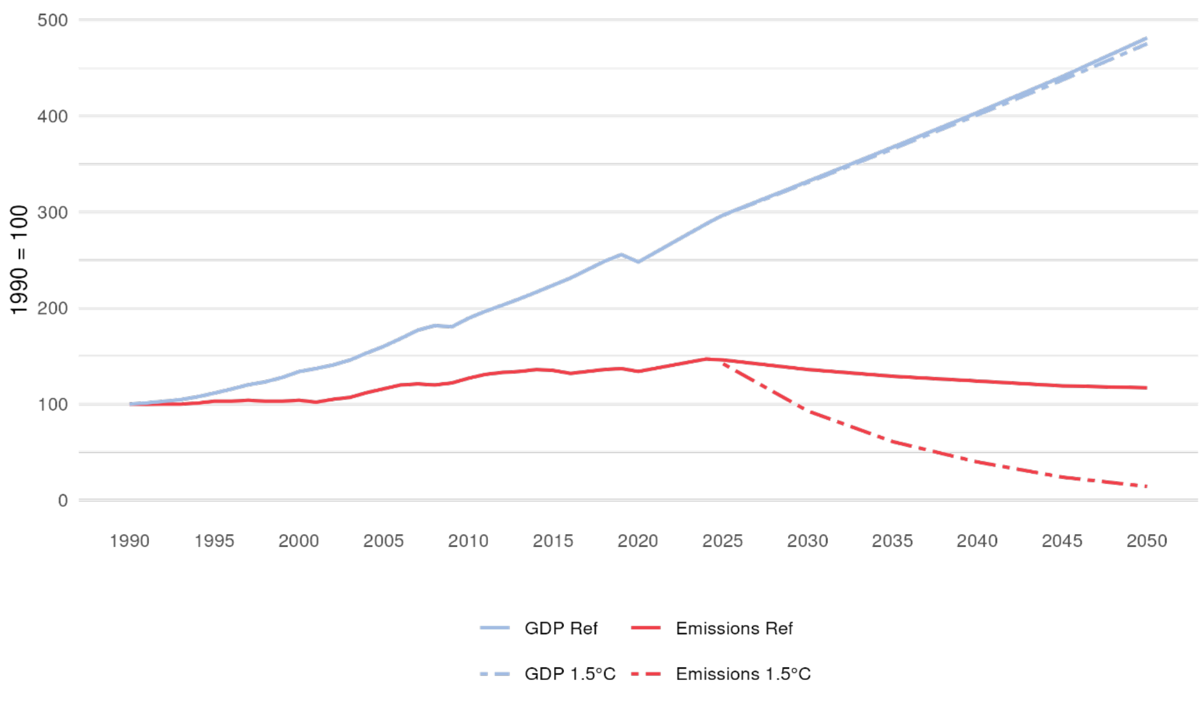
6 Macroeconomic impacts of decarbonisation

This chapter presents the macroeconomic impacts in the 1.5°C scenario compared to the Reference scenario, outlining the development of the global Gross Domestic Product (GDP), investment, consumption, production, and employment impacts. It presents how the global energy transition in the 1.5°C scenario drives sectoral shifts, but has a limited aggregate impact at the macroeconomic level. Overall spending shifts from fossil fuels towards new low-carbon infrastructure, while capital flows to low-emission technologies. Employment moves between and within sectors, with increasing employment in low-carbon technologies and decreasing employment in fossil fuel-related sectors.

6.1 Minor impacts on global GDP in the 1.5°C scenario

Figure 23 shows the development of GDP and global GHG emissions in the 1.5°C and Reference scenarios. In the Reference scenario, global GDP is projected to grow by an average of 2.66% per year from 2020 to 2050[9]. Despite an 85% emission reduction from 1990 levels in the 1.5°C scenario, the global GDP growth rate is almost identical to the Reference scenario, growing at a fraction of a percent slower after 2030. Global GDP in 2050 is merely 1.2% lower in the 1.5°C scenario than in the Reference scenario. This suggests that the aggregated cost of decarbonising the global economy is minor and potentially substantially lower than the cost of inaction, which entails both higher climate impacts and costs of adaptation that would occur in the Reference scenario (Feyen et al., 2020).

Figure 23. Global GDP (excluding effects of climate change impacts) and global GHG emissions (including LULUCF), by scenario

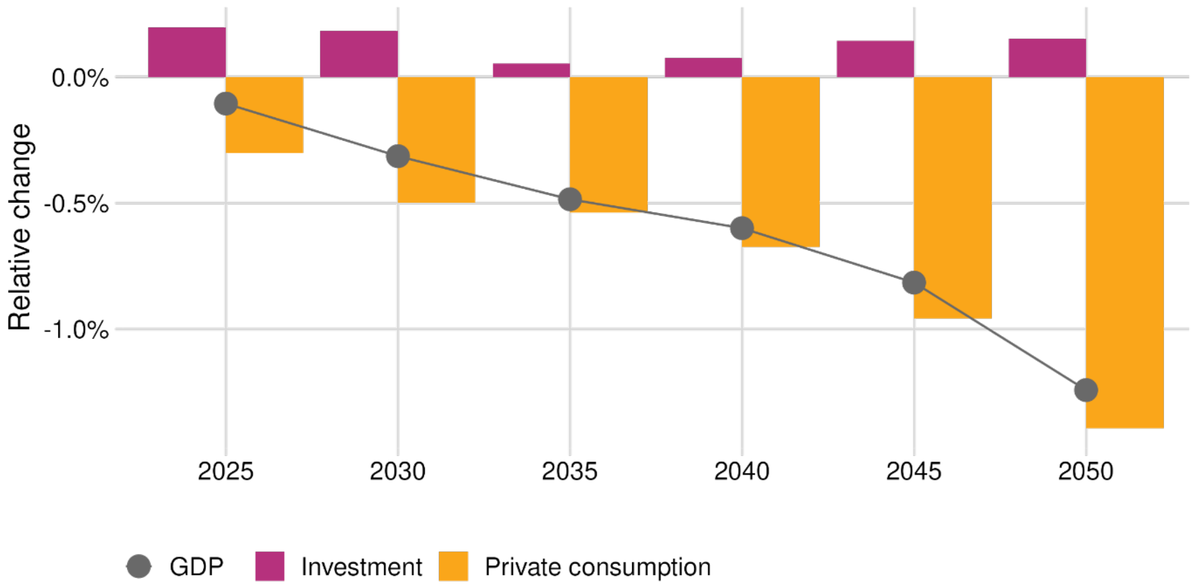


Source: JRC-GEM-E3.

[9] The JRC-GEM-E3 is solved in five-year steps, hence we represent the latest historical year available, which is 2020. GDP growth rates are exogenous in the Reference scenarios and harmonised to the POLES-JRC model. Annex 4 provides detailed socio-economic assumptions used in the scenarios. For EU countries, the GDP projections follow the 2024 Ageing Report (European Commission: Directorate-General for Economic and Financial Affairs, 2024); for non-EU countries, it follows the IMF World Economic Outlook (IMF, 2024a, 2024b) and the OECD long-tern baseline projections (OECD, 2021). Historical GDP levels are taken from the World Bank (World Bank, 2024).

Figure 24 decomposes GDP in the 1.5°C scenario compared to the Reference scenario into relative changes in investment and private consumption. Decarbonising the global economy in a 1.5°C trajectory requires scaling up low-carbon technologies, which are often capital-intensive, thus requiring additional investments. Accordingly, investments increase GDP by 0.1% in the 1.5°C scenario compared to the Reference scenario. However, the contraction in private consumption offsets this increase in demand for capital goods. Global GDP decreases by 1.3% in 2050 relative to the Reference[10]. Household consumption (taken as a proxy of welfare, i.e. a metric to assess overall well-being) grows by 1.99% per year in the Reference scenario over 2025-2050, and only slightly slower at 1.91% per year in the 1.5°C scenario over the same timeframe.

Figure 24. Global GDP, decomposed by changes in investment and private consumption over 2025-2050 in the 1.5°C scenario compared to the Reference scenario.



Source: JRC-GEM-E3.

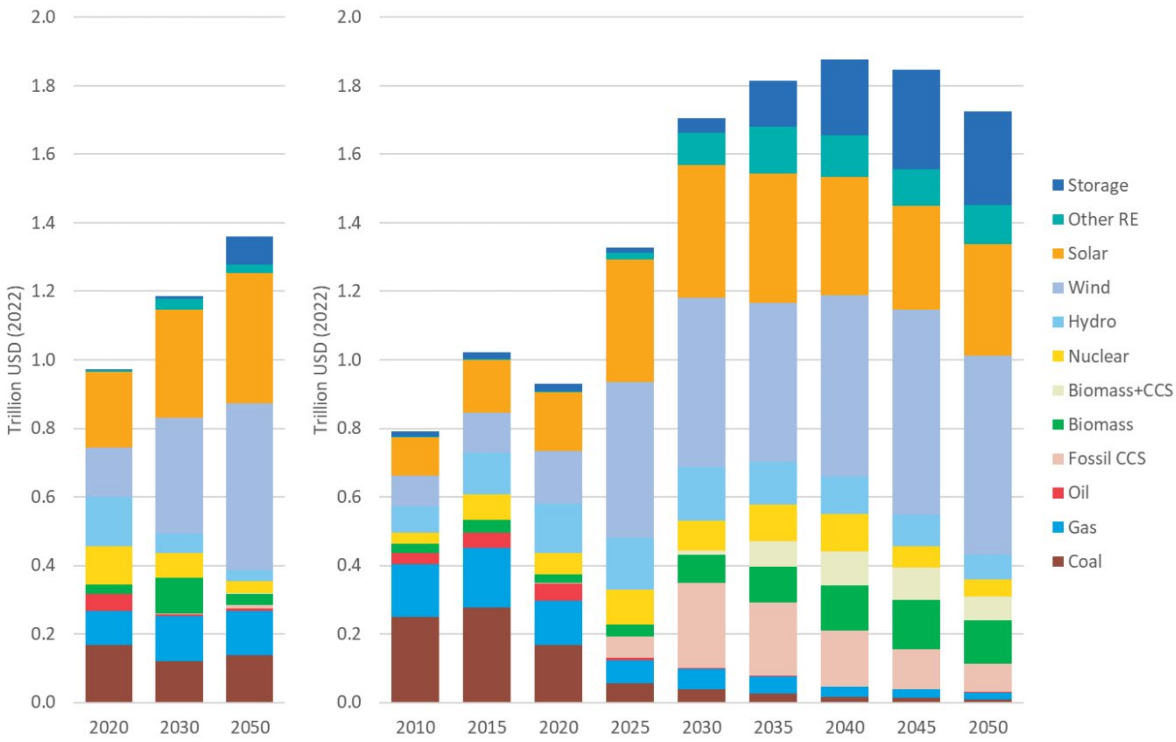
6.2 Energy investments are the backbone of the transition

Economy-wide investments in 2050 increase to 26.9% of global GDP in the 1.5°C scenario, up from 26.4% in the Reference scenario, mainly driven by additional investments in the energy sector in the 1.5°C scenario. The increase in investments is particularly sharp during the current decade and is less pronounced thereafter.

Figure 25 shows that global power sector investments in both the Reference and 1.5°C scenario are dominated by wind and solar PV, which account for over half of all investments throughout the projection period, reflecting their cost-competitiveness already in the Reference despite the remaining sizable fossil fuel investments.

[10] By design, the decline in private consumption is due to crowding out, as the assumption of the JRC-GEM-E3 model is that the economy is supply constrained. Government consumption is kept fixed in the analysis, thus it does not lead to any relative change compared to the Reference. It is also worth noting that there are no (net) trade effects when considering global GDP.

Figure 25. Global annual power sector investments in the Reference and 1.5°C scenarios.



Source: POLES-JRC model.

In the 1.5°C scenario, investment in unabated coal generation virtually disappears in 2030, and investments in fossil fuel capacity only remain fitted with CCS. To provide stability to a power mix dominated by wind and solar generation, investments in storage increase, particularly after 2030, as batteries become cheaper. Investments in biomass and nuclear generation increase after 2030, along with other renewables (e.g., geothermal), while fossil investments are almost phased out by 2050, with only minimal expenditures for gas remaining.

Box 5. Just Energy Transition Partnerships (JETPs)

Just Energy Transition Partnerships (JETPs) are recently established investment partnerships to accelerate the energy transition of developing and emerging economies. JETPs bundle financial support from high-income countries into high-level cooperation agreements to facilitate the achievement of energy and climate targets of recipient countries. Four JETPs have been established so far: the first, between South Africa and the International Partners Group (IPG) during COP26, committing the mobilisation of US$8.5 billion to support the achievement of South Africa´s most ambitious 2030 NDC target. Indonesia, Vietnam and Senegal followed, agreeing on initial financial support volumes of US$20, 15.5 and 2.5 billion, respectively, towards power sector-related energy and climate targets. With a combined volume of US$45 billion over a 3–5-year period, JETPs represent a substantial mobilisation of climate finance from developed to developing countries.

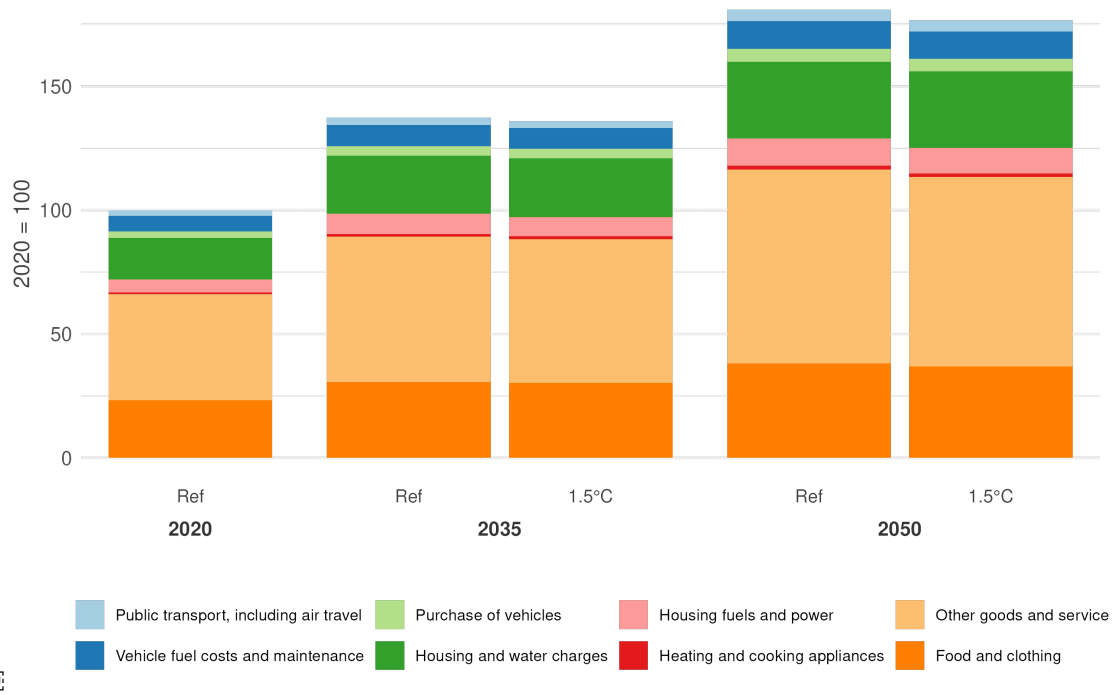
JETPs are designed as catalytic mechanisms, aiming to improve conditions for private investment in renewable energy. An extensive analysis of JETPs based on GECO 2022 was published in the article 'Just Energy Transition Partnerships and the future of Coal' (Ordonez et al., 2024). In view of the cost-competitiveness of renewables already in the Reference scenario, as well as the lower investments for fossil fuels, the analysis indicates that the financial support volumes foreseen in the JETPs are substantial and cover a large share of the *additional investments* required when moving from a Reference to a 1.5°C trajectory.

6.3 Household investments in the energy transition reduce fuel-related spending

Purchases of durable goods, such as heat pumps and electric cars, are treated as private consumption by national statistics whereas this can also be considered as energy-related investments by households. Following the categorisation of national statistics, these types of durable purchases are considered as household consumption in this report. This section explores the effects of decarbonisation on household consumption, particularly related to housing and mobility.

Figure 26 visualises the development of private consumption by scenario for different consumption categories, which continues to grow over time in both scenarios. The largest share of global household consumption is devoted to basic goods, such as food, clothing, housing and water charges, and other goods and services. However, a closer look at the different consumption categories shows that the change is heterogeneous across categories.

Figure 26. Real global household consumption of different goods and services in the Reference and 1.5°C scenarios (index 2020 = 100).



Source: JRC-GEM-E3.

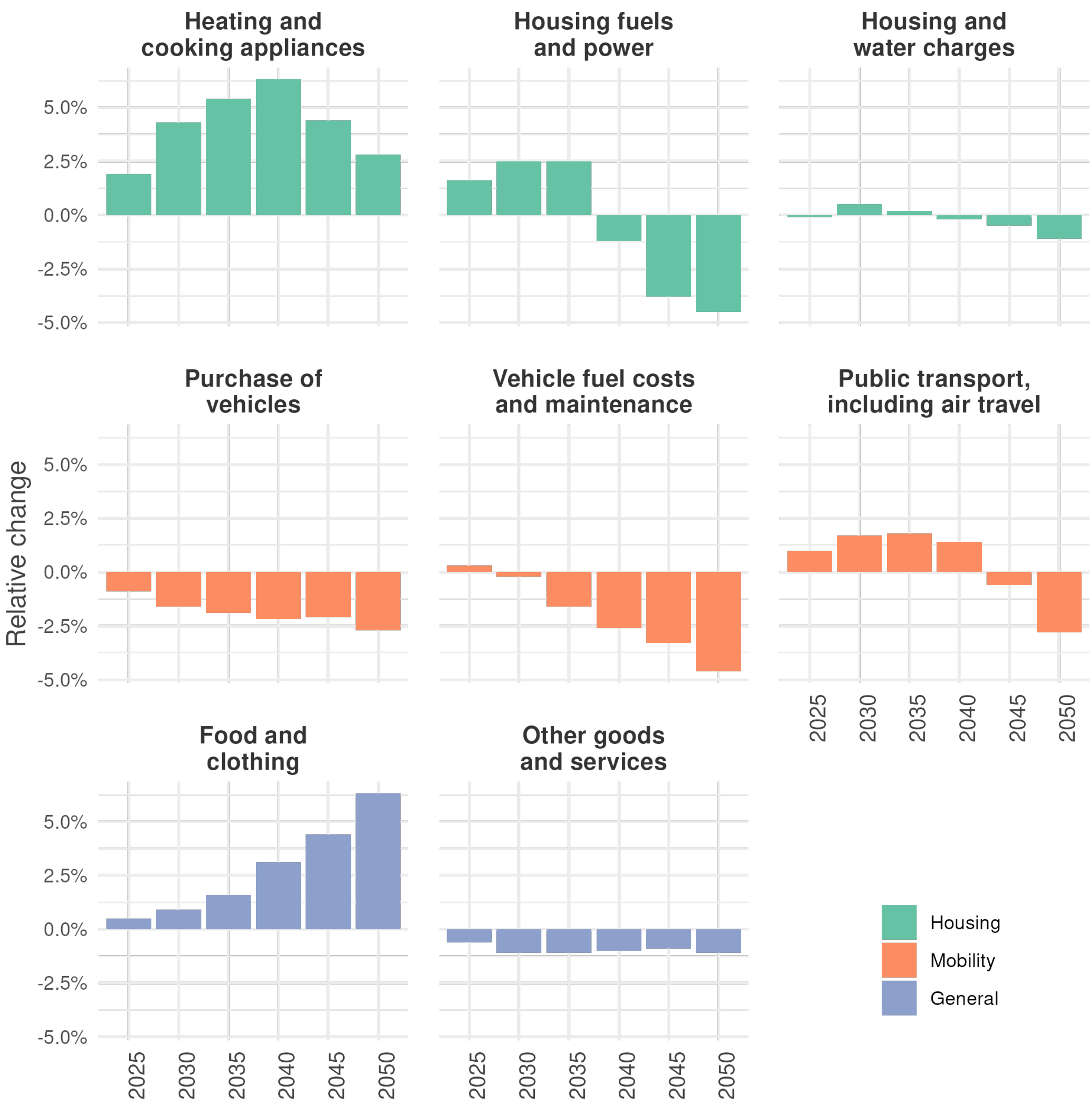
To illustrate this heterogeneity, Figure 27 displays the relative change in the share of household expenditure on different consumption categories in the 1.5°C scenario compared to the Reference scenario. Compared to Figure 26, Figure 27 visualises expenditure rather than real consumption, meaning that it also takes into account the prices of the different goods and services in each year and per scenario. The categories are also grouped into spending on housing, mobility, and other general spending.

For general spending, there is an increase in the share of expenditure for food and clothing, reflecting a gradual increase in the prices of these goods over time in the 1.5°C scenario compared to the Reference scenario. This is partly due to the assumption of a uniform carbon price for all sectors, including non-CO_2 emissions from agriculture, which leads to increased food prices in the 1.5°C scenario.

Within housing-related expenditure, there is a shift from expenditures on consumable fuels to expenditure on durable goods. This mirrors the shift in industry from operating expenses related to (fossil) fuel costs towards more investments for capital-intensive renewable energy technologies. There is a relative increase in spending on heating and cooking appliances, and housing and water charges. This is related to households' investment in more energy-efficient heating equipment and electric appliances, as well as housing renovations. Figure 27 shows how the share of household expenditure dedicated to the energy transition expands most between 2030 and 2040. As a result of more energy-efficient housing, the share of expenditure on fuels and power in 2050 is 4.5% lower in the 1.5°C scenario than in the Reference scenario. This reflects how these investments by households result in energy and cost savings in the long run. Note that this reduction in expenditures of fuels and power affects the welfare of households only marginally after accounting for the higher energy efficiency of houses.

For mobility-related expenditure, both the share of expenditure on private vehicles (e.g., cars, motorbikes) and the related fuel and maintenance costs decrease, with the latter category decreasing more strongly leading to a shift of expenditure from consumables towards durable goods. However, as private transport is a luxury good and purchases depend on the available income after buying necessities such as food, vehicle purchases and expenditures for operating them are lower in the 1.5°C scenario than in the Reference scenario. At the same time, the share of expenditure on public transport increases between 2025 and 2040 by around 1.5%.

Figure 27. Share of global household expenditure on different goods and services. Relative change (%) in the 1.5°C scenario compared to the Reference scenario



Source: JRC-GEM-E3.

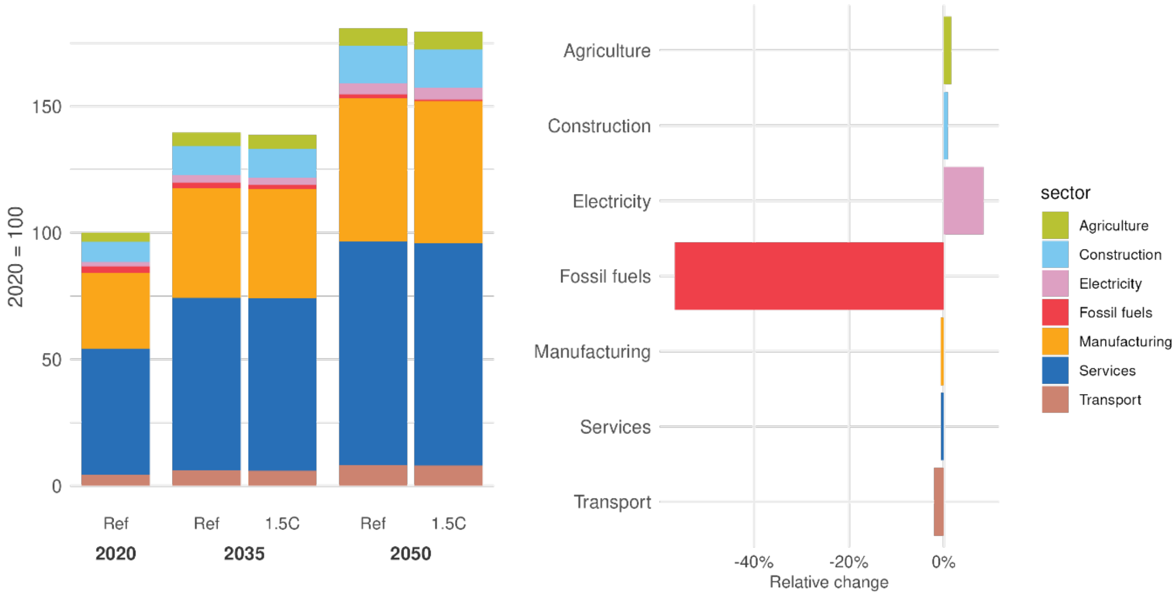
6.4 Decarbonisation has different impacts on sectors

Overall, the changes in aggregate output, measured by production in each sector in monetary terms, are marginal in 2050 under the 1.5°C scenario compared to the Reference scenario (Figure 28). Apart from the fossil fuel sector, which declines even faster in the 1.5°C scenario than in the Reference scenario, differences in the output of individual sectors in both scenarios are small considering the global economy. This indicates that the general impact of climate mitigation and the energy transition may be limited on the aggregate structure of the economy, even under the deep decarbonisation of the 1.5°C target. Nonetheless, despite the minimal impact of reaching a 1.5°C target on total output, decarbonisation has different local impacts depending on the sector[11].

As fossil fuel production decreases over time in both scenarios, Figure 28 shows that there is a faster decrease in the value of output of fossil fuel sectors in the 1.5°C scenario. The right-hand panel of Figure 28 demonstrates that, as expected under a 1.5°C scenario, the value of output reduces by 57% compared to the Reference scenario in 2050. This is mainly driven by a decrease in the demand for fossil fuels, with the decarbonisation of power generation and the electrification of transport as main drivers of this change. By 2050, only limited uses of fossil fuels remain, such as feedstock in industrial and energy transformation sectors (e.g., natural gas as a feedstock in chemicals).

While the use and therefore also the production of fossil fuels is reduced under the 1.5°C scenario, electricity generation and distribution increases faster than in the Reference scenario (increase of 8.3% in the 1.5°C scenario in 2050). The increased investment in capital-intensive power generation technologies has spill-over effects to other sectors. Notably, construction (which increases by 0.9% under the 1.5°C scenario compared to the Reference scenario in 2050) is positively affected as additional investments to decarbonise the economy generate more demand for construction services. In addition, investments in biomass production for power generation and biofuels, plus the need for afforestation as a carbon sink in the 1.5°C scenario, promote increased production in the agriculture sector, which is 1.5% higher than in the Reference scenario. Output by the transport sector decreases by 2% in 2050 in the 1.5°C scenario compared to the Reference scenario. This reflects a relative reduction in all modes of transport (air, land, and water) that is mainly driven by a contraction of land transport (-2%) as the largest provider of transport services. Air and water transport, which make up 16% and 9% of total transport, decrease by 2% and 4% respectively in 2050 under the 1.5°C scenario compared to the Reference scenario.

Figure 28. Total value of output by sector (index 2020 = 100) over 2020-2050 (left) and relative change in the 1.5°C scenario compared to the Reference in 2050 (right).



Source: JRC-GEM-E3.

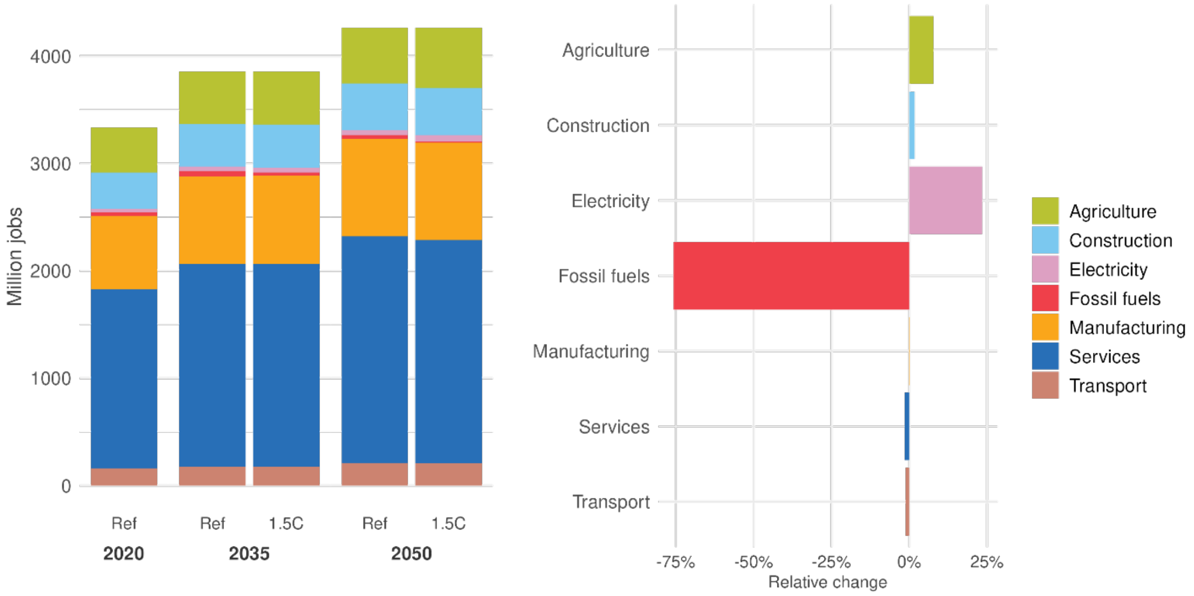
[11] In some sectors, a modest change in output may hide larger transformations *within* certain sectors due to changes in production processes (e.g., manufacturing of electric vehicles, electrification of iron and steel industry). We also note that Figures 28 and 29 aggregate crops, livestock and forestry sectors into agriculture.

6.5 Employment shifts away from fossil fuel sectors in the energy transition

Changes in output in the 1.5°C scenario also affect sectoral employment. Figure 29 illustrates absolute worldwide employment in the Reference and 1.5°C scenarios by sector (left panel), and the change in the 1.5°C scenario relative to the Reference scenario in 2050 (right panel).[12] Globally, jobs are mainly concentrated in services, followed by manufacturing, agriculture and construction. Electricity (including power generation and transmission and distribution) and fossil fuels represent a smaller share of total global employment.

With the decrease in production due to lower demand, fossil fuel sectors face a substantial contraction in the number of jobs by 2050 in the 1.5°C scenario relative to the Reference scenario. However, at the global level, fossil fuel sectors make up a small share of overall employment, as represented in the stacked bar graph (Figure 29 left), decreasing from 1.1% in 2020 to 0.8% and 0.2% in 2050 in the Reference and the 1.5°C scenarios, respectively. The impacts on fossil fuel-related jobs are offset by the job creation from to the deployment of renewables and greater electrification. Because of the transition to a low-carbon economy, there are more job opportunities in the electricity sector (pink bar), agriculture (green) and construction (blue) under the 1.5°C scenario compared to the Reference, as indicated in Figure 29 (right).

Figure 29. Absolute worldwide employment in the Reference in millions of jobs in the Reference and 1.5°C scenarios by sector over 2020-50 (left). Relative change by sector in the 1.5°C scenario from the Reference scenario in 2050.



Source: JRC-GEM-E3.

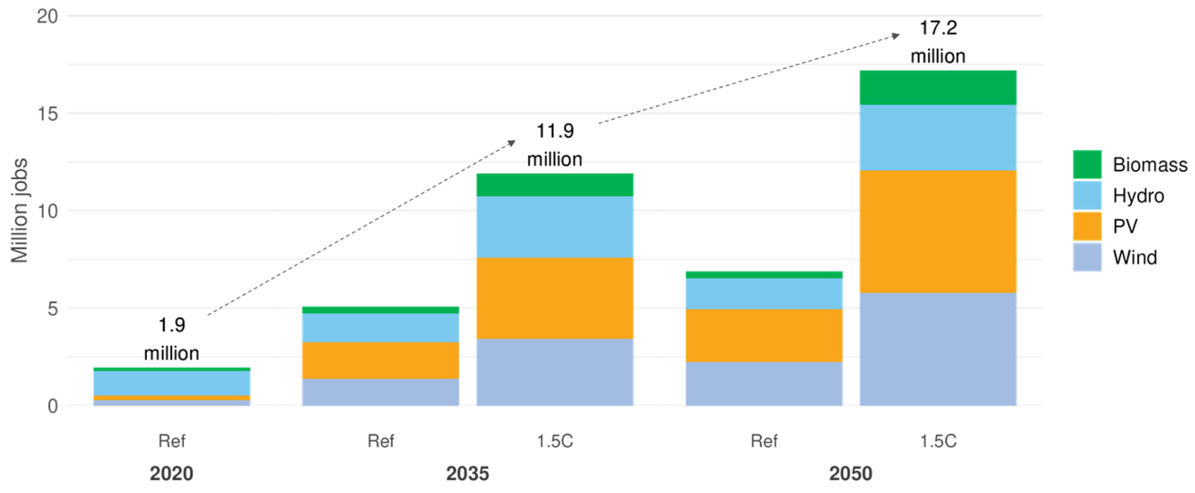
The shift in the power generation mix in the 1.5°C scenario from coal- and gas-fired generation towards wind, solar PV and biomass generation has impacts on employment, creating job opportunities related to the deployment of renewable technologies. Figure 30 shows the projected number of jobs in selected renewable power generation technologies in the 1.5°C scenario over the 2020-2050 period, including jobs related to the manufacture and deployment of these technologies[13]. Compared to the Reference scenario, 10.3 million additional jobs are created under the 1.5°C scenario by 2050. Over time, total jobs related to those technologies

[12] Note that the same level of long-run unemployment is assumed in both scenarios, leading to aggregate employment being equal in the Reference and the 1.5°C scenario. Annex 4 provides an overview of the assumptions for the construction of the JRC-GEM-E3 Reference scenario, including those related to employment.

[13] Previous work (Garaffa et al., 2023; Vandyck et al., 2016) has assessed the additional number of direct jobs (in operation and maintenance) of power generation technologies.

are projected to grow from 1.9 million in 2020 to 11.9 million in 2035, reaching 17.2 million jobs in 2050 in the 1.5°C scenario, with the bulk resulting from wind and solar PV deployment.

Figure 30. Total jobs related to the manufacturing, deployment, operation and maintenance of selected power generation technologies in the Reference and 1.5°C scenarios over 2020-50.



Source: JRC-GEM-E3.

7 Conclusions

This report provides a comprehensive analysis of countries' emission reduction goals, and the gap between those goals and what is required to be on a 1.5°C-aligned pathway. Although global emissions peak in the near term, there remain significant ambition and implementation gaps that need to be addressed to stay on track for the global target of limiting climate change to 1.5°C above pre-industrial levels by the end of the century. As countries prepare their next round of Nationally Determined Contributions, the next decade represents a decisive period for climate action, with 2030 and 2035 marking key milestones in emission reductions.

Achieving COP28's ambitious global targets by 2030, tripling renewable energy capacity and doubling energy efficiency improvement rate, is the first crucial milestone. Missing these targets risks increasing peak warming and increasing the impacts of climate change, even if a 1.5°C end-of-century goal is achieved.

By 2035, NDCs can align more closely with 1.5°C-compatible emission levels, targeting a 56% global emissions reduction from 2022 levels. Four common strategies are outlined in this report to guide the global transition to a low-carbon economy in a cost-efficient manner, providing a robust roadmap for policymakers and investors alike:

- **Producing clean electricity**: in 2035 in the 1.5°C scenario, all G20 countries have a share of non-fossil electricity generation lower than 55%.
- **Electrifying end-uses and improving energy efficiency:** in 2035 in the 1.5°C scenario, G20 countries achieve at least 35% electrification in final energy consumption, with continued improvements in energy efficiency.
- **Decarbonising hard-to-abate sectors**: in 2035 in the 1.5°C scenario, G20 countries capture approximately 10% of industrial emissions through carbon capture and storage (CCS) technologies and expand hydrogen production capacities for longer term mitigation.
- **Scaling-up negative emissions**: in the 1.5°C scenario, G20 countries stop deforestation and reverse it with afforestation, while expanding the deployment of novel negative emissions technologies such as direct air capture of CO_2 for longer term mitigation.

Achieving these milestones requires tailored strategies, as emission reduction contributions from each strategy vary by national context. For example, countries with carbon-intensive power sectors see more emission reductions from producing clean electricity, while nations with large electrifiable end-uses and substantial hard-to-abate sectors see greater impacts from electrification and CCS. Countries with large carbon sink potential see immediate and significant emissions reductions coming from LULUFC.

Macroeconomic analysis indicates that the overall impacts of pursuing the 1.5°C pathway on global GDP, employment and investment are modest. The shift away from fossil fuels primarily impacts carbon-intensive sectors, while low-carbon industries and associated supply chains expand, driving growth and job creation. The overall small cost of decarbonisation is also particularly modest when contrasted with the potentially higher costs of inaction, which could lead to severe climate impacts and increased adaptation expenses.

This report is supplemented with detailed materials at the country level. Annex 1 presents country sheets for selected G20 economies, presenting economy-wide and sectoral energy and emission trajectories, key indicators across the 4 main strategies to decarbonise, as well as employment impacts over time. Additionally, detailed energy and emission balances for all scenarios, as well as the Multi-Regional Input-Output tables of the world economy serving as macro-economic baseline are available for download.

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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
DAC	Direct Air CO_2 Capture
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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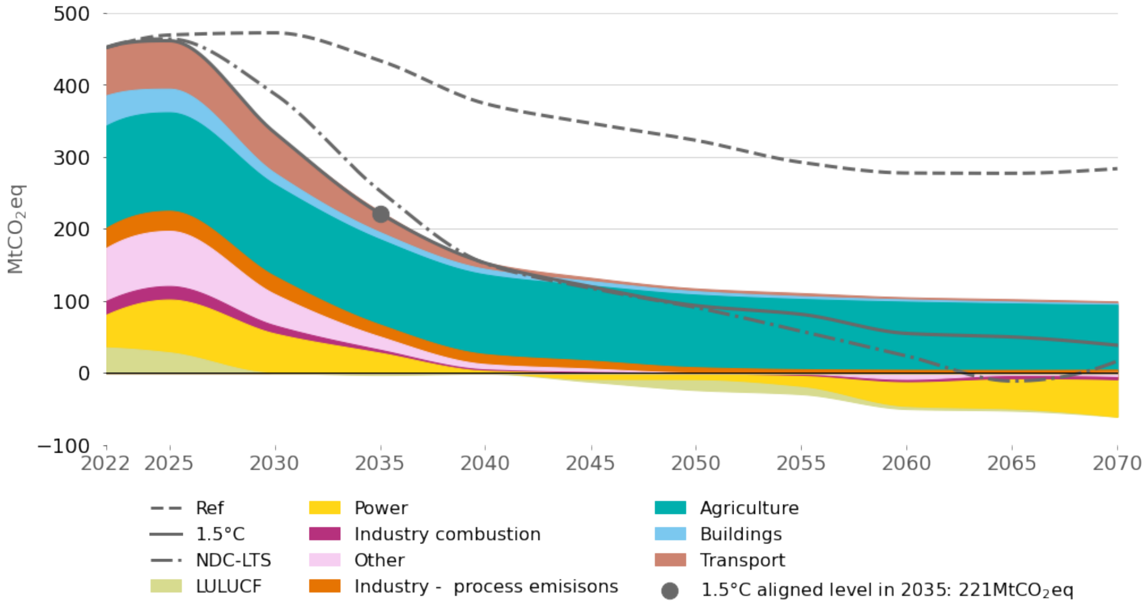
Annexes

Annex 1: GECO 2024 Country Sheets

Argentina

Argentina's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Argentina



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Argentina's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**452**	**221**	**-51%**
Power	45	28	-38%
Industry	47	21	-56%
Transport	62	25	-59%
Buildings	30	2	-93%
LULUCF	35	-3	-109%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

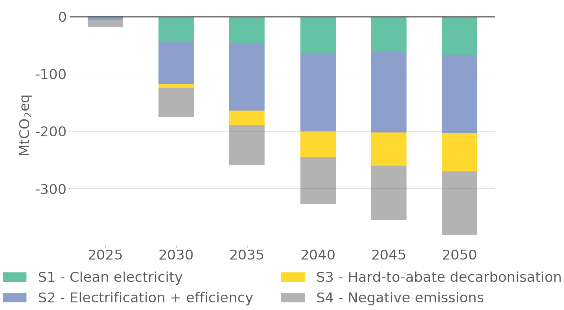
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

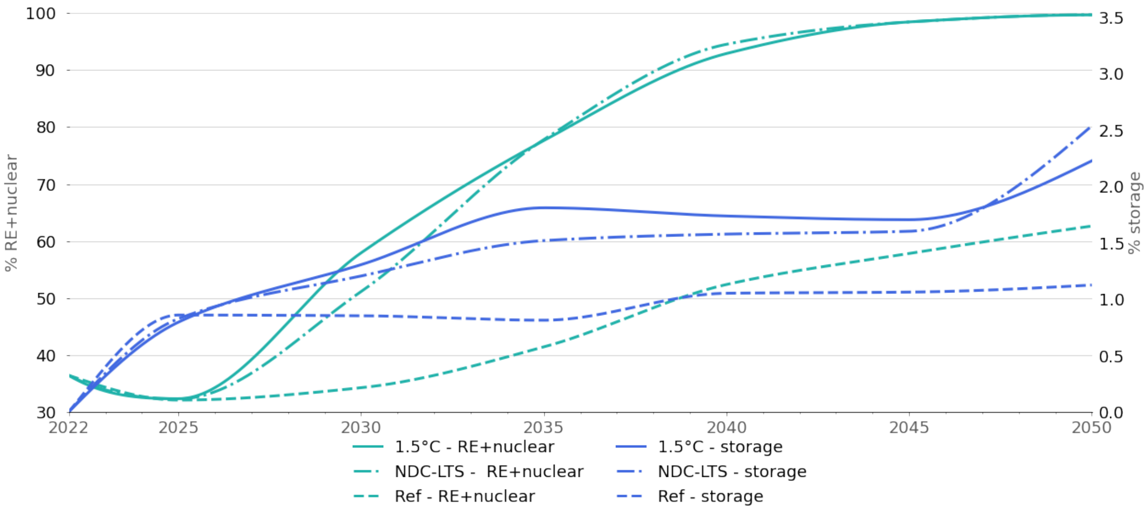
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Argentina



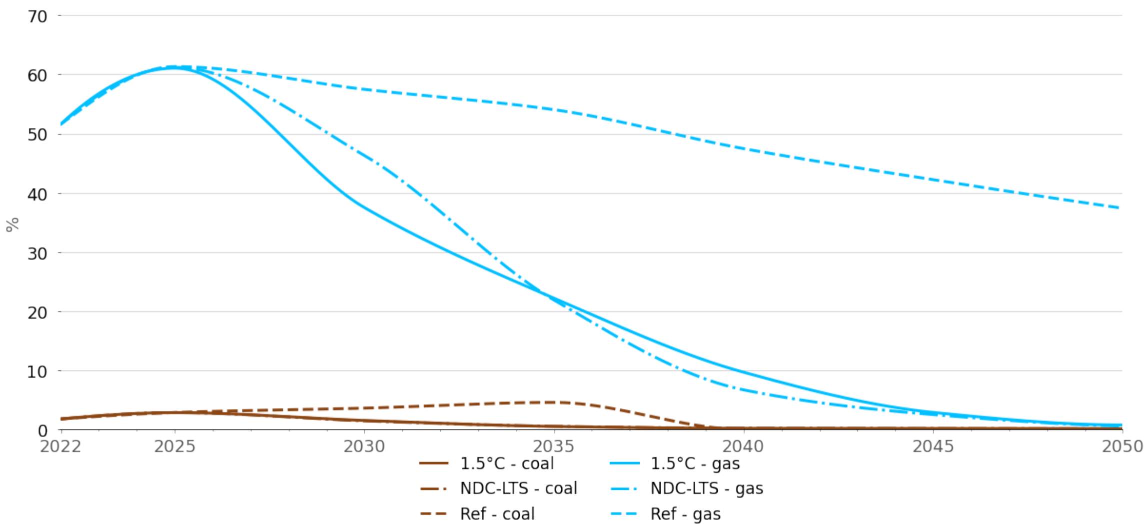
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Argentina



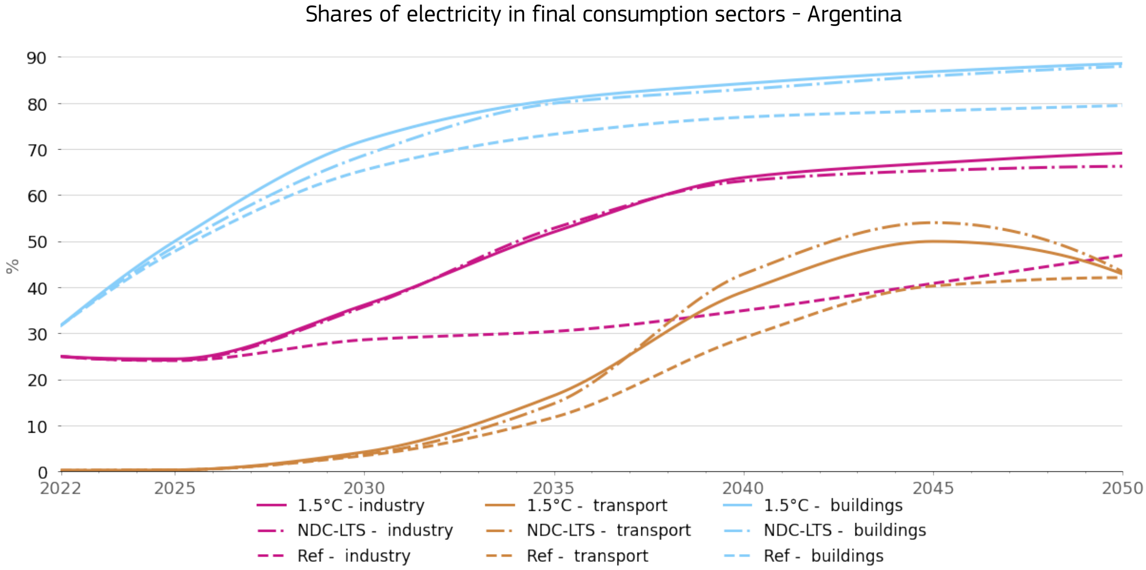
Shares of coal & gas power generation technologies - Argentina

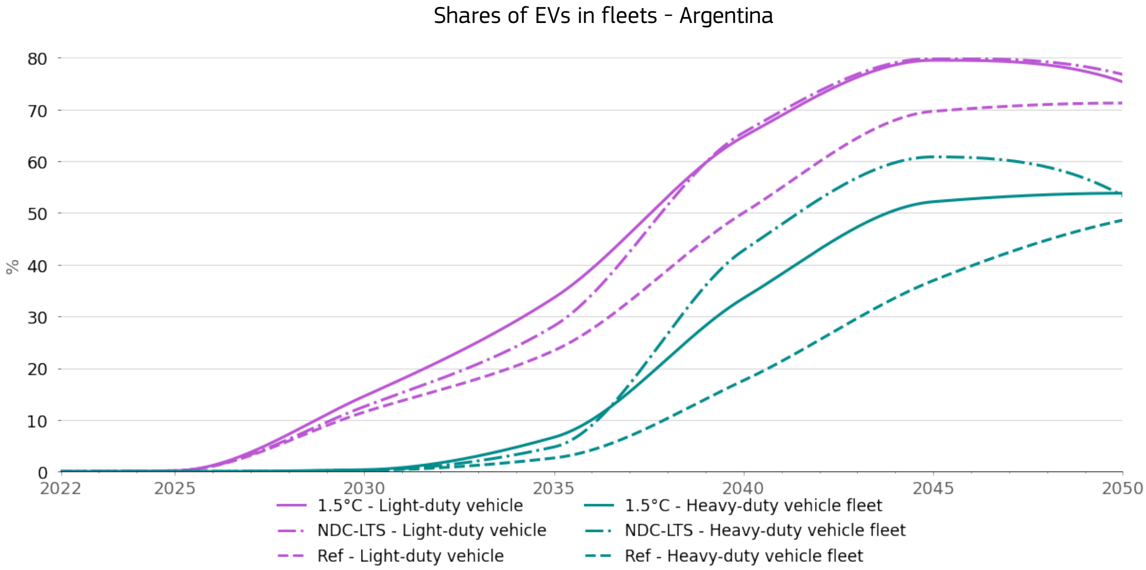


Clean electricity indicators in 1.5ºC scenario - Argentina

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	0	5	6	6	6
Wind+solar share of annual additions	%	2%	68%	71%	71%	71%
Annual additions of storage	GW	0	0.32	0.40	0.52	0.72
Carbon content of electricity	gCO_2/MWh	300	199	74	6	-18
Emissions from power sector	$MtCO_2eq$	45	54	28	3	-8
First year of no unabated coal generation				2034		

Strategy 2 – Electrify end-uses and improve energy efficiency



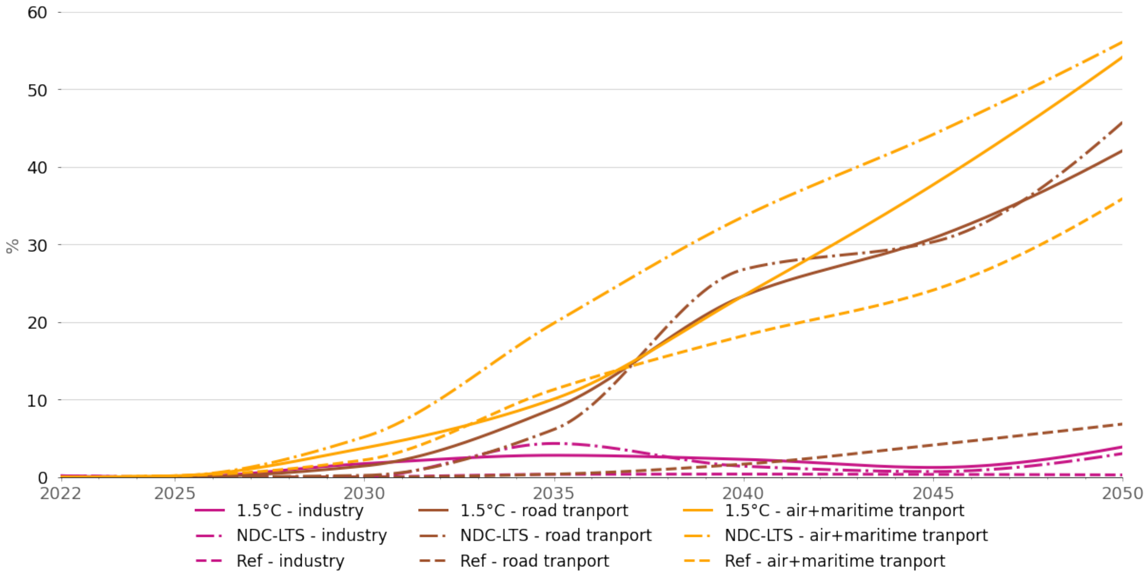


Electrification indicators in 1.5ºC scenario - Argentina

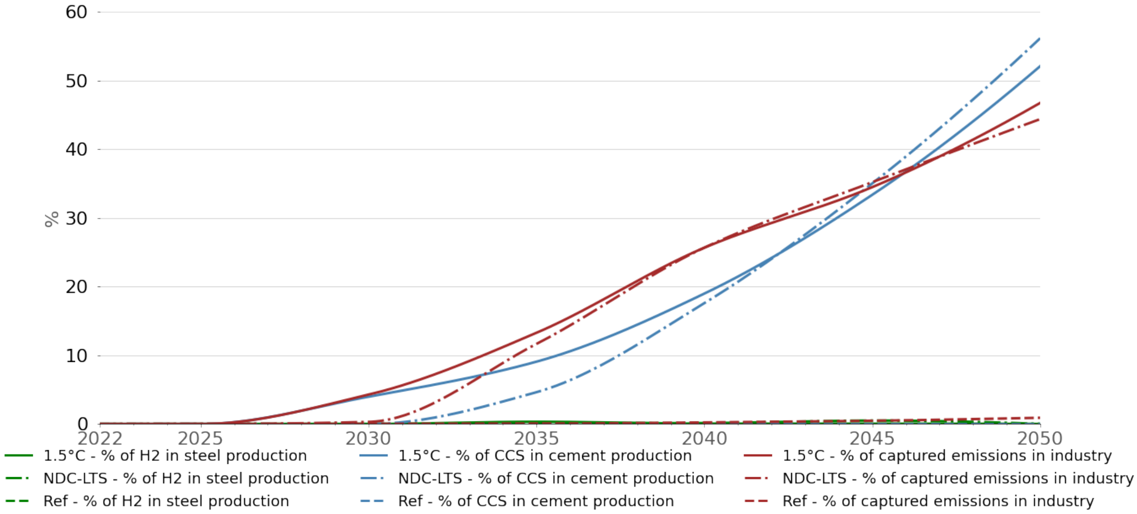
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	0	1103	2049	1955	2178
Share of EVs in total car sales	%	0%	37%	75%	74%	60%
Annual sales of EV HDV	thousands	0	0	0	6	66
Share of EVs in total HDV sales	%	0%	0%	0%	4%	37%
Annual sales of small-scale heat pumps in buildings	GW	2	6	1	5	1
Annual sales of large-scale heat pumps in industry	GW	0	19	23	8	31
Share of heat pumps in buildings heating demand	%	0%	29%	40%	57%	72%

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - Argentina



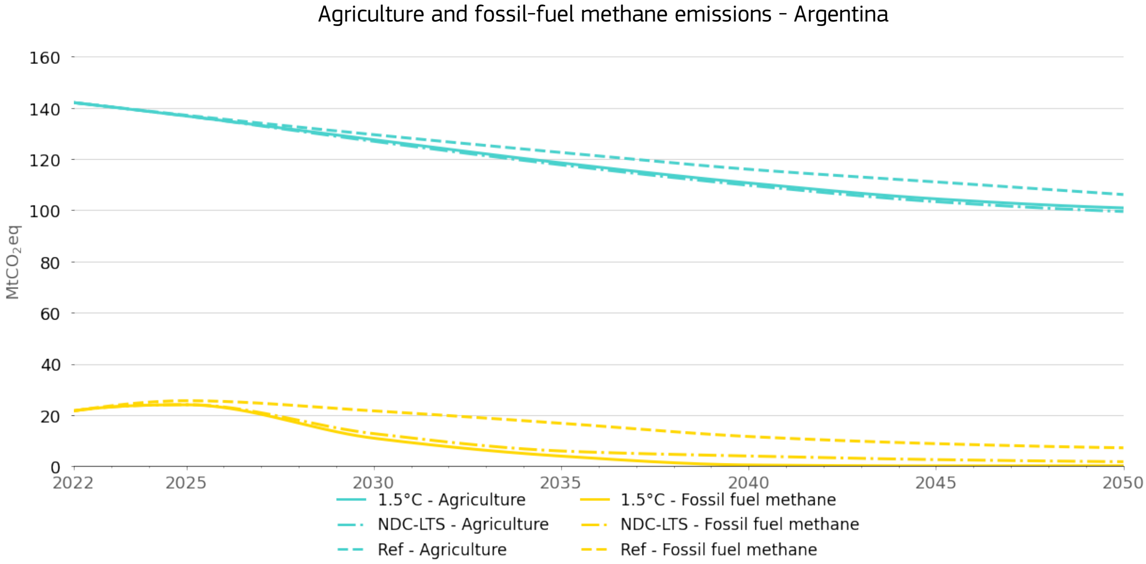
Penetration of low-emissions industrial production - Argentina

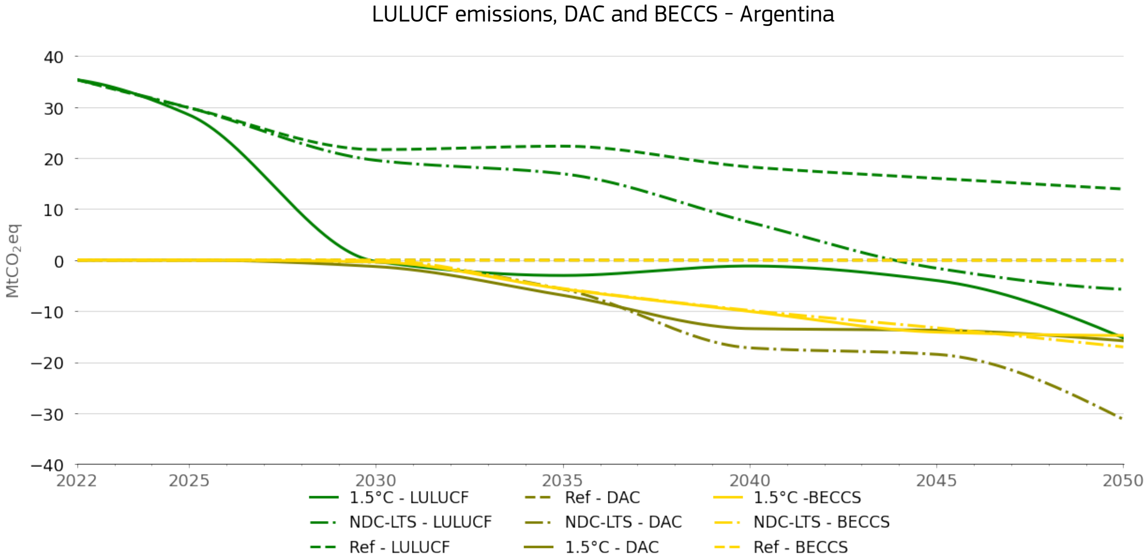


Non-electricity decarbonisation indicators in 1.5ºC scenario - Argentina

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	661	1544	1736	2928
Domestic production of gaseous e-fuels	bcm	0	0	2	1	6
Domestic production of liquid e-fuels	barrels	0	1588	7523	15356	16346
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	12839	28969	31773	51038
Yearly additions of electrolysers	MW	0	1931	2010	2481	3529

Strategy 4 – Scale-up negative emissions and reduce residual emissions



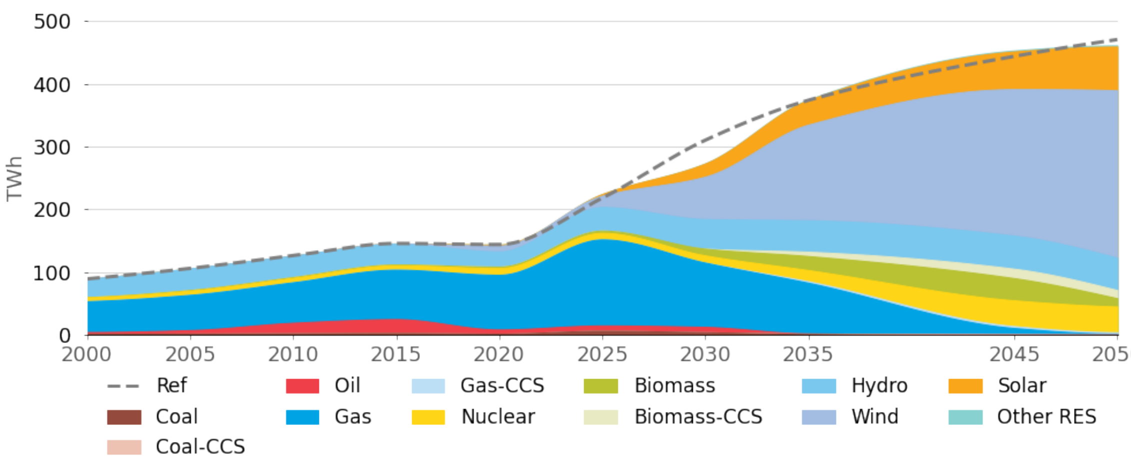


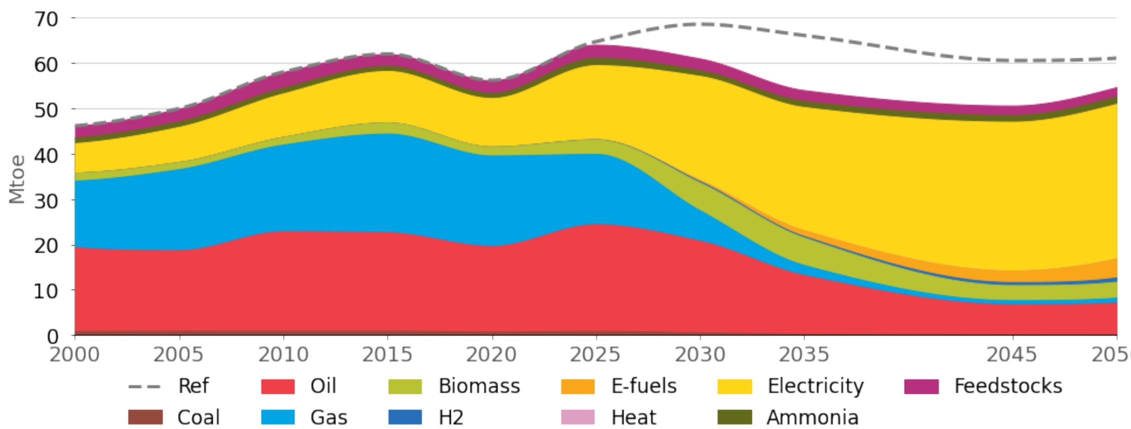
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Argentina

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	7	13	16
Biomass emissions captured	$MtCO_2eq$	0	0	6	10	15
LULUCF emissions	$MtCO_2eq$	35	0	-3	-1	-15
Agriculture emissions	$MtCO_2eq$	142	128	118	111	101
Methane emissions	$MtCO_2eq$	39	24	13	10	7
Methane emission from fossil fuel production	$MtCO_2eq$	22	11	4	0	0

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

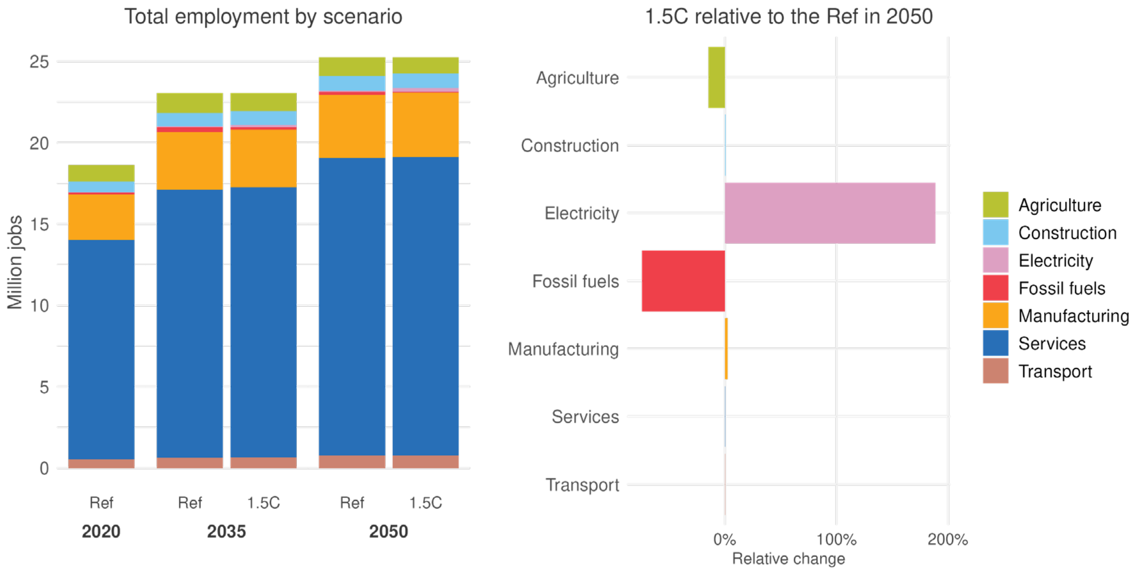
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	3%	-24%	-56%
Annual energy import bill	billion USD	-1	-14	-27
Air pollution emissions - PM2.5	Mt	659	538	405
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	2	1
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	23%	41%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	2	5
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	51%	95%

Labour market dynamics

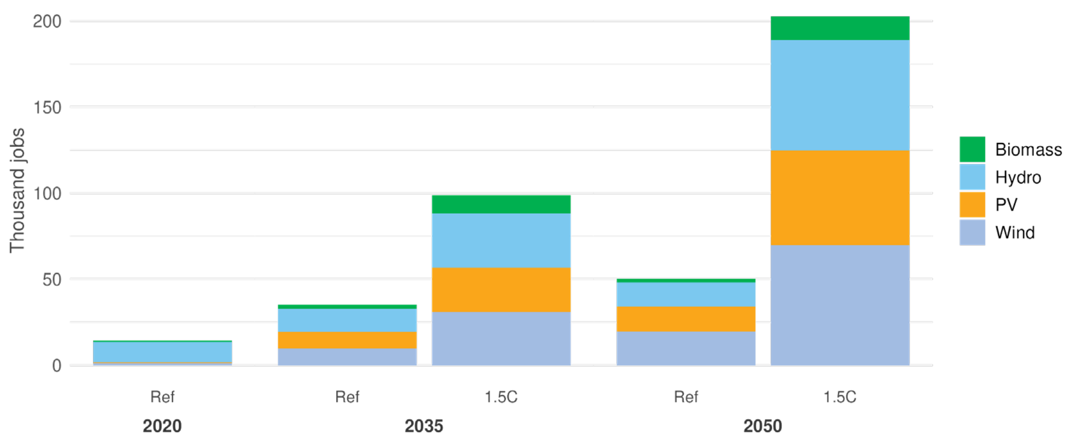
These graphs show the breakdown of employment in Argentina, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Argentina



Note: Electricity includes all power generation technologies as well as transmission and distribution.

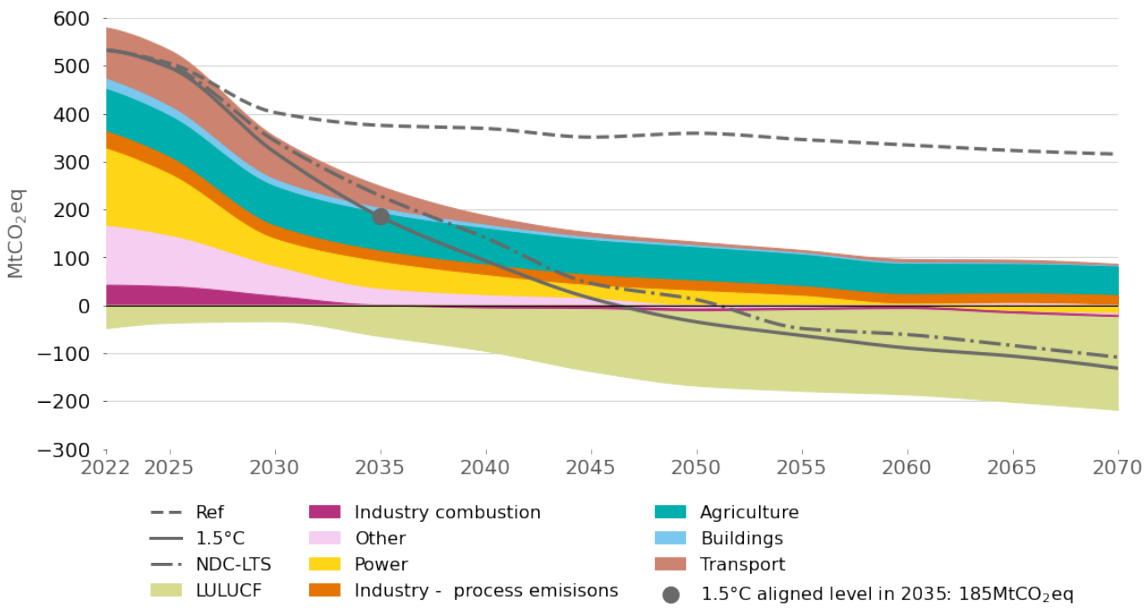
Jobs in renewable technologies by scenario – Argentina



Australia

Australia's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Australia



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Australia's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**533**	**185**	**-65%**
Power	161	57	-65%
Industry	79	24	-69%
Transport	89	37	-58%
Buildings	15	6	-59%
LULUCF	-47	-64	35%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

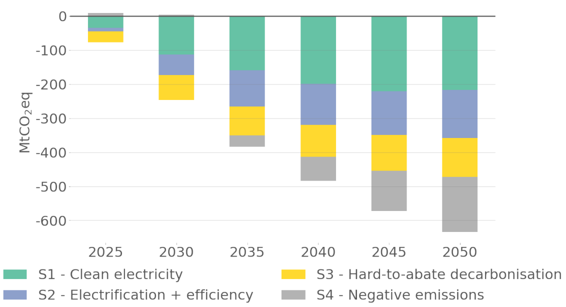
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

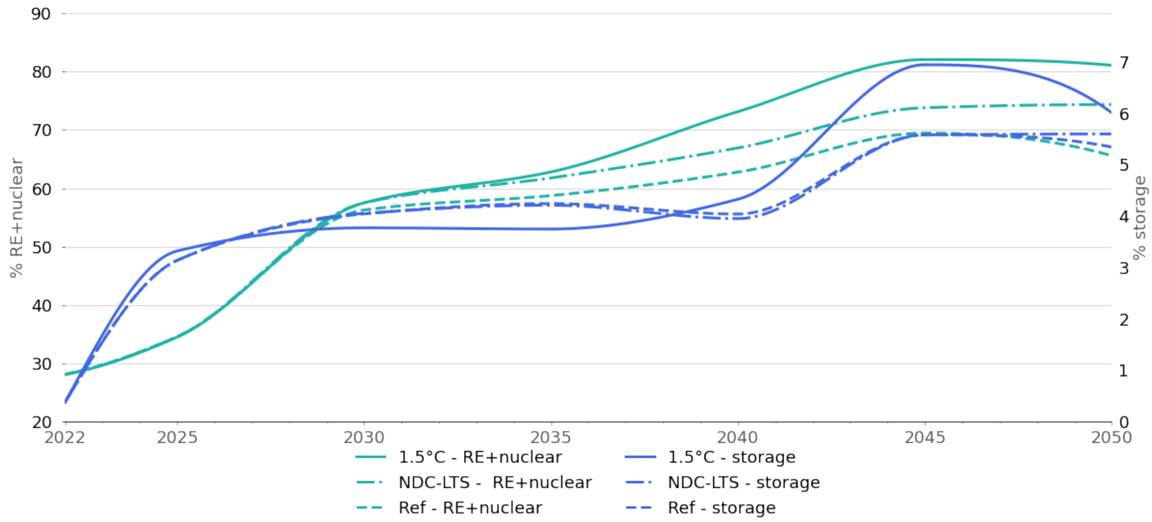
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Australia



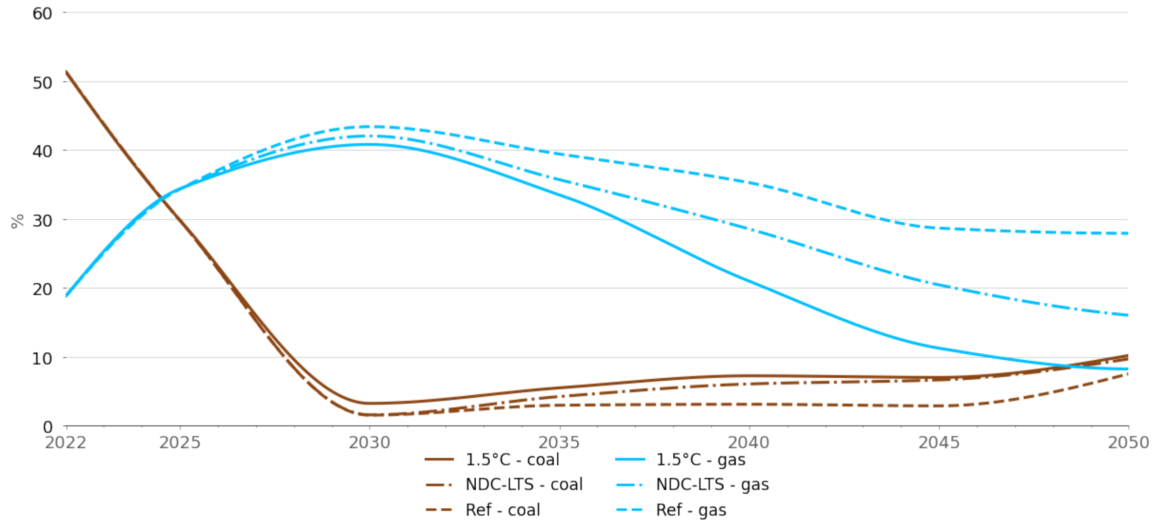
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Australia



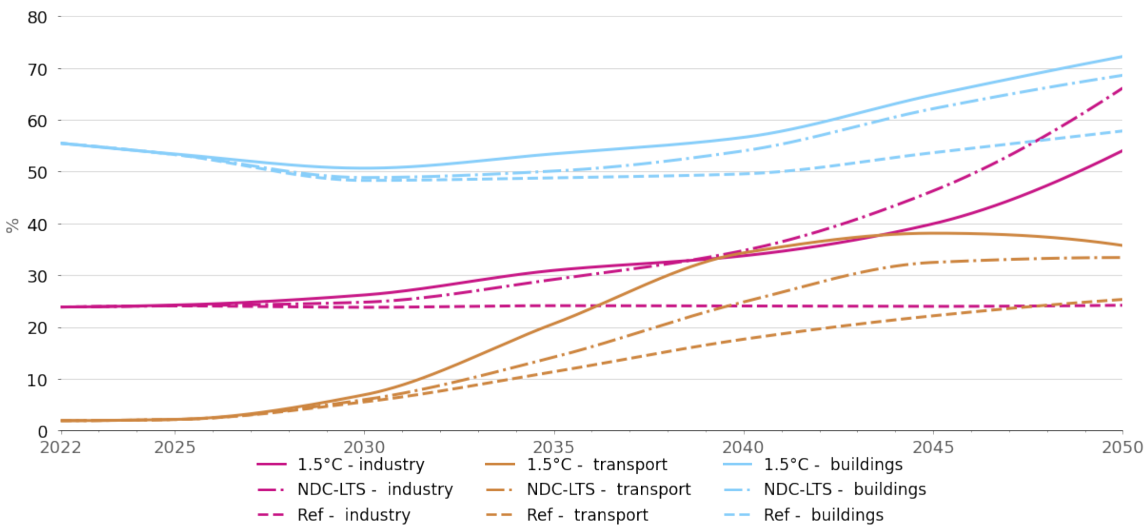
Shares of coal & gas power generation technologies - Australia

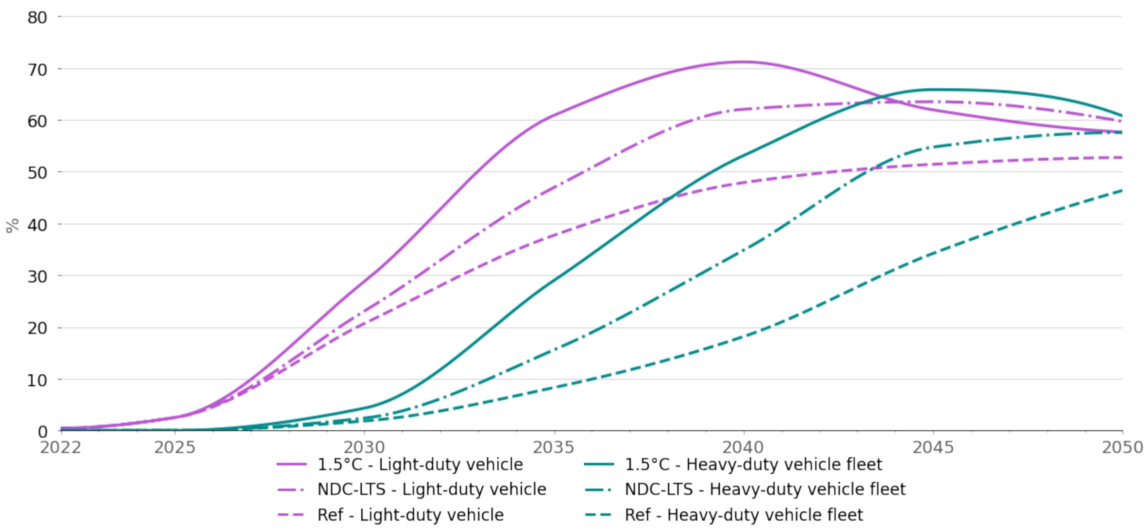


Clean electricity indicators in 1.5ºC scenario - Australia

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	4	5	6	8	9
Wind+solar share of annual additions	%	83%	69%	71%	71%	68%
Annual additions of storage	GW	0.31	0.42	0.72	1.10	1.49
Carbon content of electricity	gCO_2/MWh	619	218	188	122	69
Emissions from power sector	$MtCO_2eq$	161	58	57	42	30
First year of no unabated coal generation				2062		

Strategy 2 – Electrify end-uses and improve energy efficiency

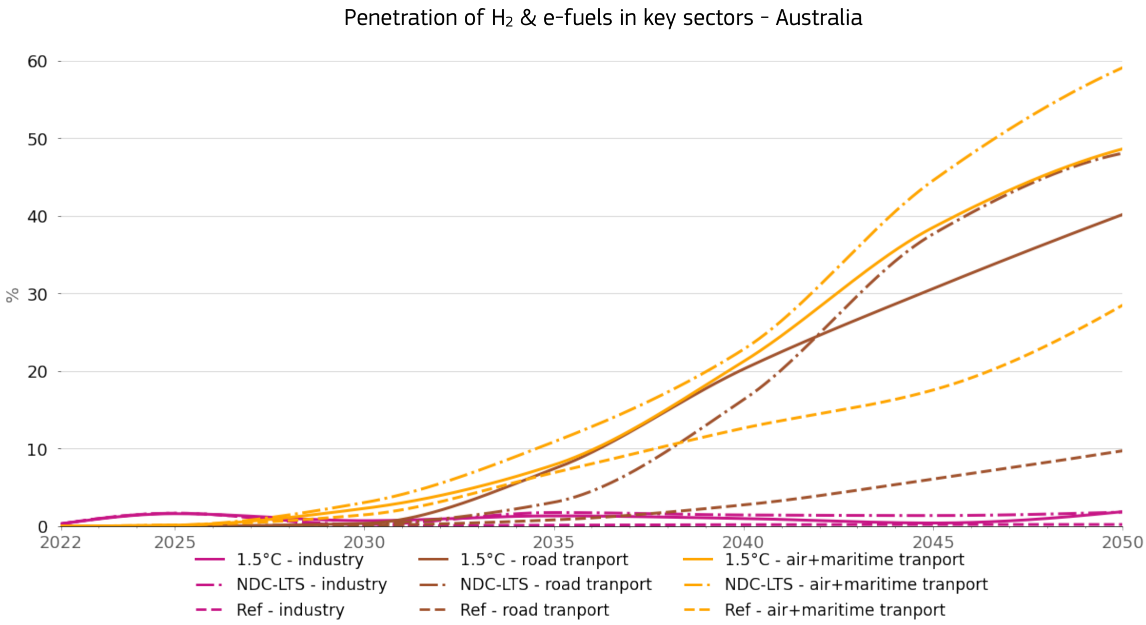


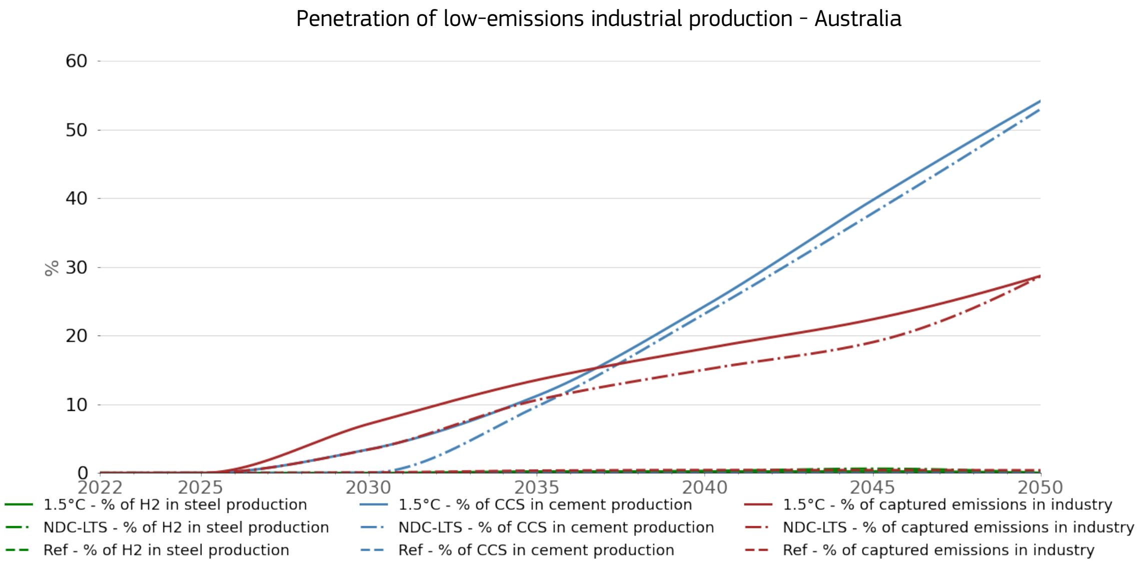


Electrification indicators in 1.5ºC scenario - Australia

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	33	871	1144	1006	961
Share of EVs in total car sales	%	2%	57%	72%	60%	54%
Annual sales of EV HDV	thousands	0	0	1	18	59
Share of EVs in total HDV sales	%	0%	0%	1%	20%	60%
Annual sales of small-scale heat pumps in buildings	GW	7	3	4	2	5
Annual sales of large-scale heat pumps in industry	GW	0	3	5	10	67
Share of heat pumps in buildings heating demand	%	0%	8%	14%	24%	49%

Strategy 3 – Decarbonise hard-to-abate sectors



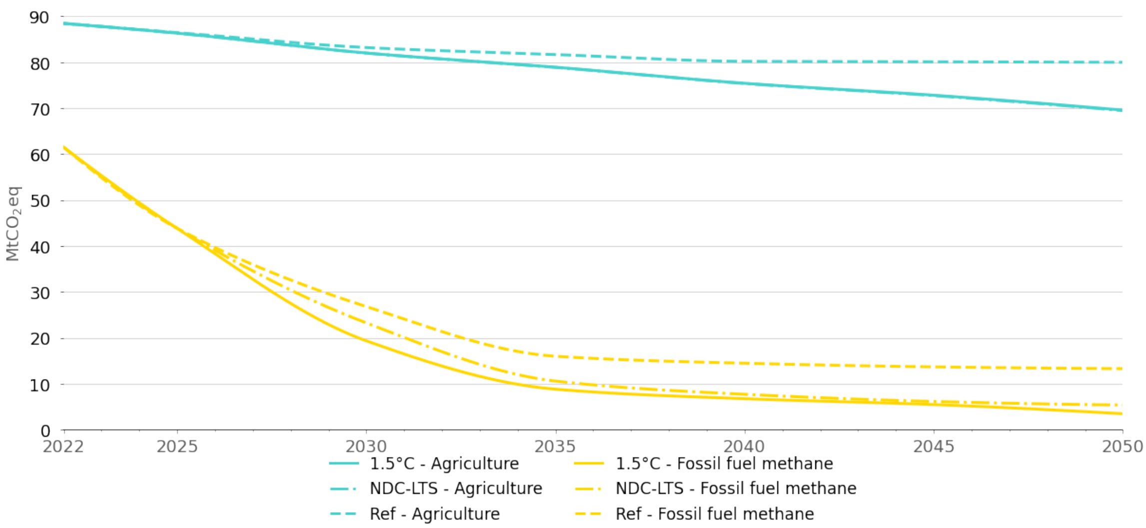


Non-electricity decarbonisation indicators in 1.5ºC scenario - Australia

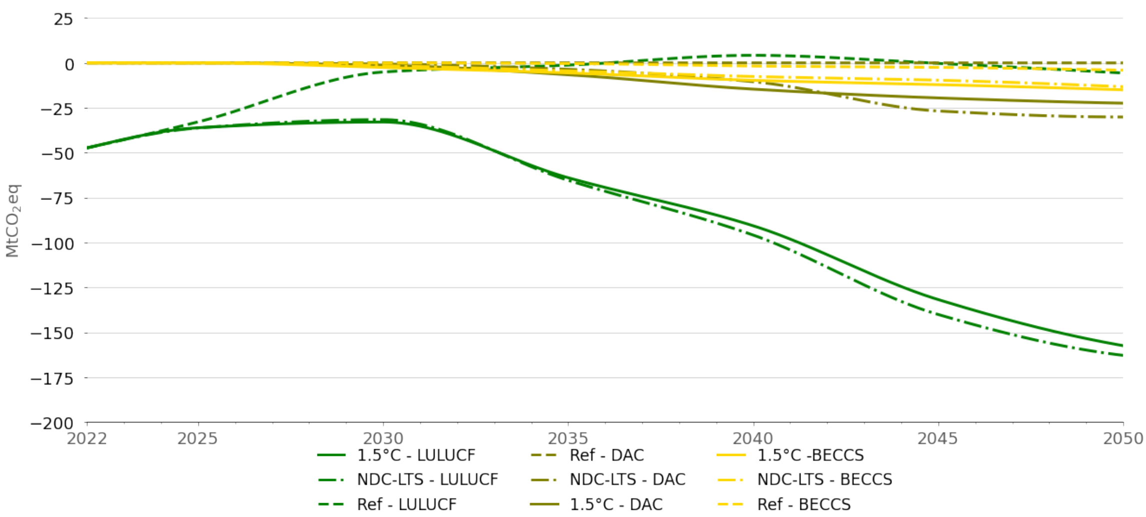
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	84	999	1842	3620
Domestic production of gaseous e-fuels	bcm	0	0	2	1	4
Domestic production of liquid e-fuels	barrels	0	380	7079	16752	4944
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	1871	30550	57716	101729
Yearly additions of electrolysers	MW	0	2736	4468	5193	4428

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - Australia



LULUCF emissions, DAC and BECCS - Australia



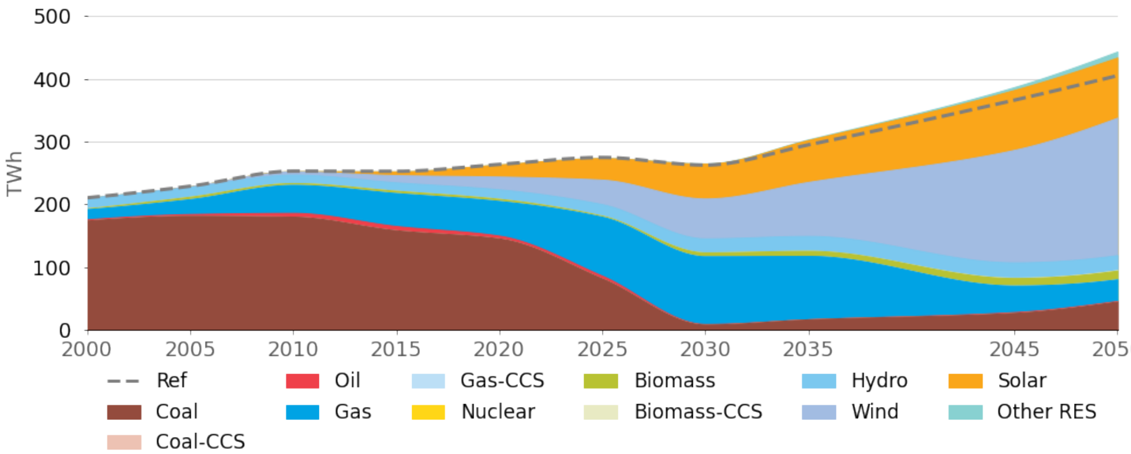
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Australia

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	7	15	22
Biomass emissions captured	$MtCO_2eq$	0	3	6	10	15
LULUCF emissions	$MtCO_2eq$	-47	-33	-64	-91	-157
Agriculture emissions	$MtCO_2eq$	88	82	79	75	70
Methane emissions	$MtCO_2eq$	76	27	13	11	7
Methane emission from fossil fuel production	$MtCO_2eq$	61	19	9	7	3

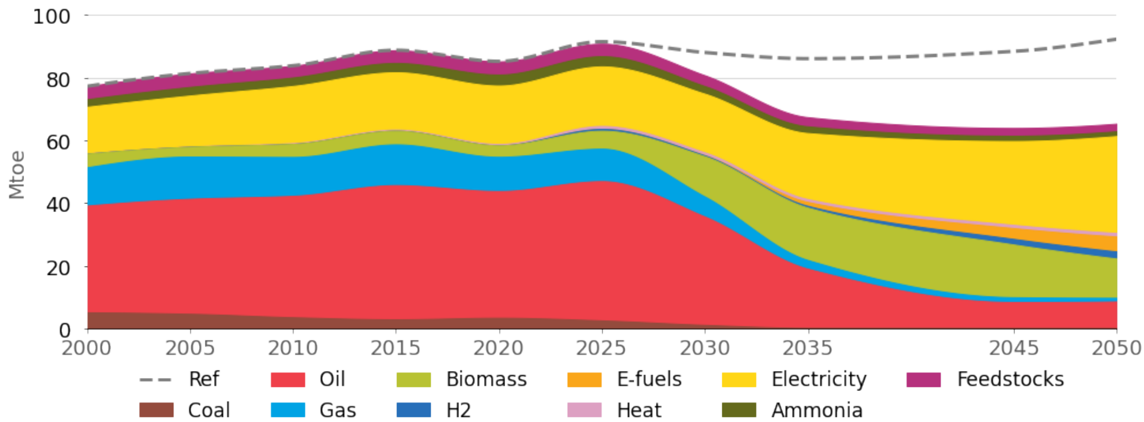
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - Australia



Final energy consumption in the 1.5ºC scenario - Australia



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

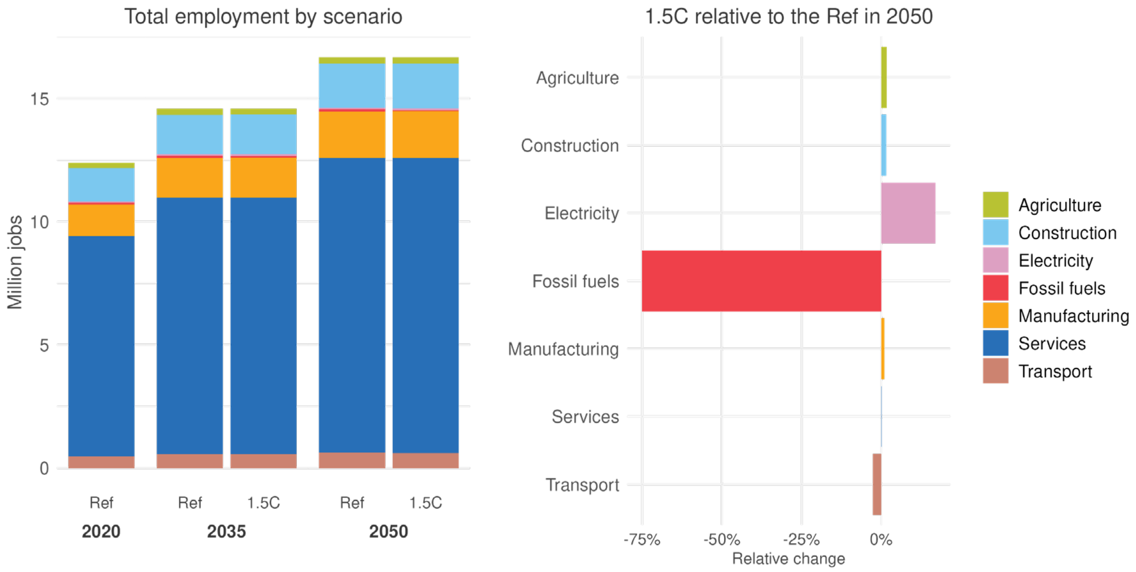
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-232%	-114%	-41%
Annual energy import bill	billion USD	-279	-26	0
Air pollution emissions - PM2.5	Mt	813	702	570
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	-1	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	-16%	10%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	5	9
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	53%	84%

Labour market dynamics

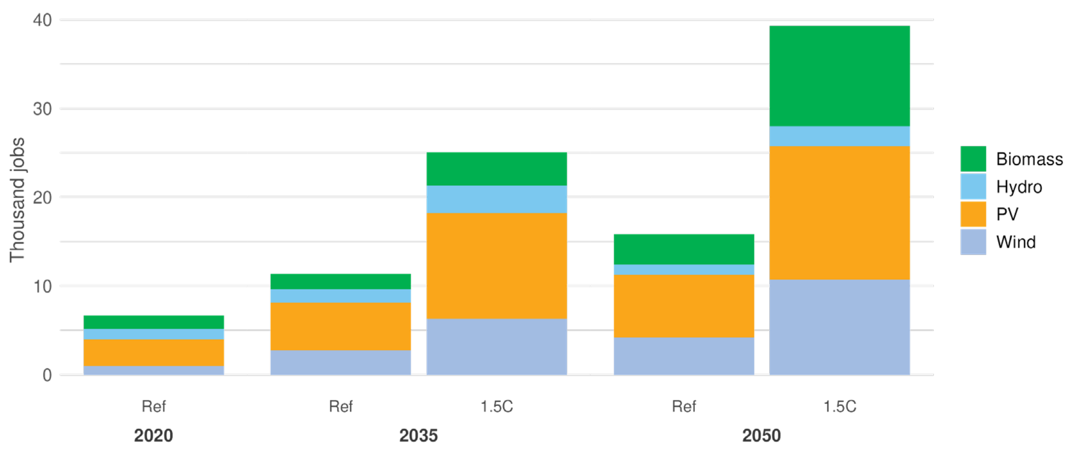
These graphs show the breakdown of employment in Australia, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Australia



Note: Electricity includes all power generation technologies as well as transmission and distribution.

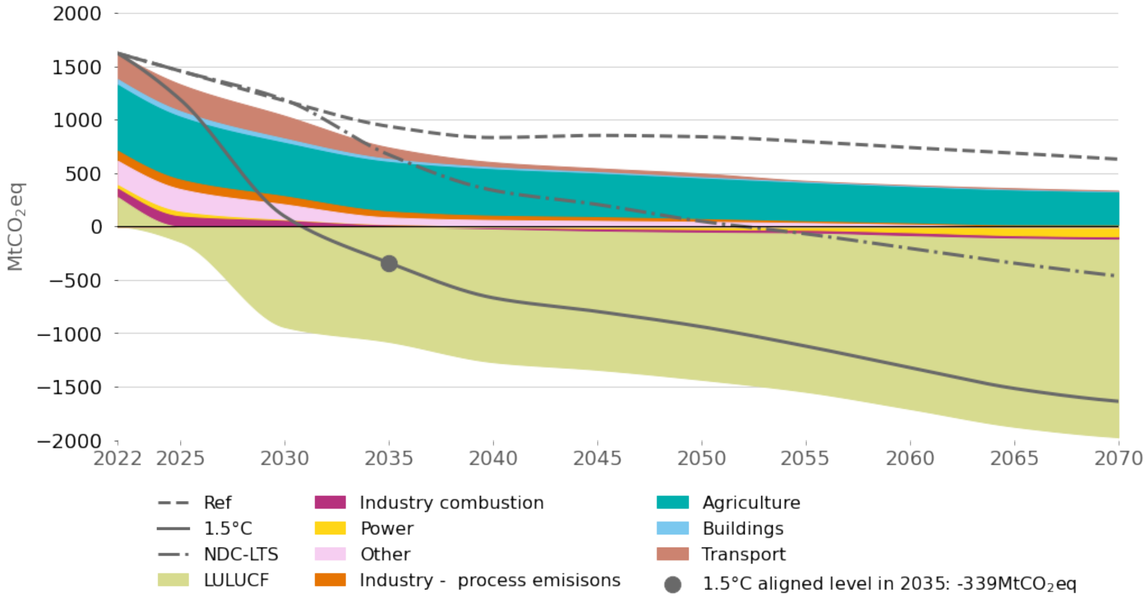
Jobs in renewable technologies by scenario – Australia



Brazil

Brazil's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Brazil



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Brazil's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**1621**	**-340**	**-121%**
Power	33	3	-92%
Industry	174	66	-62%
Transport	223	98	-56%
Buildings	32	15	-52%
LULUCF	274	-1080	-494%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

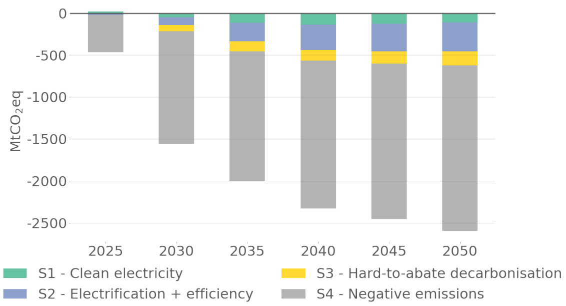
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

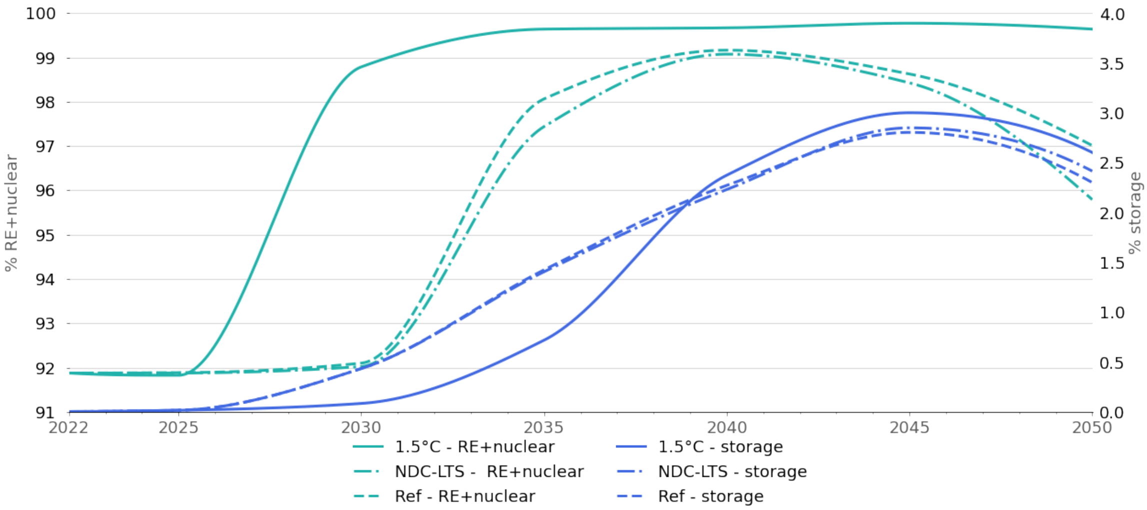
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Brazil



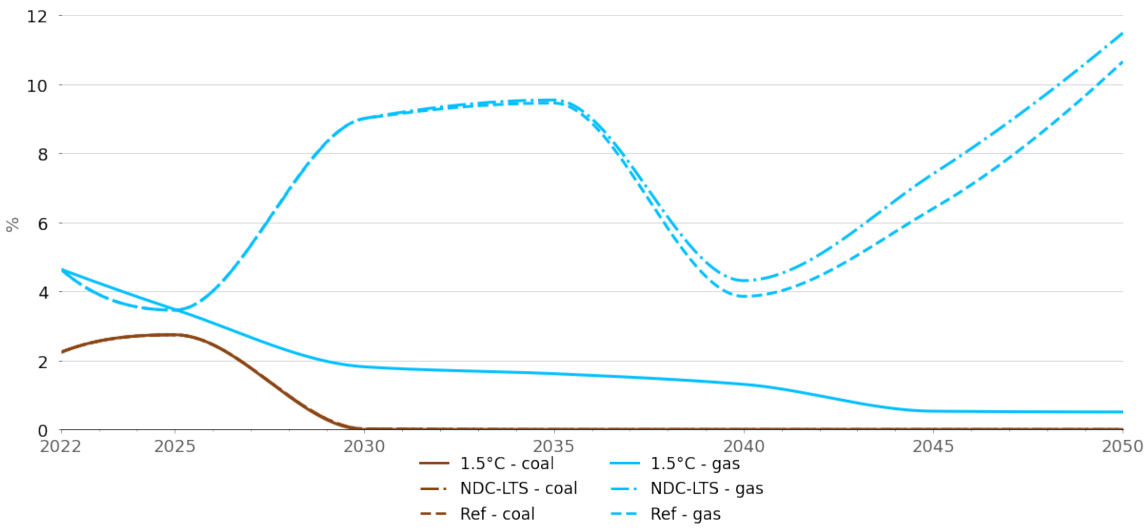
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Brazil



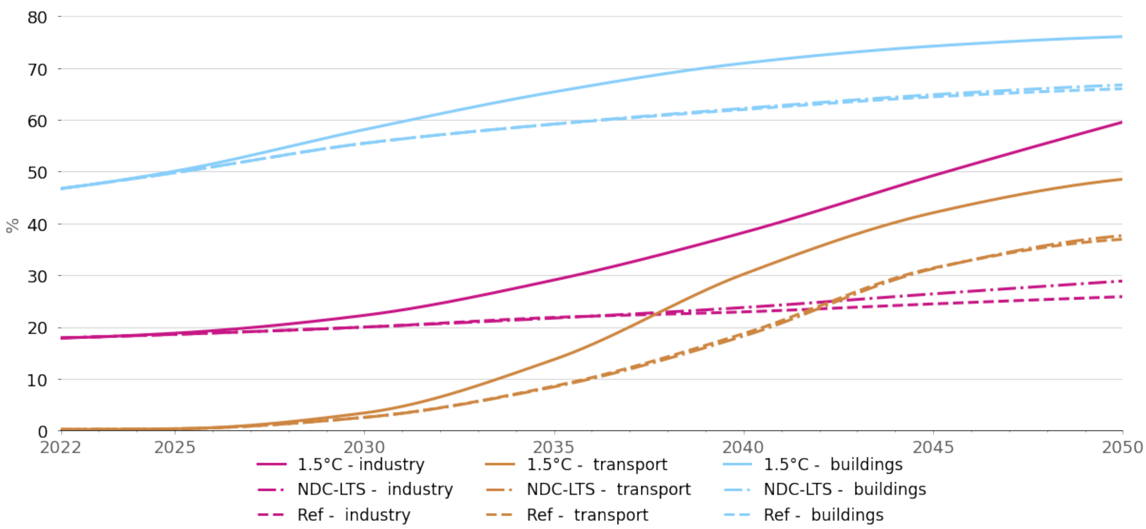
Shares of coal & gas power generation technologies - Brazil

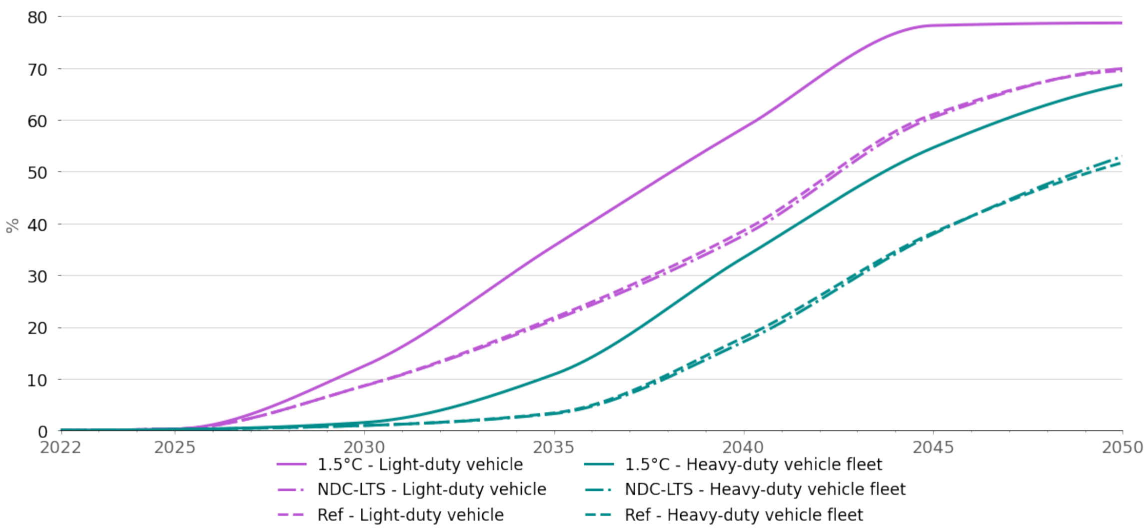


Clean electricity indicators in 1.5ºC scenario - Brazil

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	14	14	16	17	23
Wind+solar share of annual additions	%	84%	75%	67%	61%	66%
Annual additions of storage	GW	0.05	0.58	1.92	2.92	3.62
Carbon content of electricity	gCO_2/MWh	49	7	2	-4	-14
Emissions from power sector	$MtCO_2eq$	33	6	3	-6	-25
First year of no unabated coal generation				2026		

Strategy 2 – Electrify end-uses and improve energy efficiency

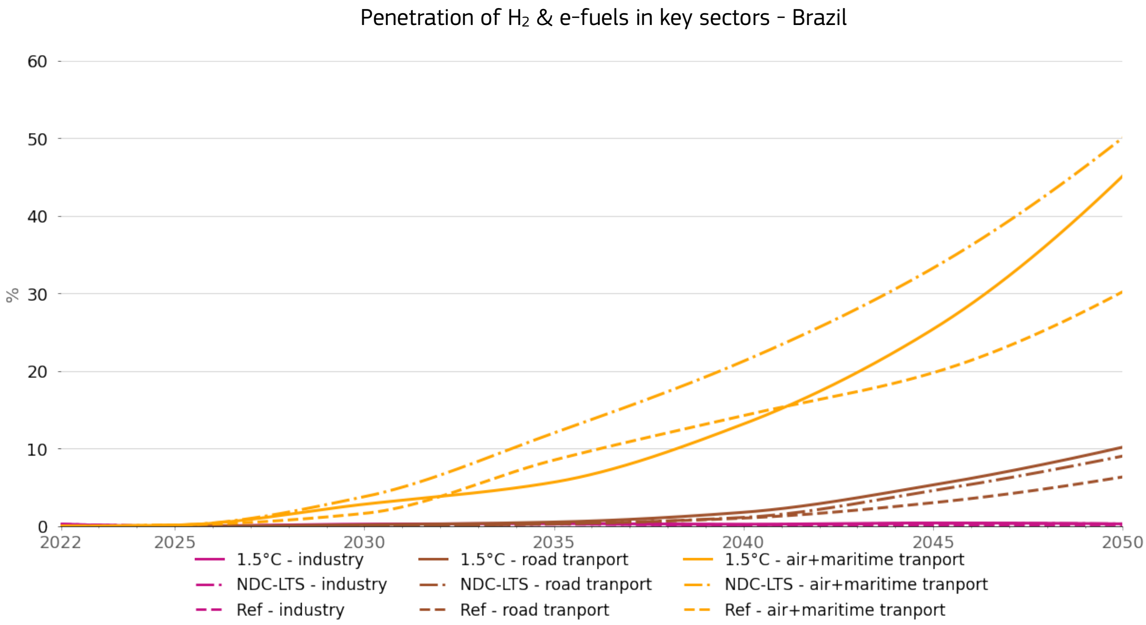


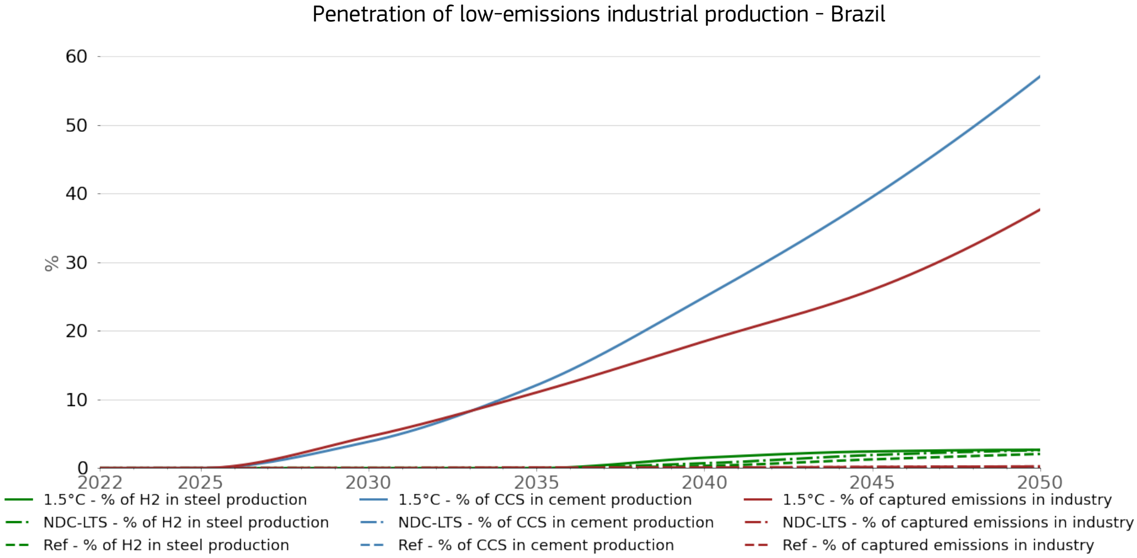


Electrification indicators in 1.5ºC scenario - Brazil

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	8	3439	7496	7945	8616
Share of EVs in total car sales	%	0%	34%	75%	81%	71%
Annual sales of EV HDV	thousands	0	1	4	41	339
Share of EVs in total HDV sales	%	0%	0%	1%	6%	46%
Annual sales of small-scale heat pumps in buildings	GW	0	0	0	1	0
Annual sales of large-scale heat pumps in industry	GW	0	111	114	314	359
Share of heat pumps in buildings heating demand	%	n/a	n/a	n/a	n/a	n/a

Strategy 3 – Decarbonise hard-to-abate sectors

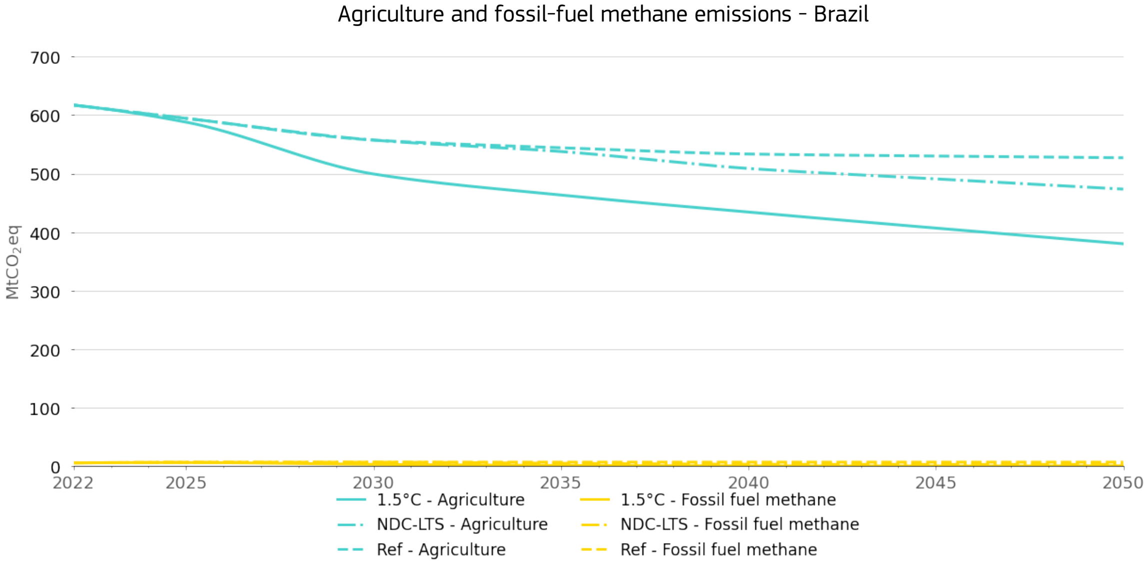


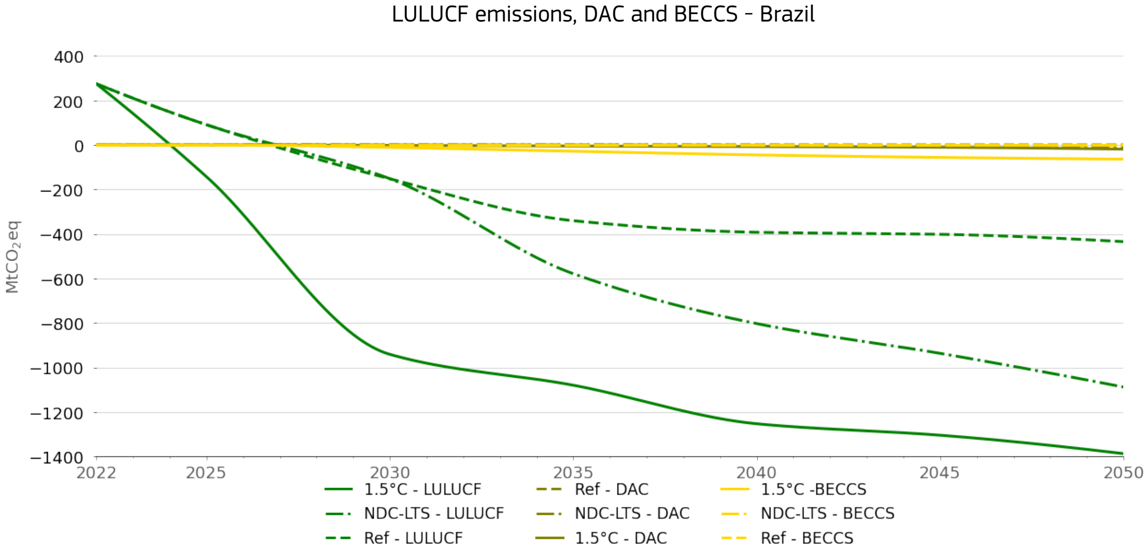


Non-electricity decarbonisation indicators in 1.5ºC scenario - Brazil

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	92	108	102	1117
Domestic production of gaseous e-fuels	bcm	0	1	0	0	1
Domestic production of liquid e-fuels	barrels	0	657	872	898	9068
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	1395	1395	1229	29905
Yearly additions of electrolysers	MW	0	93	0	512	15743

Strategy 4 – Scale-up negative emissions and reduce residual emissions



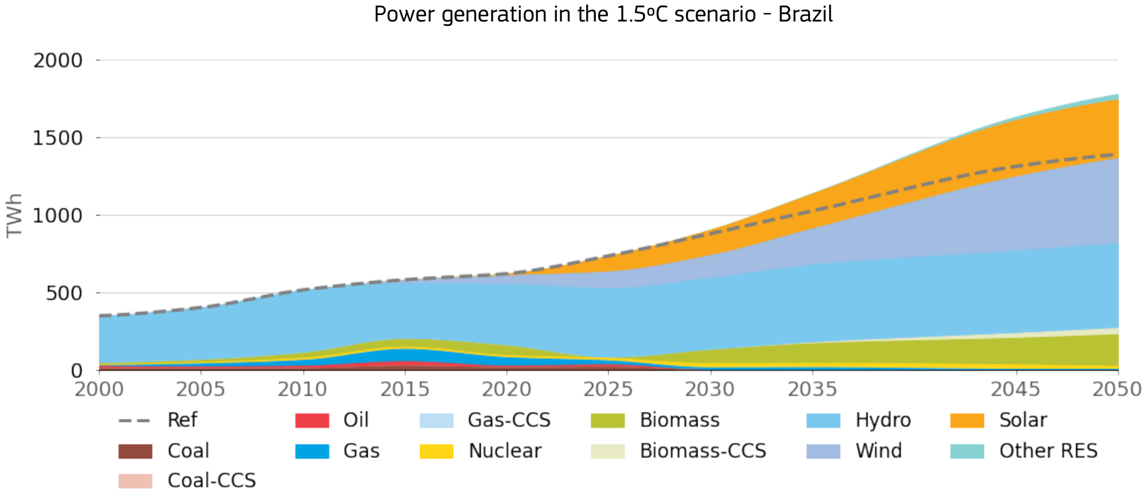


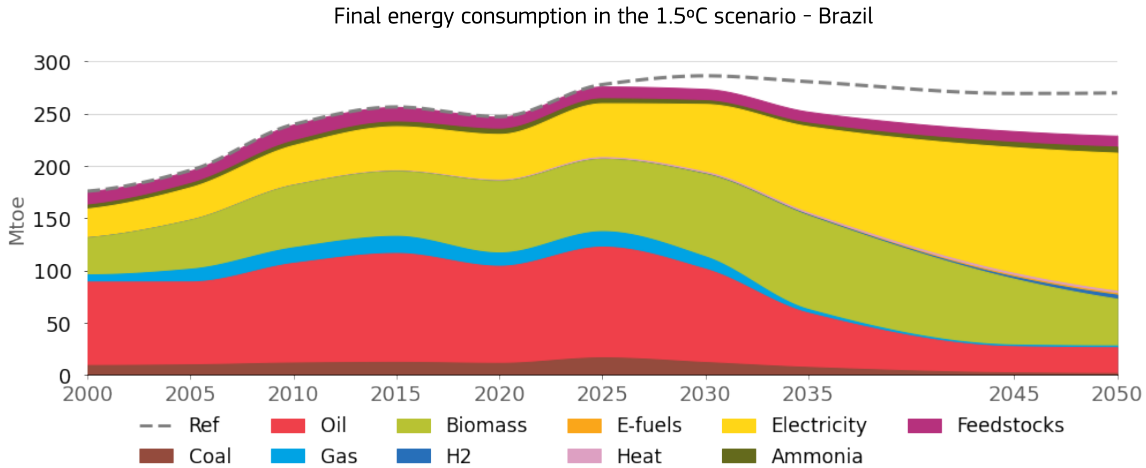
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Brazil

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	2	6	8	19
Biomass emissions captured	$MtCO_2eq$	0	11	29	45	64
LULUCF emissions	$MtCO_2eq$	274	-941	-1080	-1253	-1387
Agriculture emissions	$MtCO_2eq$	617	499	463	434	380
Methane emissions	$MtCO_2eq$	178	112	64	62	47
Methane emission from fossil fuel production	$MtCO_2eq$	6	3	1	1	1

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

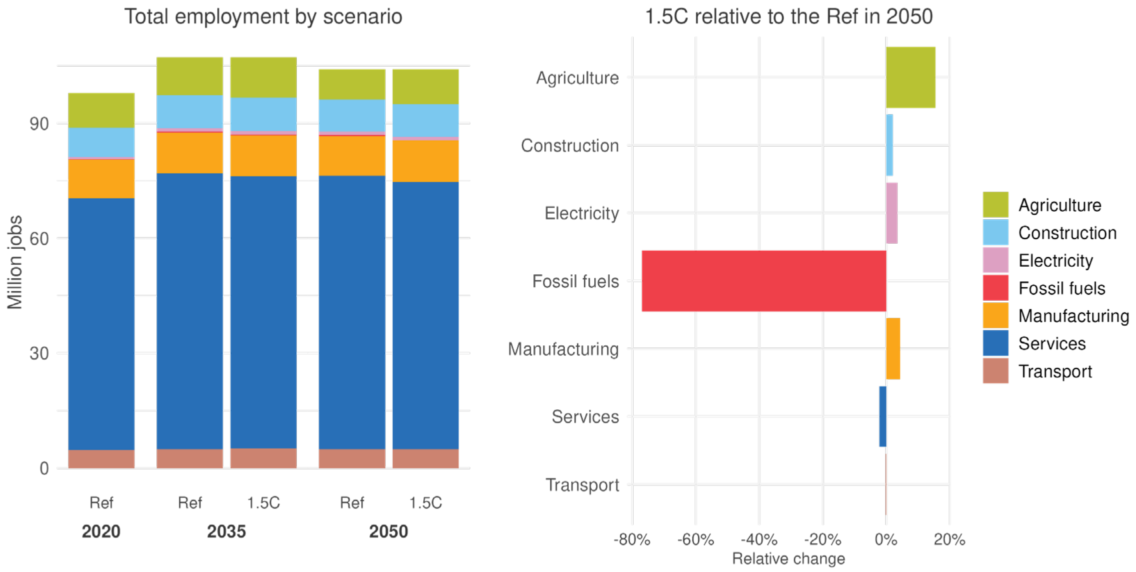
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-6%	-9%	-60%
Annual energy import bill	billion USD	-22	-12	-117
Air pollution emissions - PM2.5	Mt	2381	2027	1287
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	10	5
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	51%	20%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	6	7
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	54%	69%

Labour market dynamics

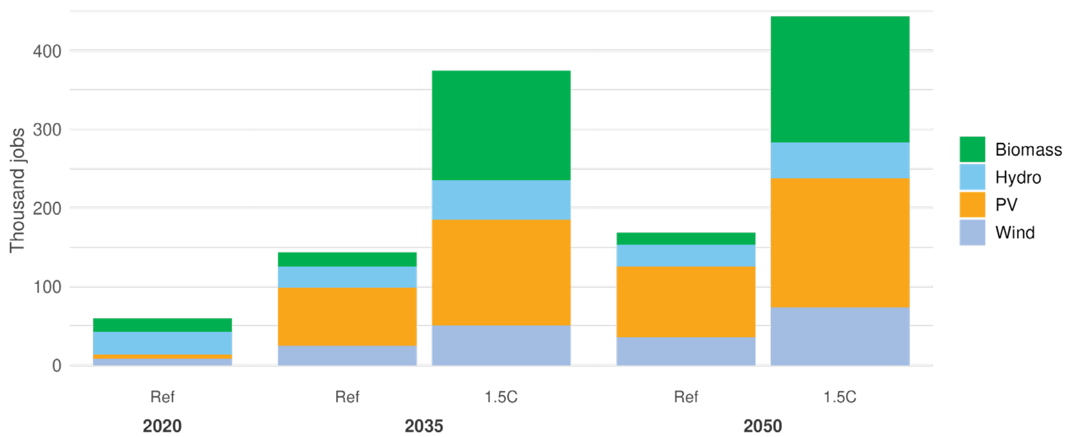
These graphs show the breakdown of employment in Brazil, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Brazil



Note: Electricity includes all power generation technologies as well as transmission and distribution.

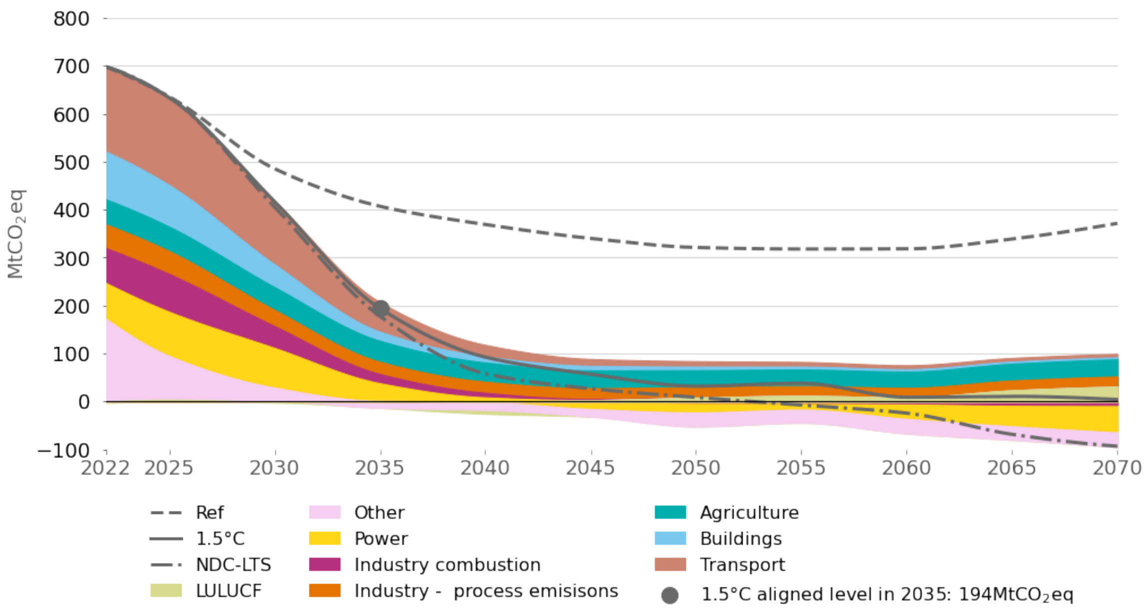
Jobs in renewable technologies by scenario – Brazil



Canada

Canada's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Canada



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Canada's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**698**	**194**	**-72%**
Power	75	37	-51%
Industry	122	45	-63%
Transport	157	48	-69%
Buildings	82	8	-91%
LULUCF	-3	1	-148%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

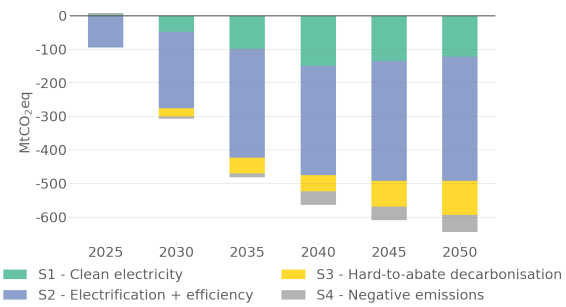
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

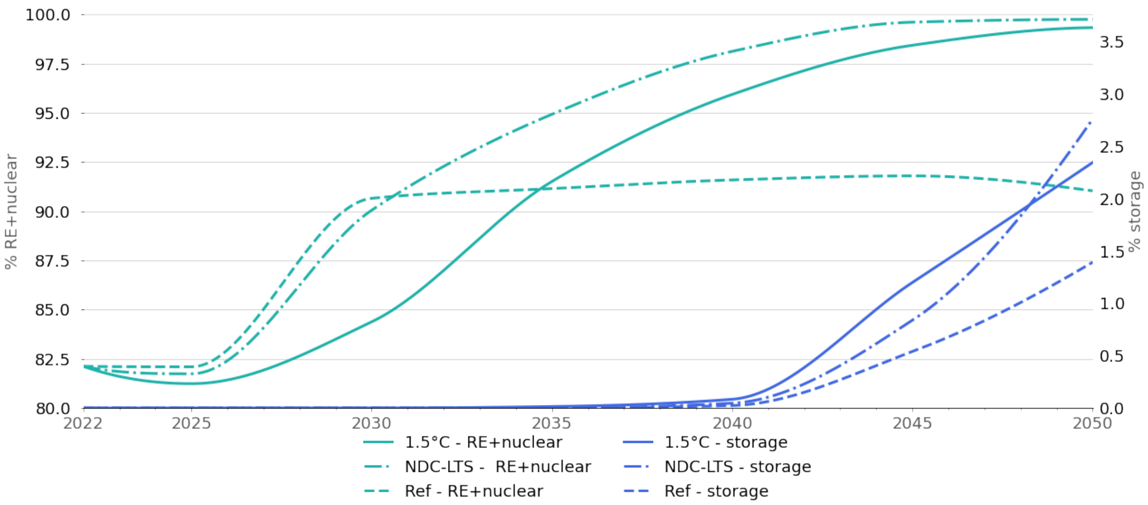
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Canada



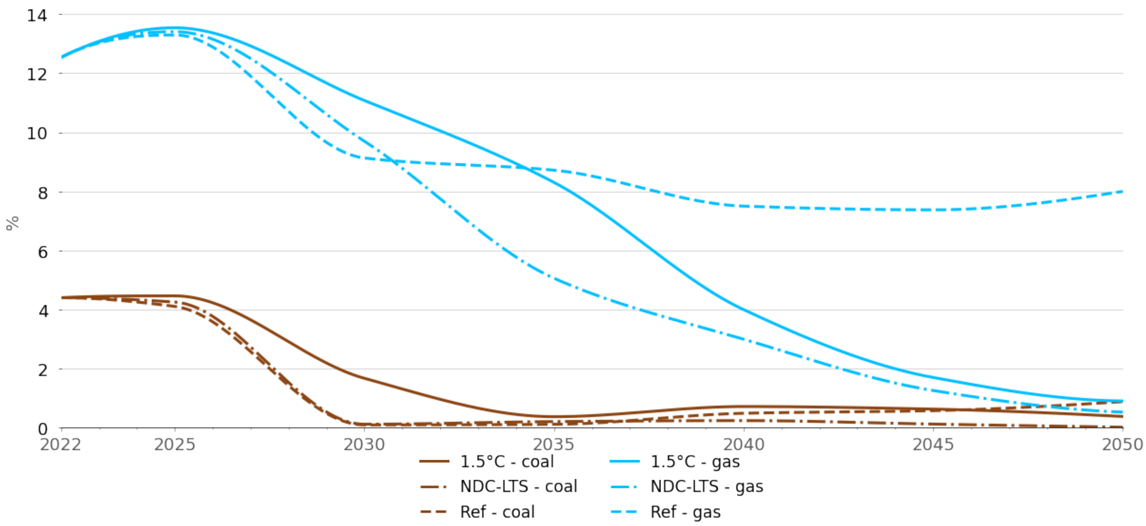
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Canada



Shares of coal & gas power generation technologies - Canada

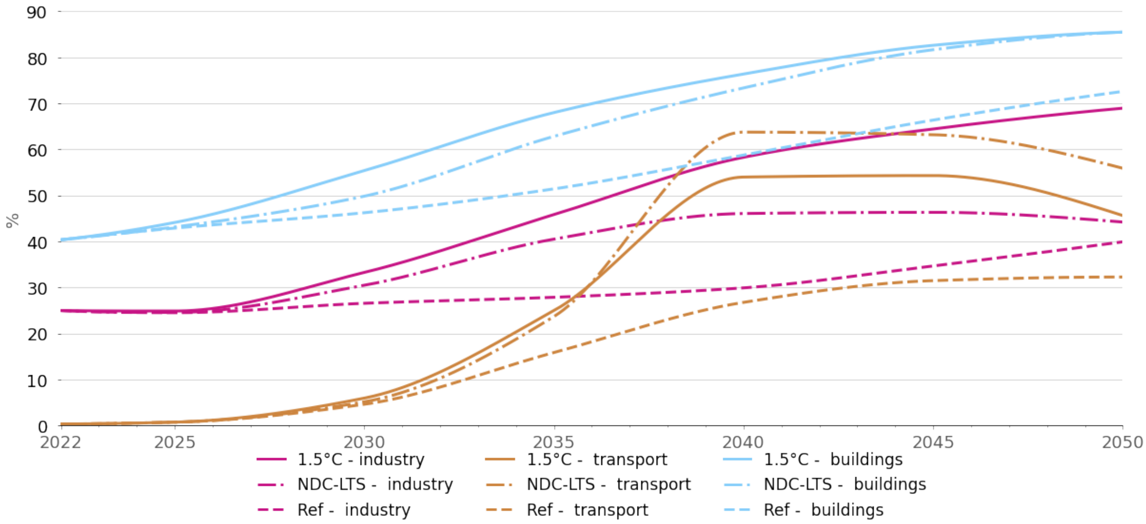


Clean electricity indicators in 1.5ºC scenario - Canada

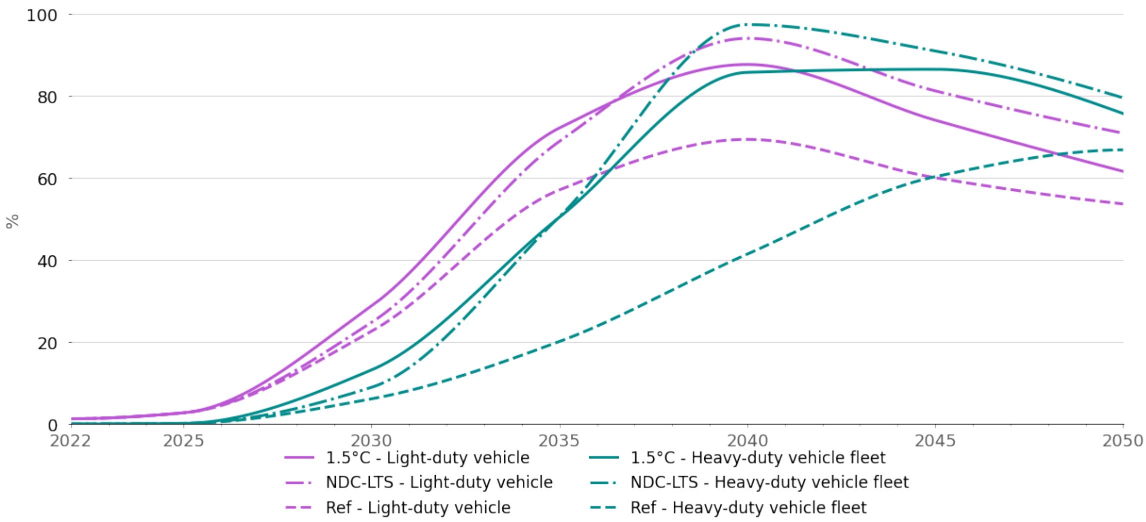
		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	2	11	14	14	11
Wind+solar share of annual additions	%	35%	72%	75%	70%	60%
Annual additions of storage	GW	0.08	0.02	0.33	1.31	3.25
Carbon content of electricity	gCO_2/MWh	114	96	36	7	-15
Emissions from power sector	$MtCO_2eq$	74	82	37	9	-18
First year of no unabated coal generation				2033		

Strategy 2 – Electrify end-uses and improve energy efficiency

Shares of electricity in final consumption sectors - Canada



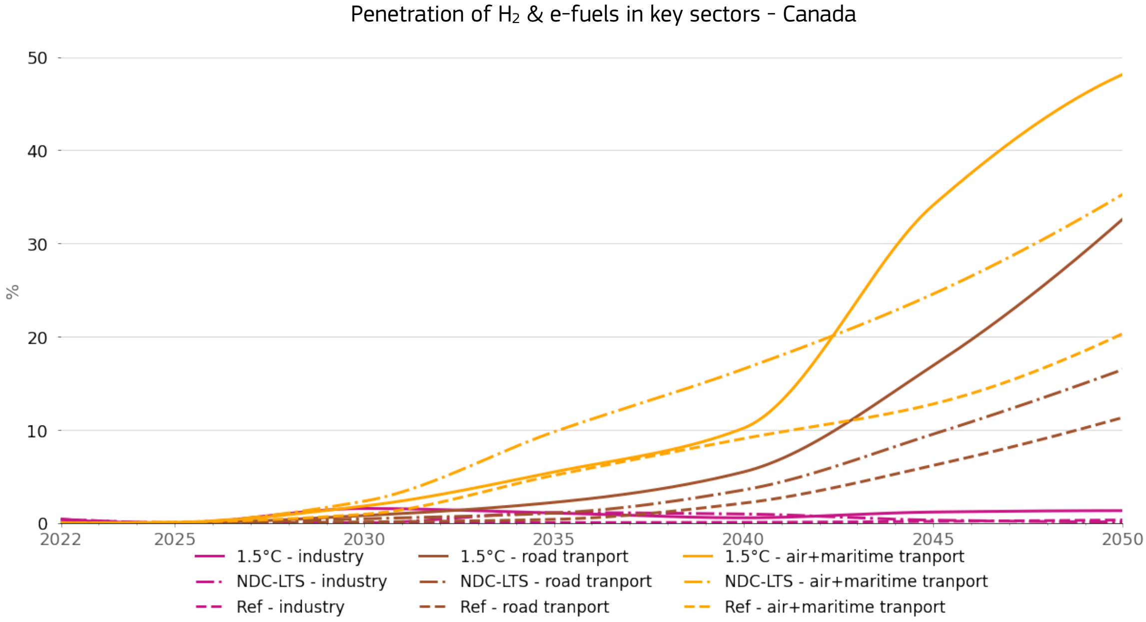
Shares of EVs in fleets - Canada

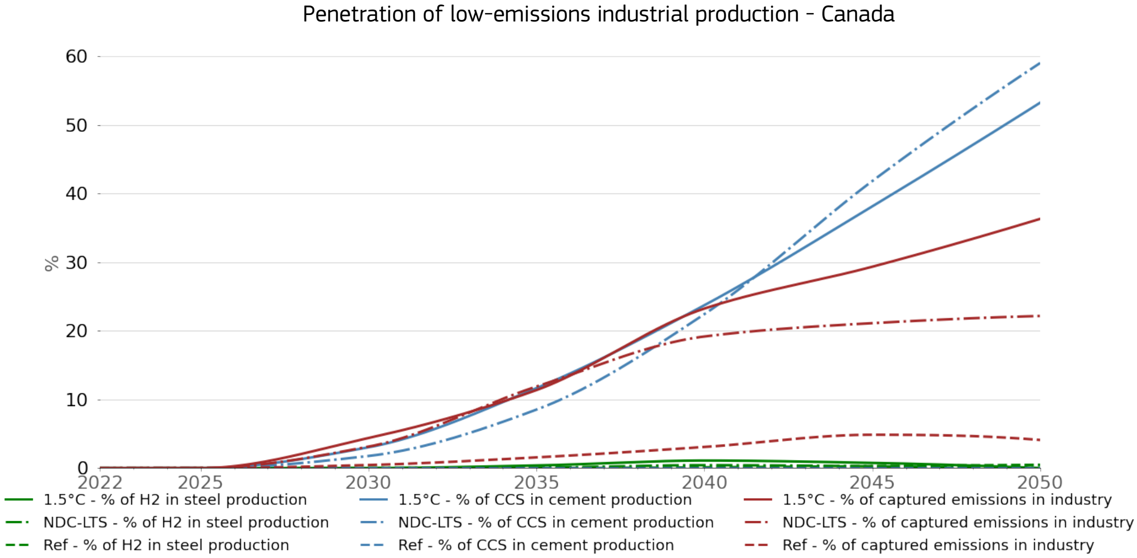


Electrification indicators in 1.5ºC scenario - Canada

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	91	1435	1975	1473	1164
Share of EVs in total car sales	%	4%	62%	95%	65%	52%
Annual sales of EV HDV	thousands	0	0	5	38	81
Share of EVs in total HDV sales	%	0%	0%	5%	38%	81%
Annual sales of small-scale heat pumps in buildings	GW	7	17	16	25	15
Annual sales of large-scale heat pumps in industry	GW	0	54	54	74	77
Share of heat pumps in buildings heating demand	%	0%	12%	24%	34%	51%

Strategy 3 – Decarbonise hard-to-abate sectors

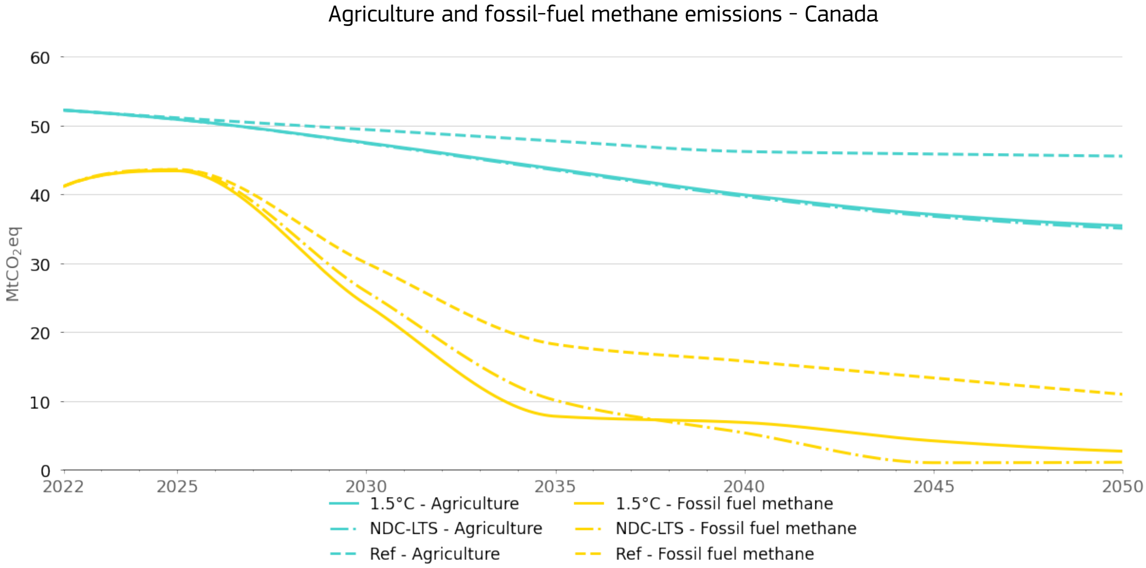


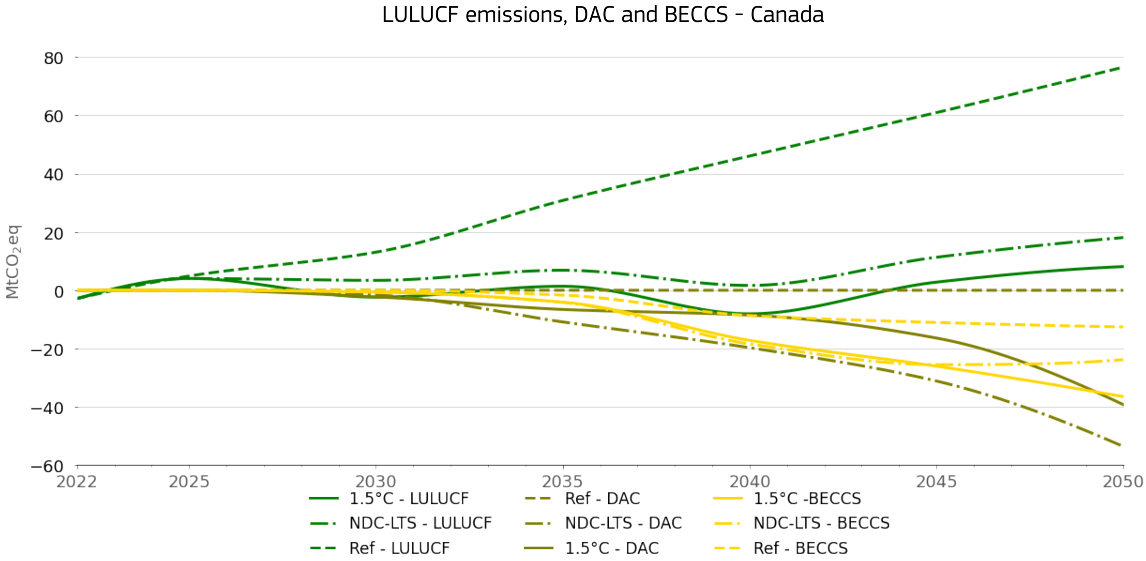


Non-electricity decarbonisation indicators in 1.5ºC scenario - Canada

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	539	540	667	4910
Domestic production of gaseous e-fuels	bcm	0	0	0	0	4
Domestic production of liquid e-fuels	barrels	0	1979	4029	4125	47587
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	11648	11699	11388	157250
Yearly additions of electrolysers	MW	0	782	306	7748	11123

Strategy 4 – Scale-up negative emissions and reduce residual emissions





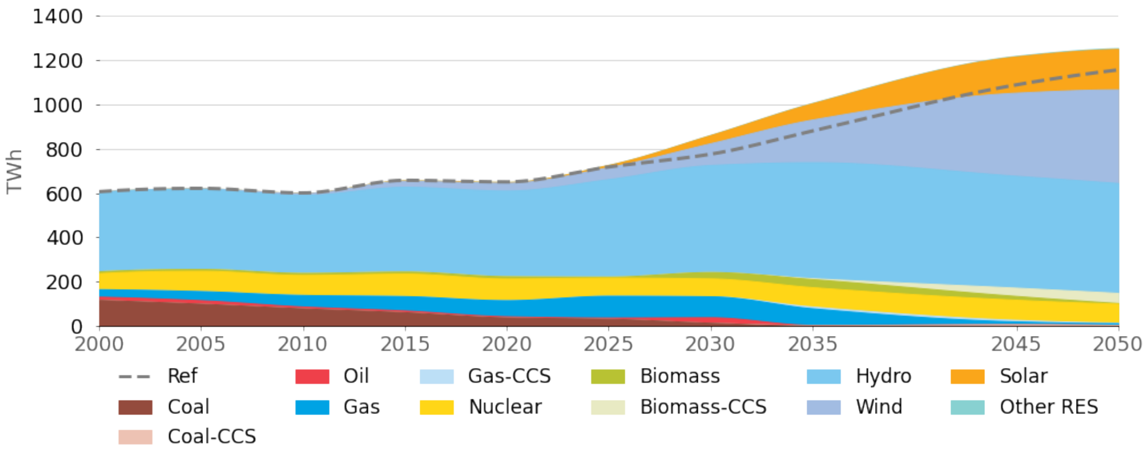
Negative emissions and non-CO_2 indicators in 1.5°C scenario - Canada

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	2	7	9	39
Biomass emissions captured	$MtCO_2eq$	0	1	4	17	36
LULUCF emissions	$MtCO_2eq$	-3	-2	1	-8	8
Agriculture emissions	$MtCO_2eq$	52	48	44	40	35
Methane emissions	$MtCO_2eq$	68	37	12	11	5
Methane emission from fossil fuel production	$MtCO_2eq$	41	24	8	7	3

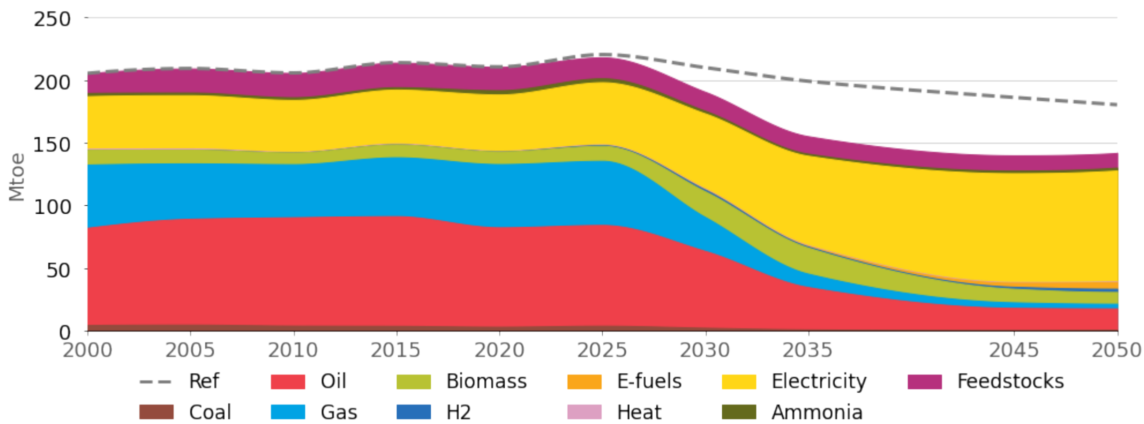
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - Canada



Final energy consumption in the 1.5ºC scenario - Canada



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

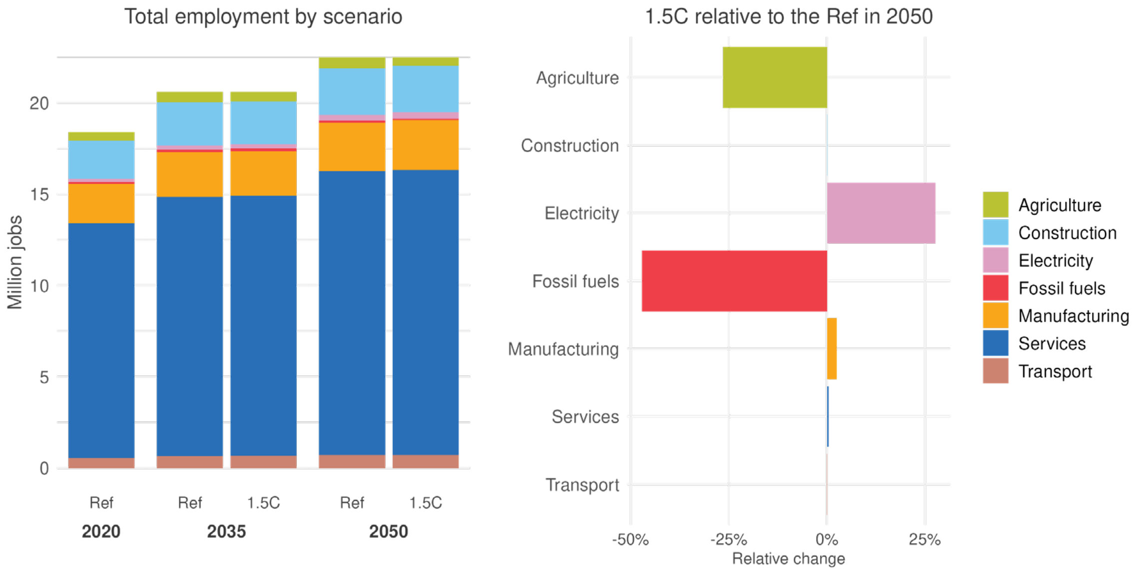
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-88%	-46%	-58%
Annual energy import bill	billion USD	-151	-12	-49
Air pollution emissions - PM2.5	Mt	211	163	96
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	9	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	45%	-3%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	14	19
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	63%	84%

Labour market dynamics

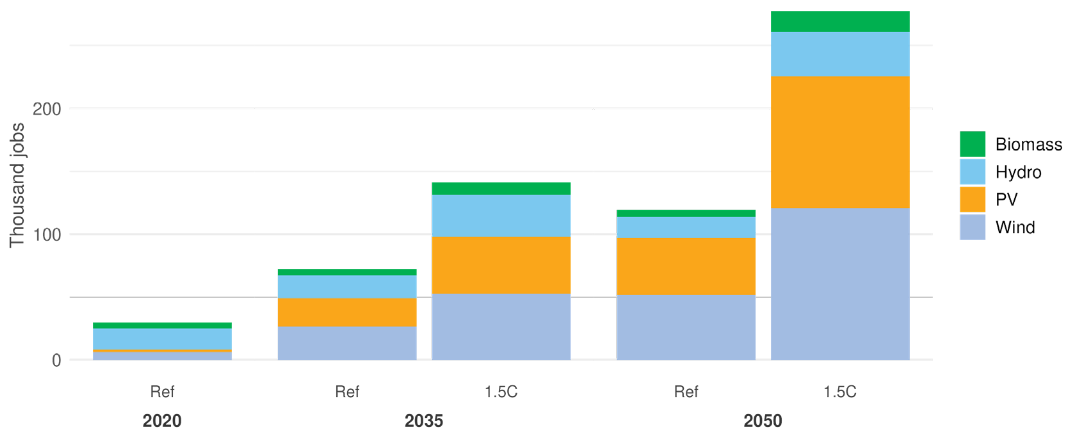
These graphs show the breakdown of employment in Canada, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Canada



Note: Electricity includes all power generation technologies as well as transmission and distribution.

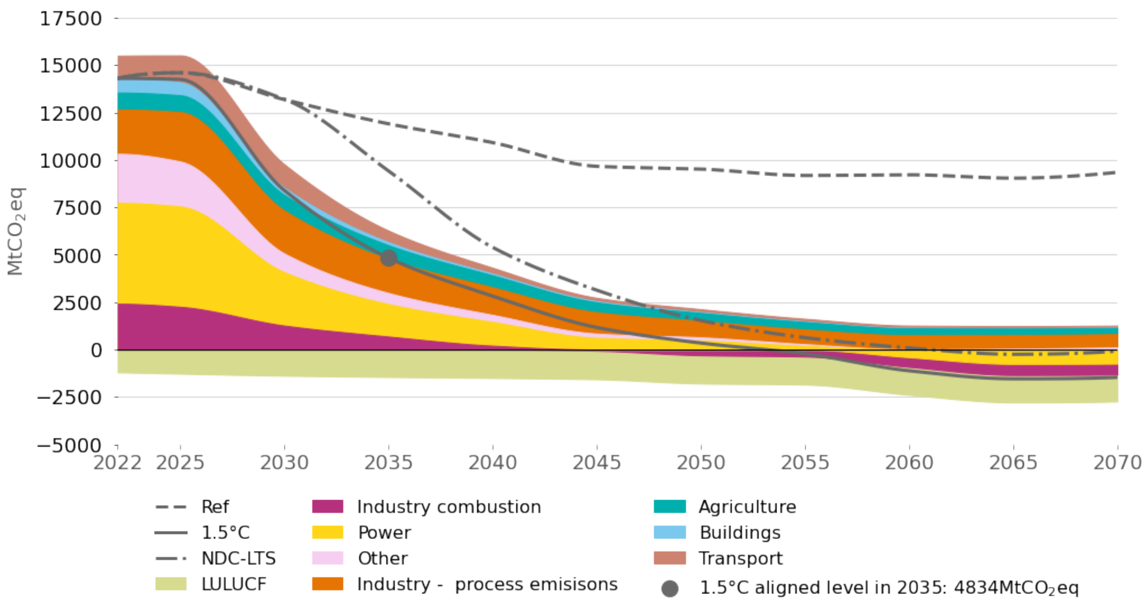
Jobs in renewable technologies by scenario – Canada



China

China's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - China



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows China's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**14304**	**4834**	**-66%**
Power	5317	1714	-68%
Industry	4755	2478	-48%
Transport	1038	502	-52%
Buildings	665	109	-84%
LULUCF	-1198	-1444	21%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

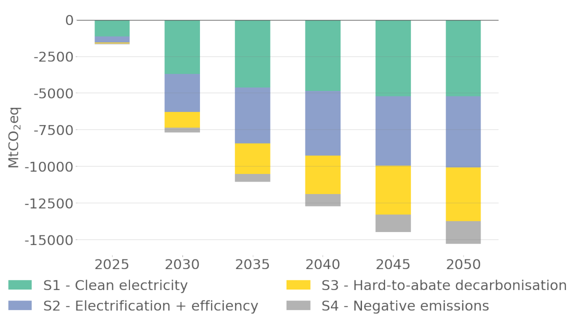
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - China



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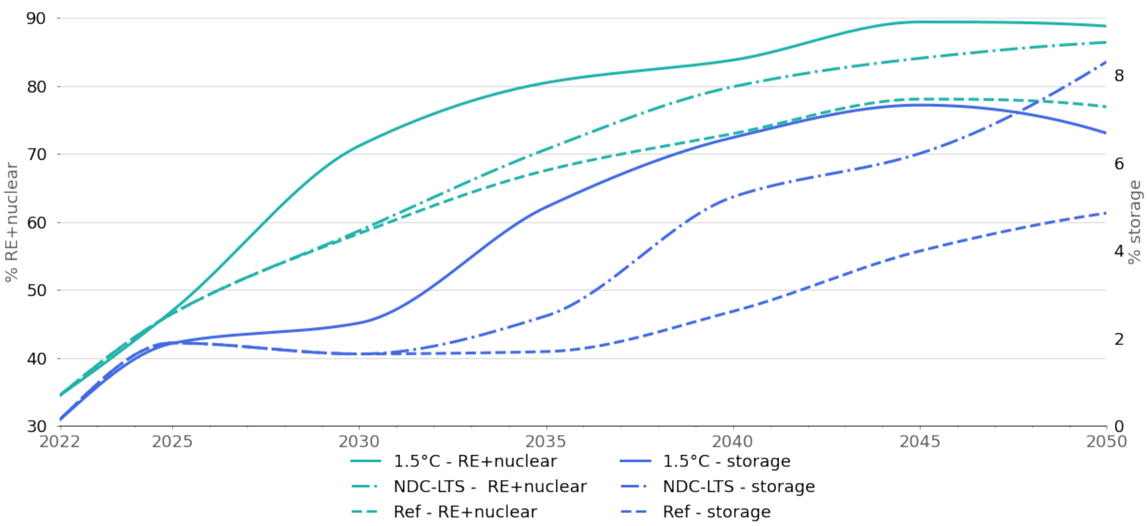
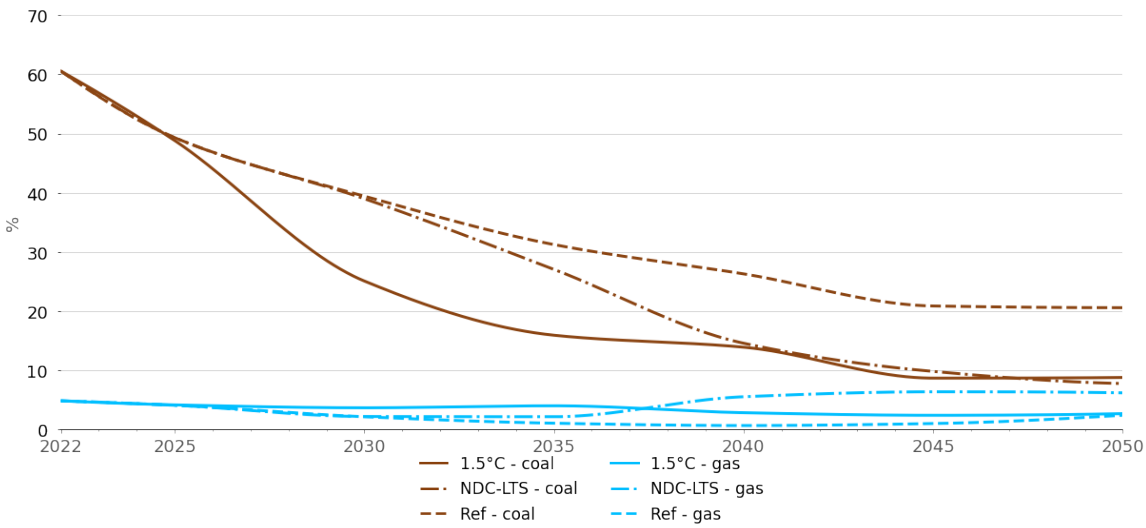
Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - China



Shares of coal & gas power generation technologies - China

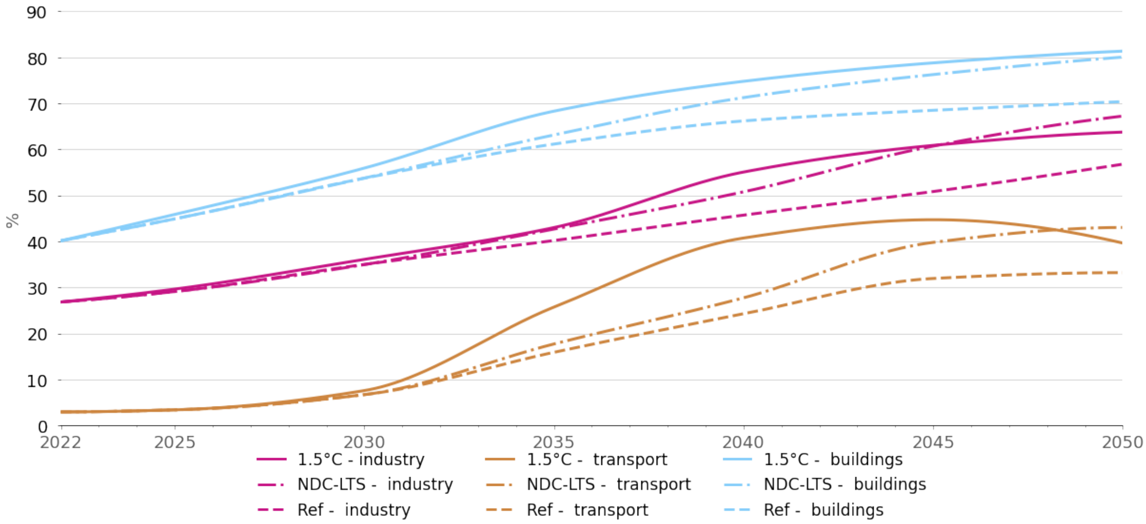


Clean electricity indicators in 1.5ºC scenario - China

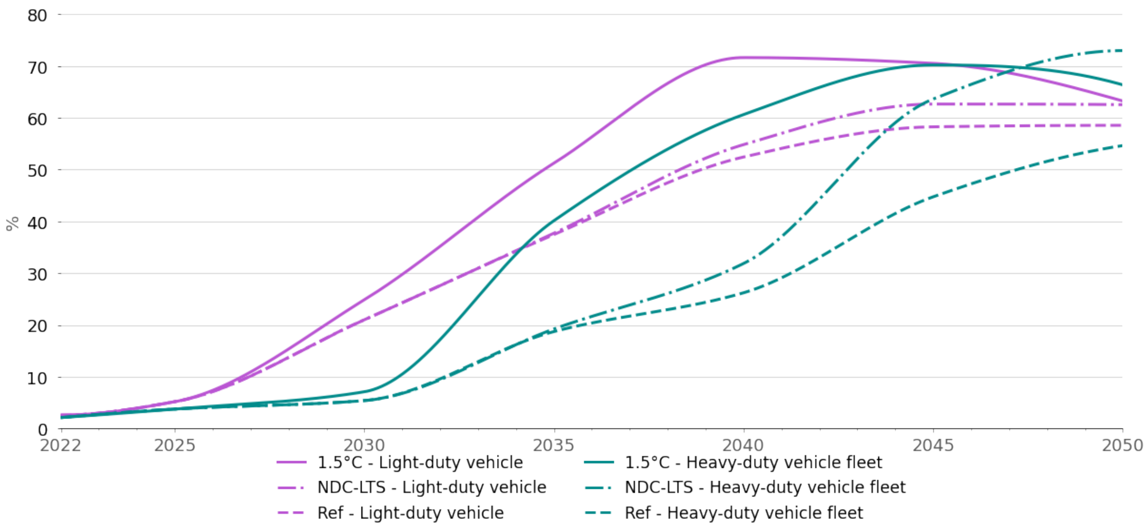
		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	123	287	252	256	315
Wind+solar share of annual additions	%	67%	74%	64%	58%	61%
Annual additions of storage	GW	18.58	37.82	73.44	106.30	100.31
Carbon content of electricity	gCO_2/MWh	581	228	122	78	24
Emissions from power sector	$MtCO_2eq$	5239	2765	1687	1225	448
First year of no unabated coal generation				2063		

Strategy 2 – Electrify end-uses and improve energy efficiency

Shares of electricity in final consumption sectors - China



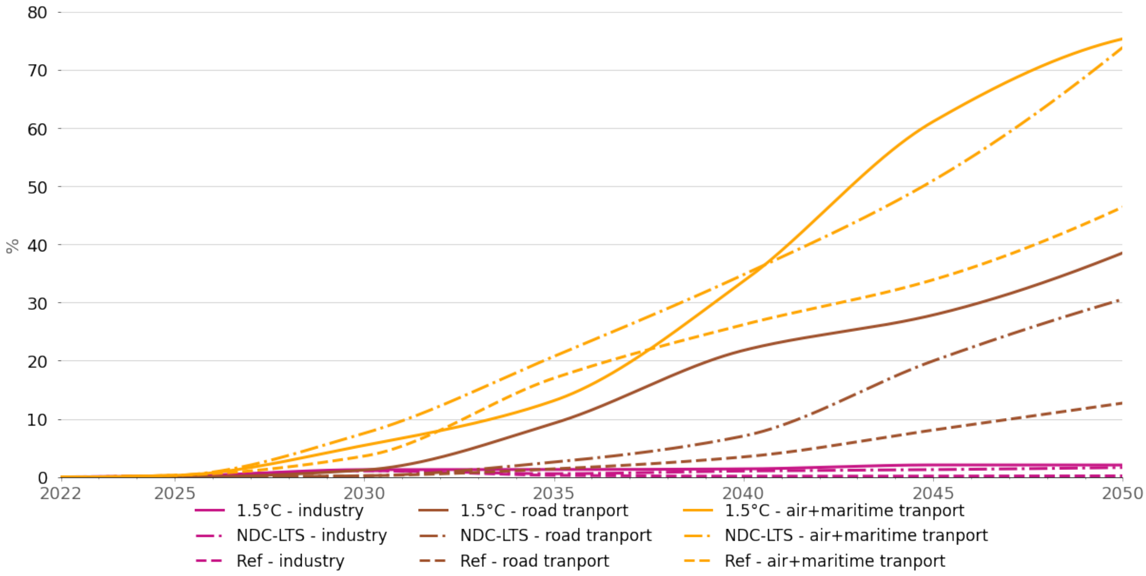
Shares of EVs in fleets - China

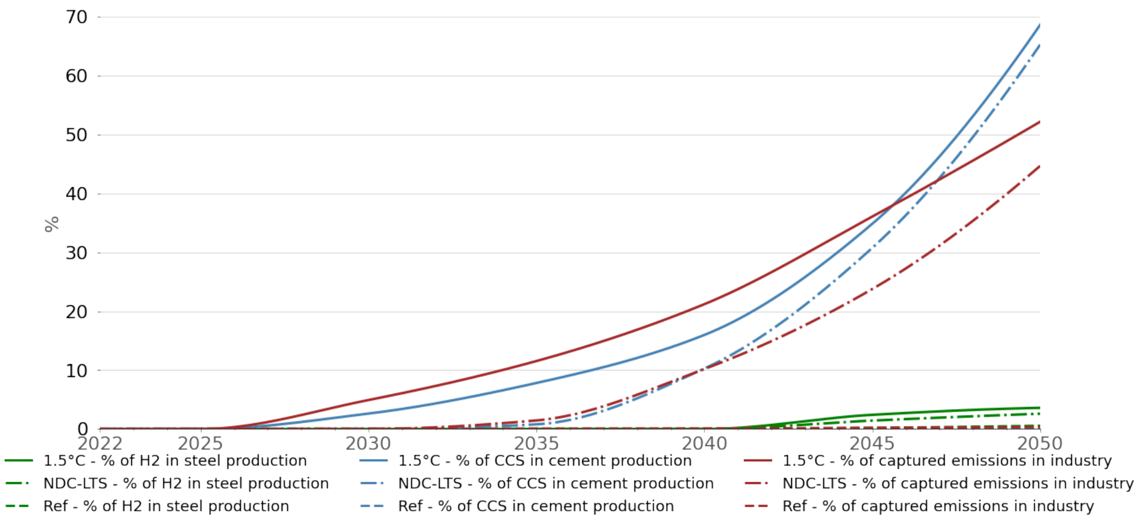


Electrification indicators in 1.5ºC scenario - China

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	4400	23773	39922	19462	31787
Share of EVs in total car sales	%	10%	48%	71%	62%	55%
Annual sales of EV HDV	thousands	10	59	108	614	1366
Share of EVs in total HDV sales	%	0%	2%	4%	21%	49%
Annual sales of small-scale heat pumps in buildings	GW	8	70	59	48	52
Annual sales of large-scale heat pumps in industry	GW	0	452	857	1341	1287
Share of heat pumps in buildings heating demand	%	0%	6%	18%	27%	37%

Strategy 3 – Decarbonise hard-to-abate sectors

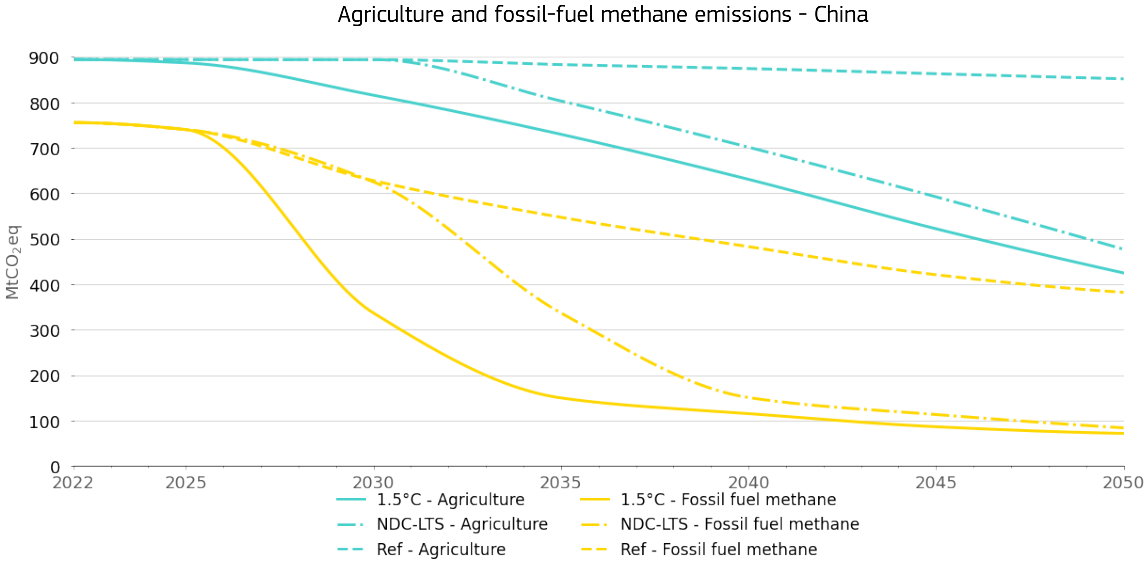


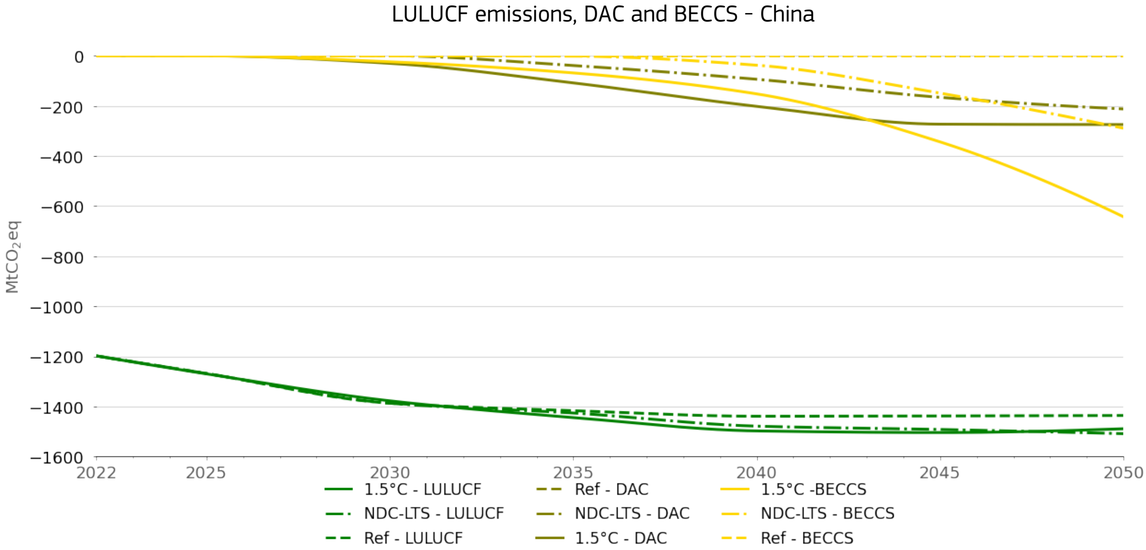


Non-electricity decarbonisation indicators in 1.5ºC scenario - China

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	8474	9129	18717	45446
Domestic production of gaseous e-fuels	bcm	0	3	77	187	208
Domestic production of liquid e-fuels	barrels	0	5106	23007	23352	37952
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	162725	162725	471038	1431920
Yearly additions of electrolysers	MW	0	16717	36455	49391	182259

Strategy 4 – Scale-up negative emissions and reduce residual emissions





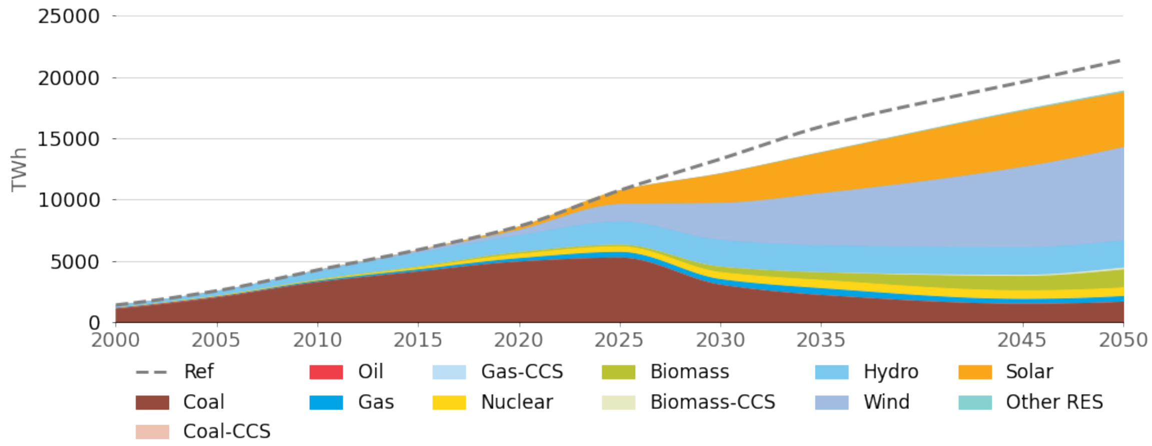
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - China

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	30	108	201	274
Biomass emissions captured	$MtCO_2eq$	0	24	68	152	643
LULUCF emissions	$MtCO_2eq$	-1198	-1378	-1444	-1498	-1489
Agriculture emissions	$MtCO_2eq$	894	816	730	631	425
Methane emissions	$MtCO_2eq$	1324	743	528	465	335
Methane emission from fossil fuel production	$MtCO_2eq$	755	337	150	115	72

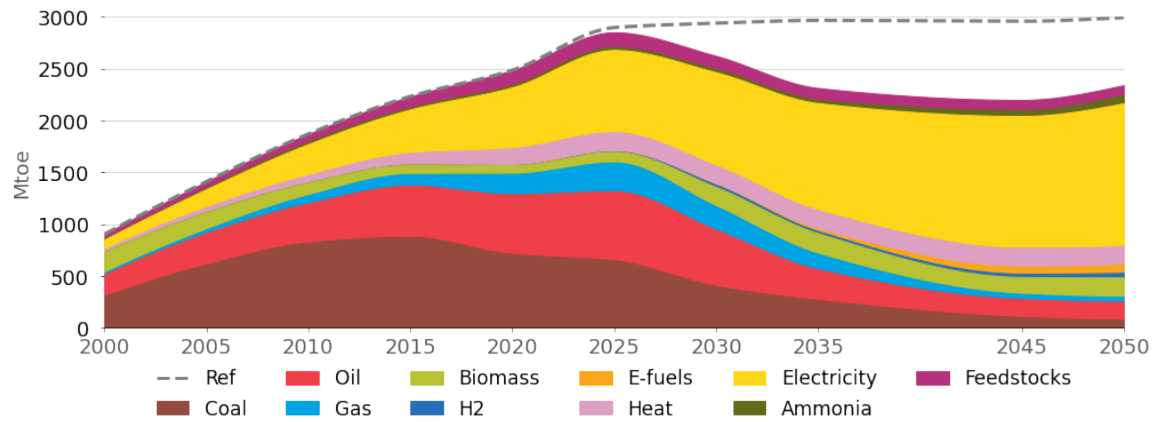
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - China



Final energy consumption in the 1.5ºC scenario - China



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

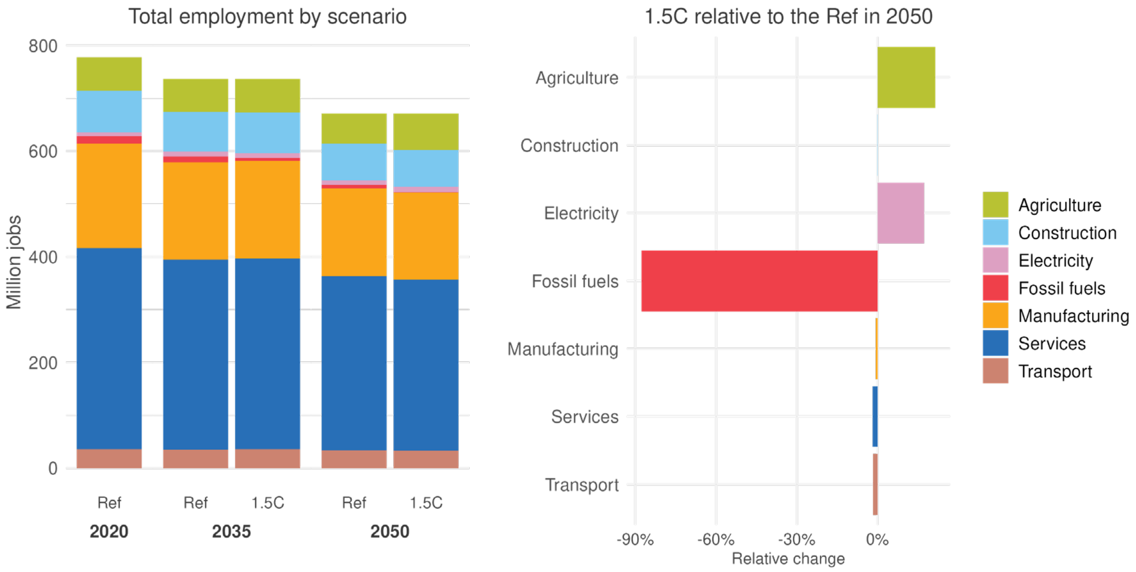
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	23%	20%	28%
Annual energy import bill	billion USD	656	495	749
Air pollution emissions - PM2.5	Mt	10212	5199	1807
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	-107	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	-24%	0%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	63	92
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	59%	85%

Labour market dynamics

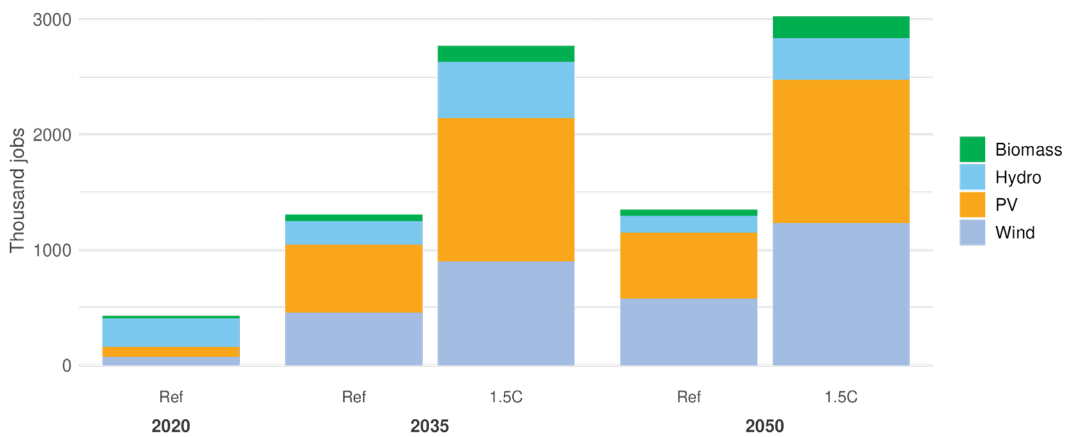
These graphs show the breakdown of employment in China, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – China



Note: Electricity includes all power generation technologies as well as transmission and distribution.

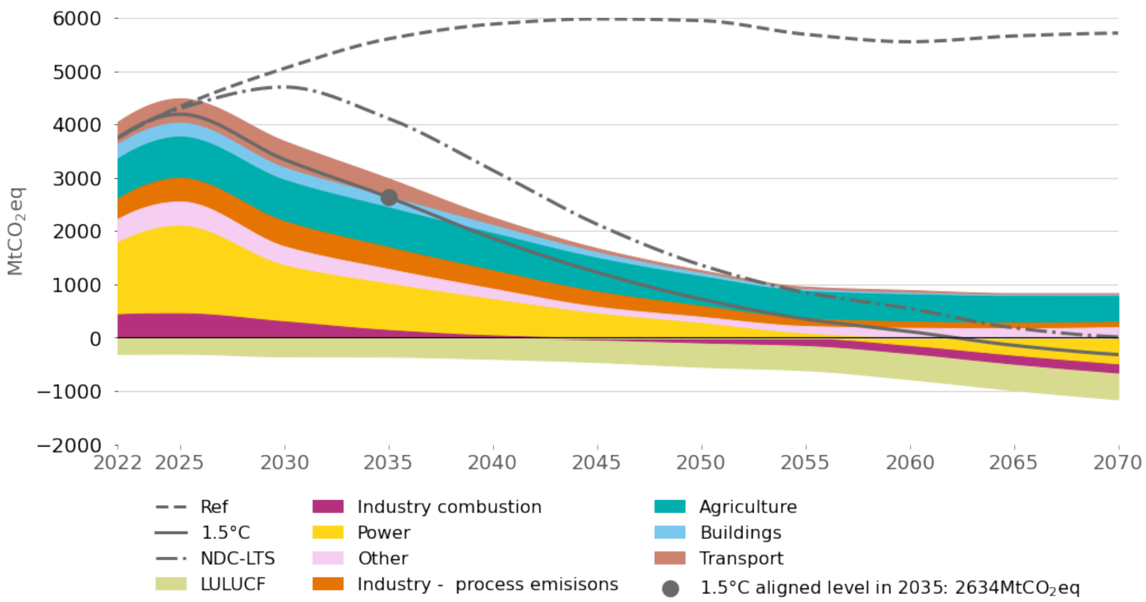
Jobs in renewable technologies by scenario – China



India

India's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - India



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows India's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**3745**	**2634**	**-30%**
Power	1349	871	-35%
Industry	819	552	-33%
Transport	345	277	-20%
Buildings	235	180	-23%
LULUCF	-303	-354	17%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
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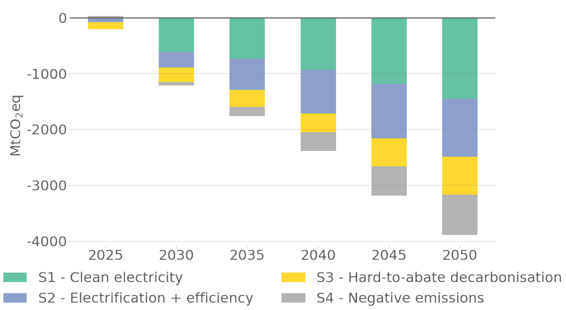
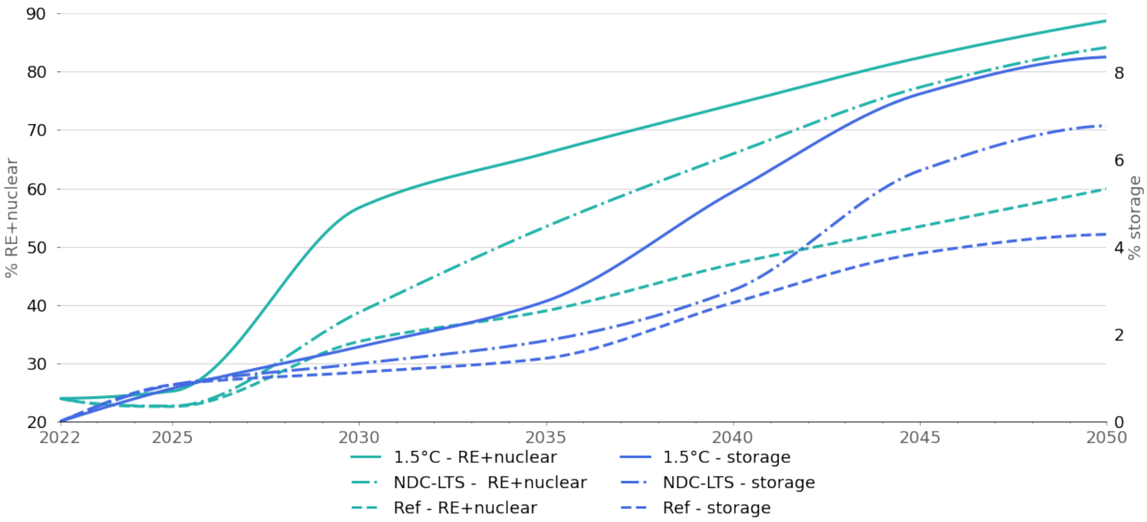
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - India



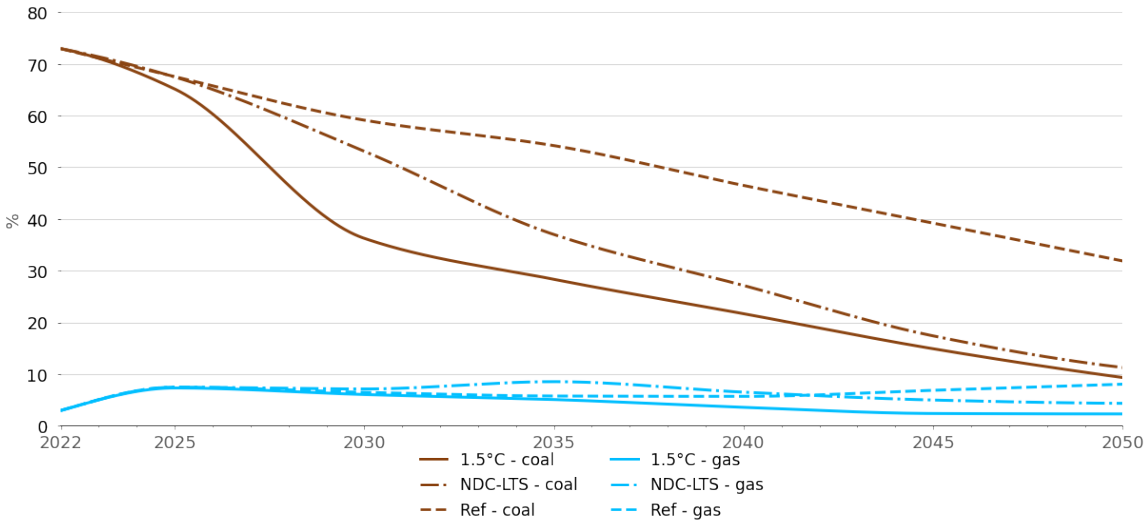
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - India



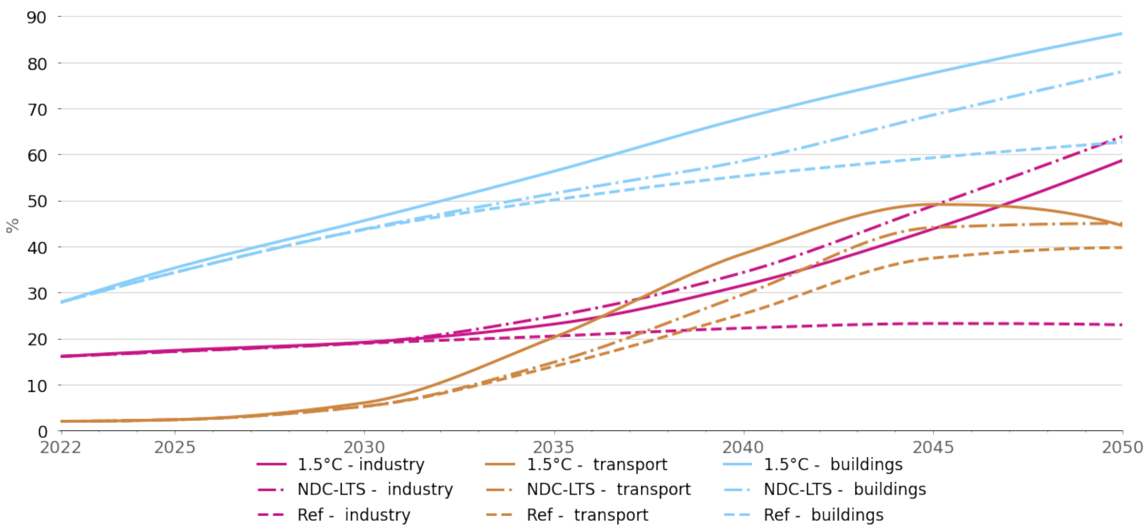
Shares of coal & gas power generation technologies - India

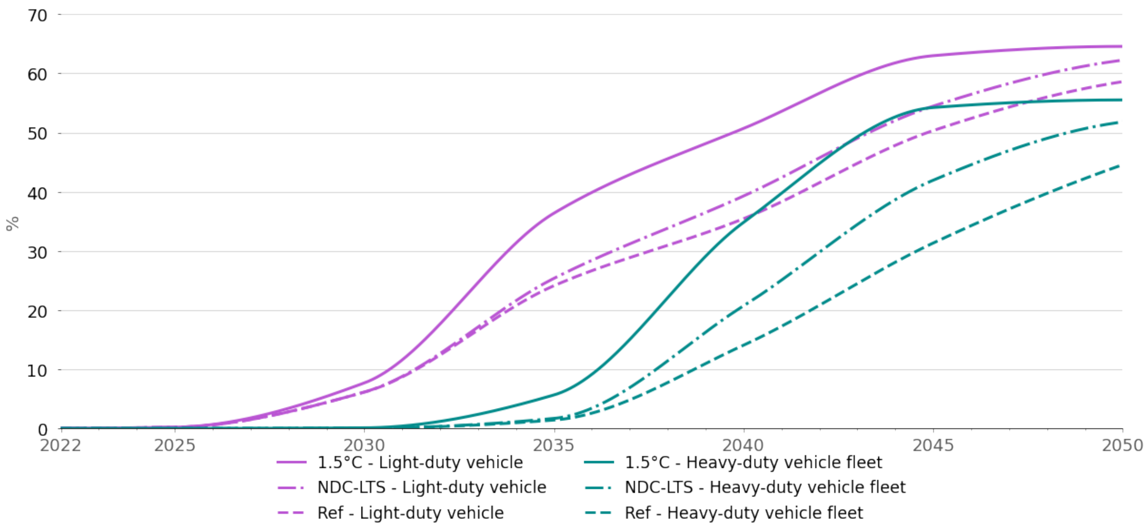


Clean electricity indicators in 1.5ºC scenario - India

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	15	81	110	141	180
Wind+solar share of annual additions	%	70%	72%	70%	69%	64%
Annual additions of storage	GW	0.01	7.03	17.68	29.13	44.24
Carbon content of electricity	gCO_2/MWh	752	354	222	132	35
Emissions from power sector	$MtCO_2eq$	1341	1047	867	674	266
First year of no unabated coal generation				2061		

Strategy 2 – Electrify end-uses and improve energy efficiency

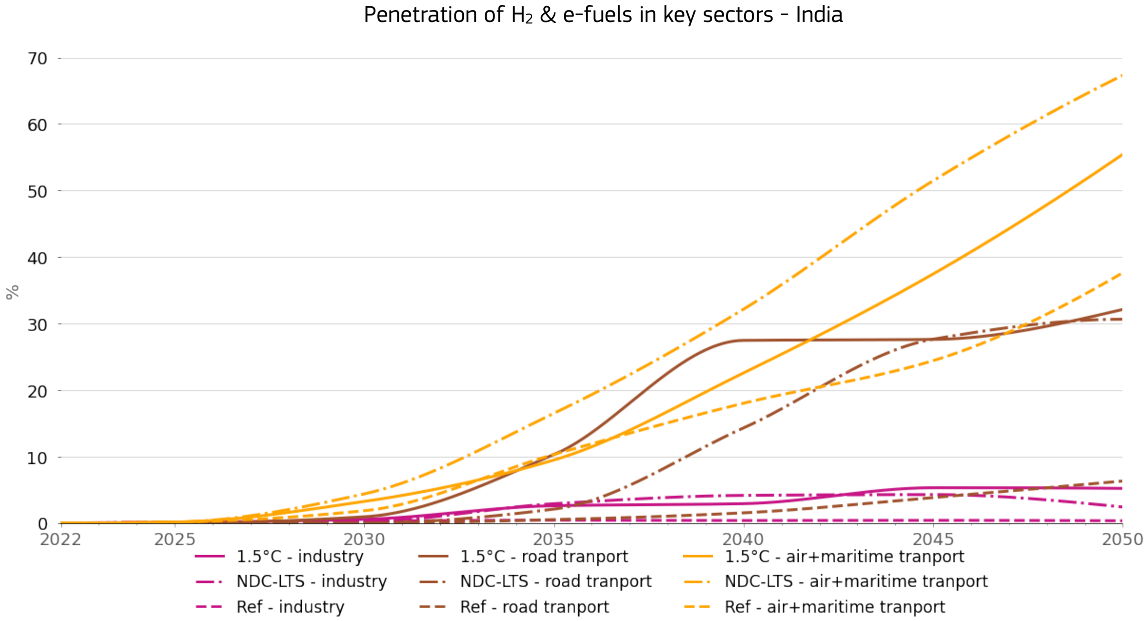


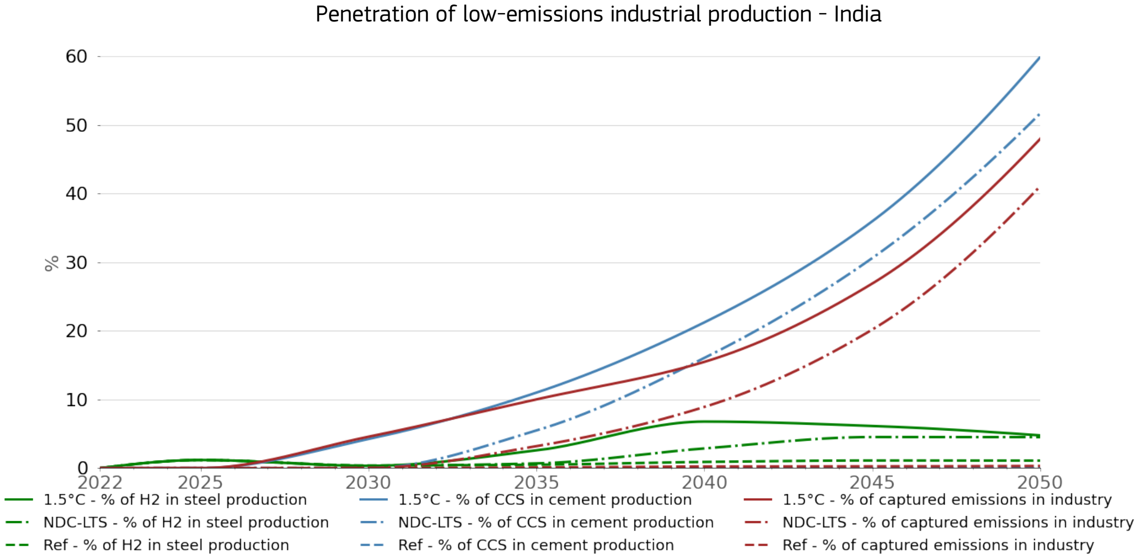


Electrification indicators in 1.5ºC scenario - India

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	48	12714	39016	44972	45818
Share of EVs in total car sales	%	0%	23%	64%	67%	54%
Annual sales of EV HDV	thousands	0	0	0	38	628
Share of EVs in total HDV sales	%	0%	0%	0%	3%	45%
Annual sales of small-scale heat pumps in buildings	GW	0	1	1	1	4
Annual sales of large-scale heat pumps in industry	GW	0	109	134	484	1280
Share of heat pumps in buildings heating demand	%	n/a	n/a	n/a	n/a	n/a

Strategy 3 – Decarbonise hard-to-abate sectors

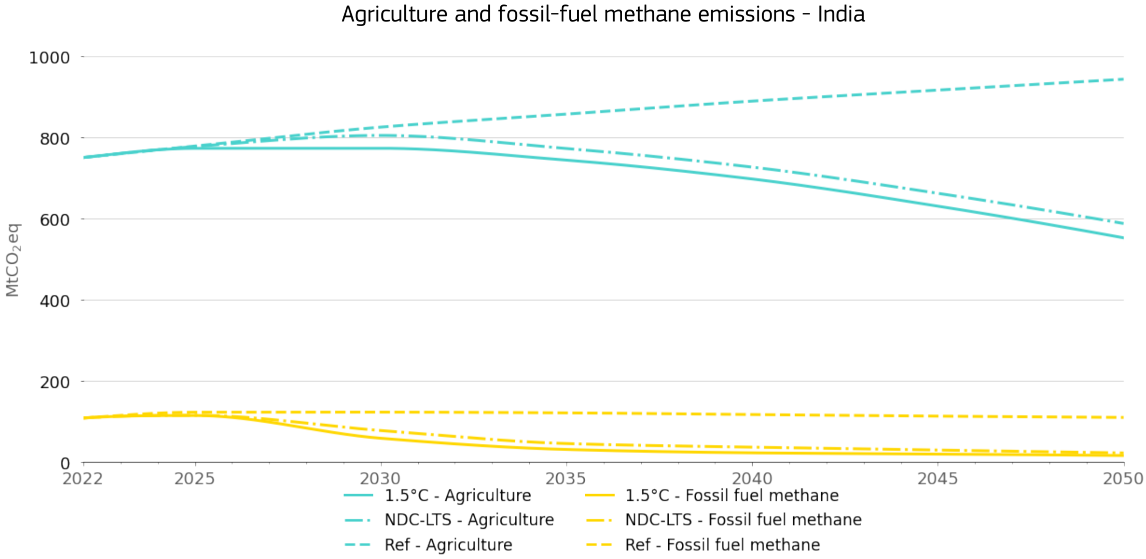


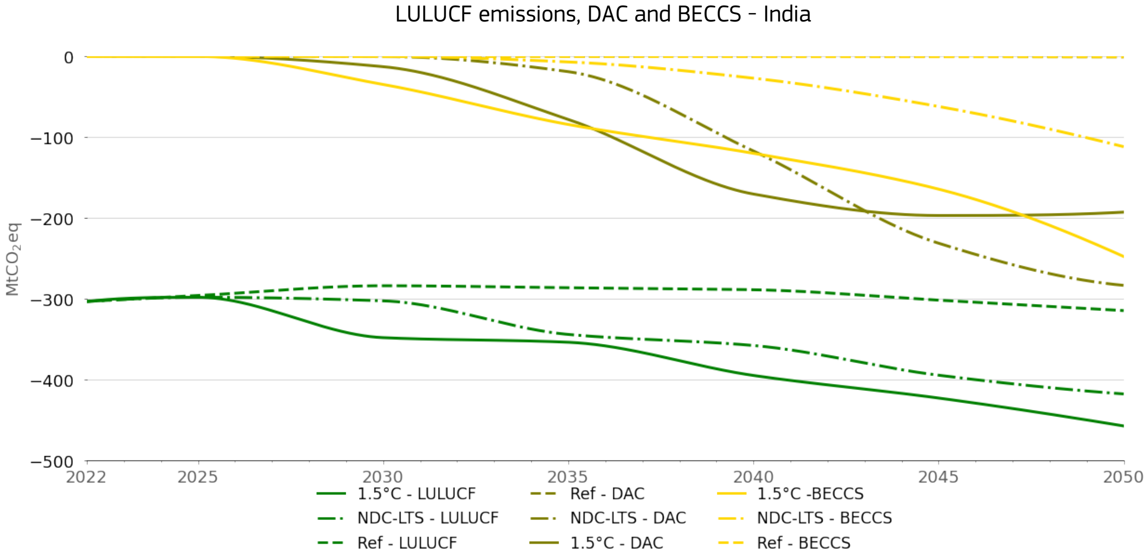


Non-electricity decarbonisation indicators in 1.5ºC scenario - India

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	2198	13369	24040	30010
Domestic production of gaseous e-fuels	bcm	0	1	19	23	120
Domestic production of liquid e-fuels	barrels	0	8718	82878	151046	44041
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	70440	521642	820189	785812
Yearly additions of electrolysers	MW	0	48827	56289	45502	38778

Strategy 4 – Scale-up negative emissions and reduce residual emissions



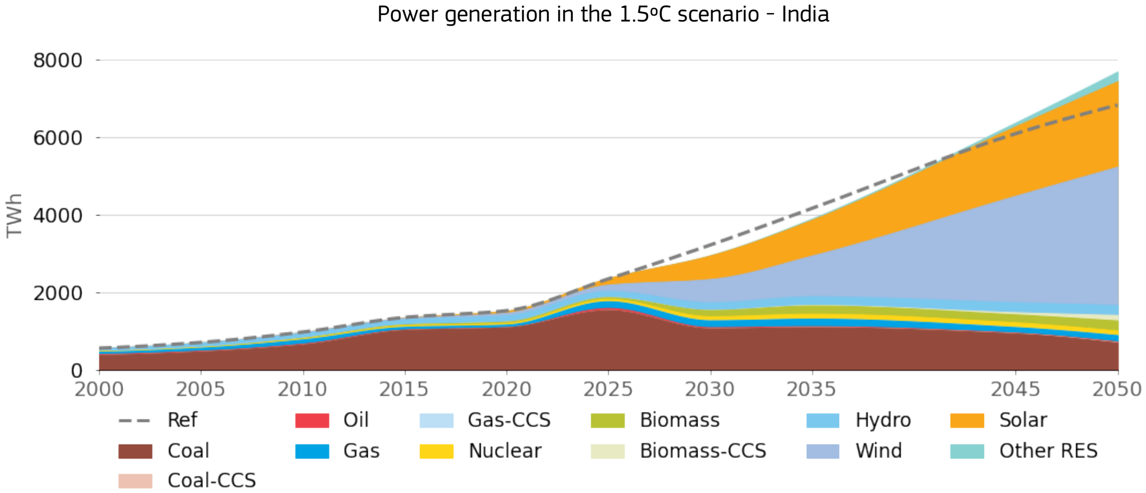


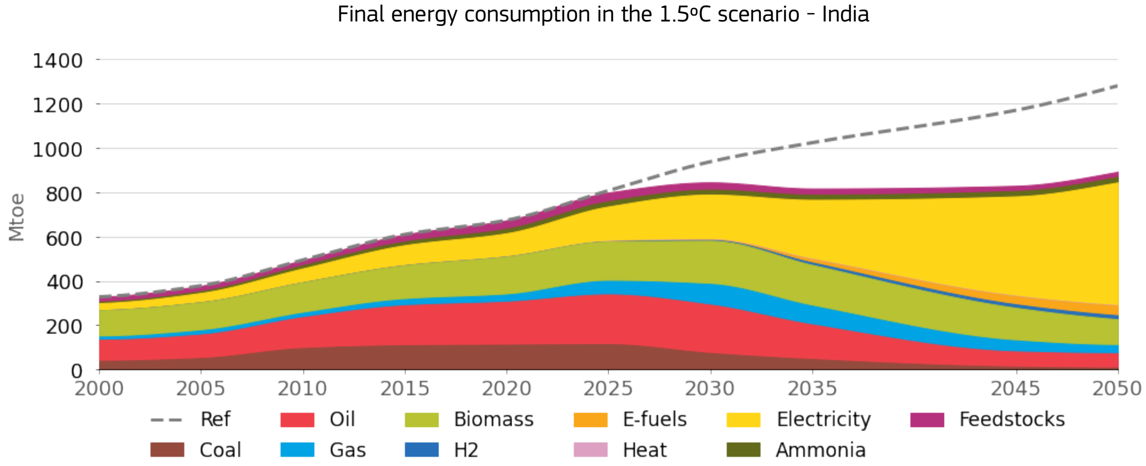
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - India

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	13	78	170	193
Biomass emissions captured	$MtCO_2eq$	0	35	84	120	248
LULUCF emissions	$MtCO_2eq$	-303	-348	-354	-395	-457
Agriculture emissions	$MtCO_2eq$	751	774	744	698	553
Methane emissions	$MtCO_2eq$	365	266	256	263	267
Methane emission from fossil fuel production	$MtCO_2eq$	109	59	31	23	17

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





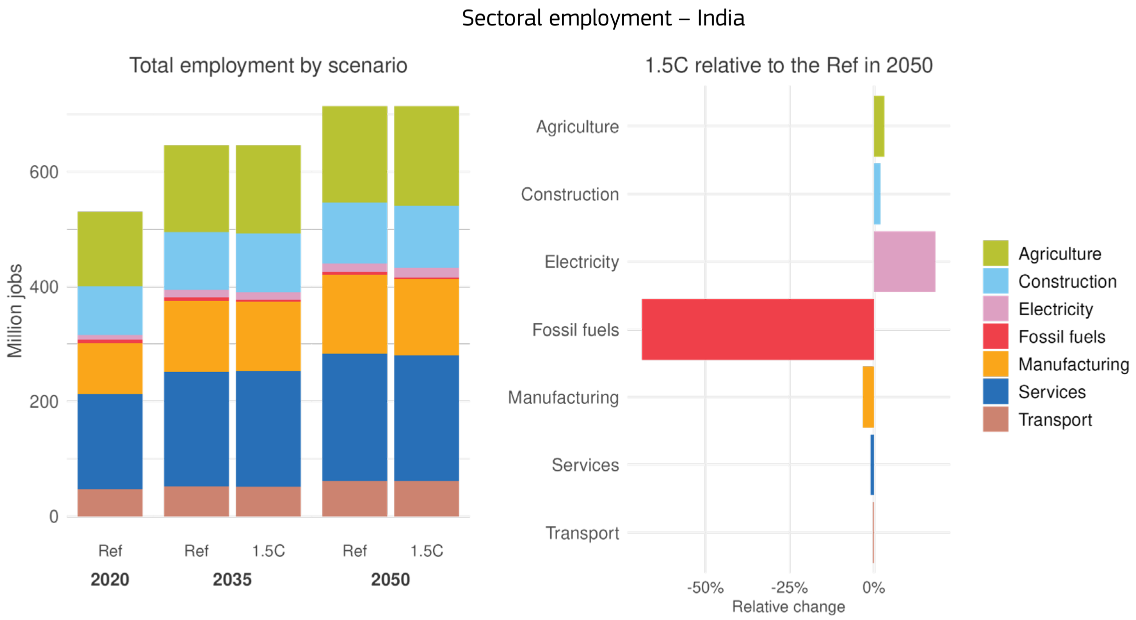
Co-benefits and investments related to decarbonisation in the 1.5°C scenario

This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

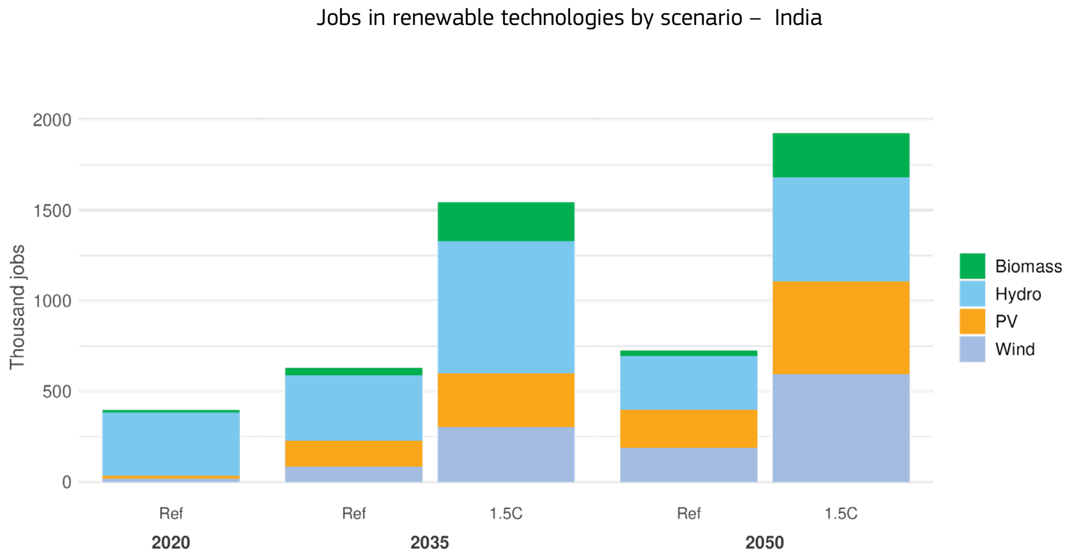
		2022	2035	2050
Share of energy demand from imports	%	36%	14%	0%
Annual energy import bill	billion USD	299	95	38
Air pollution emissions - PM2.5	Mt	7340	5492	2706
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	3	163
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	2%	138%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	2	9
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	18%	73%

Labour market dynamics

These graphs show the breakdown of employment in India, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.



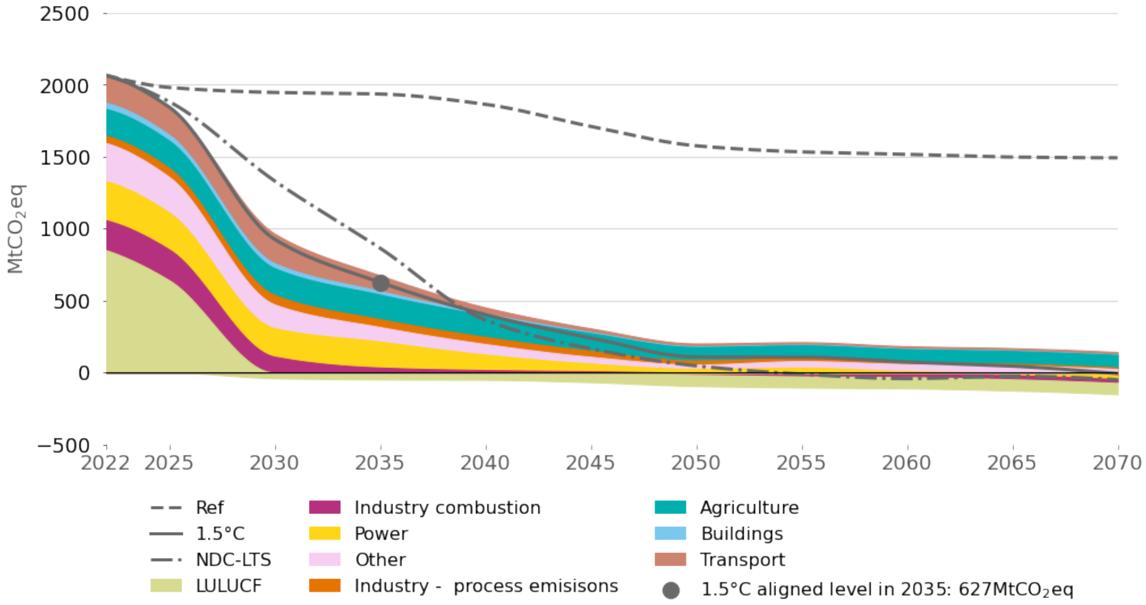
Note: Electricity includes all power generation technologies as well as transmission and distribution.



Indonesia

Indonesia's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Indonesia



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Indonesia's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**2066**	**627**	**-70%**
Power	271	181	-33%
Industry	259	89	-66%
Transport	148	85	-43%
Buildings	40	24	-41%
LULUCF	851	-48	-106%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

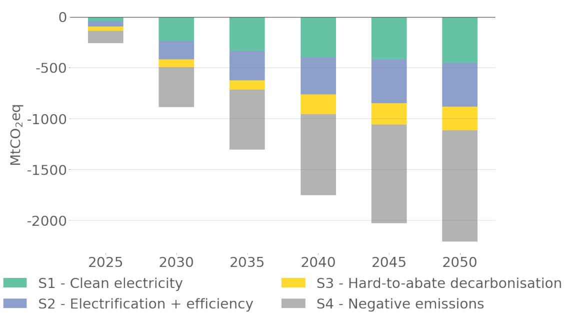
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

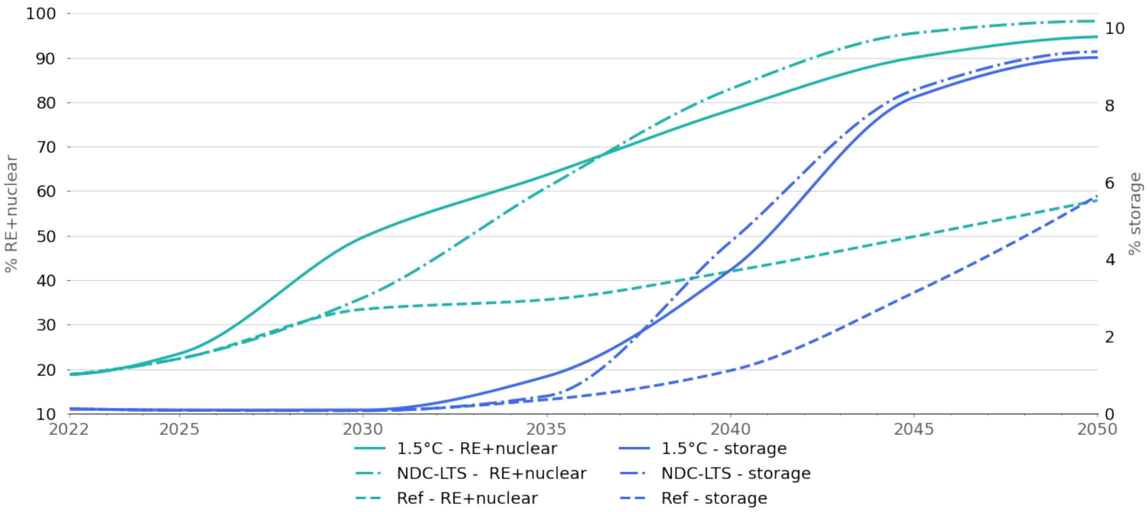
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Indonesia



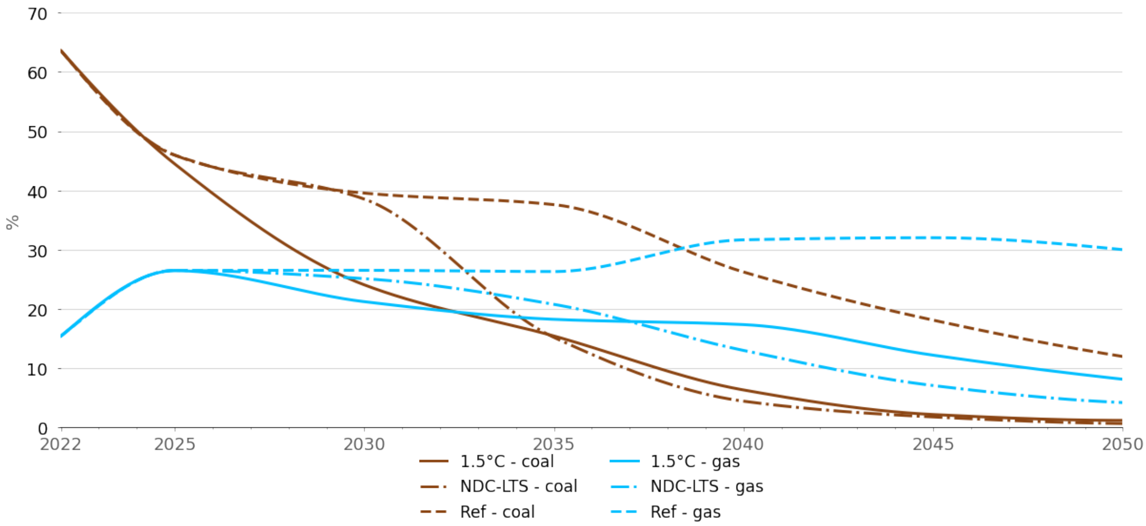
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Indonesia



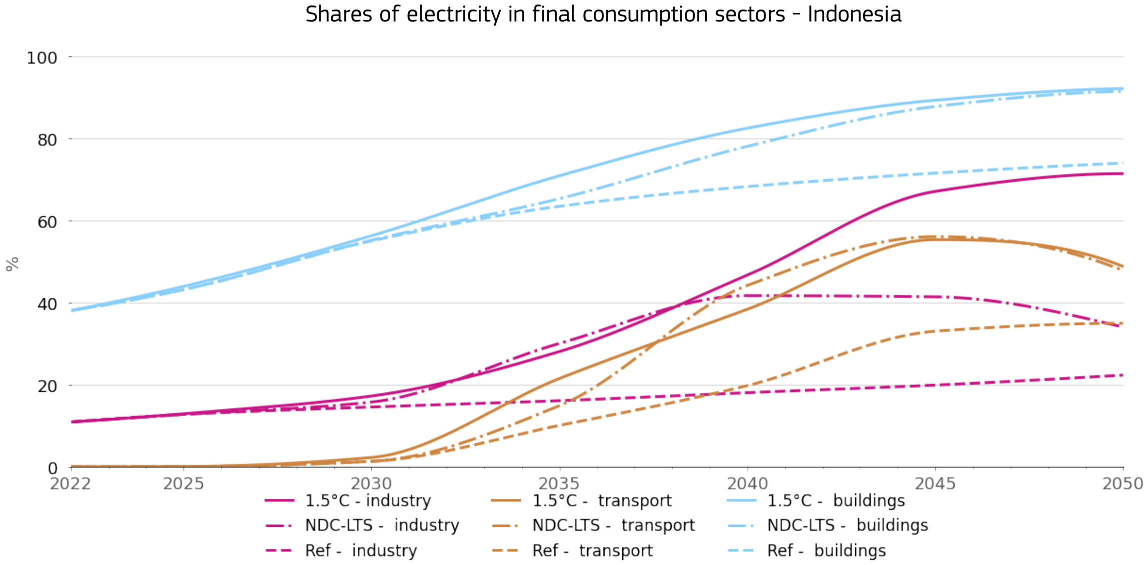
Shares of coal & gas power generation technologies - Indonesia

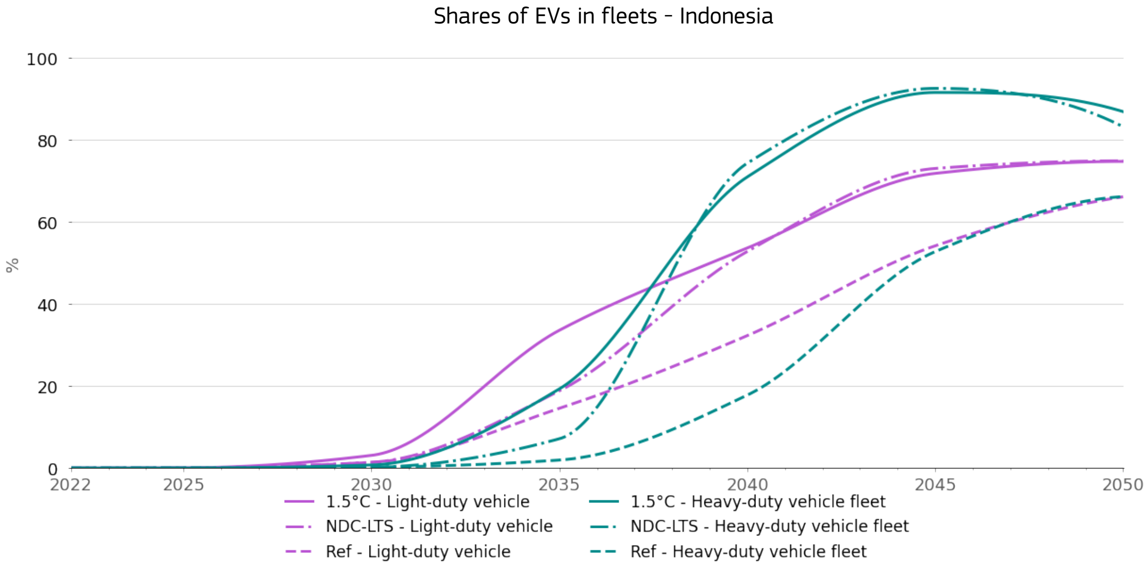


Clean electricity indicators in 1.5ºC scenario - Indonesia

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	0	14	24	27	20
Wind+solar share of annual additions	%	1%	50%	62%	59%	46%
Annual additions of storage	GW	0.02	0.32	1.44	3.56	8.97
Carbon content of electricity	gCO_2/MWh	808	331	192	86	15
Emissions from power sector	$MtCO_2eq$	270	197	180	107	24
First year of no unabated coal generation				2046		

Strategy 2 – Electrify end-uses and improve energy efficiency

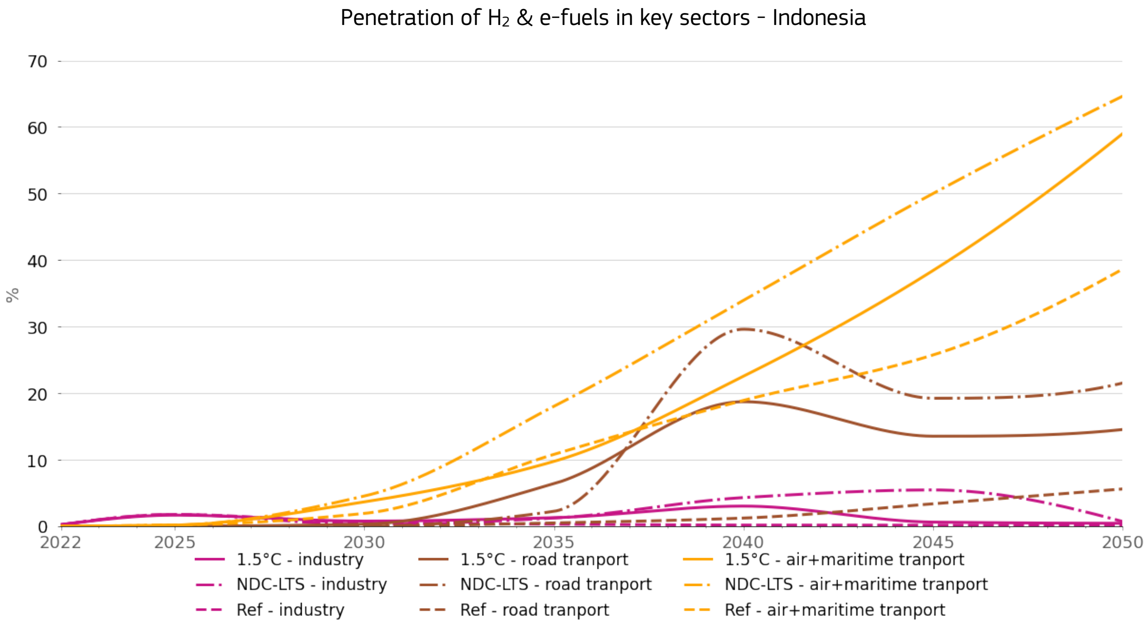


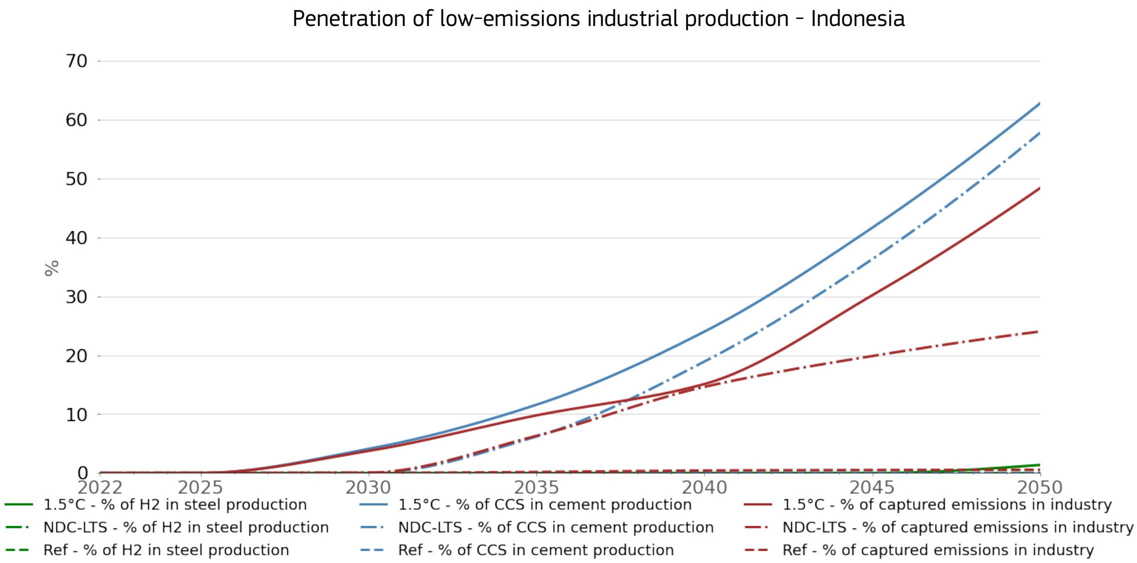


Electrification indicators in 1.5ºC scenario - Indonesia

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	0	2175	12683	13756	15591
Share of EVs in total car sales	%	0%	13%	68%	66%	64%
Annual sales of EV HDV	thousands	0	0	0	31	266
Share of EVs in total HDV sales	%	0%	0%	0%	8%	73%
Annual sales of small-scale heat pumps in buildings	GW	0	0	0	0	0
Annual sales of large-scale heat pumps in industry	GW	0	54	54	128	80
Share of heat pumps in buildings heating demand	%	n/a	n/a	n/a	n/a	n/a

Strategy 3 – Decarbonise hard-to-abate sectors

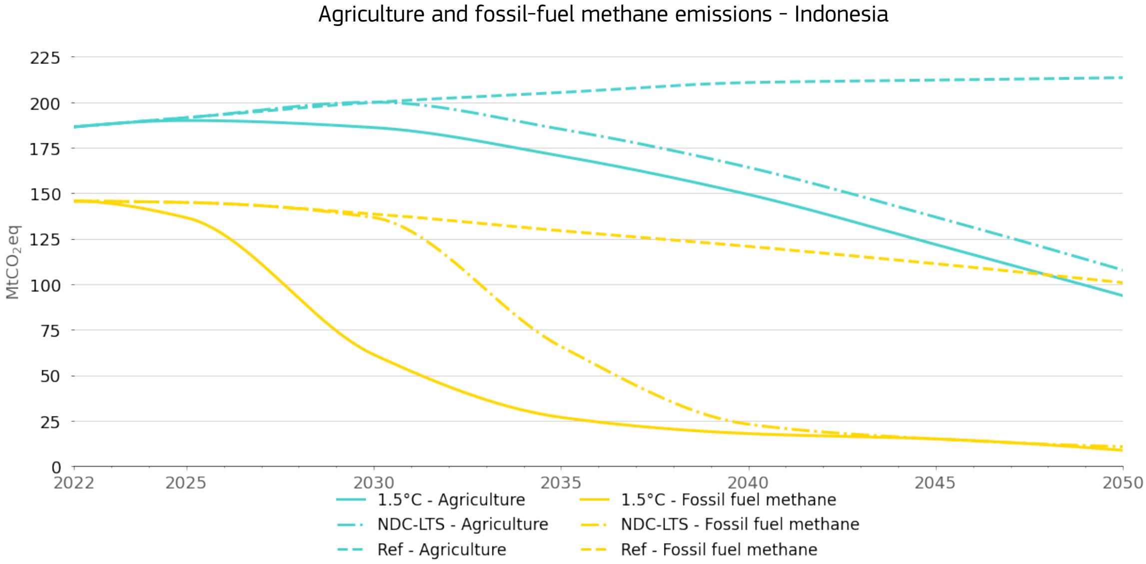


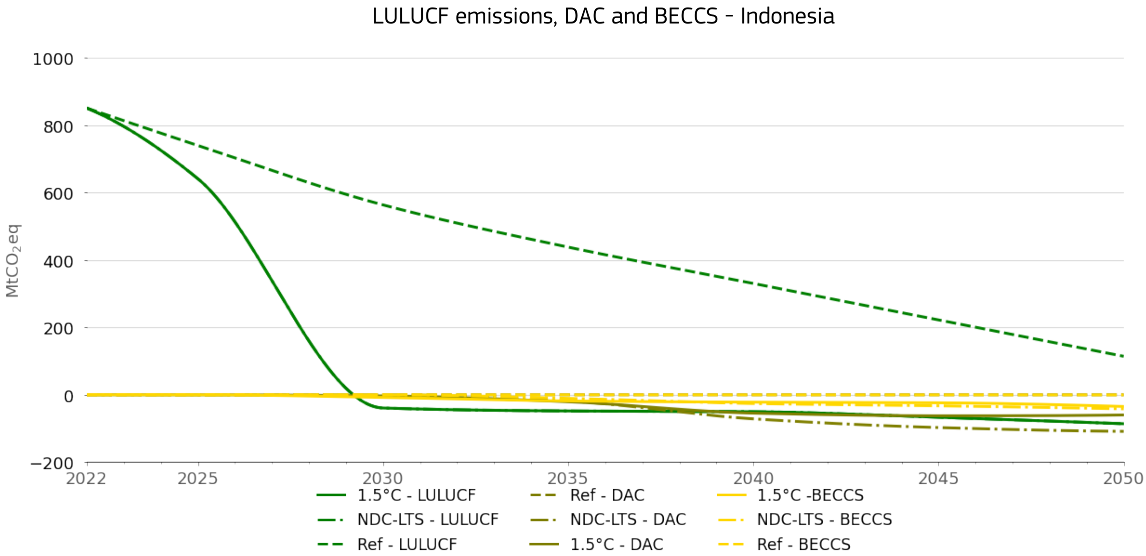


Non-electricity decarbonisation indicators in 1.5ºC scenario - Indonesia

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	662	3818	6792	4004
Domestic production of gaseous e-fuels	bcm	0	0	5	15	0
Domestic production of liquid e-fuels	barrels	0	2811	22020	63469	56145
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	17313	133930	209818	178966
Yearly additions of electrolysers	MW	0	11120	13301	10228	3095

Strategy 4 – Scale-up negative emissions and reduce residual emissions





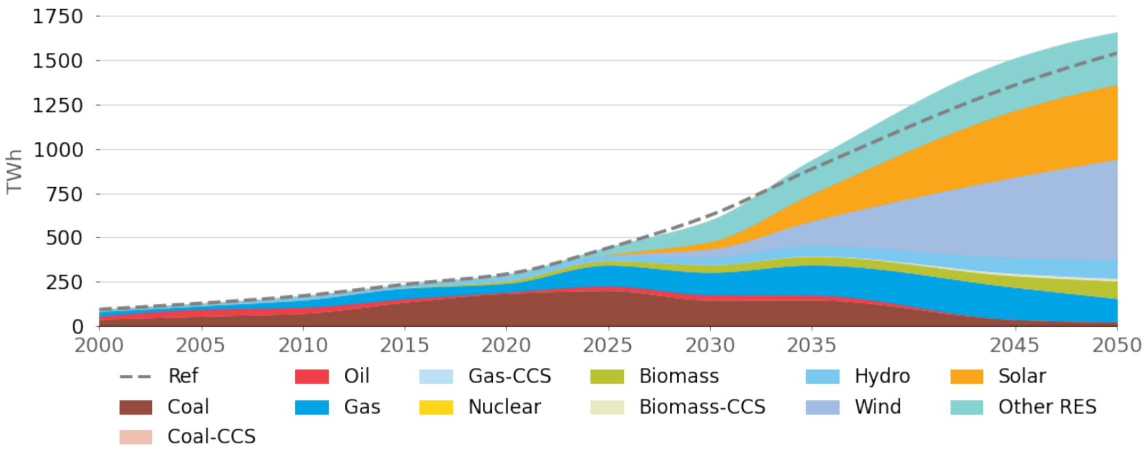
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Indonesia

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	3	21	55	60
Biomass emissions captured	$MtCO_2eq$	0	8	18	22	35
LULUCF emissions	$MtCO_2eq$	851	-39	-48	-50	-86
Agriculture emissions	$MtCO_2eq$	186	186	170	149	94
Methane emissions	$MtCO_2eq$	231	130	91	82	67
Methane emission from fossil fuel production	$MtCO_2eq$	146	61	27	18	9

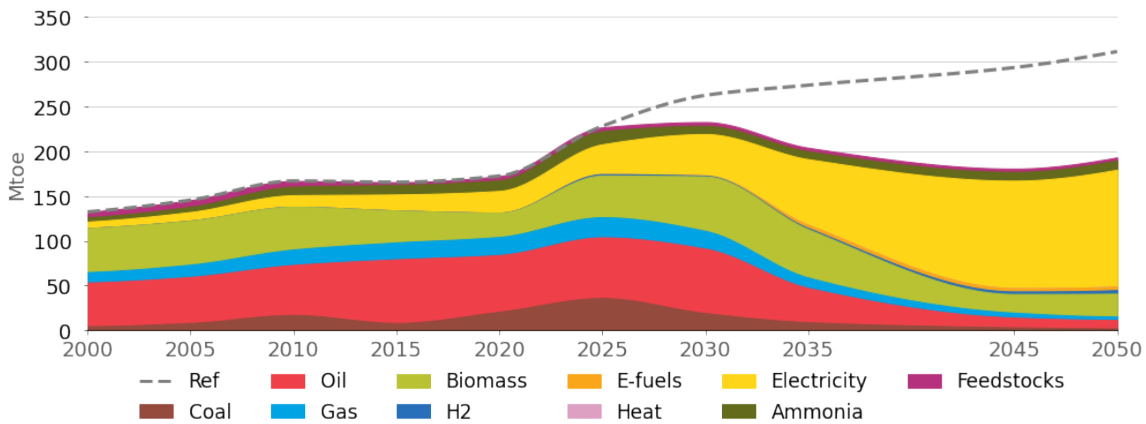
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5°C scenario - Indonesia



Final energy consumption in the 1.5°C scenario - Indonesia



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

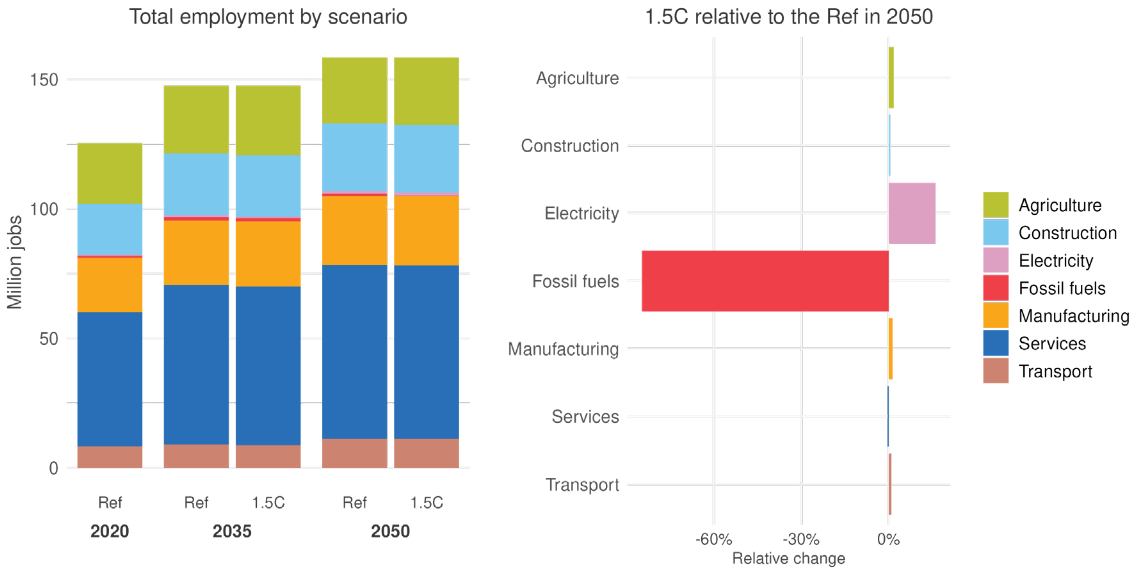
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-75%	-18%	-18%
Annual energy import bill	billion USD	-203	-21	-29
Air pollution emissions - PM2.5	Mt	3007	2432	1791
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	28	12
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	101%	51%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	11	14
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	69%	91%

Labour market dynamics

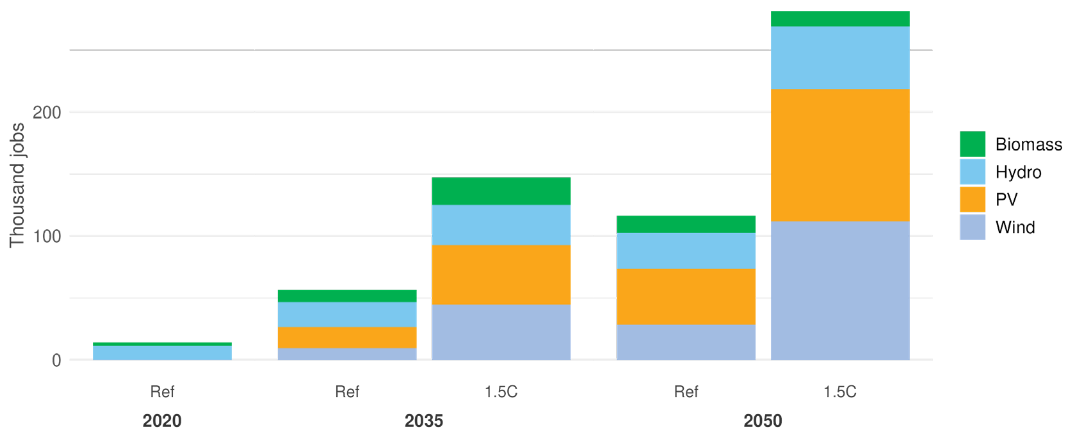
These graphs show the breakdown of employment in Indonesia, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Indonesia



Note: Electricity includes all power generation technologies as well as transmission and distribution.

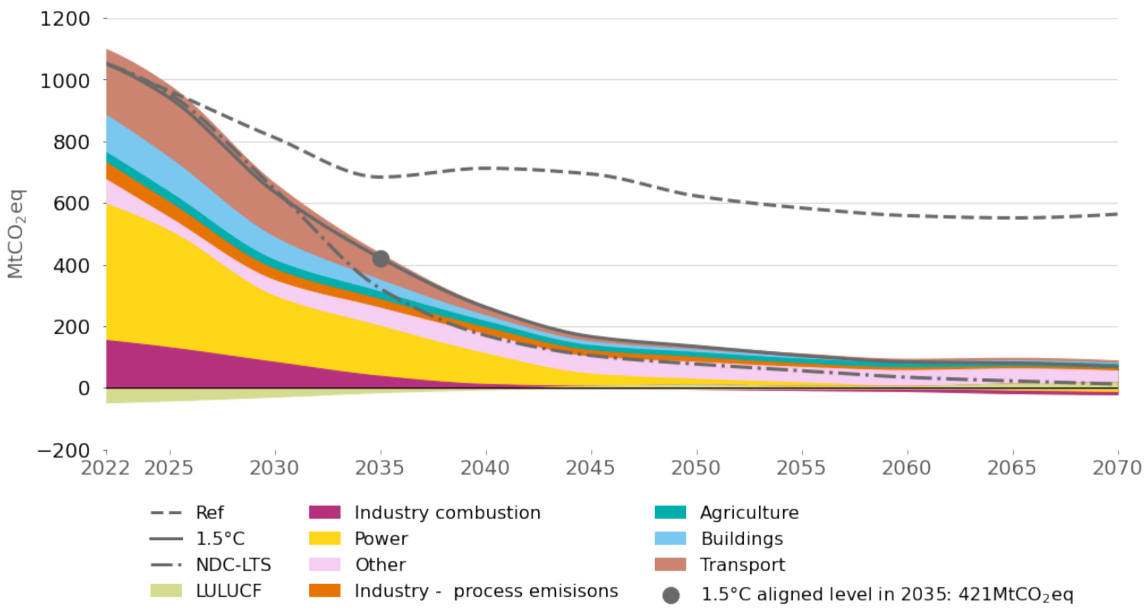
Jobs in renewable technologies by scenario – Indonesia



Japan

Japan's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Japan



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Japan's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**1052**	**422**	**-60%**
Power	441	162	-63%
Industry	210	67	-68%
Transport	177	69	-61%
Buildings	109	31	-72%
LULUCF	-47	-14	-70%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

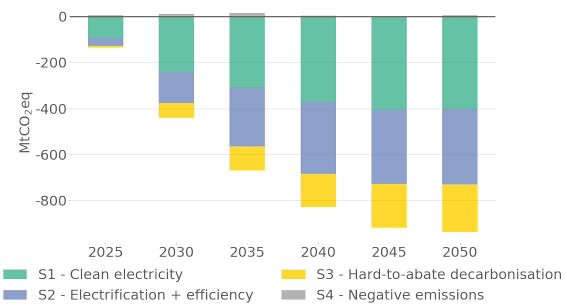
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

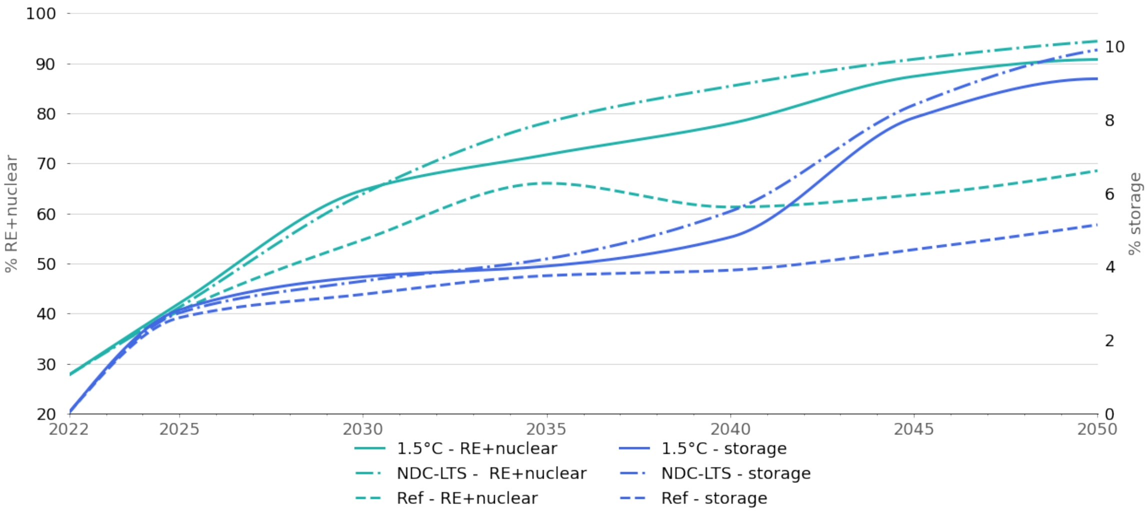
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Japan



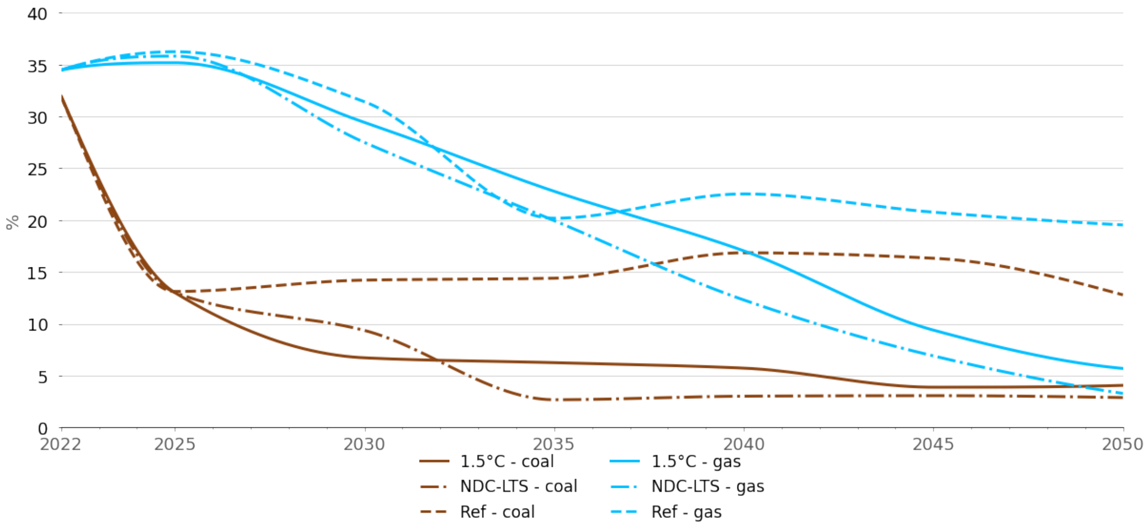
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Japan



Shares of coal & gas power generation technologies - Japan

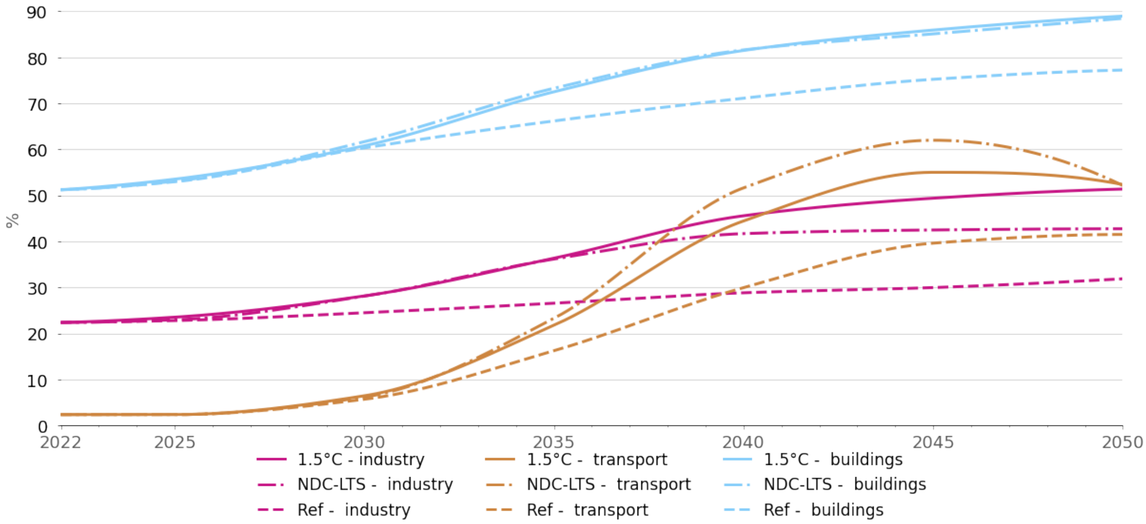


Clean electricity indicators in 1.5ºC scenario - Japan

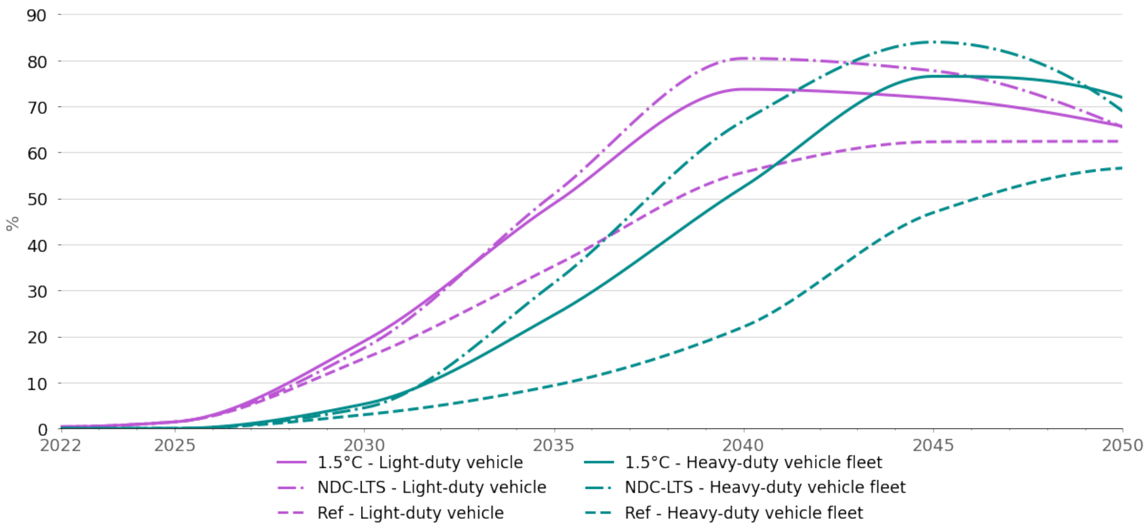
		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	5	18	22	26	21
Wind+solar share of annual additions	%	13%	75%	73%	68%	59%
Annual additions of storage	GW	0.13	0.22	0.94	3.58	6.55
Carbon content of electricity	gCO_2/MWh	432	192	130	72	13
Emissions from power sector	$MtCO_2eq$	441	213	162	99	18
First year of no unabated coal generation				2045		

Strategy 2 – Electrify end-uses and improve energy efficiency

Shares of electricity in final consumption sectors - Japan



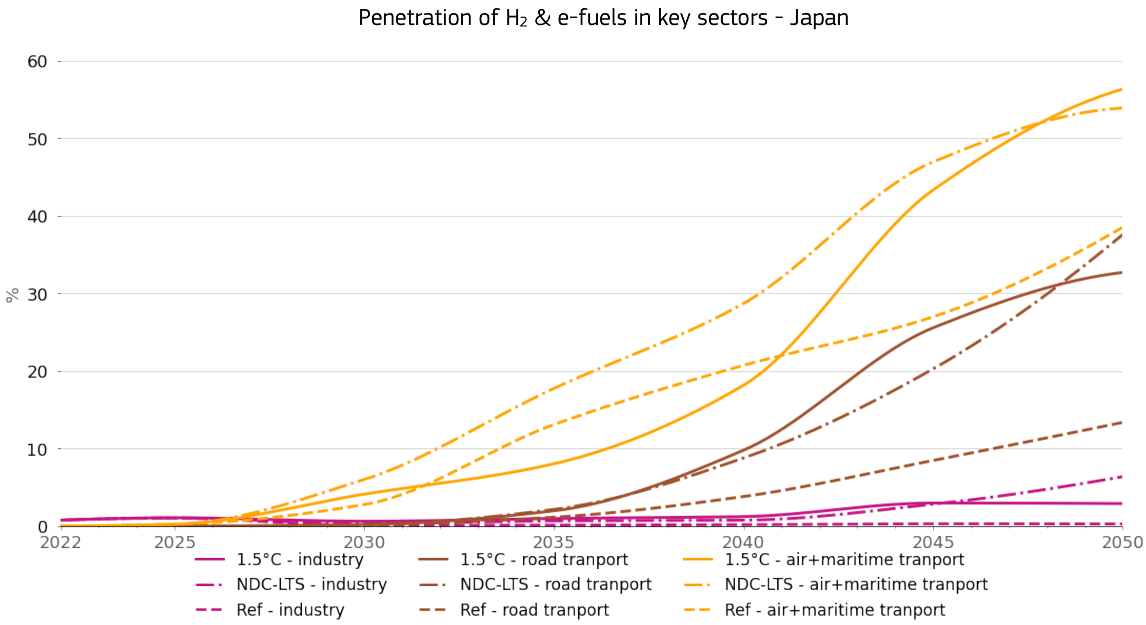
Shares of EVs in fleets - Japan

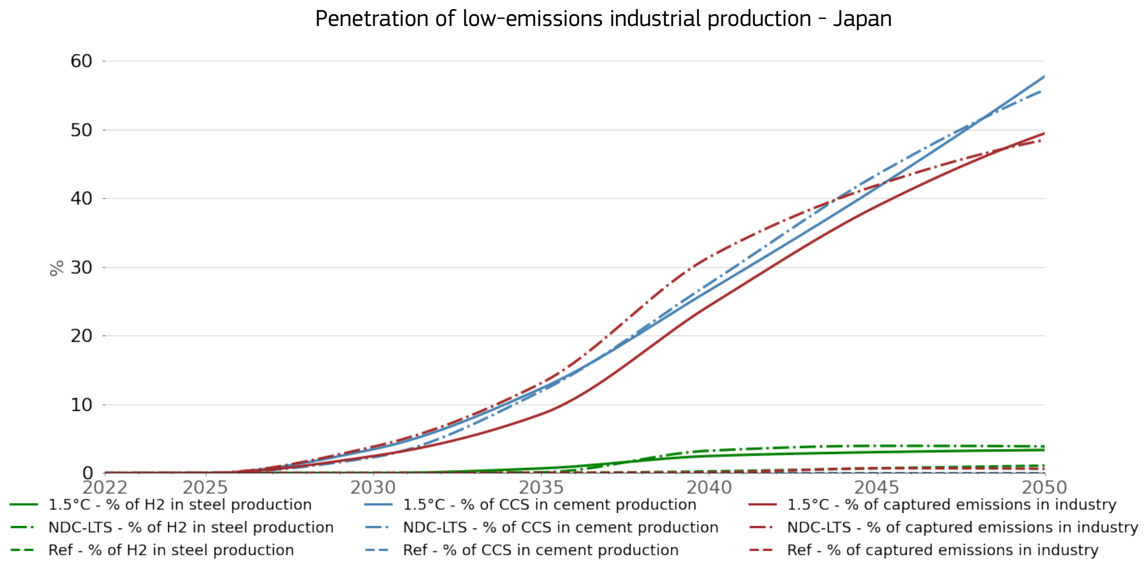


Electrification indicators in 1.5ºC scenario - Japan

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	59	2207	3769	3696	2516
Share of EVs in total car sales	%	1%	40%	74%	70%	58%
Annual sales of EV HDV	thousands	0	0	3	38	138
Share of EVs in total HDV sales	%	0%	0%	2%	16%	60%
Annual sales of small-scale heat pumps in buildings	GW	5	16	10	12	10
Annual sales of large-scale heat pumps in industry	GW	0	60	63	44	73
Share of heat pumps in buildings heating demand	%	0%	15%	33%	48%	67%

Strategy 3 – Decarbonise hard-to-abate sectors



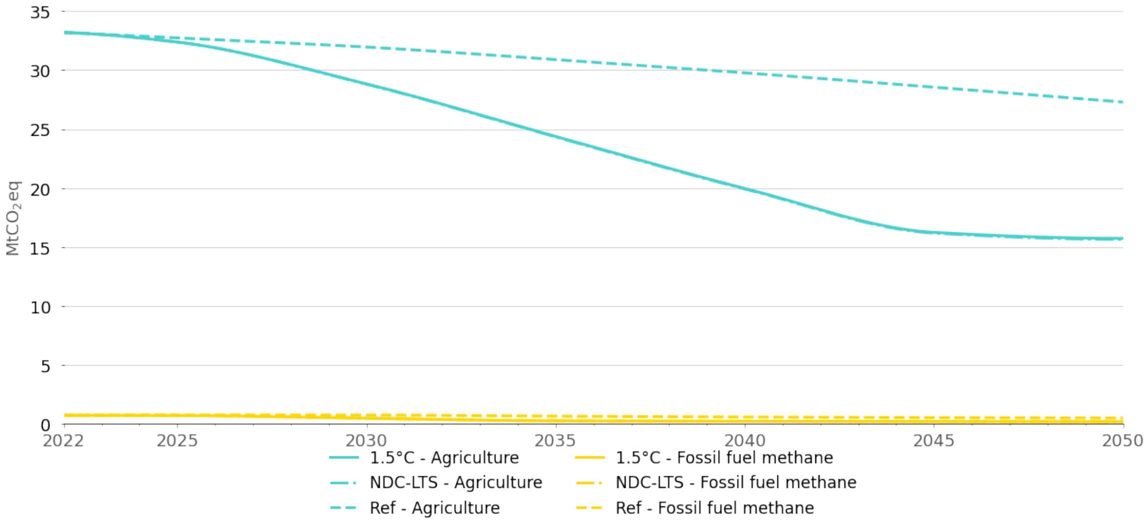


Non-electricity decarbonisation indicators in 1.5ºC scenario - Japan

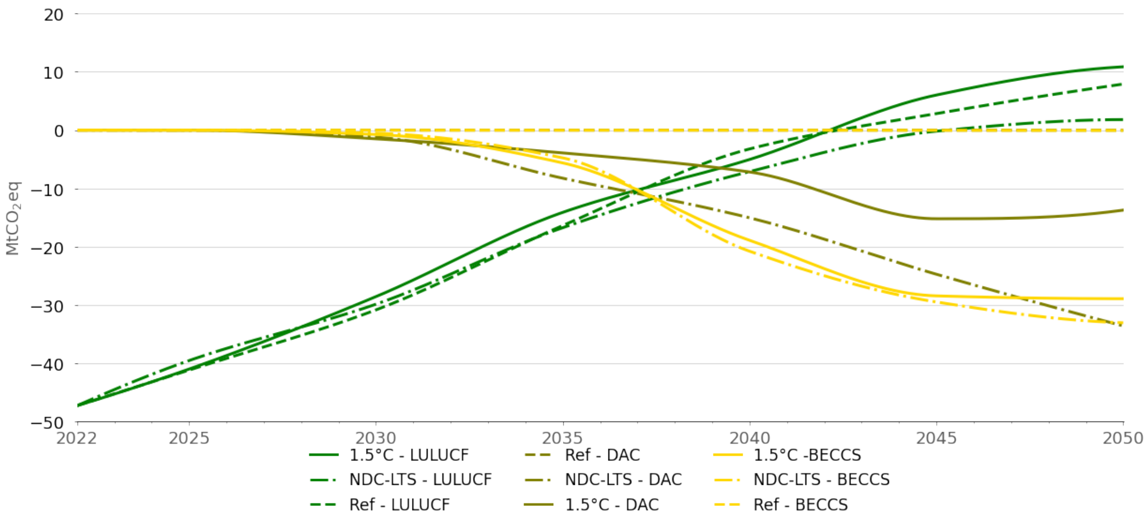
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	0	0	566	3840
Domestic production of gaseous e-fuels	bcm	0	0	0	4	17
Domestic production of liquid e-fuels	barrels	0	0	26	173	1874
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	0	0	16728	105167
Yearly additions of electrolysers	MW	0	0	3805	6809	10421

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - Japan



LULUCF emissions, DAC and BECCS - Japan



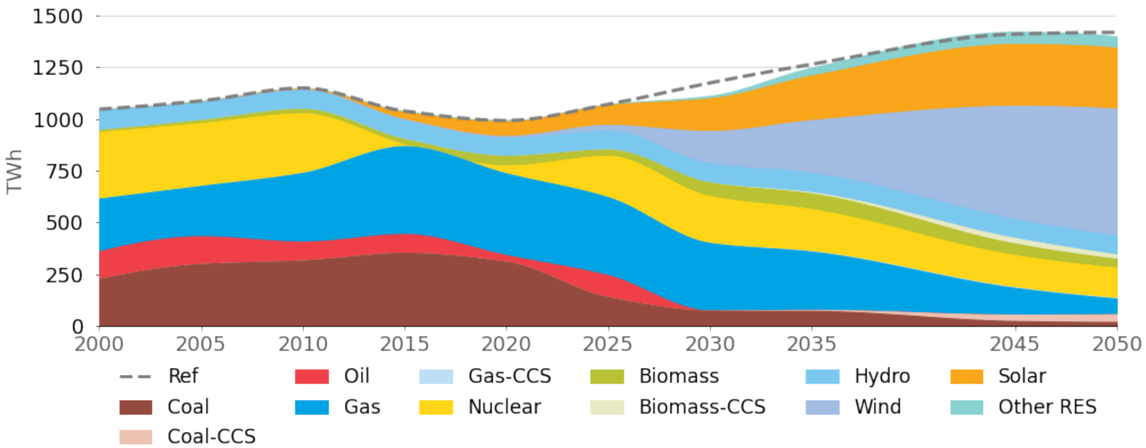
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Japan

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	4	7	14
Biomass emissions captured	$MtCO_2eq$	0	1	6	19	29
LULUCF emissions	$MtCO_2eq$	-47	-29	-14	-5	11
Agriculture emissions	$MtCO_2eq$	33	29	24	20	16
Methane emissions	$MtCO_2eq$	6	3	2	2	1
Methane emission from fossil fuel production	$MtCO_2eq$	1	0	0	0	0

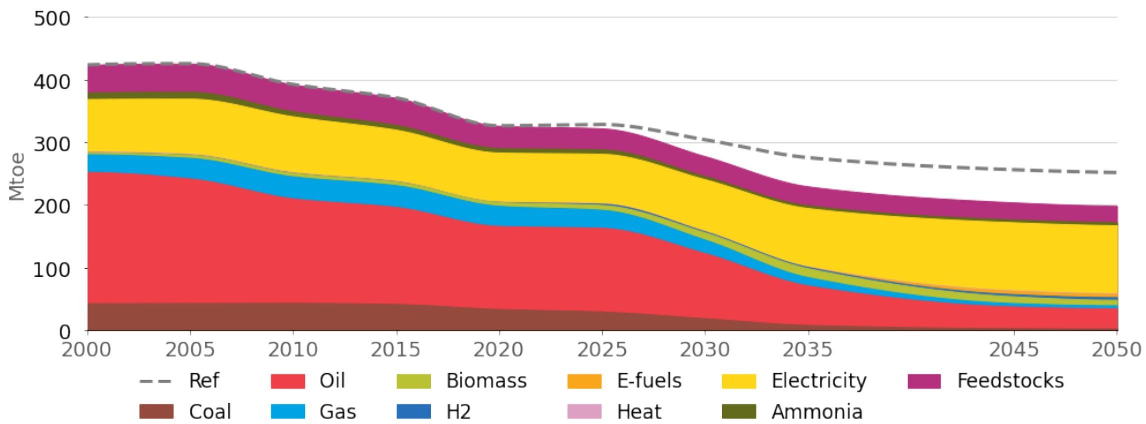
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - Japan



Final energy consumption in the 1.5ºC scenario - Japan



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

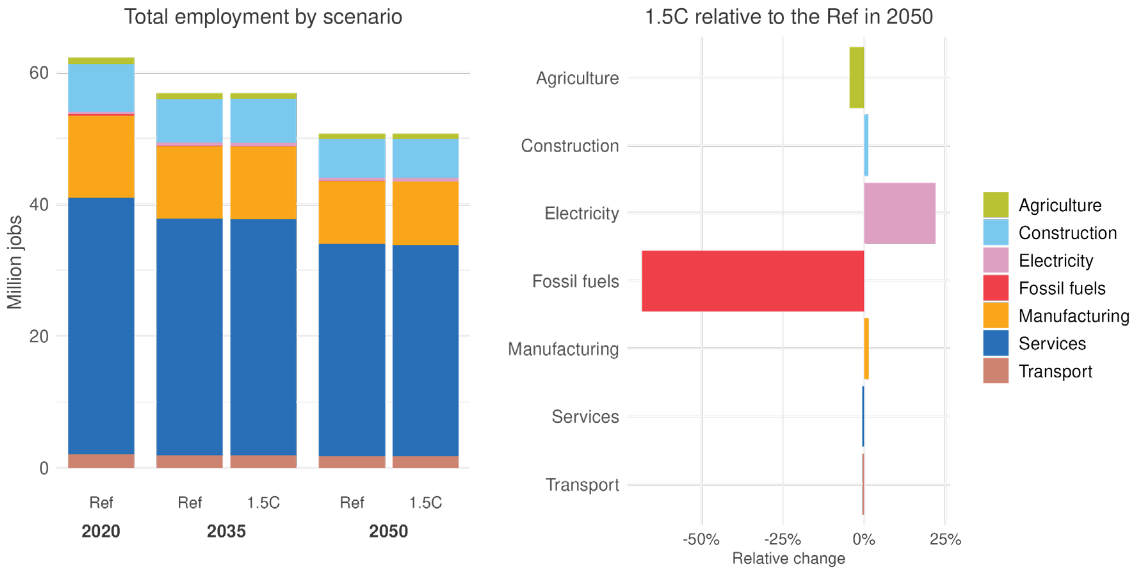
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	93%	63%	35%
Annual energy import bill	billion USD	301	115	52
Air pollution emissions - PM2.5	Mt	135	63	26
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	10	11
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	40%	66%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	0	0
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	2%	80%

Labour market dynamics

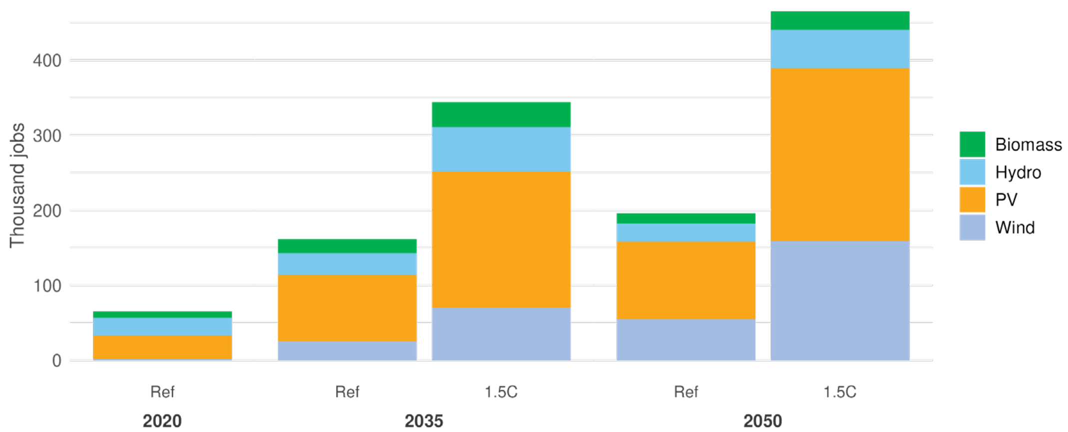
These graphs show the breakdown of employment in Japan, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Japan



Note: Electricity includes all power generation technologies as well as transmission and distribution.

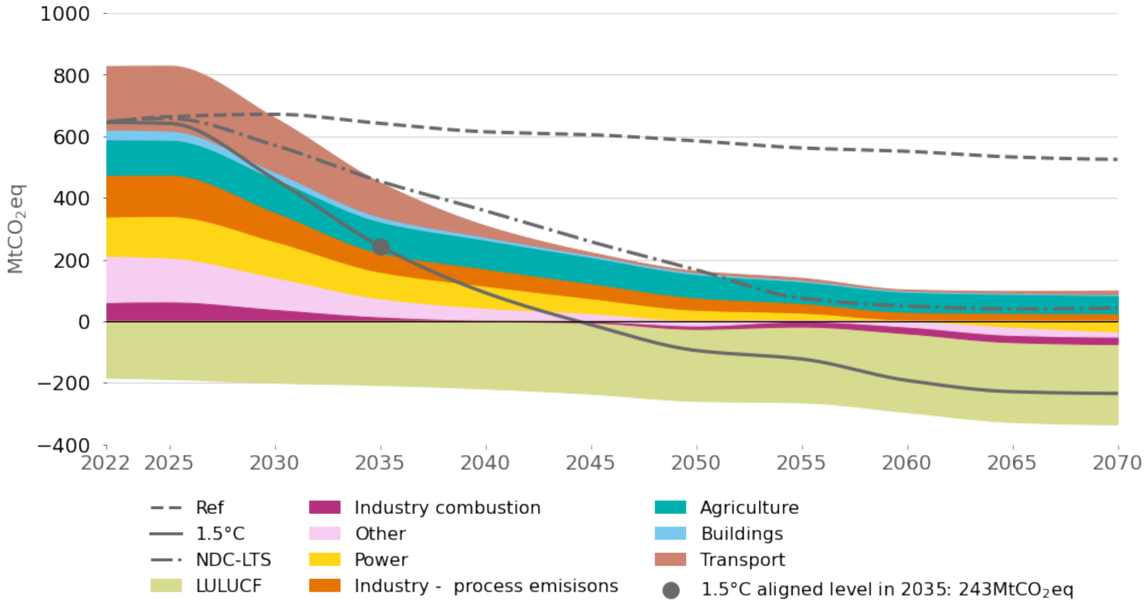
Jobs in renewable technologies by scenario – Japan



Mexico

Mexico's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Mexico



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Mexico's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**645**	**243**	**-62%**
Power	127	86	-32%
Industry	194	74	-62%
Transport	194	105	-46%
Buildings	23	10	-59%
LULUCF	-183	-207	13%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

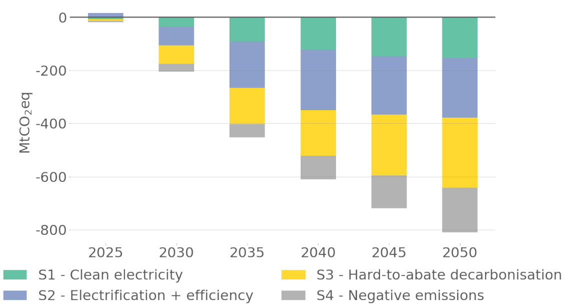
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

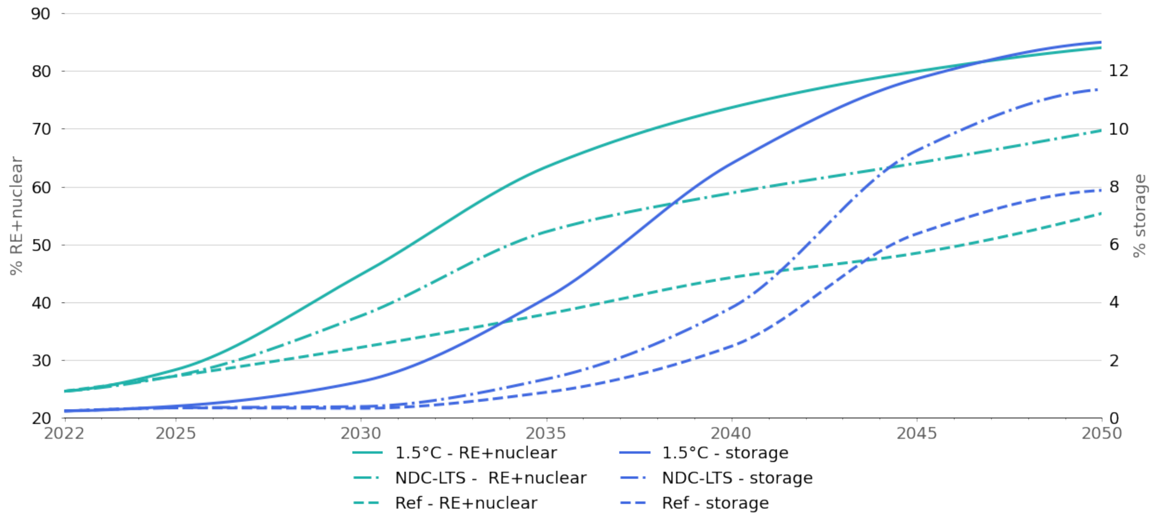
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Mexico



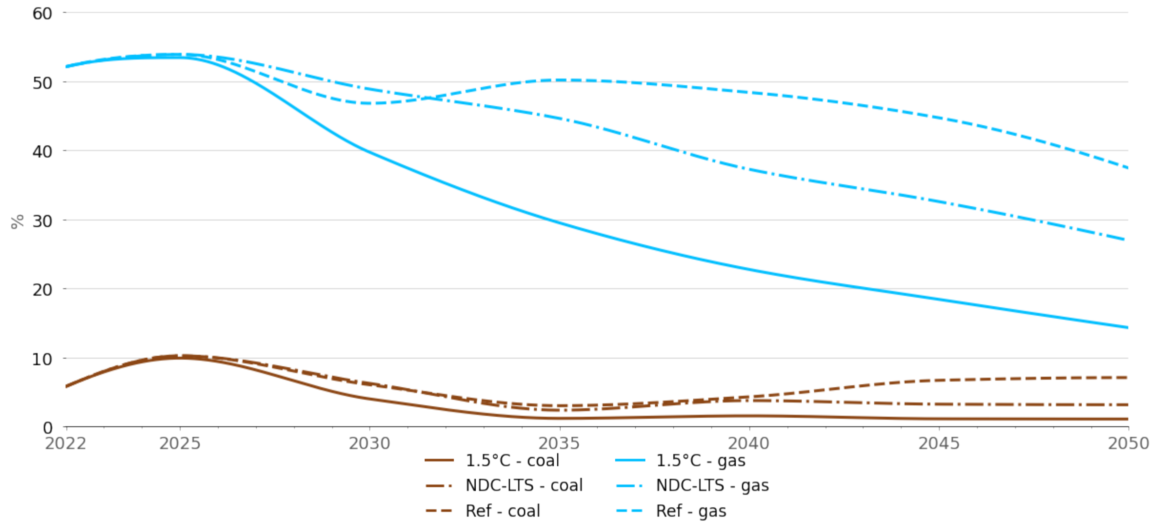
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Mexico



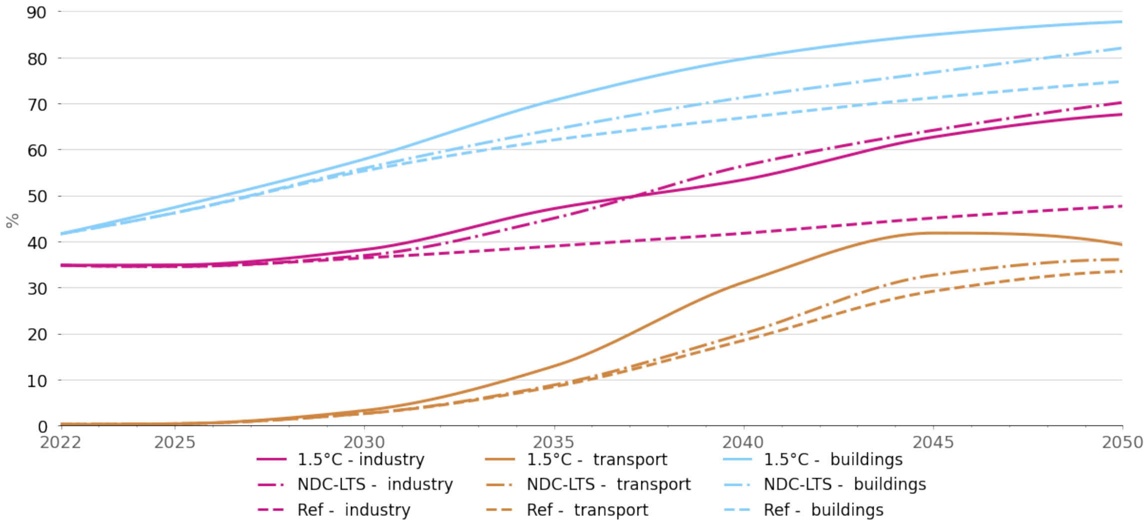
Shares of coal & gas power generation technologies - Mexico

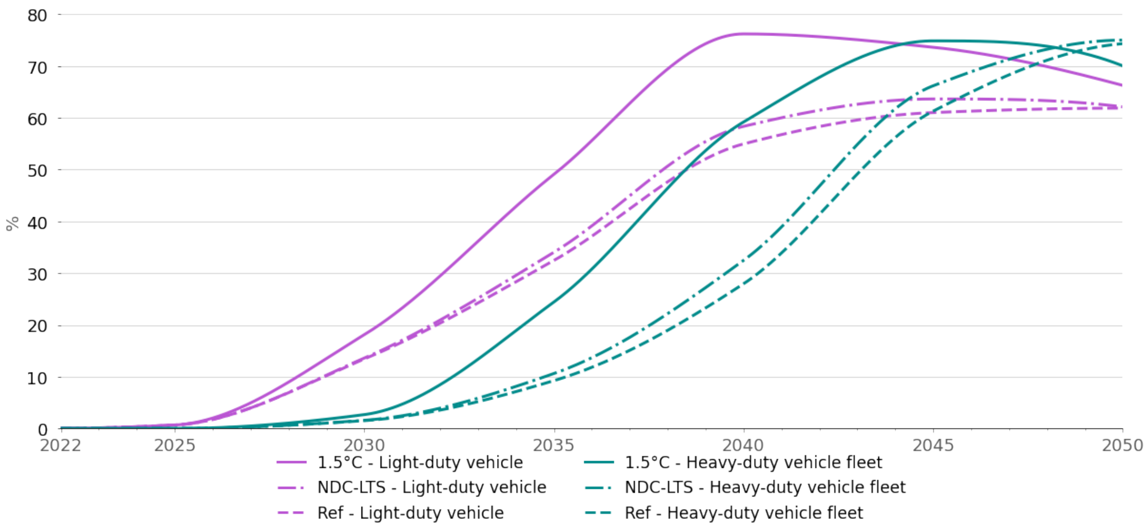


Clean electricity indicators in 1.5ºC scenario - Mexico

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	1	13	18	18	14
Wind+solar share of annual additions	%	32%	74%	70%	62%	53%
Annual additions of storage	GW	0.03	1.30	3.38	5.45	6
Carbon content of electricity	gCO_2/MWh	380	267	147	92	34
Emissions from power sector	$MtCO_2eq$	127	116	86	71	33
First year of no unabated coal generation				2041		

Strategy 2 – Electrify end-uses and improve energy efficiency

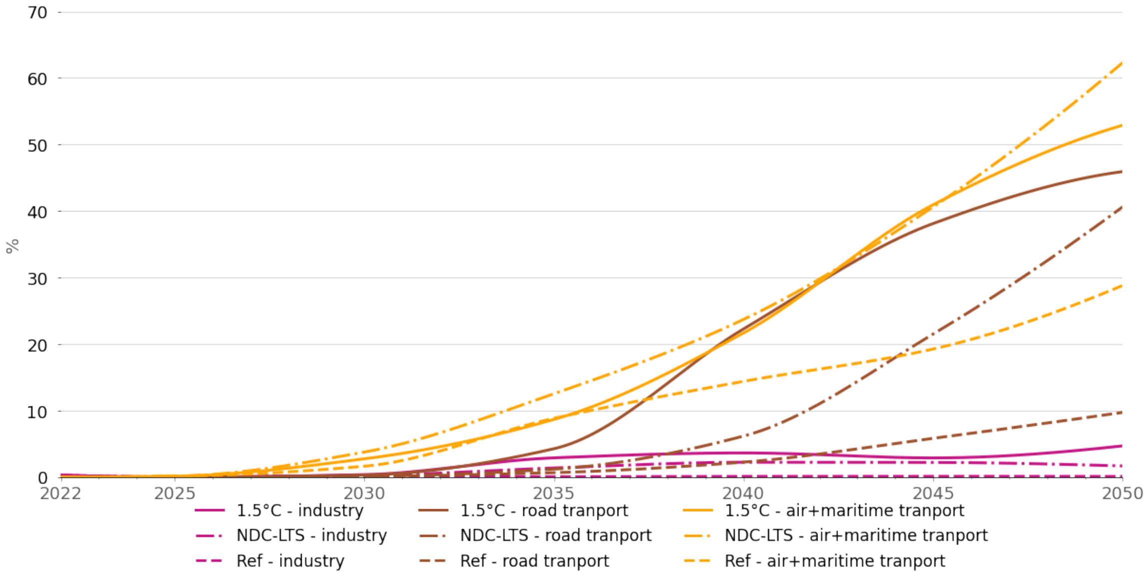


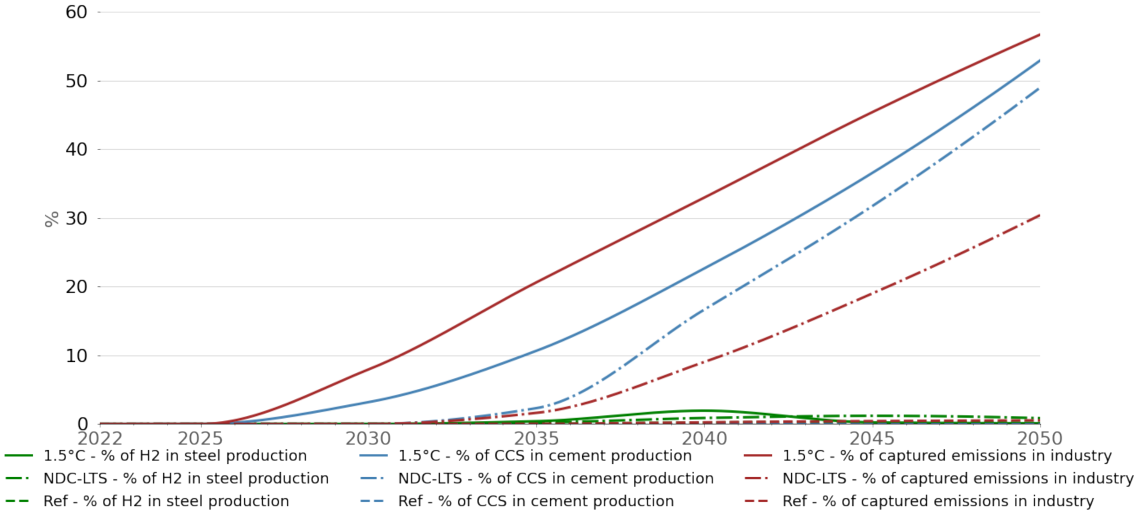


Electrification indicators in 1.5ºC scenario - Mexico

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	4	1672	3019	3042	3052
Share of EVs in total car sales	%	0%	49%	76%	71%	55%
Annual sales of EV HDV	thousands	0	0	1	45	187
Share of EVs in total HDV sales	%	0%	0%	0%	12%	52%
Annual sales of small-scale heat pumps in buildings	GW	0	1	0	0	0
Annual sales of large-scale heat pumps in industry	GW	0	19	17	51	30
Share of heat pumps in buildings heating demand	%	0%	22%	41%	56%	73%

Strategy 3 – Decarbonise hard-to-abate sectors

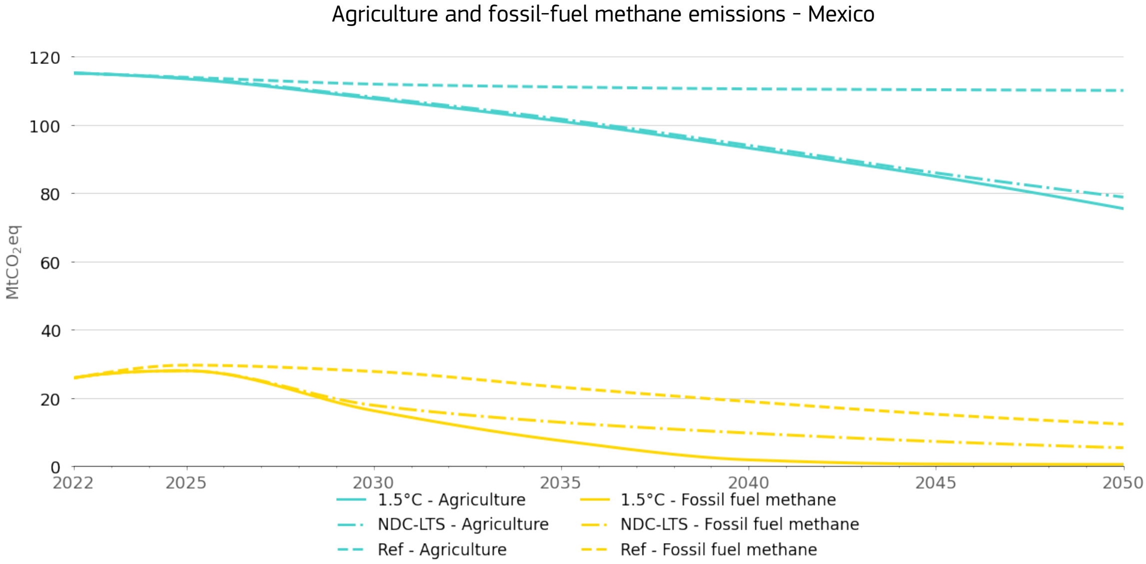


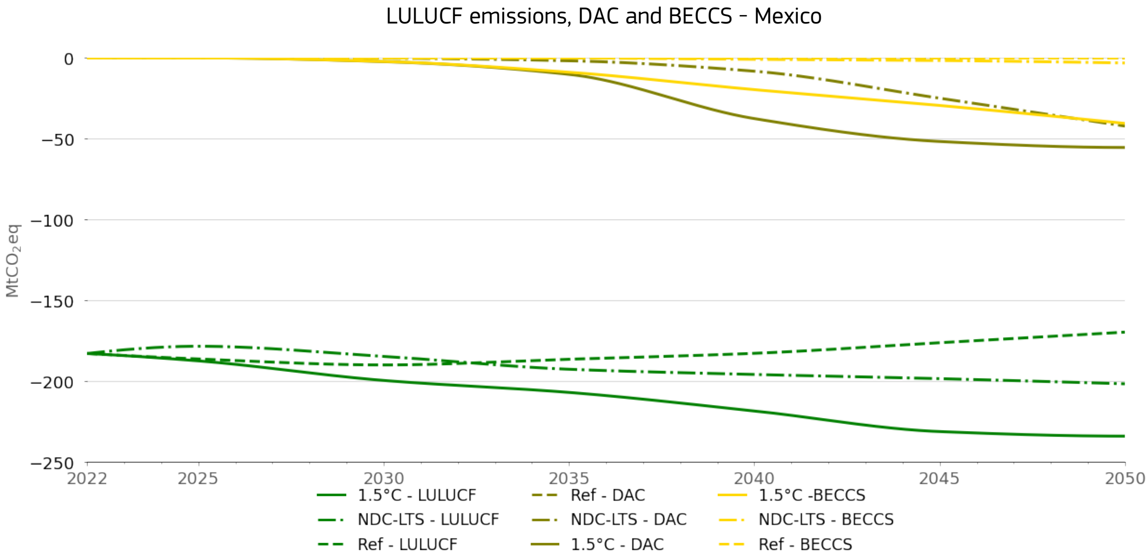


Non-electricity decarbonisation indicators in 1.5ºC scenario - Mexico

		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	104	1888	4337	8503
Domestic production of gaseous e-fuels	bcm	0	0	5	9	18
Domestic production of liquid e-fuels	barrels	0	776	9807	40230	19005
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	2841	50355	153708	303335
Yearly additions of electrolysers	MW	0	5965	10497	16397	15618

Strategy 4 – Scale-up negative emissions and reduce residual emissions





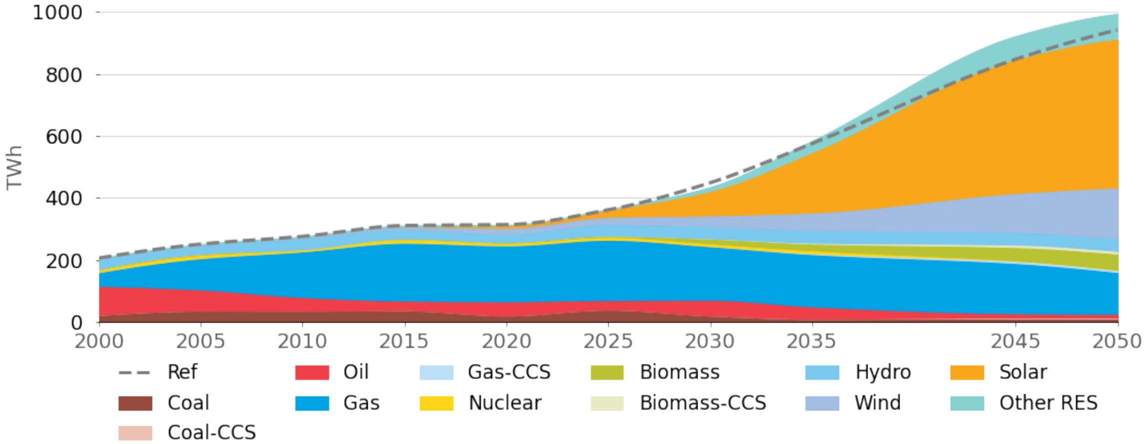
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Mexico

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	2	10	38	55
Biomass emissions captured	$MtCO_2eq$	0	2	9	20	41
LULUCF emissions	$MtCO_2eq$	-183	-199	-207	-218	-234
Agriculture emissions	$MtCO_2eq$	115	108	101	93	75
Methane emissions	$MtCO_2eq$	105	70	42	37	24
Methane emission from fossil fuel production	$MtCO_2eq$	26	16	7	2	1

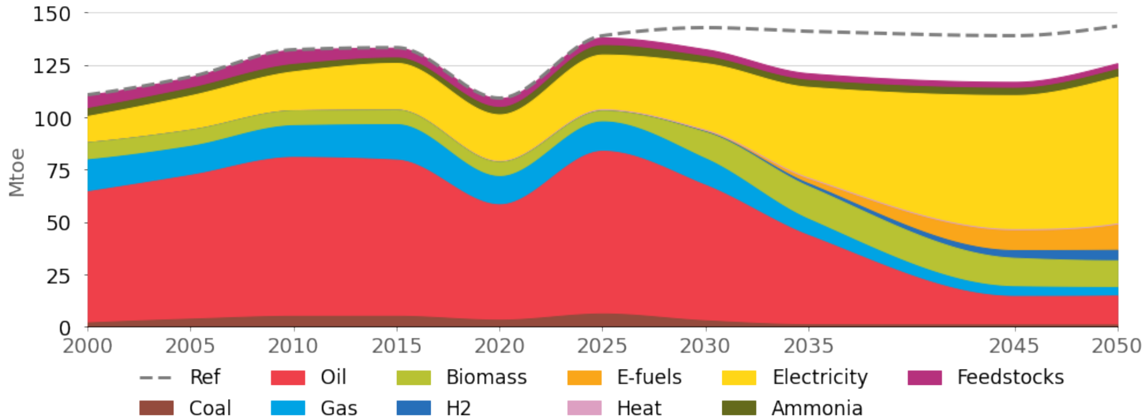
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - Mexico



Final energy consumption in the 1.5ºC scenario - Mexico



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

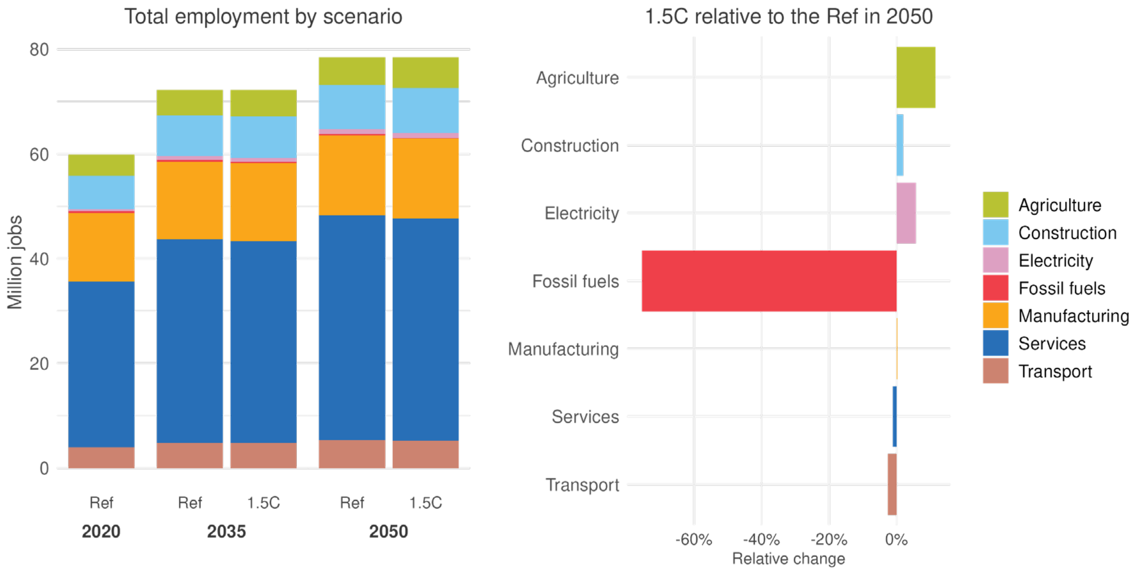
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	23%	18%	18%
Annual energy import bill	billion USD	5	7	34
Air pollution emissions - PM2.5	Mt	635	499	289
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	4	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	22%	-1%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	1	2
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	30%	76%

Labour market dynamics

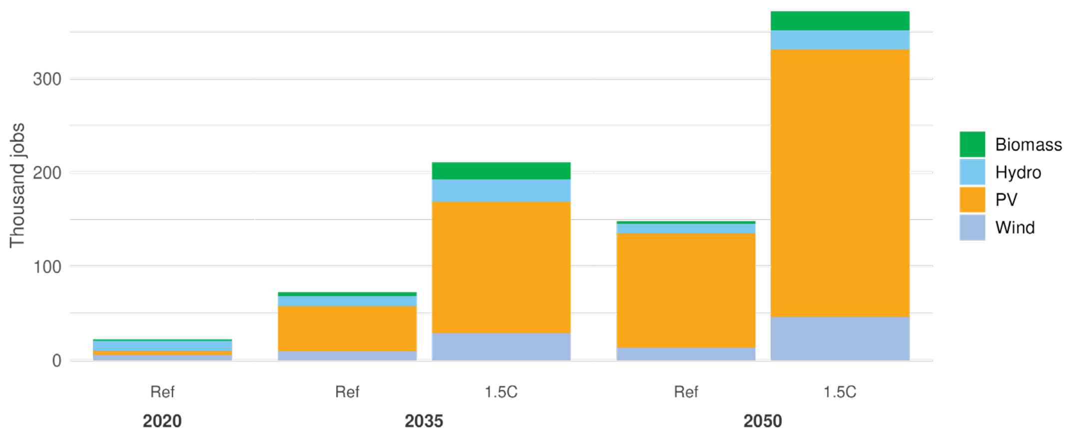
These graphs show the breakdown of employment in Mexico, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Mexico



Note: Electricity includes all power generation technologies as well as transmission and distribution.

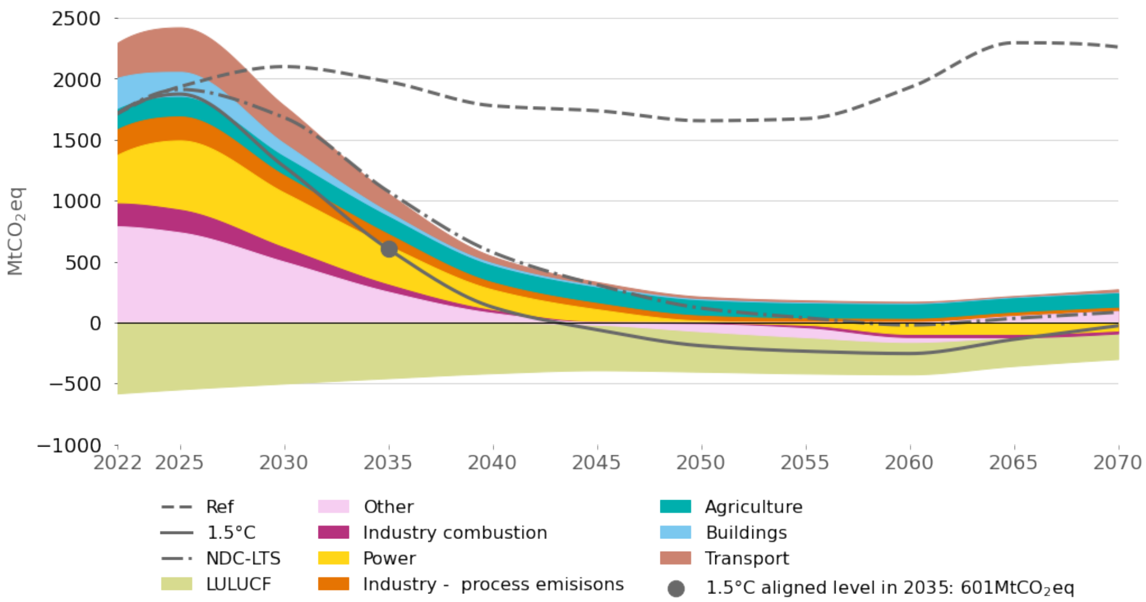
Jobs in renewable technologies by scenario – Mexico



Russia

Russia's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Russia



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Russia's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**1714**	**602**	**-65%**
Power	399	320	-20%
Industry	398	154	-61%
Transport	231	126	-45%
Buildings	241	28	-89%
LULUCF	-582	-457	-22%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

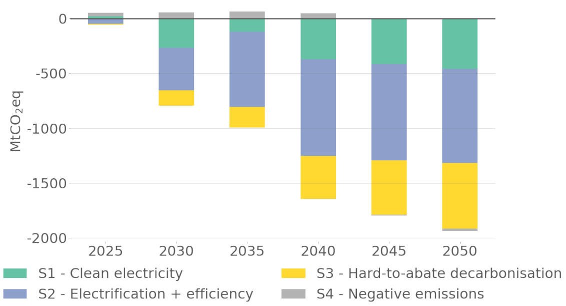
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

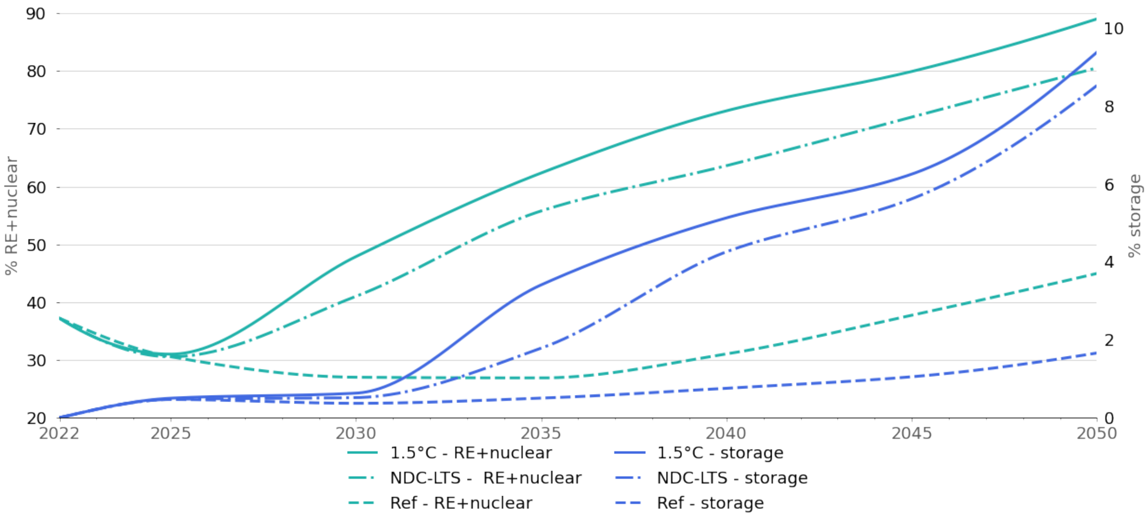
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Russia



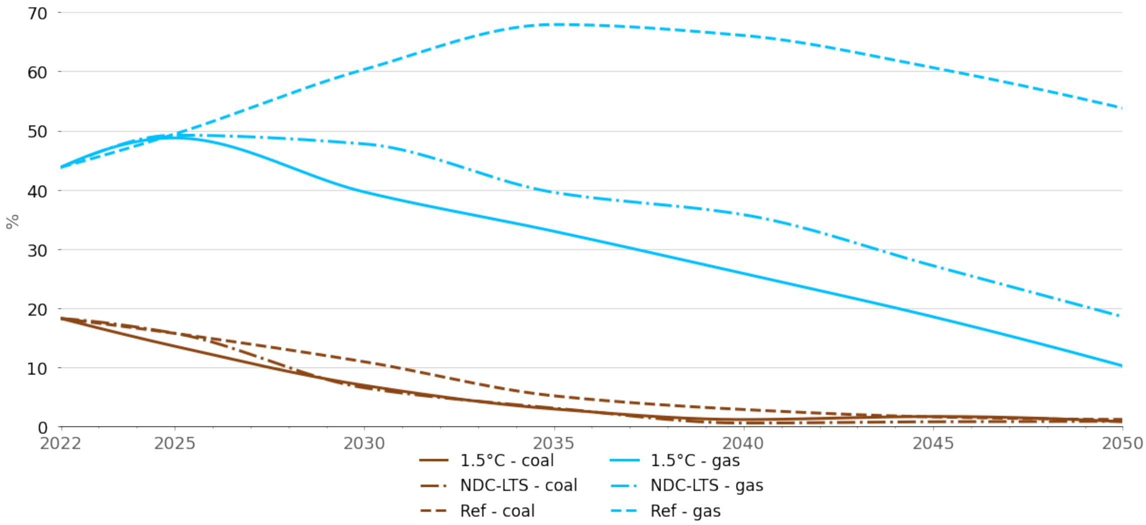
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Russia



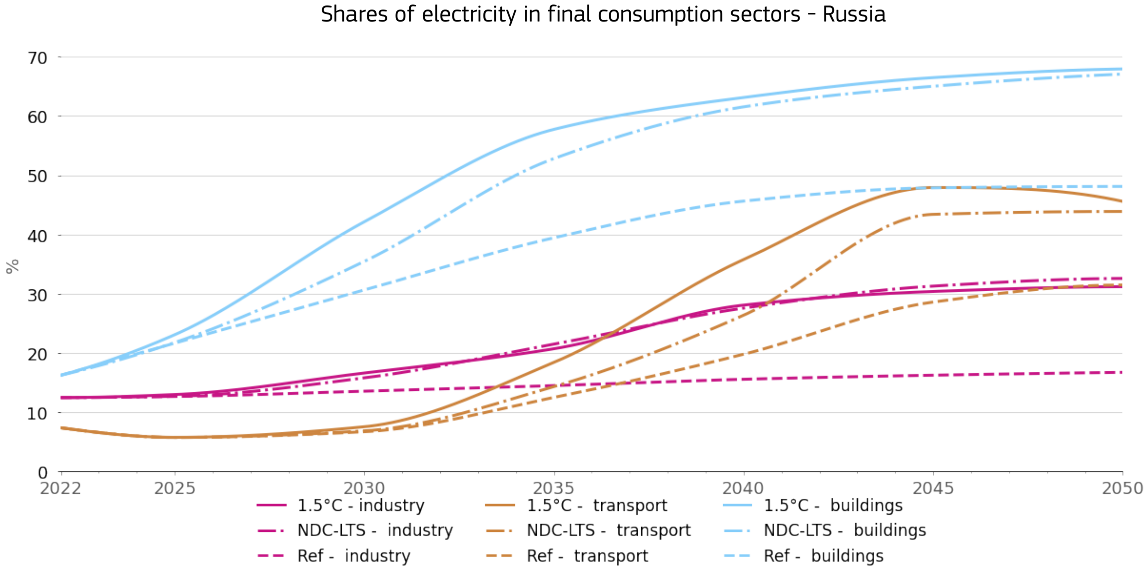
Shares of coal & gas power generation technologies - Russia

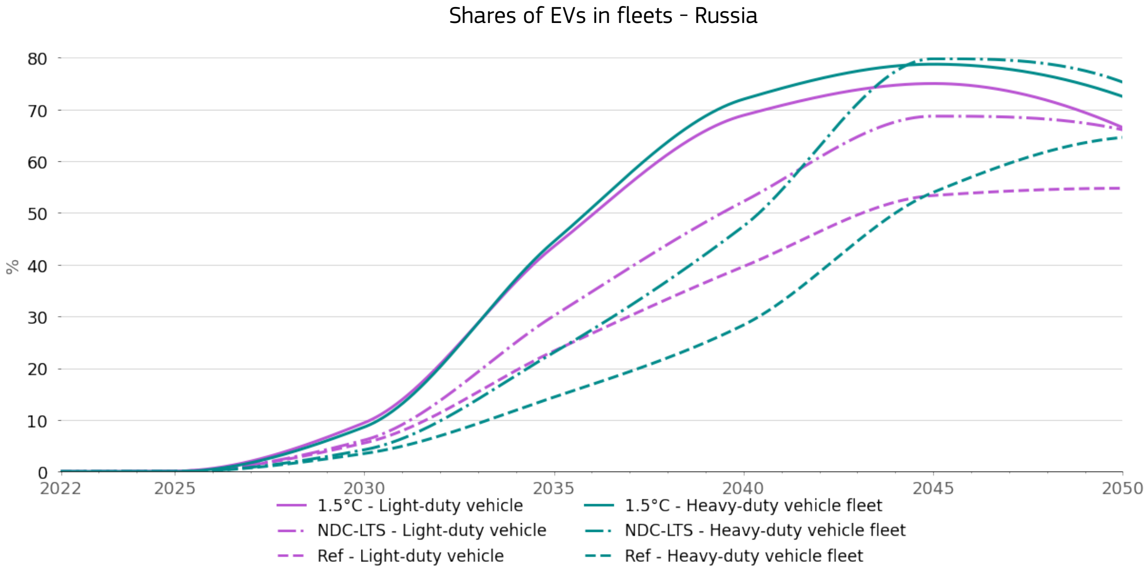


Clean electricity indicators in 1.5ºC scenario - Russia

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	0	49	60	48	37
Wind+solar share of annual additions	%	7%	62%	69%	62%	57%
Annual additions of storage	GW	0	4.80	9.68	14.43	15.66
Carbon content of electricity	gCO_2/MWh	342	273	132	64	5
Emissions from power sector	$MtCO_2eq$	399	451	319	170	15
First year of no unabated coal generation				2045		

Strategy 2 – Electrify end-uses and improve energy efficiency



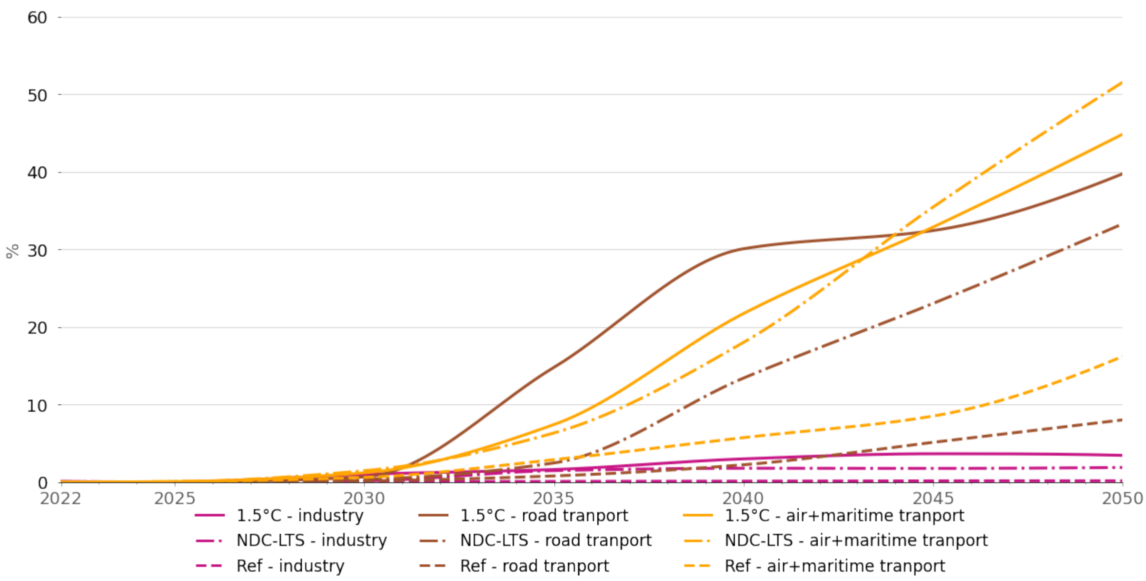


Electrification indicators in 1.5ºC scenario - Russia

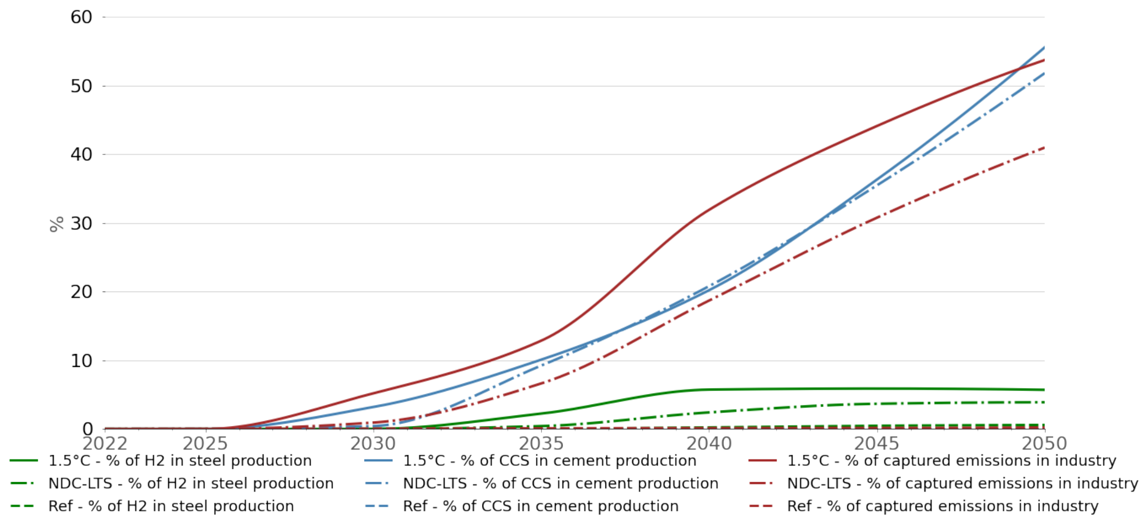
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	0	710	3084	3101	2813
Share of EVs in total car sales	%	0%	22%	73%	68%	58%
Annual sales of EV HDV	thousands	0	0	3	47	145
Share of EVs in total HDV sales	%	0%	0%	2%	21%	65%
Annual sales of small-scale heat pumps in buildings	GW	5	31	0	6	0
Annual sales of large-scale heat pumps in industry	GW	0	34	55	54	66
Share of heat pumps in buildings heating demand	%	0%	6%	13%	18%	22%

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - Russia



Penetration of low-emissions industrial production - Russia

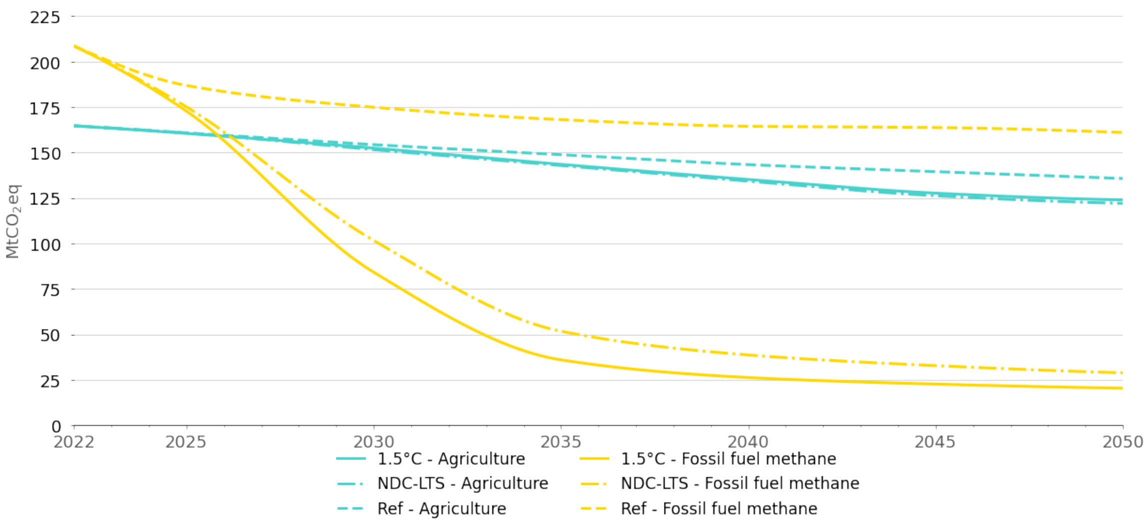


Non-electricity decarbonisation indicators in 1.5ºC scenario - Russia

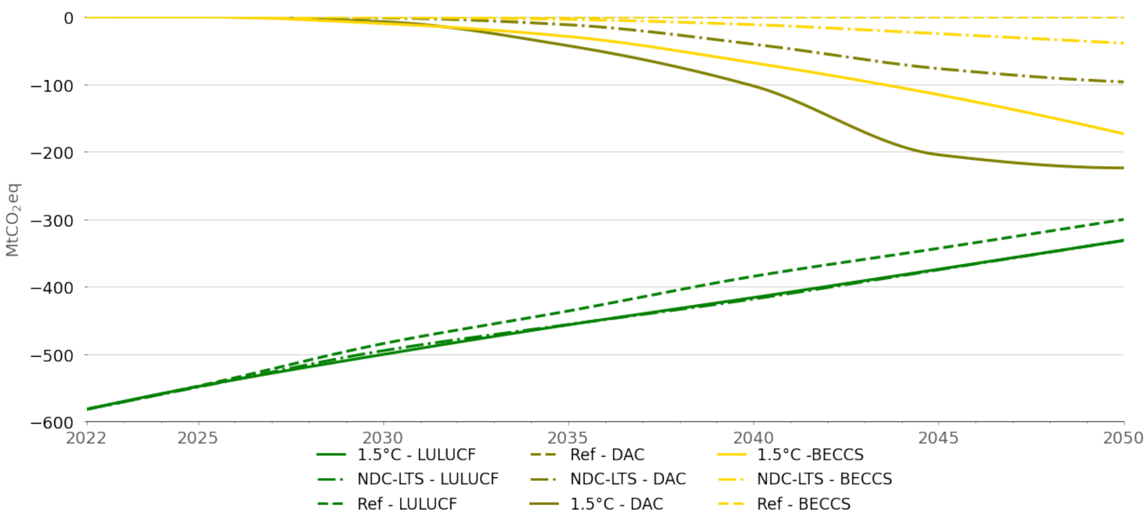
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	7923	9188	21153	46756
Domestic production of gaseous e-fuels	bcm	0	0	8	25	33
Domestic production of liquid e-fuels	barrels	0	5529	47693	129657	269550
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	267328	311540	546302	1130970
Yearly additions of electrolysers	MW	0	27487	41655	49603	57204

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - Russia



LULUCF emissions, DAC and BECCS - Russia

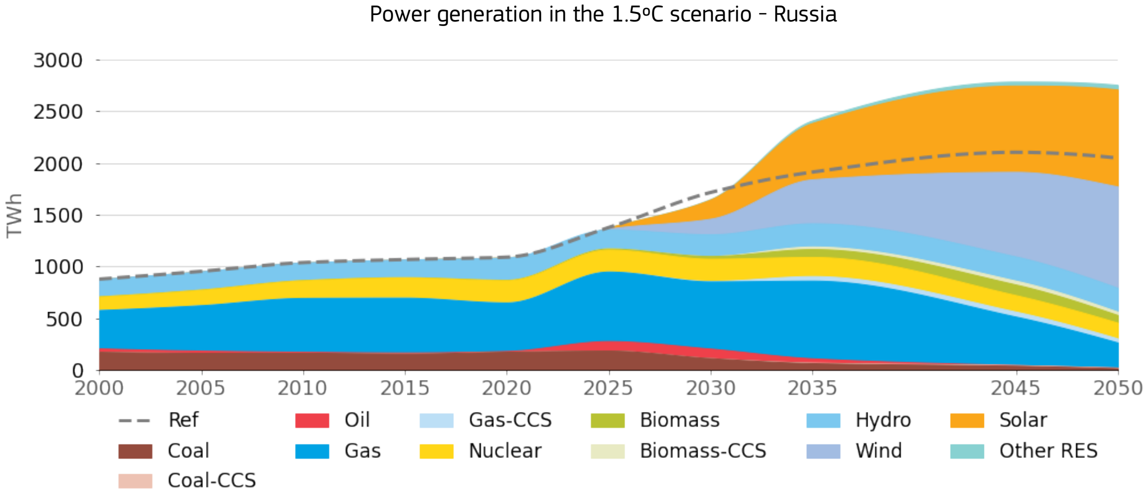


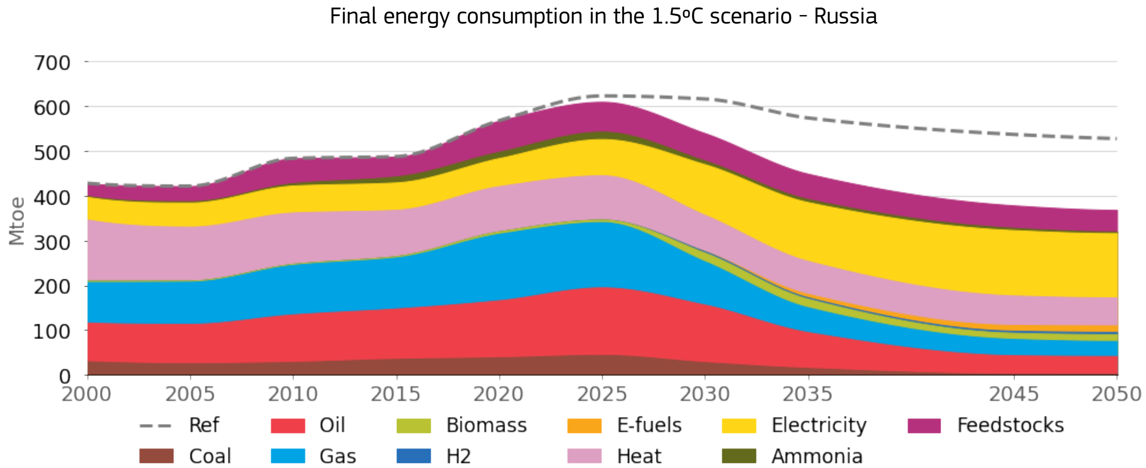
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Russia

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	7	43	102	224
Biomass emissions captured	$MtCO_2eq$	0	10	29	68	173
LULUCF emissions	$MtCO_2eq$	-582	-501	-457	-416	-331
Agriculture emissions	$MtCO_2eq$	165	152	143	135	124
Methane emissions	$MtCO_2eq$	314	143	66	49	21
Methane emission from fossil fuel production	$MtCO_2eq$	209	84	36	26	20

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

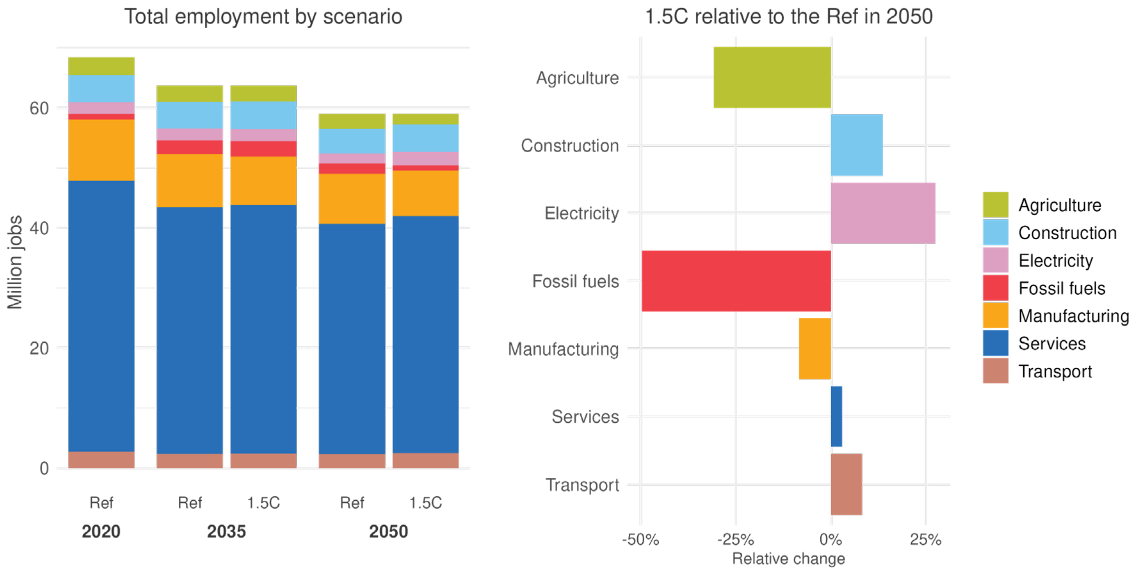
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-87%	-38%	-34%
Annual energy import bill	billion USD	-537	-234	-268
Air pollution emissions - PM2.5	Mt	2556	1374	328
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	68	36
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	246%	205%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	15	33
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	32%	71%

Labour market dynamics

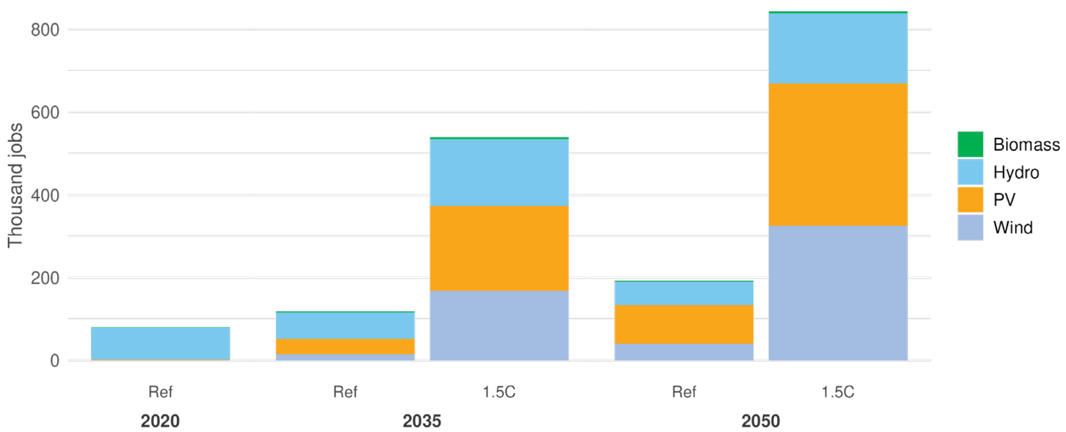
These graphs show the breakdown of employment in Russia, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Russia



Note: Electricity includes all power generation technologies as well as transmission and distribution.

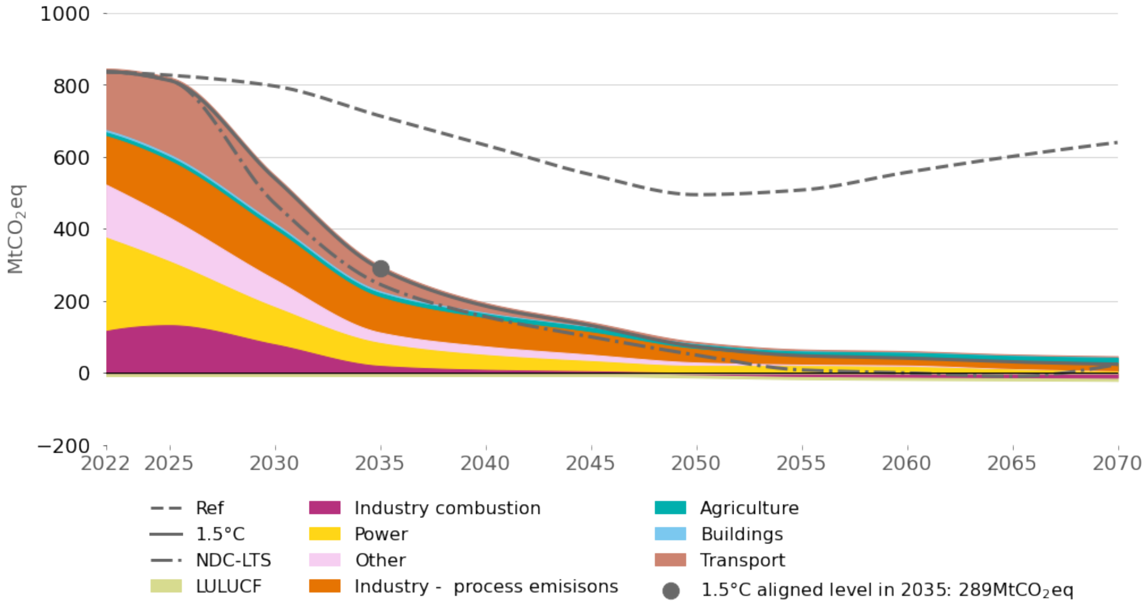
Jobs in renewable technologies by scenario – Russia



Saudi Arabia

Saudi Arabia's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Saudi Arabia



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Saudi Arabia's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**836**	**289**	**-65%**
Power	259	64	-75%
Industry	251	117	-53%
Transport	135	46	-66%
Buildings	6	5	-20%
LULUCF	-9	-9	-1%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

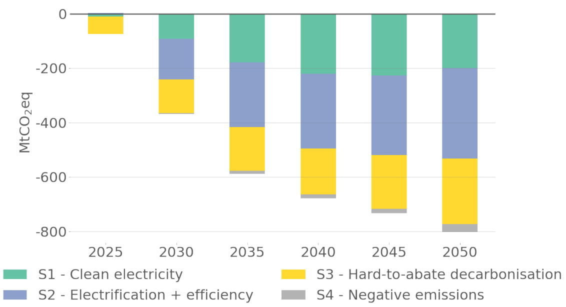
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

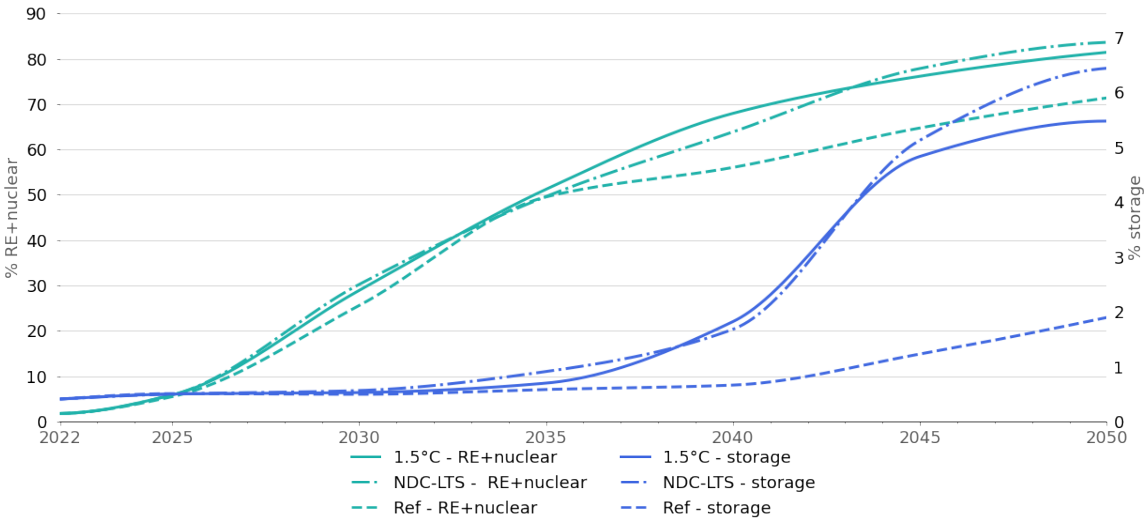
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Saudi Arabia



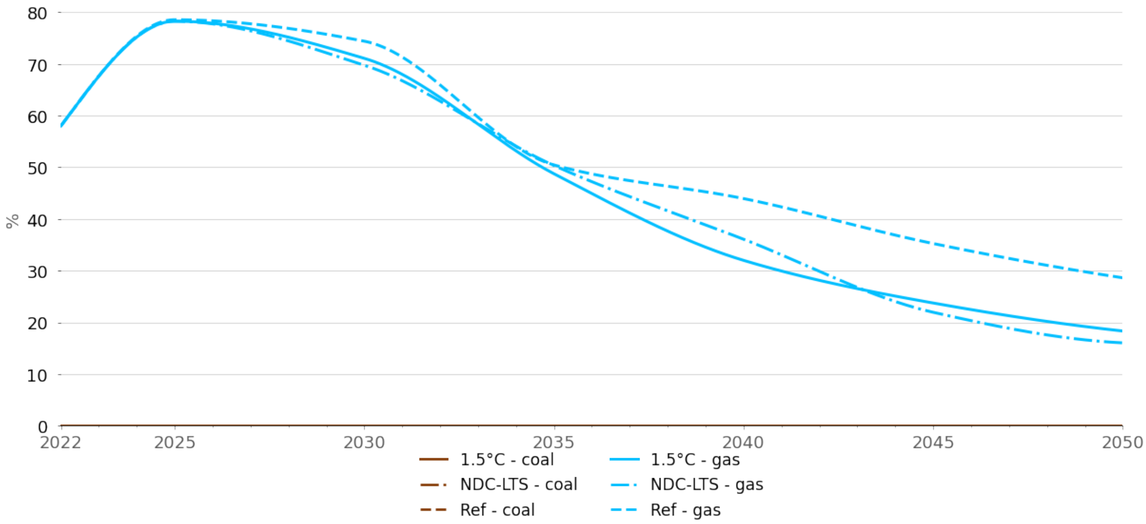
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Saudi Arabia



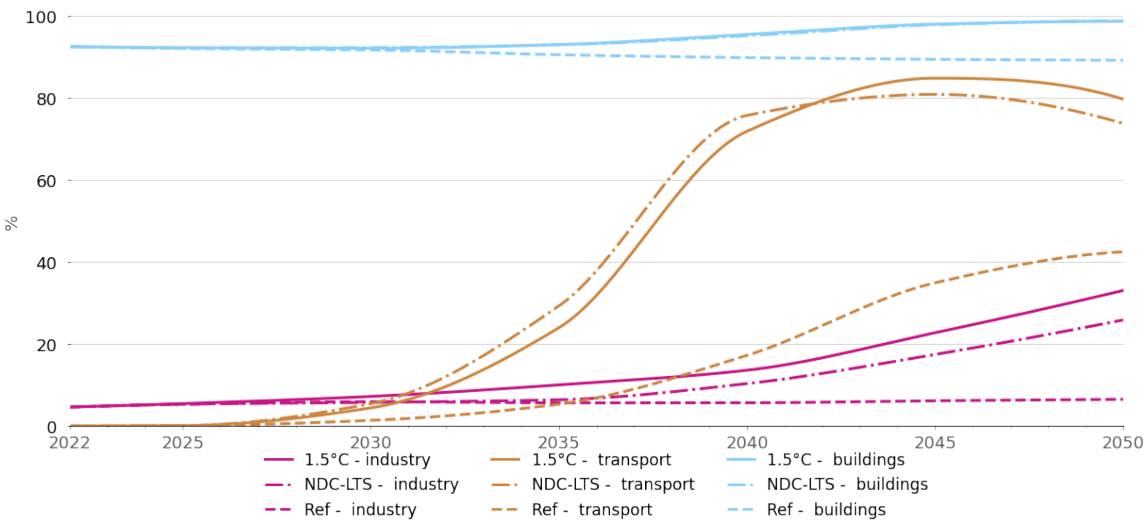
Shares of coal & gas power generation technologies - Saudi Arabia

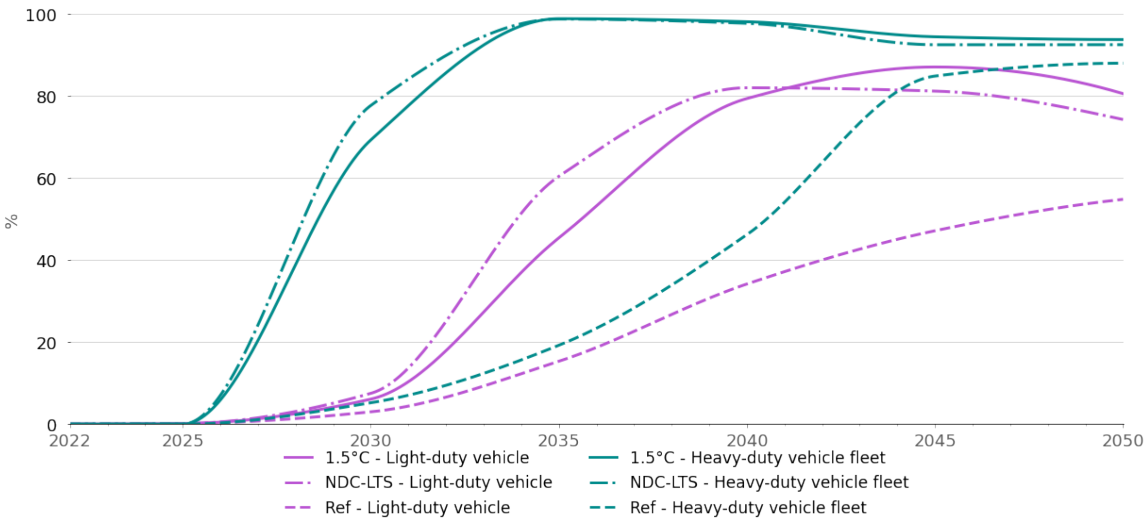


Clean electricity indicators in 1.5ºC scenario - Saudi Arabia

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	0	9	12	12	12
Wind+solar share of annual additions	%	1%	84%	90%	79%	52%
Annual additions of storage	GW	0	0.07	0.36	1.34	4.57
Carbon content of electricity	gCO_2/MWh	588	235	129	68	21
Emissions from power sector	$MtCO_2eq$	256	102	63	40	18
First year of no unabated coal generation				n/a		

Strategy 2 – Electrify end-uses and improve energy efficiency



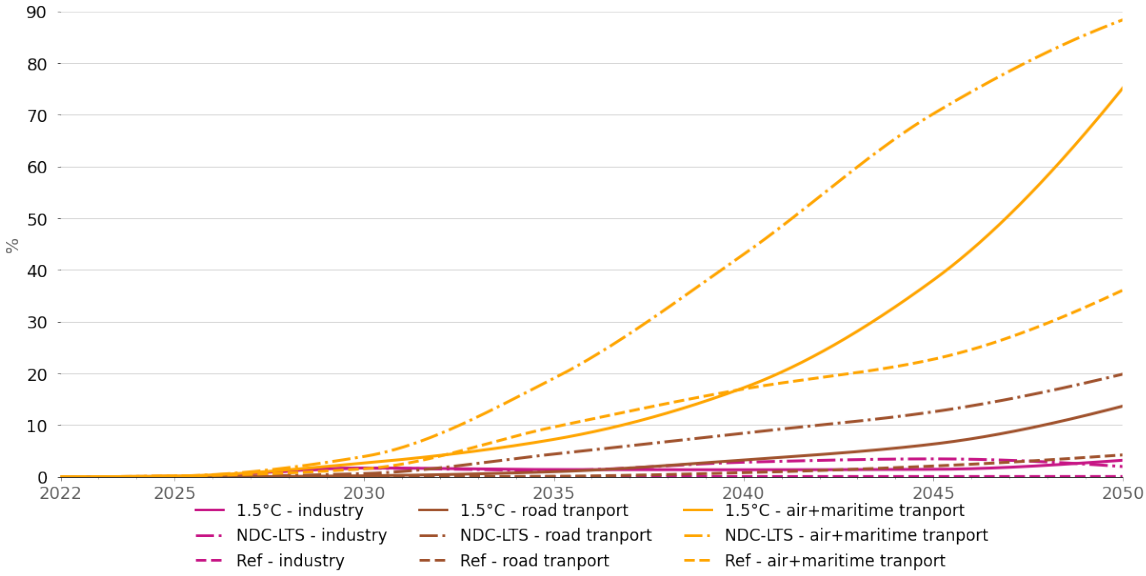


Electrification indicators in 1.5°C scenario - Saudi Arabia

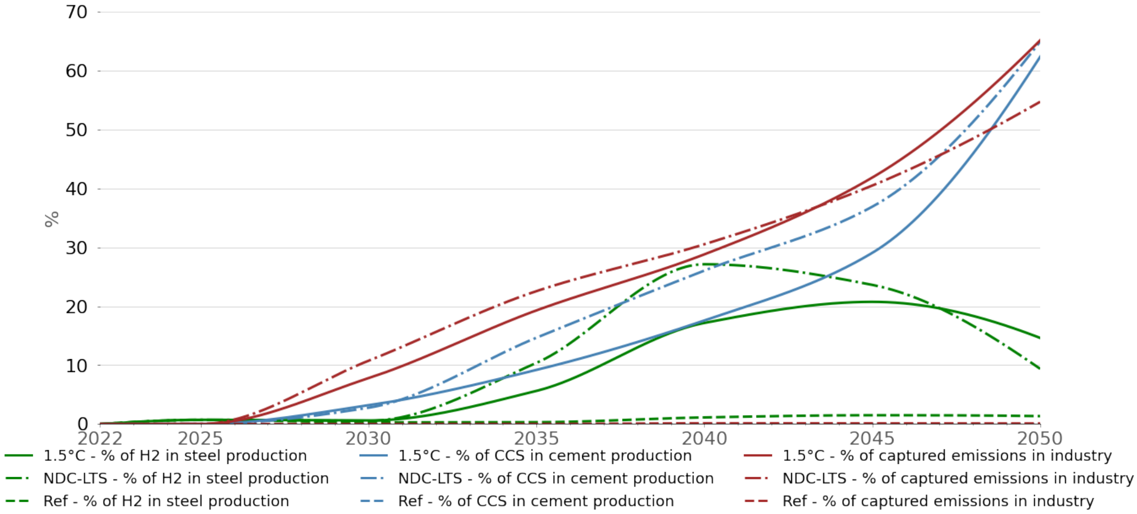
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	0	170	1146	1314	1474
Share of EVs in total car sales	%	0%	18%	76%	88%	71%
Annual sales of EV HDV	thousands	0	0	8	33	35
Share of EVs in total HDV sales	%	0%	0%	16%	65%	93%
Annual sales of small-scale heat pumps in buildings	GW	0	0	0	0	0
Annual sales of large-scale heat pumps in industry	GW	0	13	29	37	72
Share of heat pumps in buildings heating demand	%	n/a	n/a	n/a	n/a	n/a

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - Saudi Arabia



Penetration of low-emissions industrial production - Saudi Arabia

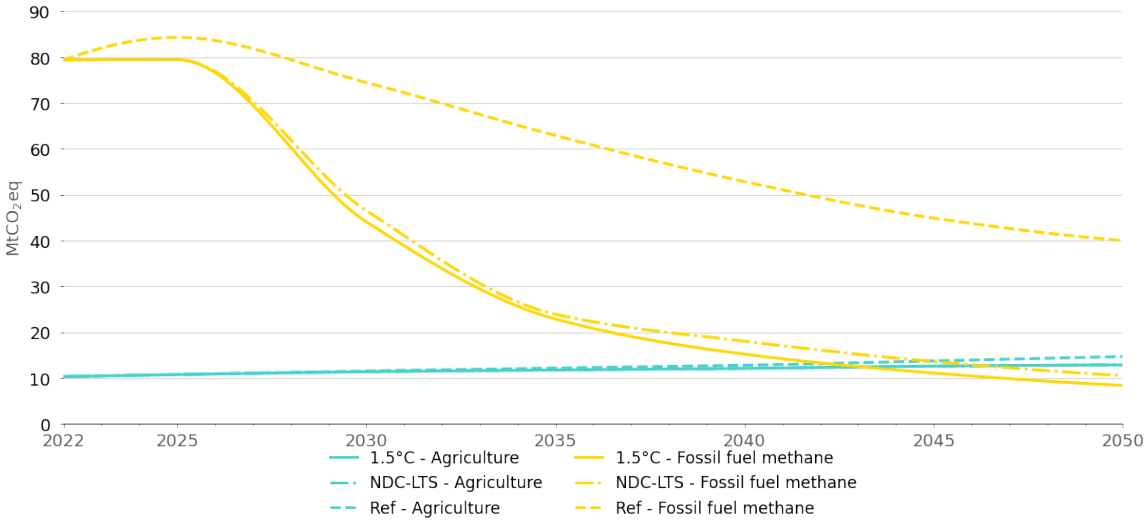


Non-electricity decarbonisation indicators in 1.5ºC scenario - Saudi Arabia

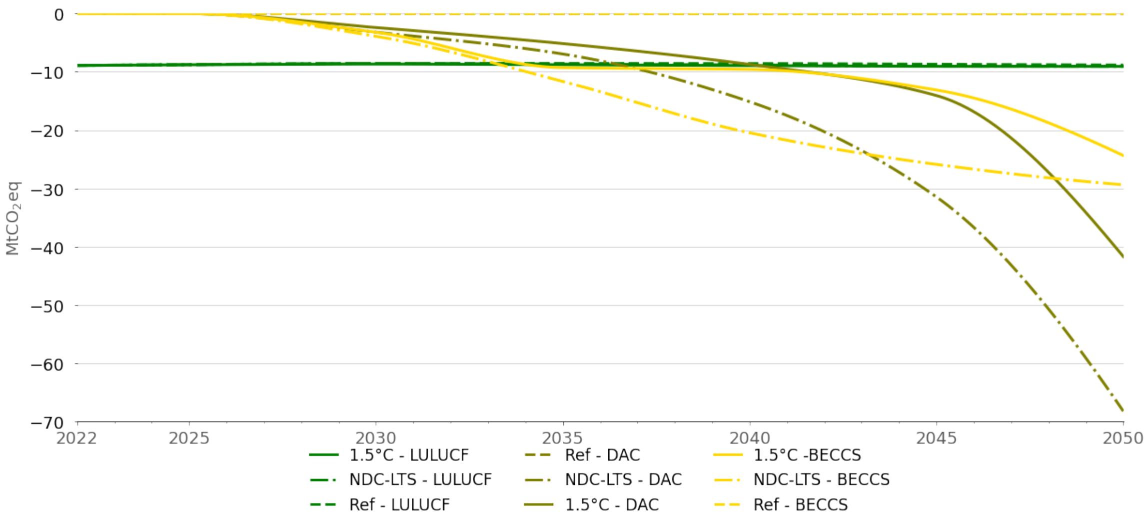
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	260	364	347	5108
Domestic production of gaseous e-fuels	bcm	0	0	0	0	11
Domestic production of liquid e-fuels	barrels	0	1586	2029	3042	51809
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	5533	6000	5617	152888
Yearly additions of electrolysers	MW	0	400	31	7673	10111

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - Saudi Arabia



LULUCF emissions, DAC and BECCS - Saudi Arabia

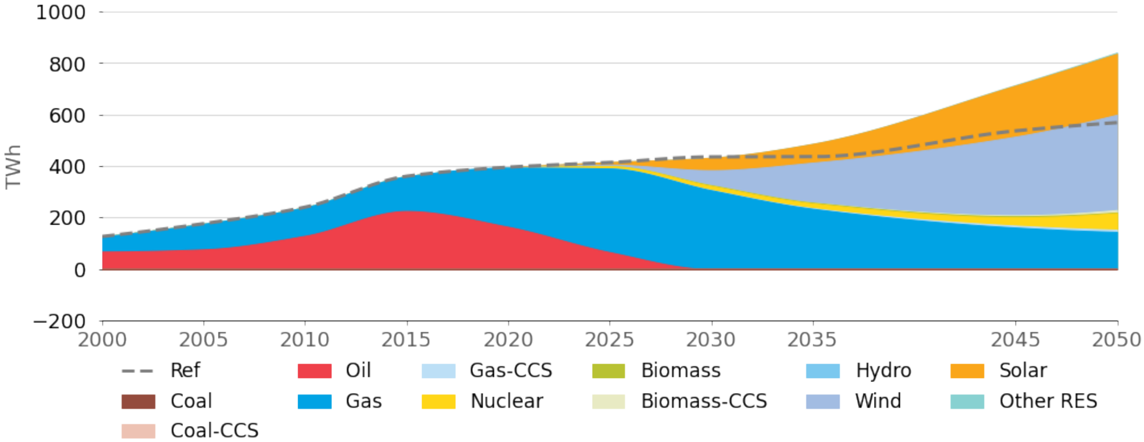


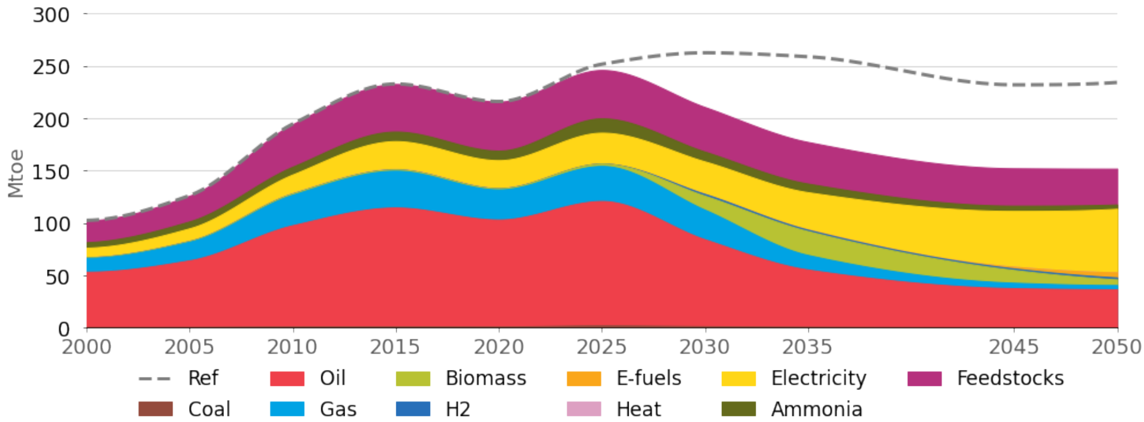
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Saudi Arabia

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	2	5	9	42
Biomass emissions captured	$MtCO_2eq$	0	3	9	10	24
LULUCF emissions	$MtCO_2eq$	-9	-9	-9	-9	-9
Agriculture emissions	$MtCO_2eq$	10	11	12	12	13
Methane emissions	$MtCO_2eq$	113	68	39	30	16
Methane emission from fossil fuel production	$MtCO_2eq$	79	44	23	15	8

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

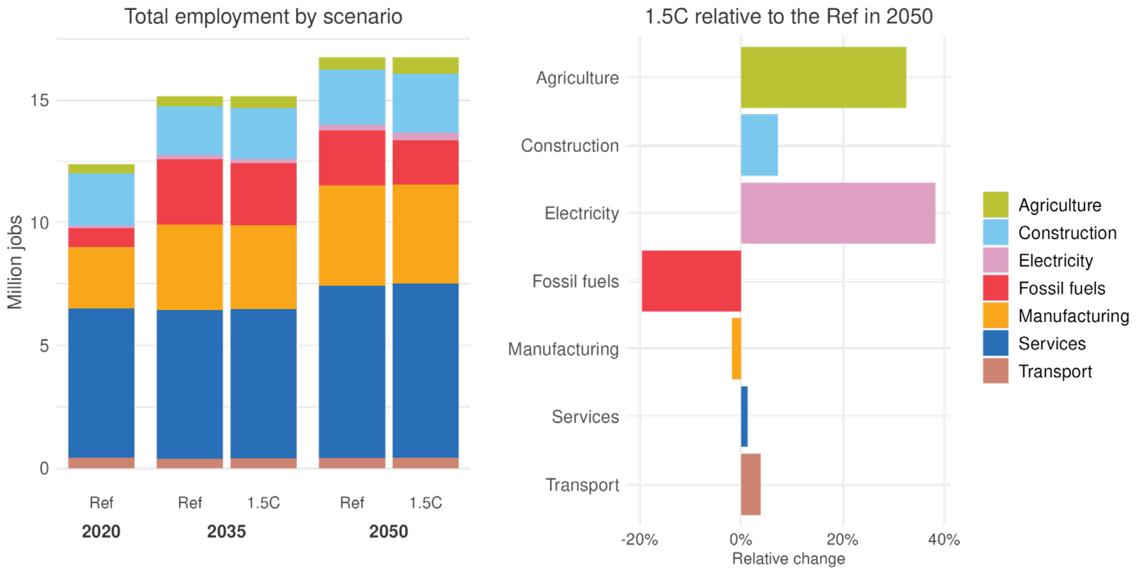
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-198%	-197%	-77%
Annual energy import bill	billion USD	-382	-229	-105
Air pollution emissions - PM2.5	Mt	251	225	50
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	2	17
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	40%	203%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	5	14
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	26%	72%

Labour market dynamics

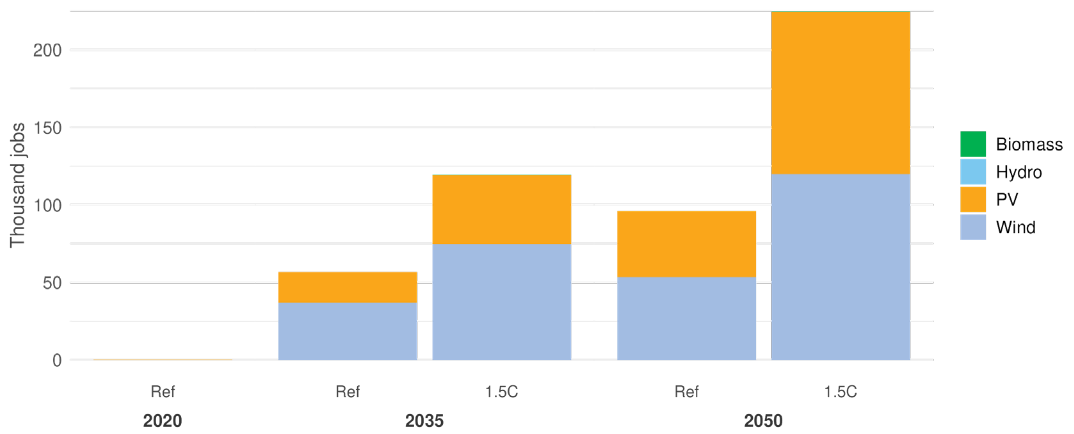
These graphs show the breakdown of employment in Saudi Arabia, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Saudi Arabia



Note: Electricity includes all power generation technologies as well as transmission and distribution.

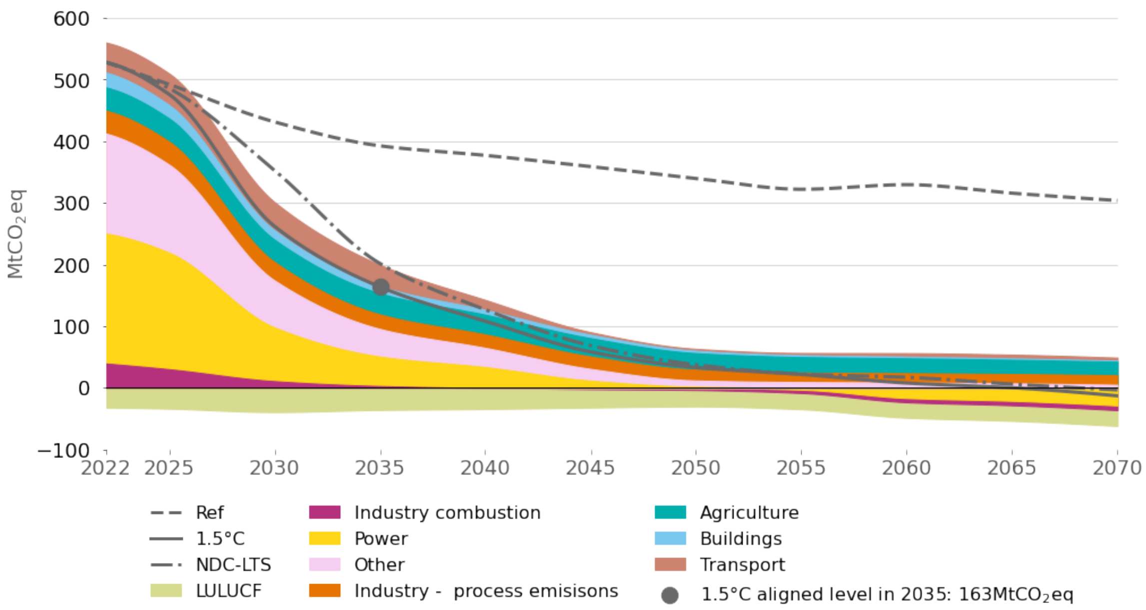
Jobs in renewable technologies by scenario – Saudi Arabia



South Africa

South Africa's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - South Africa



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows South Africa's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**528**	**164**	**-69%**
Power	211	48	-77%
Industry	76	26	-65%
Transport	44	32	-28%
Buildings	20	9	-56%
LULUCF	-32	-36	12%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

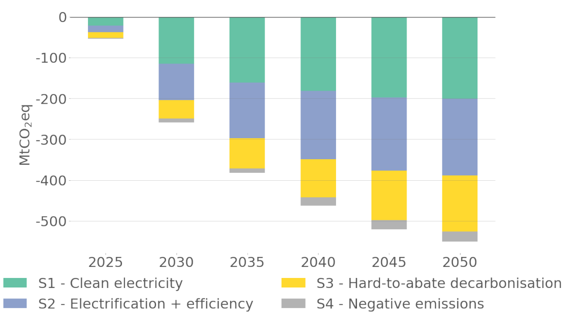
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

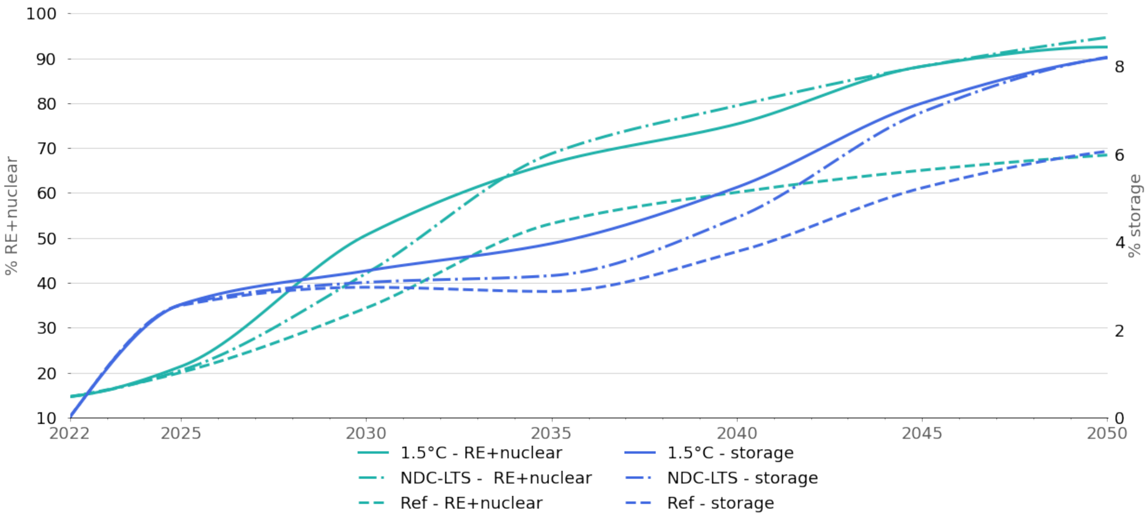
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - South Africa



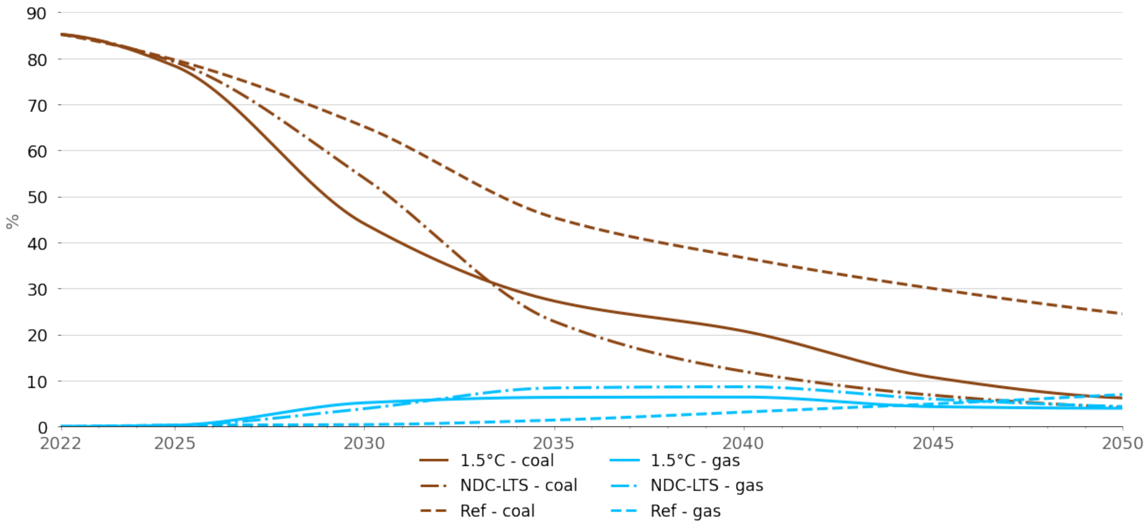
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - South Africa



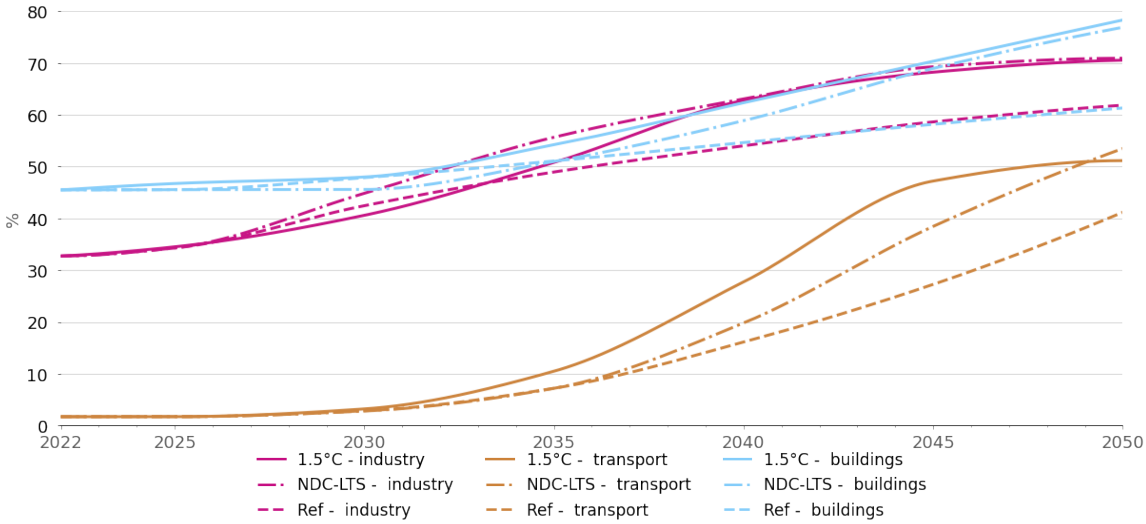
Shares of coal & gas power generation technologies - South Africa

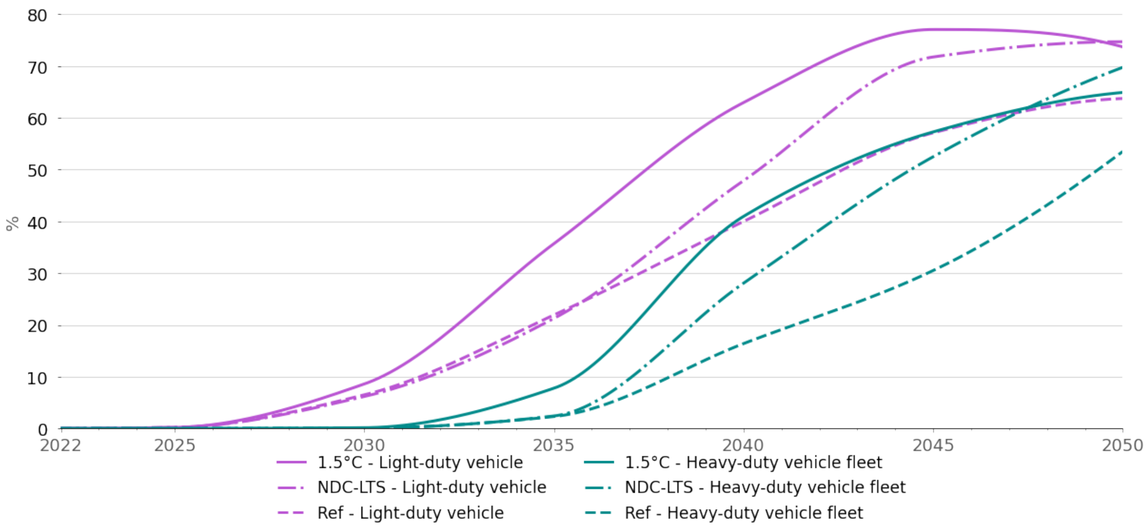


Clean electricity indicators in 1.5ºC scenario - South Africa

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	1	5	5	6	8
Wind+solar share of annual additions	%	79%	79%	76%	70%	69%
Annual additions of storage	GW	0.05	0.15	0.49	0.99	1.26
Carbon content of electricity	gCO_2/MWh	886	407	207	117	4
Emissions from power sector	$MtCO_2eq$	210	87	48	33	1
First year of no unabated coal generation				2058		

Strategy 2 – Electrify end-uses and improve energy efficiency

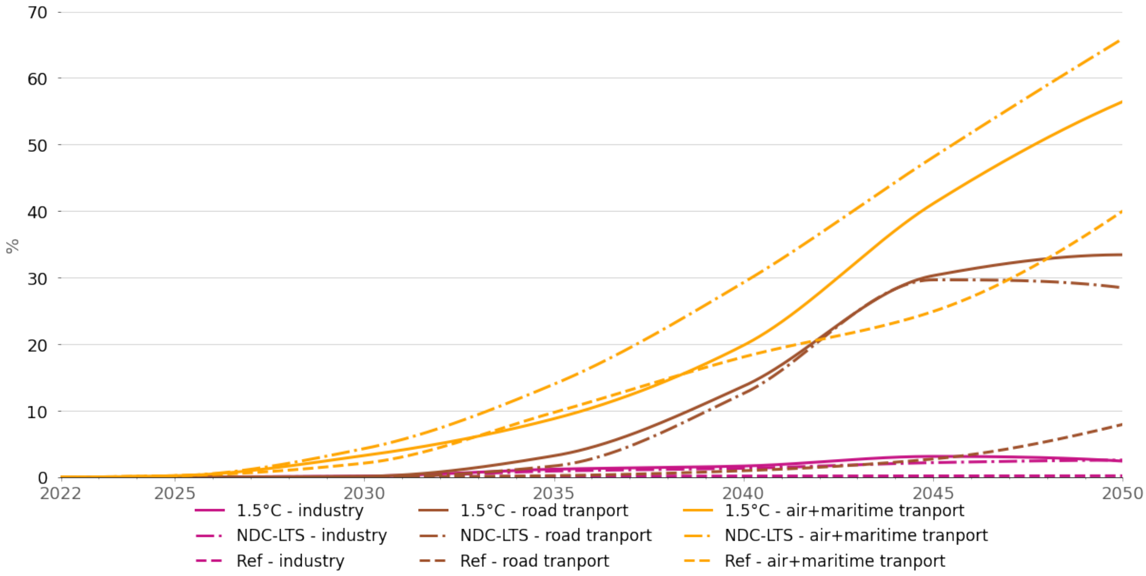


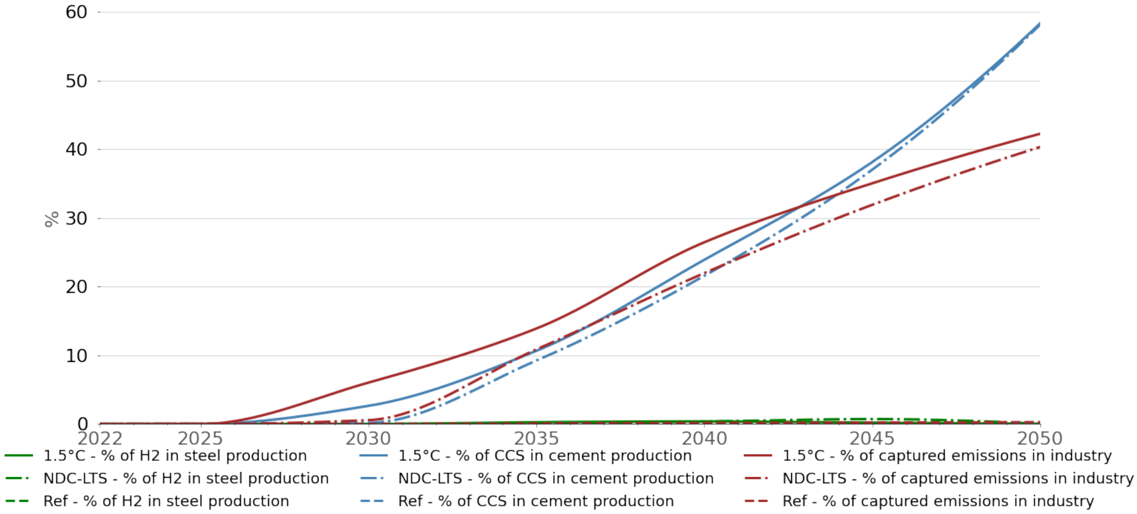


Electrification indicators in 1.5ºC scenario - South Africa

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	0	302	903	1054	999
Share of EVs in total car sales	%	0%	28%	72%	76%	57%
Annual sales of EV HDV	thousands	0	0	0	4	60
Share of EVs in total HDV sales	%	0%	0%	0%	3%	38%
Annual sales of small-scale heat pumps in buildings	GW	1	1	1	1	2
Annual sales of large-scale heat pumps in industry	GW	0	2	15	24	26
Share of heat pumps in buildings heating demand	%	0%	22%	39%	51%	78%

Strategy 3 – Decarbonise hard-to-abate sectors



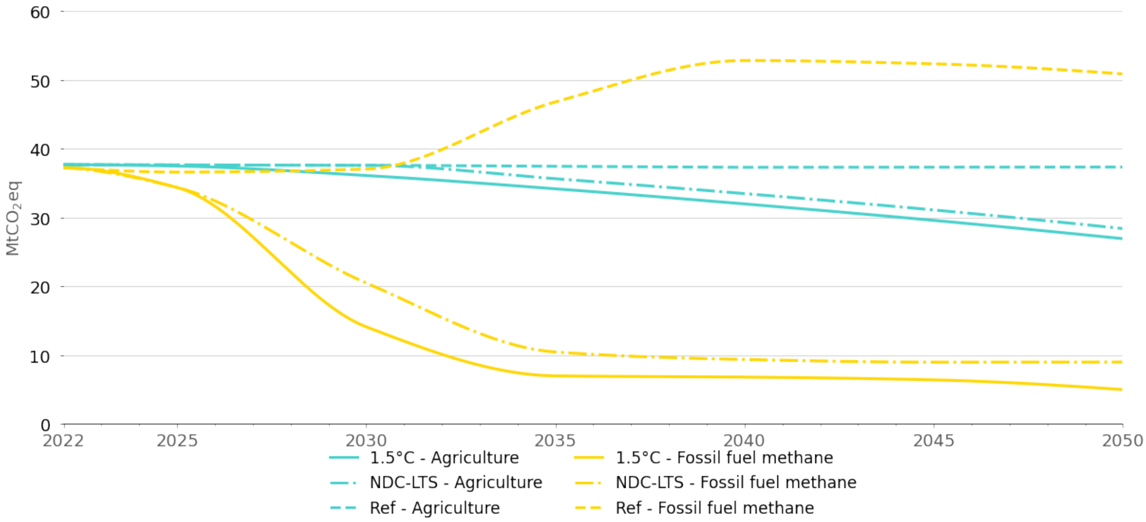


Non-electricity decarbonisation indicators in 1.5ºC scenario - South Africa

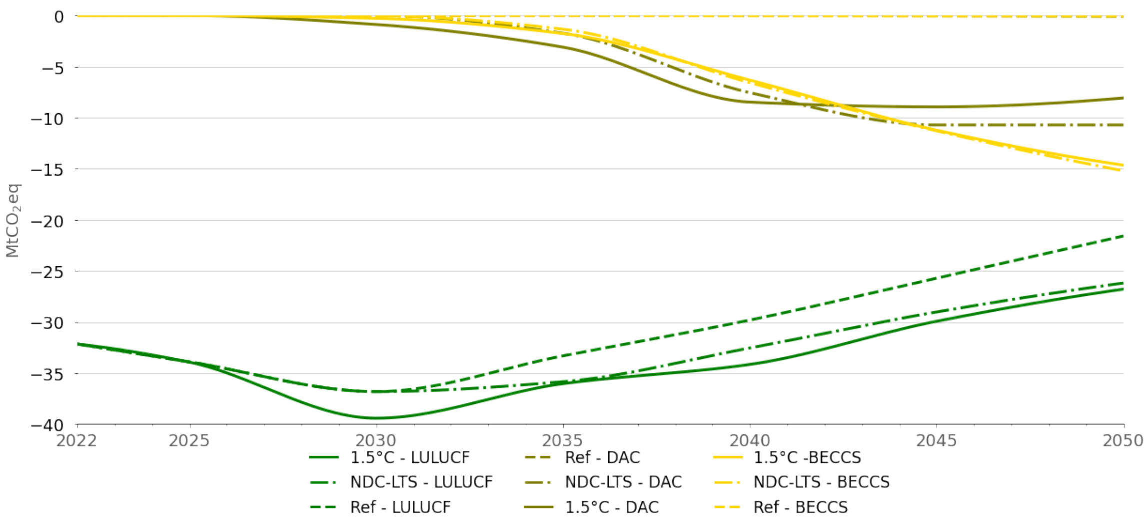
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	30	307	792	1850
Domestic production of gaseous e-fuels	bcm	0	0	1	2	6
Domestic production of liquid e-fuels	barrels	0	19	2204	2482	1681
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	640	8641	30609	57663
Yearly additions of electrolysers	MW	0	1102	3026	3820	2998

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - South Africa



LULUCF emissions, DAC and BECCS - South Africa



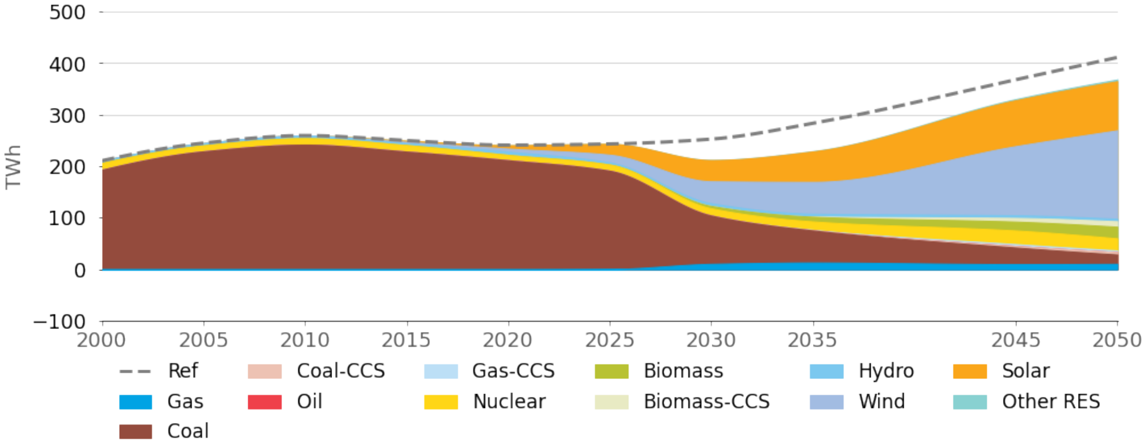
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - South Africa

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	3	8	8
Biomass emissions captured	$MtCO_2eq$	0	0	2	6	15
LULUCF emissions	$MtCO_2eq$	-32	-39	-36	-34	-27
Agriculture emissions	$MtCO_2eq$	38	36	34	32	27
Methane emissions	$MtCO_2eq$	67	36	23	21	11
Methane emission from fossil fuel production	$MtCO_2eq$	37	14	7	7	5

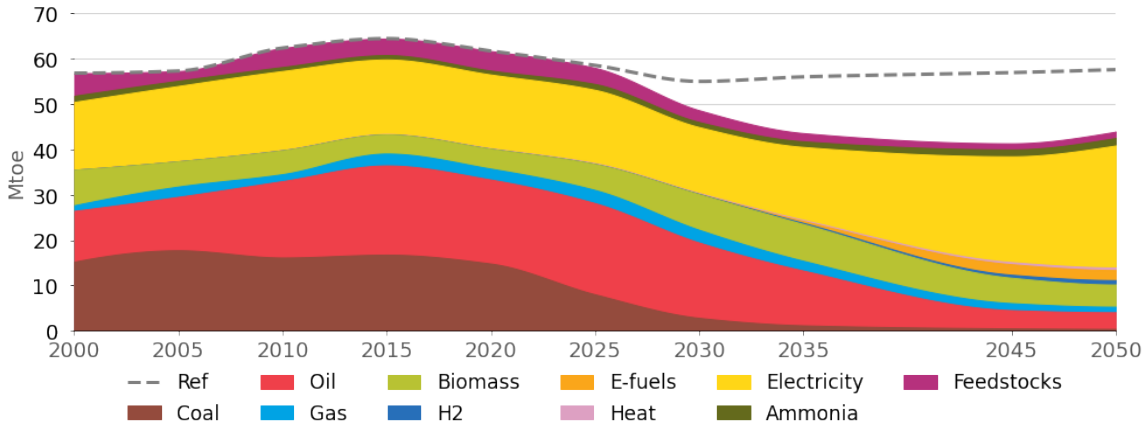
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - South Africa



Final energy consumption in the 1.5ºC scenario - South Africa



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

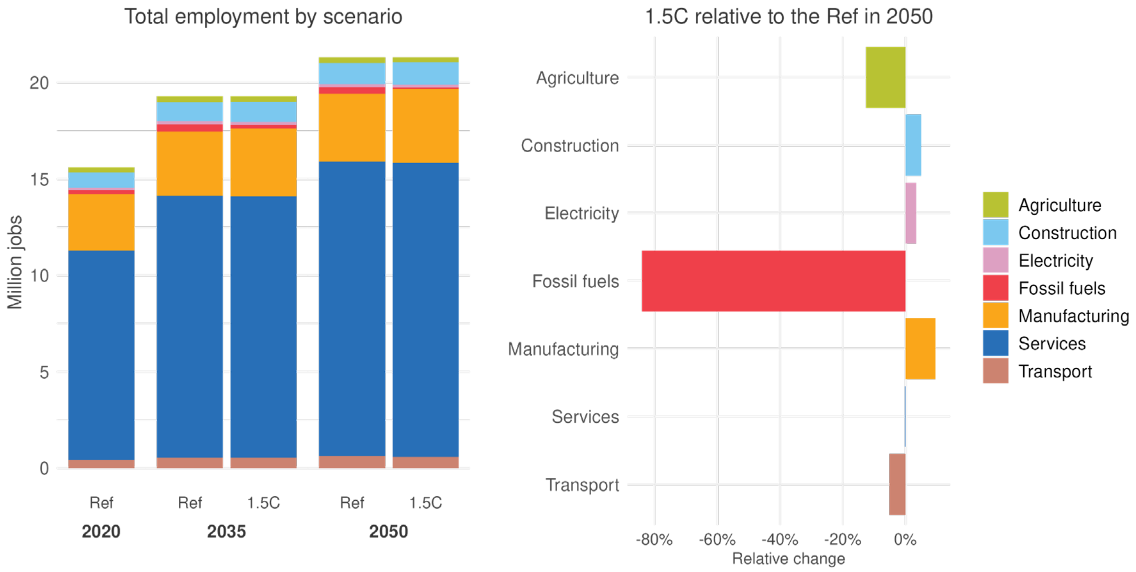
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	-16%	-80%	-97%
Annual energy import bill	billion USD	0	-9	-13
Air pollution emissions - PM2.5	Mt	619	421	277
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	-3	2
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	-35%	32%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	1	1
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	32%	45%

Labour market dynamics

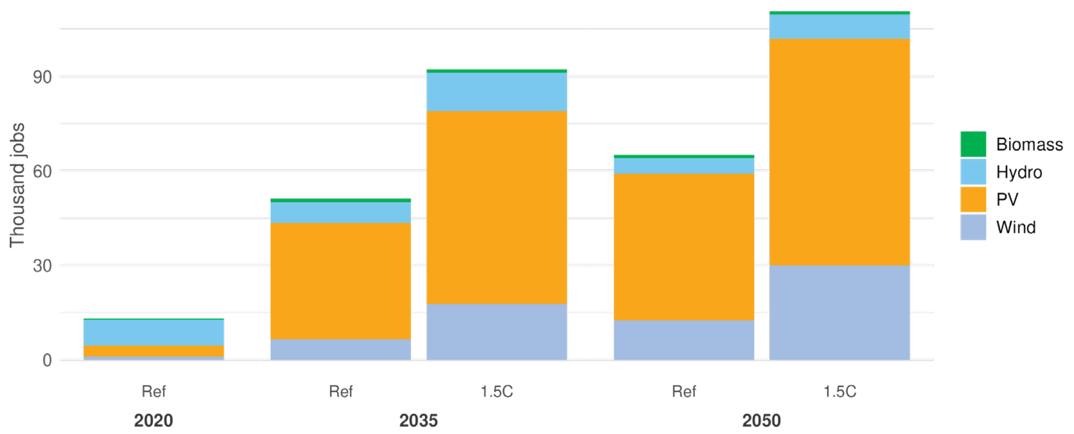
These graphs show the breakdown of employment in South Africa, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – South Africa



Note: Electricity includes all power generation technologies as well as transmission and distribution.

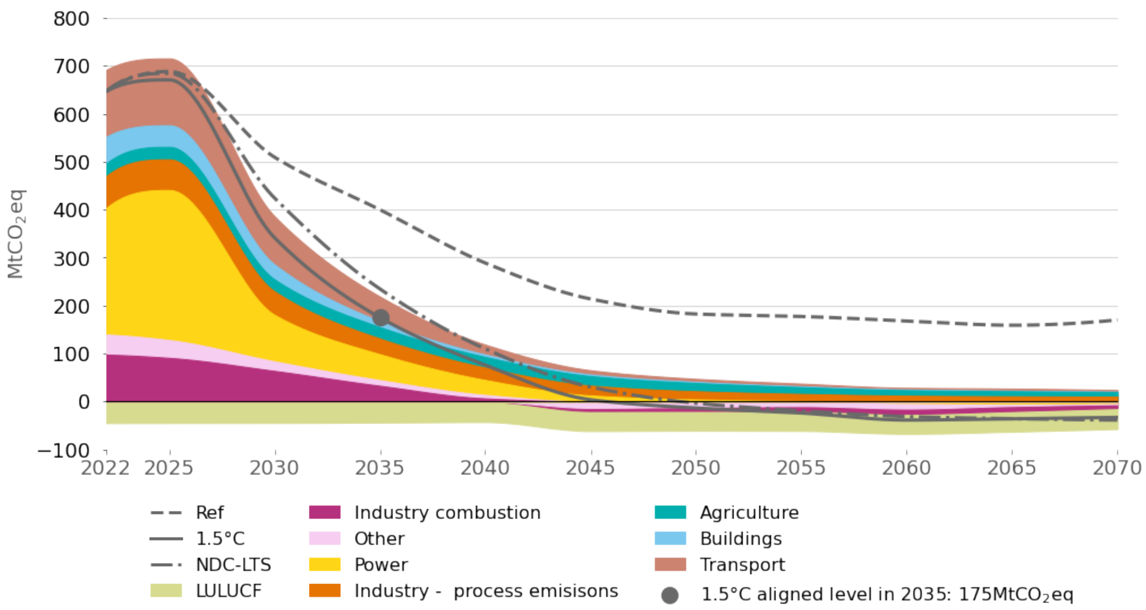
Jobs in renewable technologies by scenario – South Africa



South Korea

South Korea's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - South Korea



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows South Korea's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**646**	**175**	**-73%**
Power	263	54	-80%
Industry	164	66	-60%
Transport	104	30	-71%
Buildings	52	10	-81%
LULUCF	-45	-44	-2%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

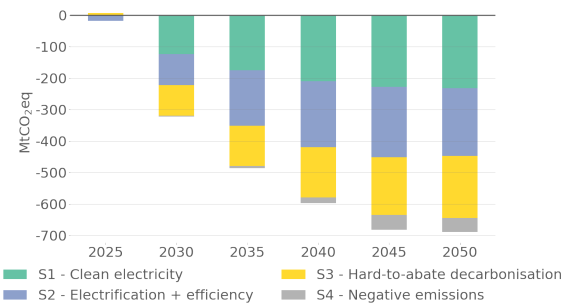
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

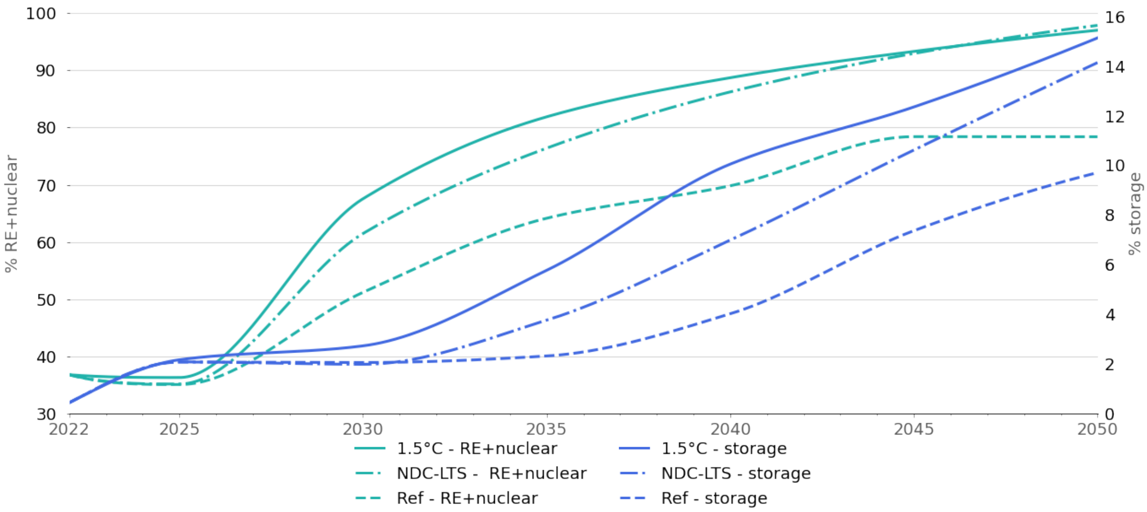
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - South Korea



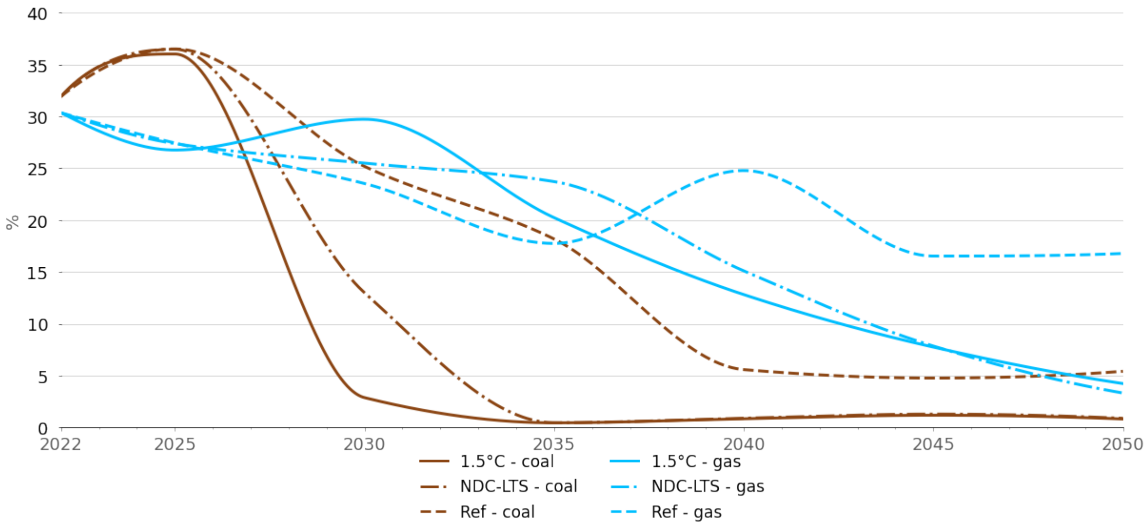
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - South Korea



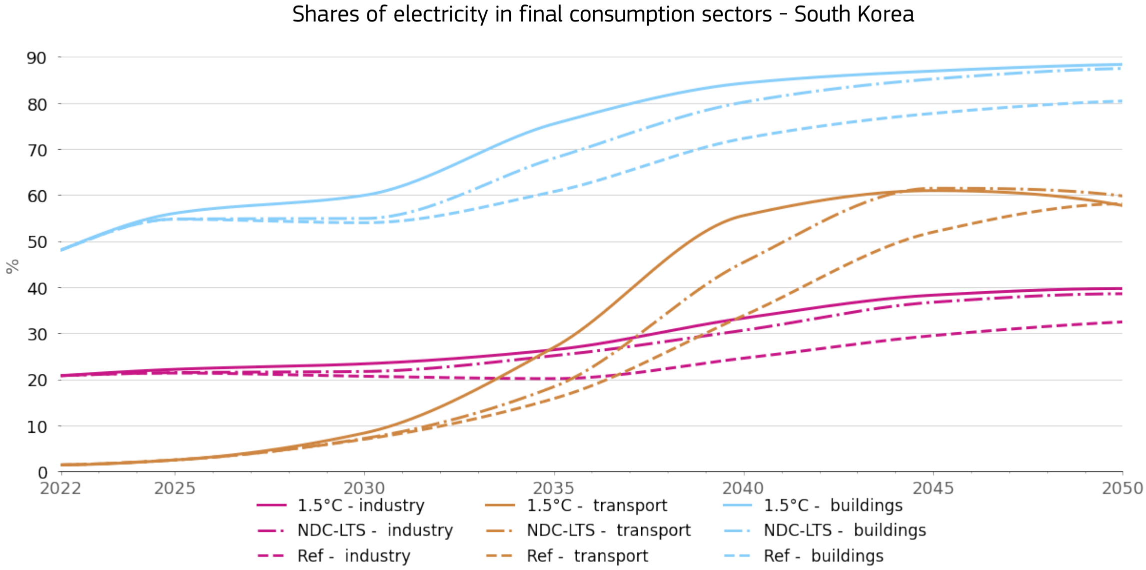
Shares of coal & gas power generation technologies - South Korea

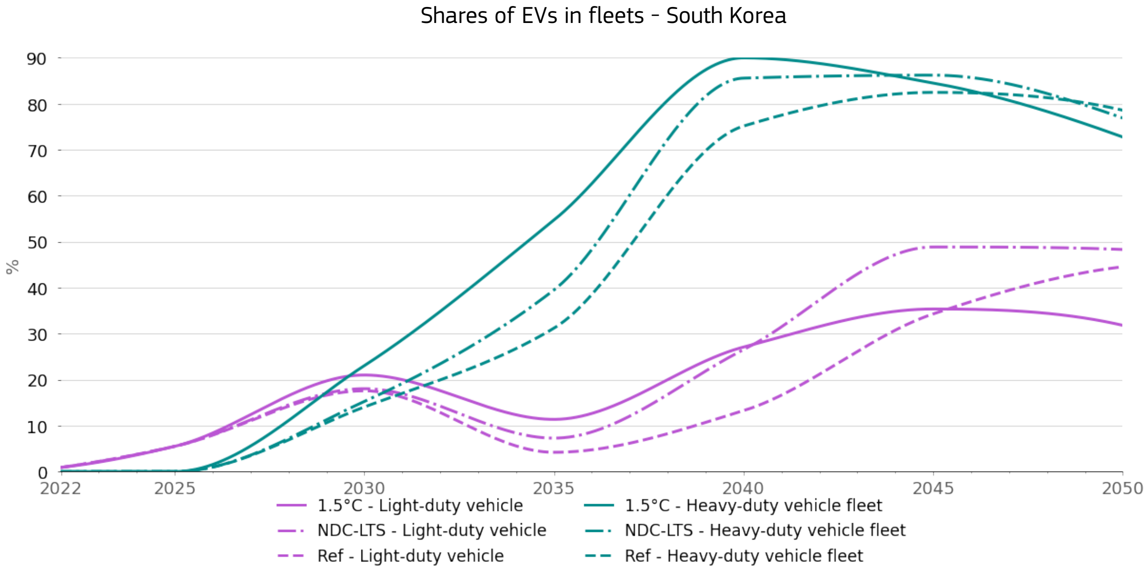


Clean electricity indicators in 1.5ºC scenario - South Korea

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	3	19	19	19	20
Wind+solar share of annual additions	%	45%	74%	67%	60%	65%
Annual additions of storage	GW	0.38	2.18	4.48	6.34	5.24
Carbon content of electricity	gCO_2/MWh	418	141	69	34	3
Emissions from power sector	$MtCO_2eq$	260	95	53	30	3
First year of no unabated coal generation				2031		

Strategy 2 – Electrify end-uses and improve energy efficiency



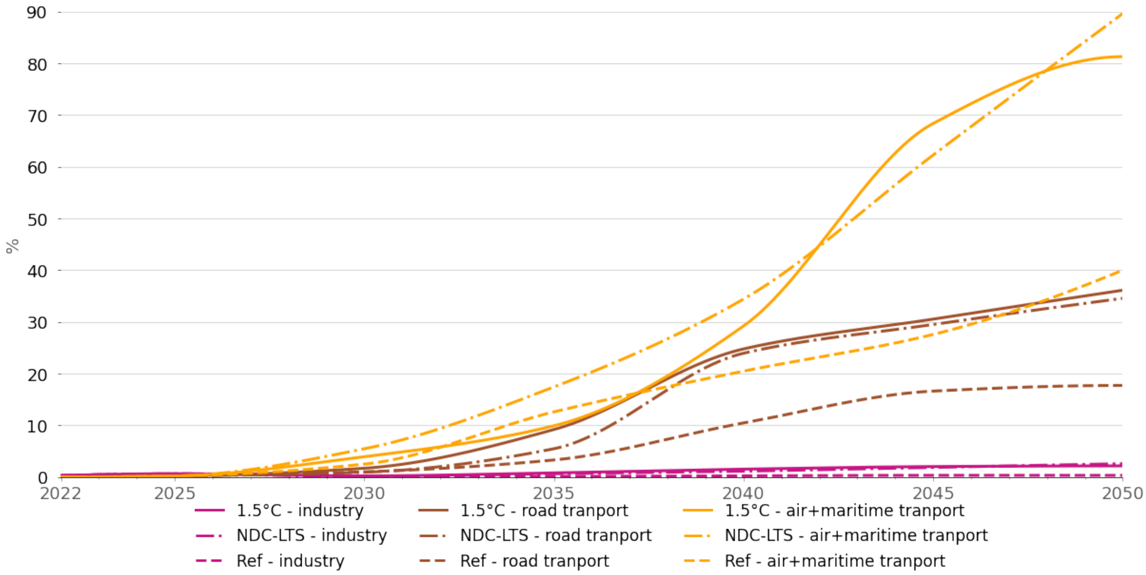


Electrification indicators in 1.5°C scenario - South Korea

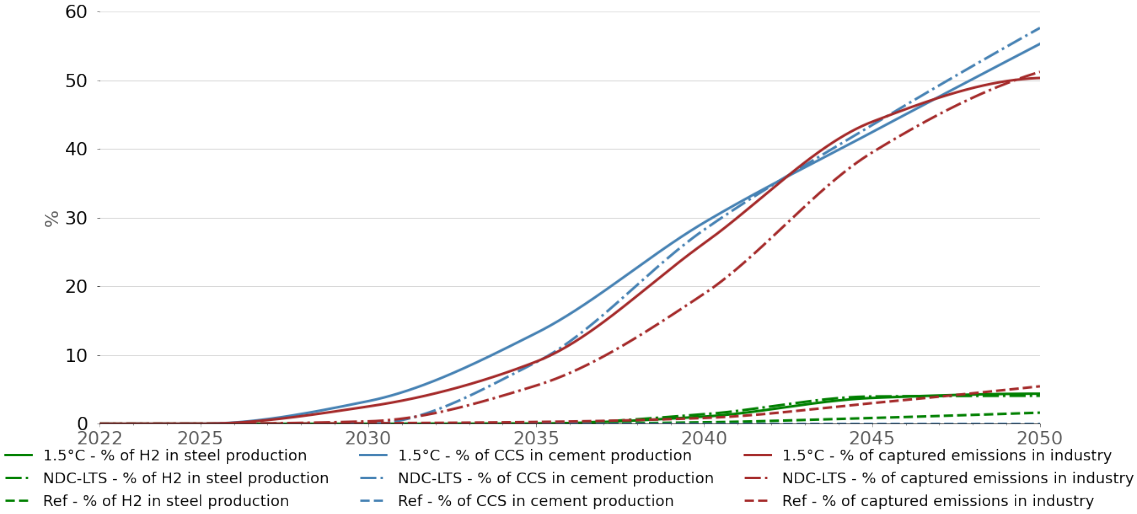
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	120	834	1424	1350	1137
Share of EVs in total car sales	%	5%	32%	59%	54%	54%
Annual sales of EV HDV	thousands	0	0	4	19	35
Share of EVs in total HDV sales	%	0%	0%	7%	39%	81%
Annual sales of small-scale heat pumps in buildings	GW	17	4	9	3	8
Annual sales of large-scale heat pumps in industry	GW	0	32	41	4	44
Share of heat pumps in buildings heating demand	%	0%	8%	25%	35%	48%

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - South Korea



Penetration of low-emissions industrial production - South Korea

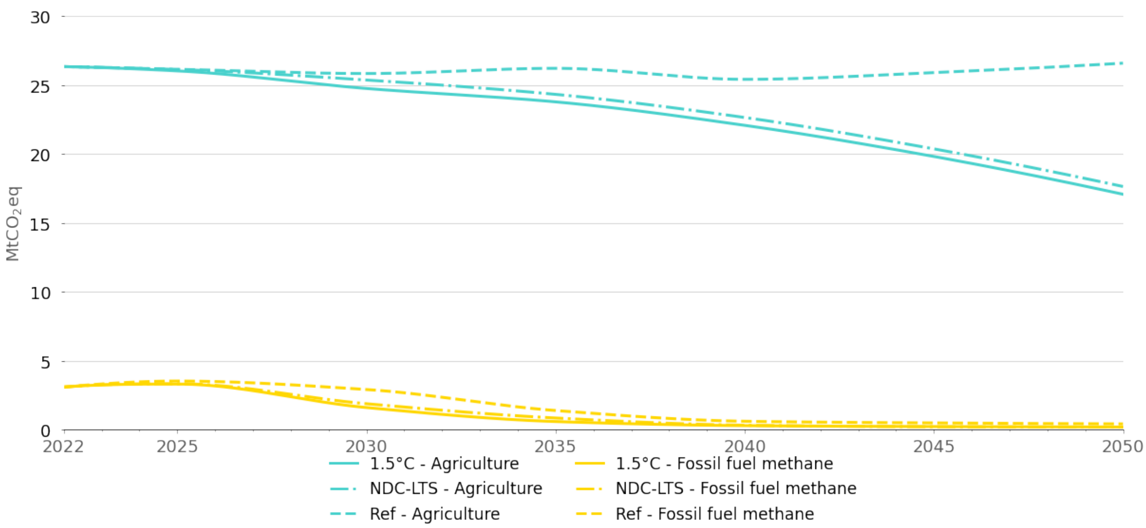


Non-electricity decarbonisation indicators in 1.5ºC scenario - South Korea

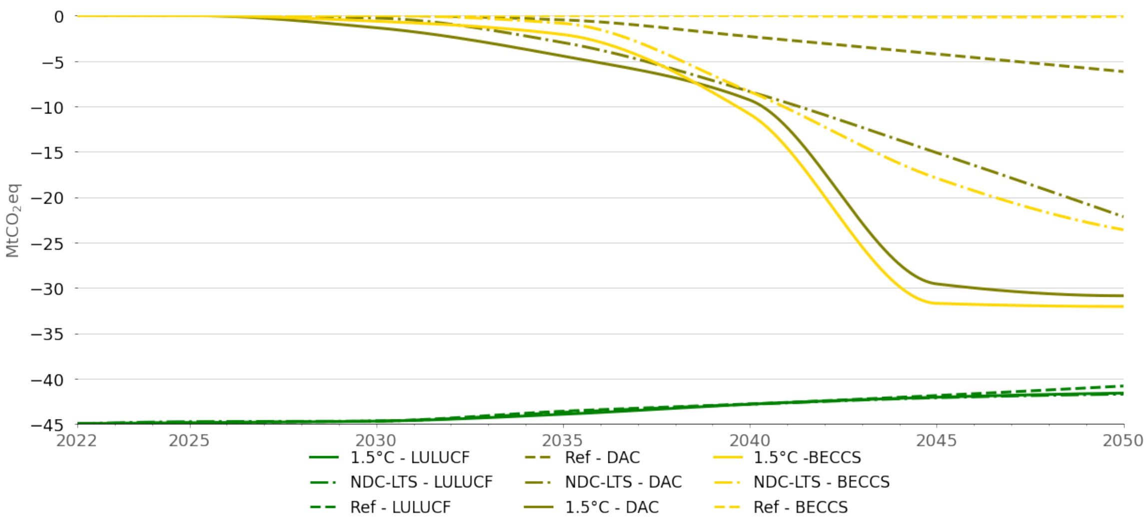
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	558	940	2438	6716
Domestic production of gaseous e-fuels	bcm	0	0	4	10	13
Domestic production of liquid e-fuels	barrels	0	252	999	3409	32701
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	12713	23200	50556	254808
Yearly additions of electrolysers	MW	0	1768	8650	16206	10599

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - South Korea



LULUCF emissions, DAC and BECCS - South Korea



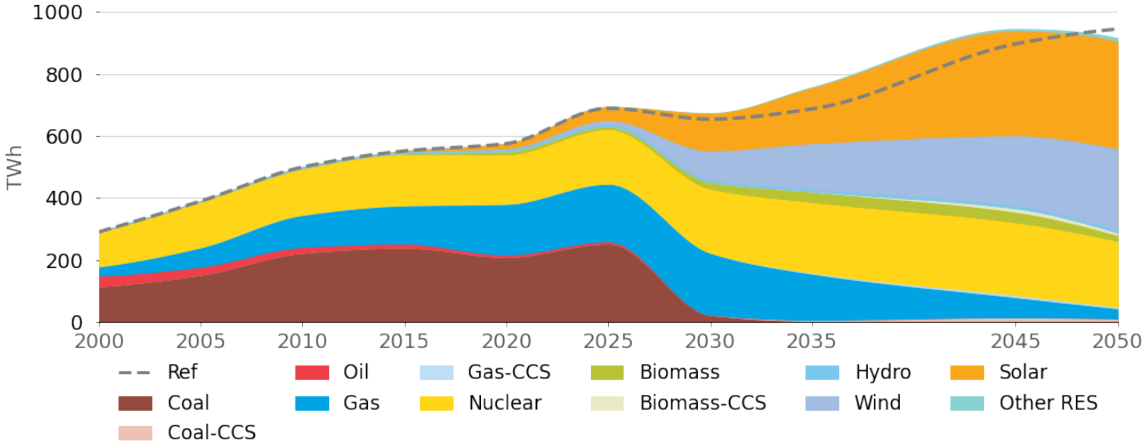
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - South Korea

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	4	9	31
Biomass emissions captured	$MtCO_2eq$	0	1	2	11	32
LULUCF emissions	$MtCO_2eq$	-45	-45	-44	-43	-42
Agriculture emissions	$MtCO_2eq$	26	25	24	22	17
Methane emissions	$MtCO_2eq$	28	18	12	10	6
Methane emission from fossil fuel production	$MtCO_2eq$	3	2	1	0	0

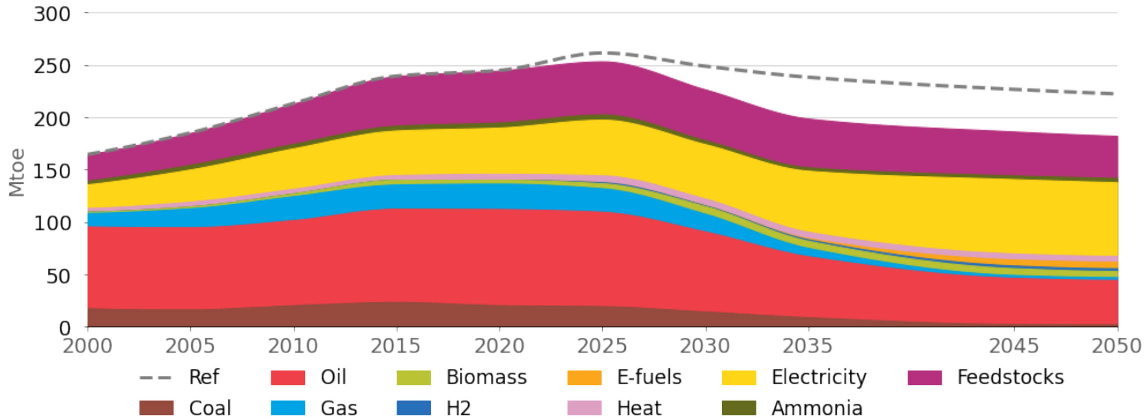
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - South Korea



Final energy consumption in the 1.5ºC scenario - South Korea



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

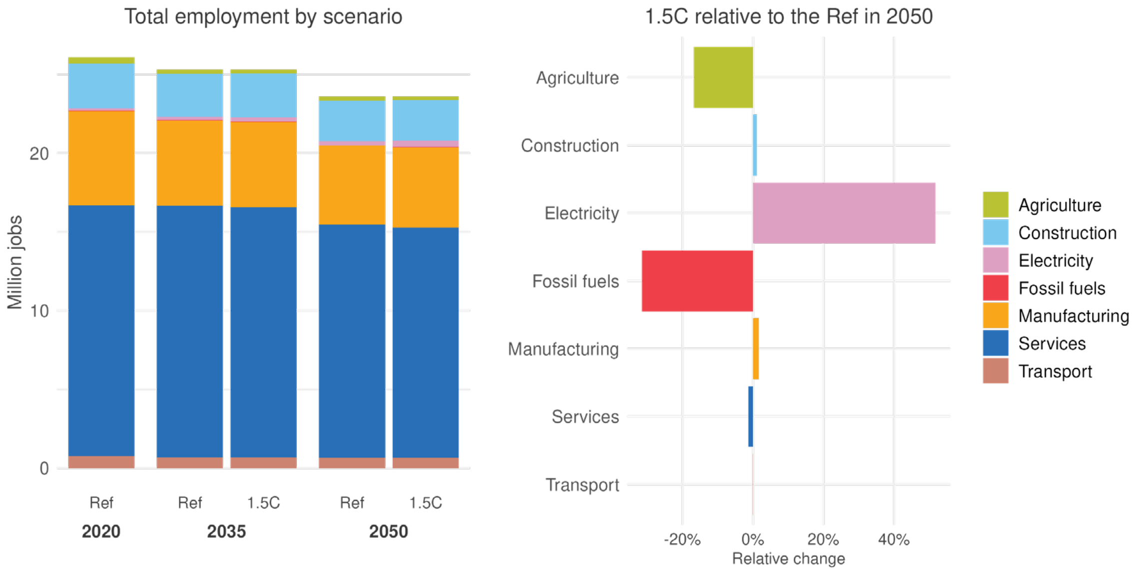
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	93%	56%	28%
Annual energy import bill	billion USD	208	71	25
Air pollution emissions - PM2.5	Mt	140	80	33
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	2	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	12%	3%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	0	0
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	63%	93%

Labour market dynamics

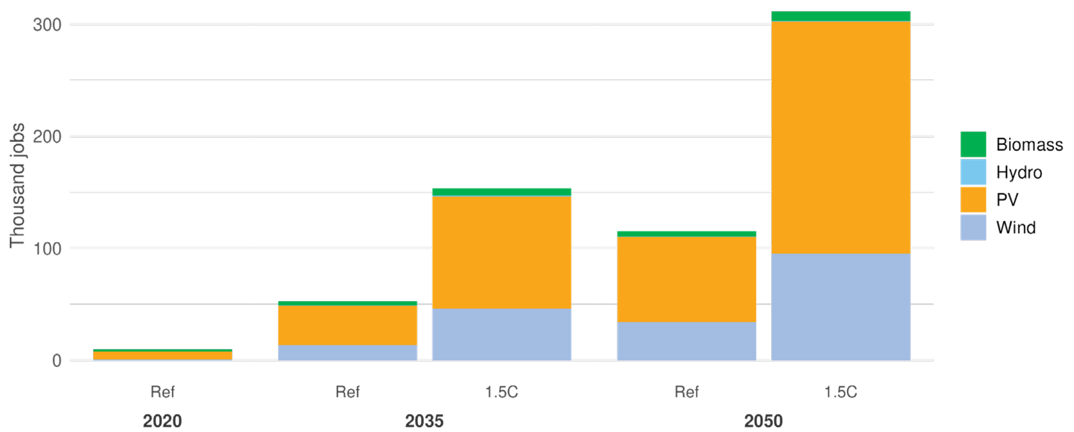
These graphs show the breakdown of employment in South Korea, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – South Korea



Note: Electricity includes all power generation technologies as well as transmission and distribution.

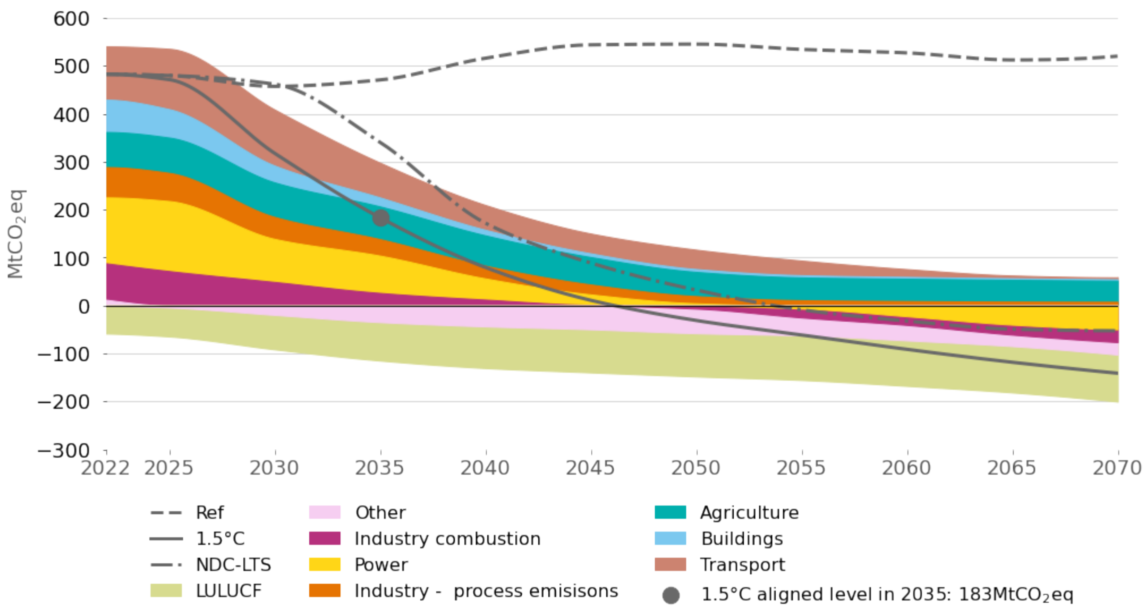
Jobs in renewable technologies by scenario – South Korea



Turkey

Turkey's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - Turkey



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows Turkey's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**483**	**183**	**-62%**
Power	137	78	-43%
Industry	139	61	-56%
Transport	88	37	-59%
Buildings	58	12	-79%
LULUCF	-58	-80	38%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

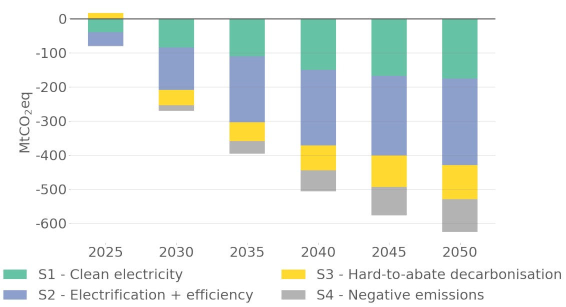
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

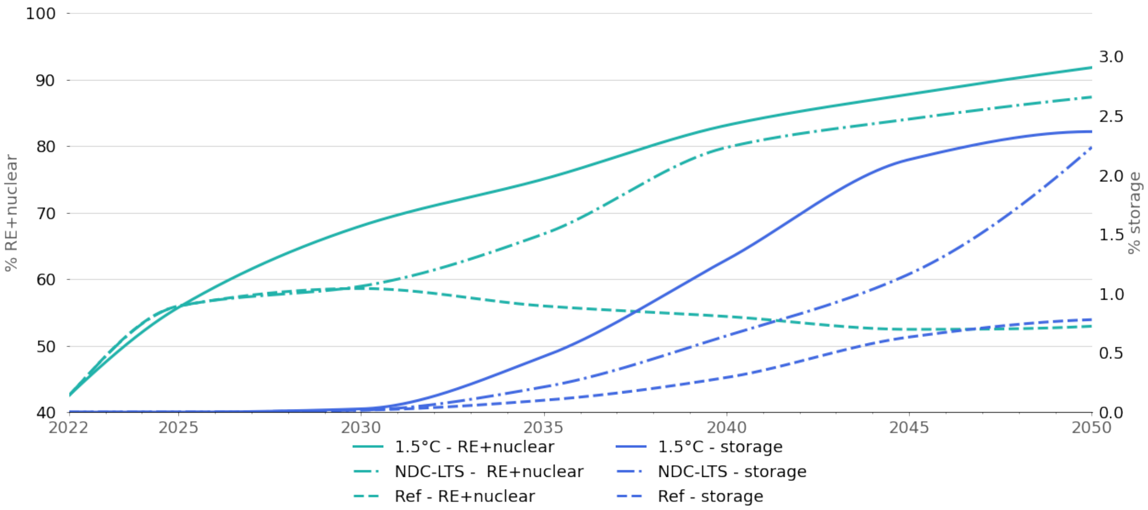
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - Turkey



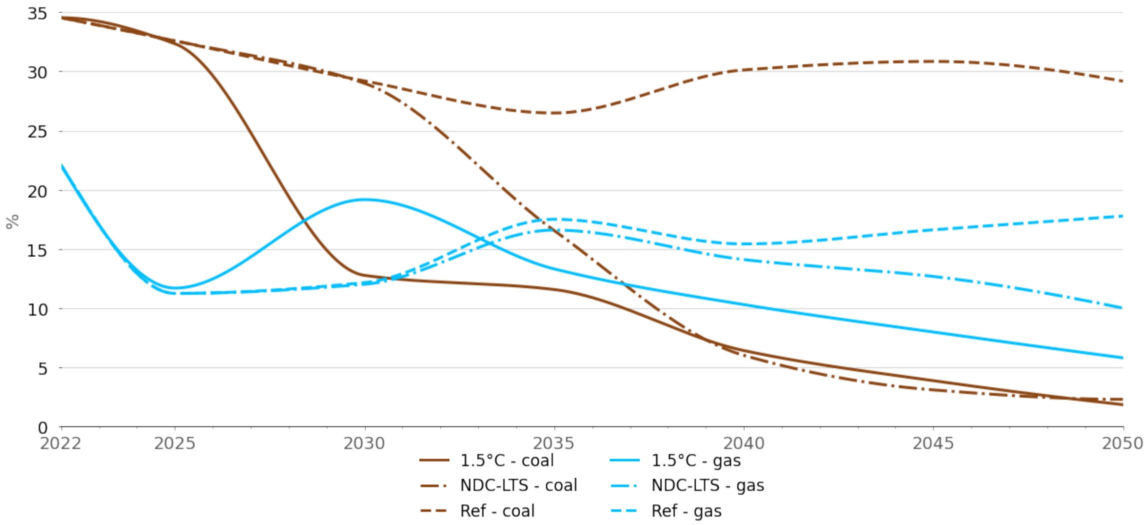
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - Turkey



Shares of coal & gas power generation technologies - Turkey

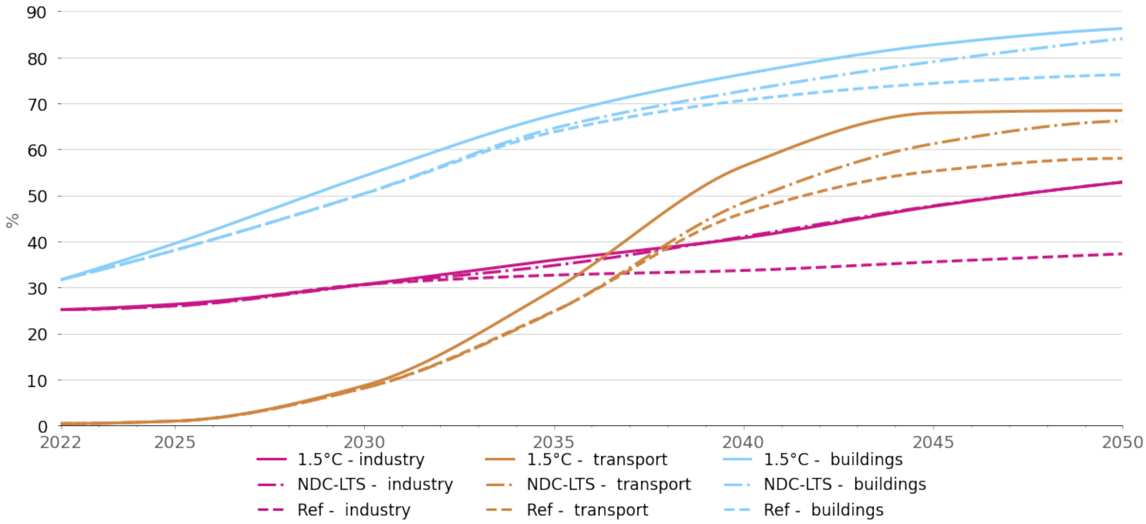


Clean electricity indicators in 1.5ºC scenario - Turkey

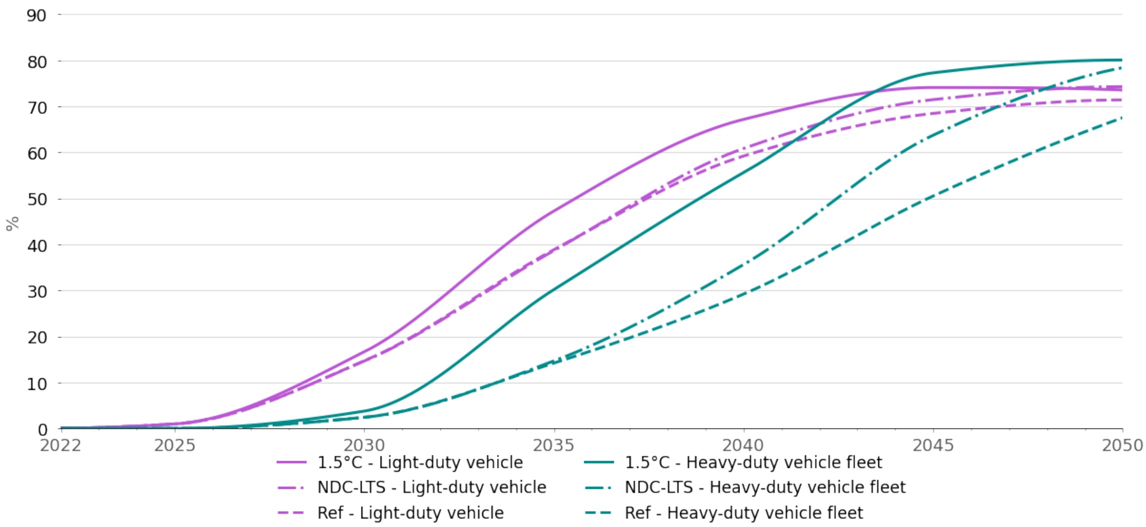
		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	2	7	9	9	13
Wind+solar share of annual additions	%	30%	58%	59%	57%	58%
Annual additions of storage	GW	0	0.38	1.61	2.47	4.41
Carbon content of electricity	gCO_2/MWh	420	182	122	56	5
Emissions from power sector	$MtCO_2eq$	137	90	78	44	5
First year of no unabated coal generation				2048		

Strategy 2 – Electrify end-uses and improve energy efficiency

Shares of electricity in final consumption sectors - Turkey



Shares of EVs in fleets - Turkey

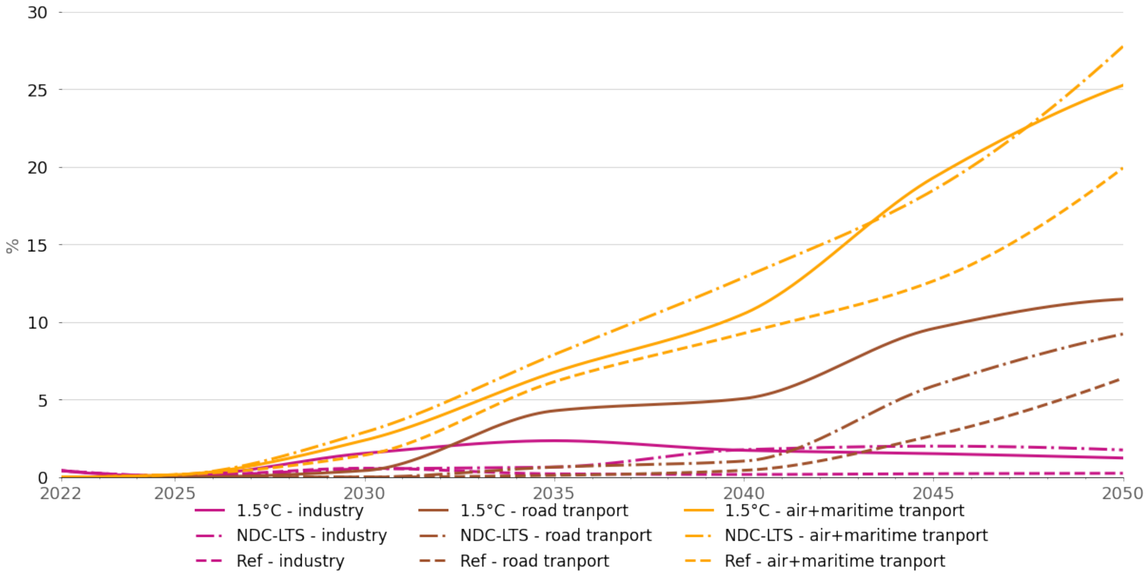


Electrification indicators in 1.5ºC scenario - Turkey

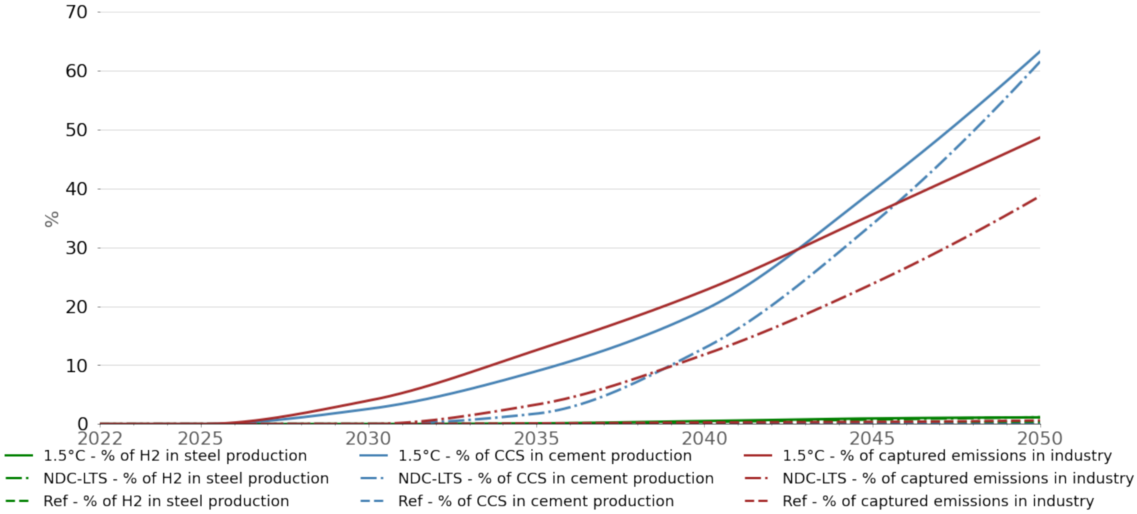
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	7	1158	2008	3369	3449
Share of EVs in total car sales	%	1%	37%	70%	79%	70%
Annual sales of EV HDV	thousands	0	0	1	14	66
Share of EVs in total HDV sales	%	0%	0%	1%	16%	68%
Annual sales of small-scale heat pumps in buildings	GW	0	9	2	8	3
Annual sales of large-scale heat pumps in industry	GW	0	7	18	17	46
Share of heat pumps in buildings heating demand	%	0%	11%	25%	34%	53%

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - Turkey



Penetration of low-emissions industrial production - Turkey

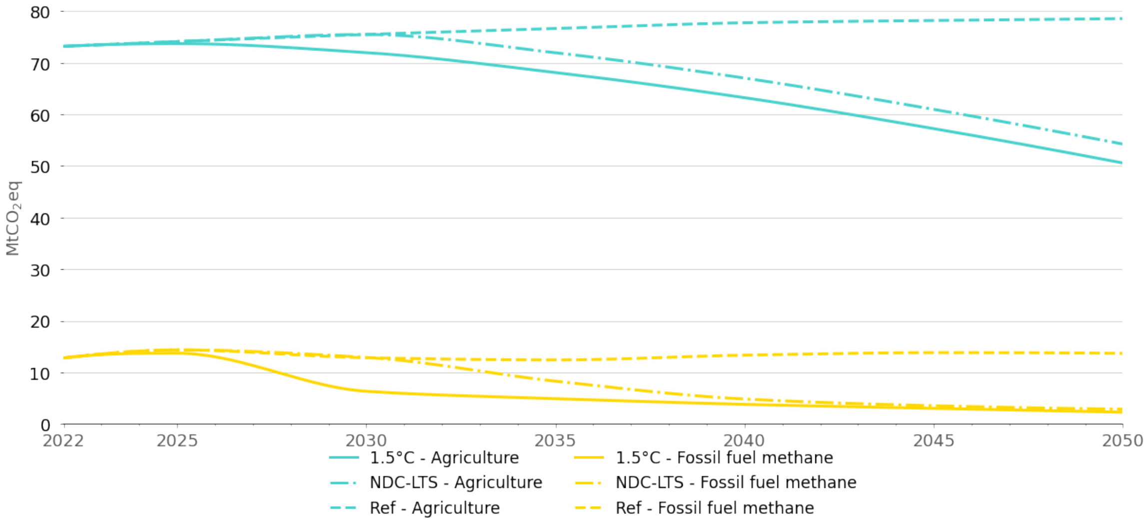


Non-electricity decarbonisation indicators in 1.5ºC scenario - Turkey

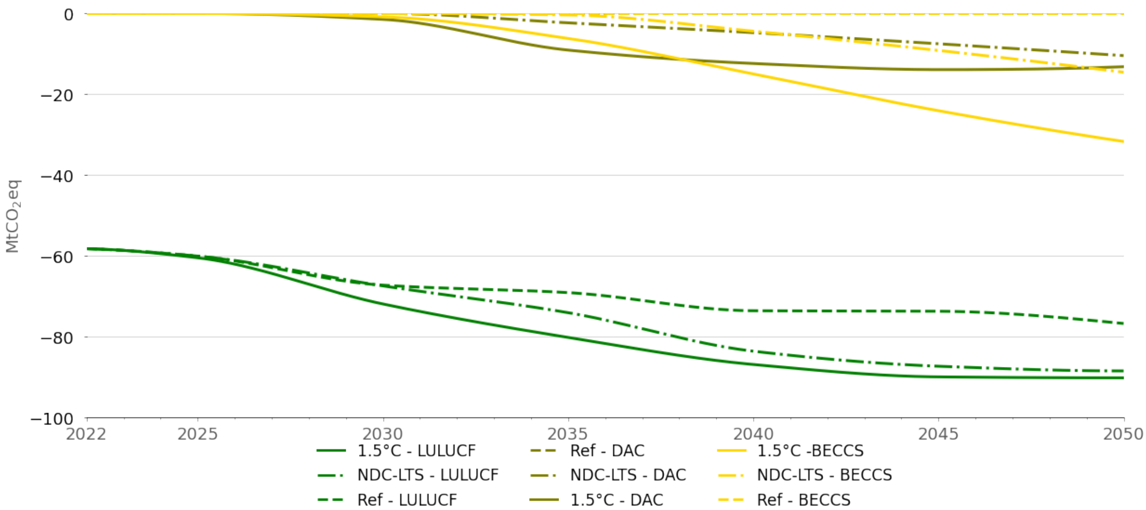
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	204	746	870	469
Domestic production of gaseous e-fuels	bcm	0	0	2	1	2
Domestic production of liquid e-fuels	barrels	0	1111	8576	8184	2638
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	4777	27842	27507	19478
Yearly additions of electrolysers	MW	0	1856	1669	770	3722

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - Turkey



LULUCF emissions, DAC and BECCS - Turkey



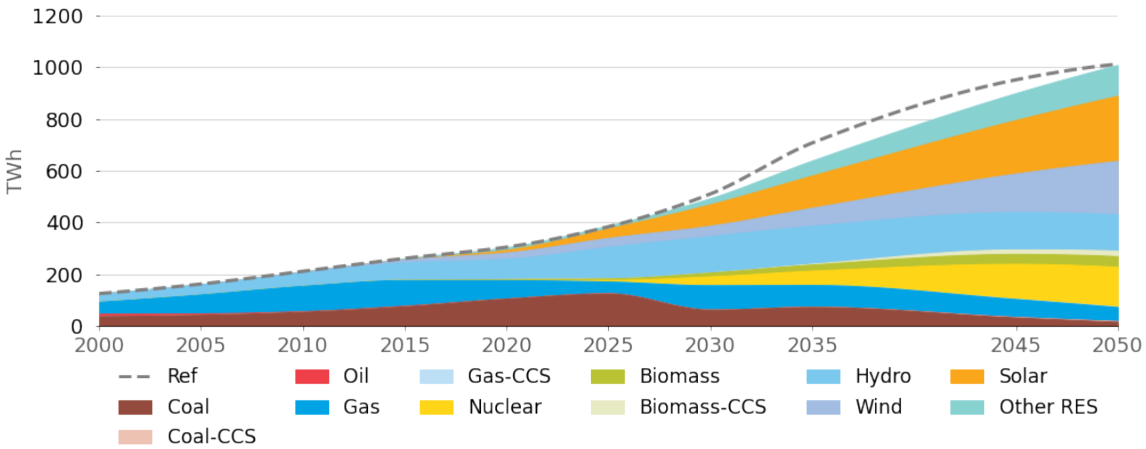
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - Turkey

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	9	12	13
Biomass emissions captured	$MtCO_2eq$	0	1	6	15	32
LULUCF emissions	$MtCO_2eq$	-58	-72	-80	-87	-90
Agriculture emissions	$MtCO_2eq$	73	72	68	63	51
Methane emissions	$MtCO_2eq$	29	15	9	7	2
Methane emission from fossil fuel production	$MtCO_2eq$	13	6	5	4	2

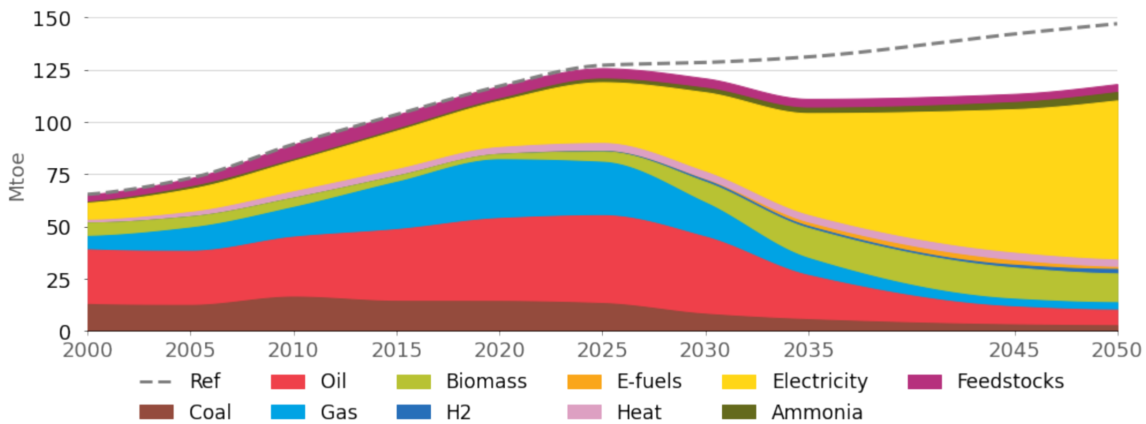
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - Turkey



Final energy consumption in the 1.5ºC scenario - Turkey



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

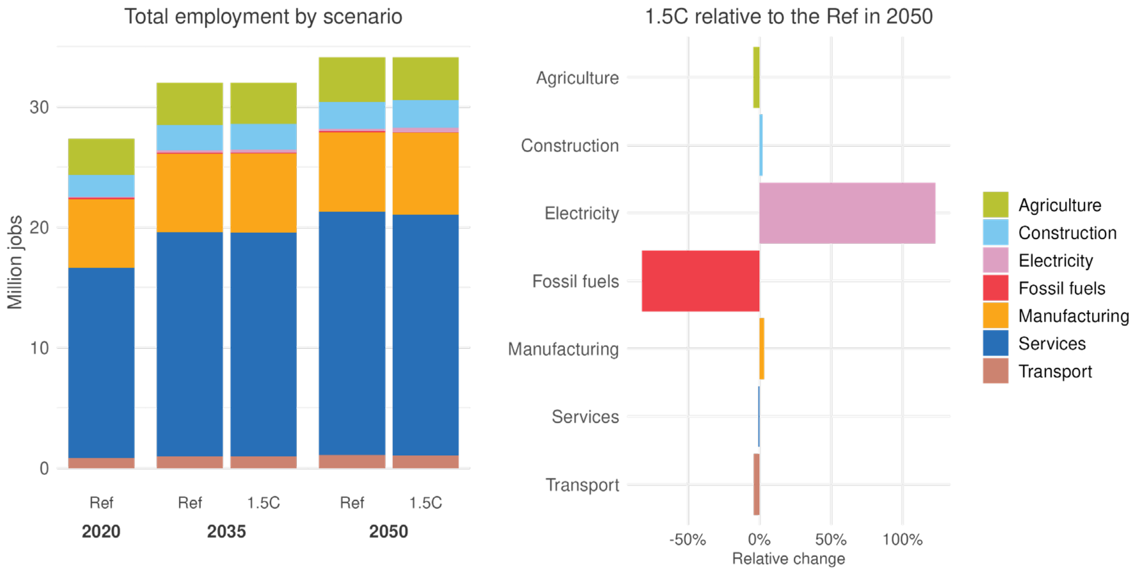
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	71%	38%	21%
Annual energy import bill	billion USD	101	37	33
Air pollution emissions - PM2.5	Mt	467	383	158
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	-1	12
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	-6%	97%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	3	4
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	65%	83%

Labour market dynamics

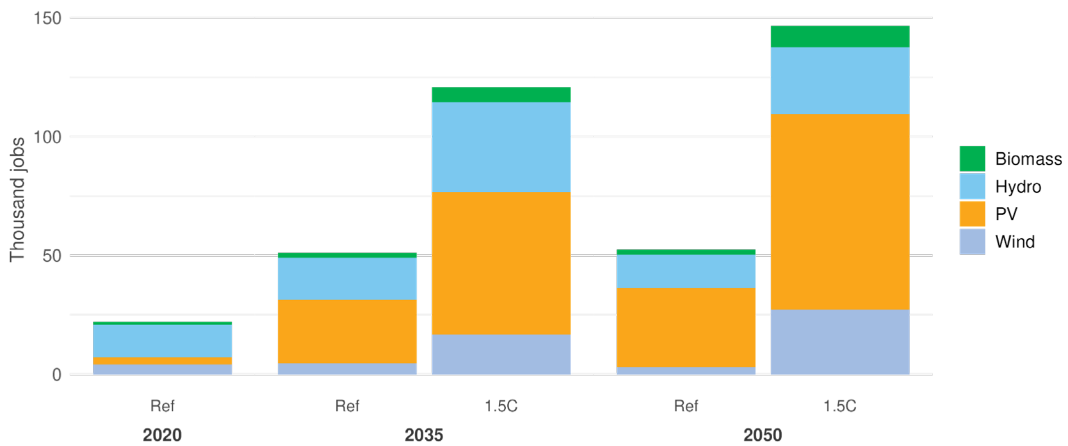
These graphs show the breakdown of employment in Turkey, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – Turkey



Note: Electricity includes all power generation technologies as well as transmission and distribution.

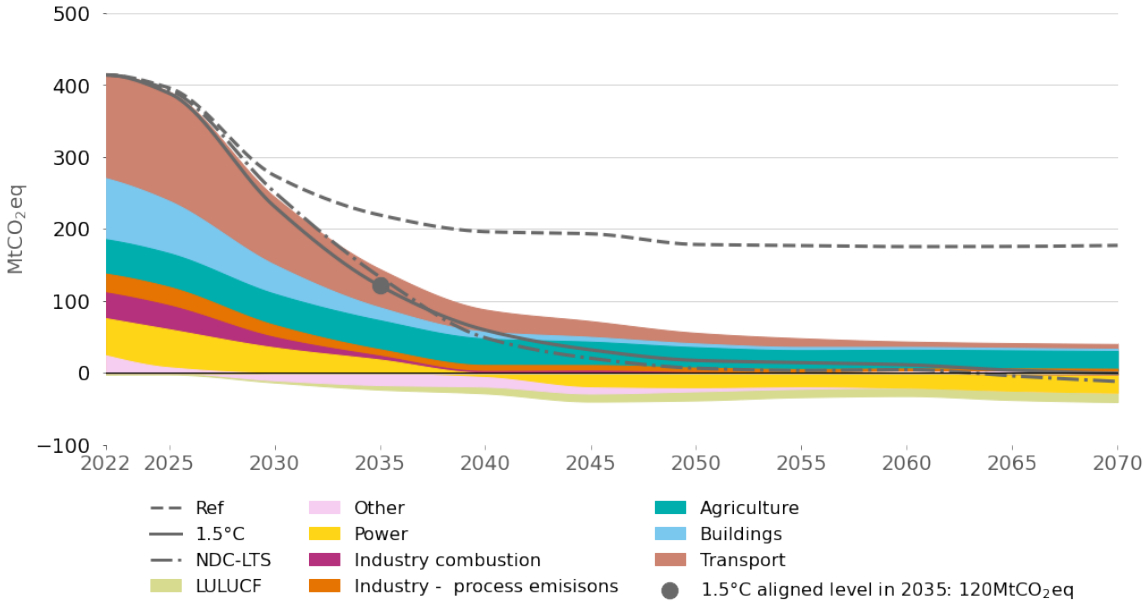
Jobs in renewable technologies by scenario – Turkey



United Kingdom

United Kingdom's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - United Kingdom



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows United Kingdom's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**414**	**121**	**-71%**
Power	52	18	-64%
Industry	62	14	-77%
Transport	108	22	-80%
Buildings	83	16	-80%
LULUCF	-3	-6	138%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

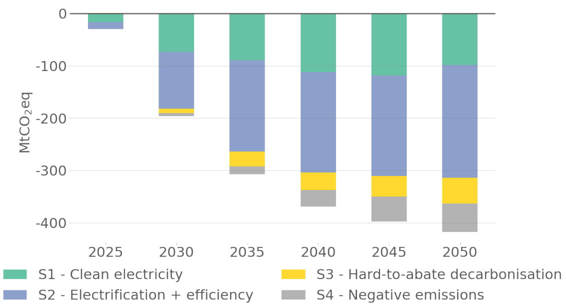
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

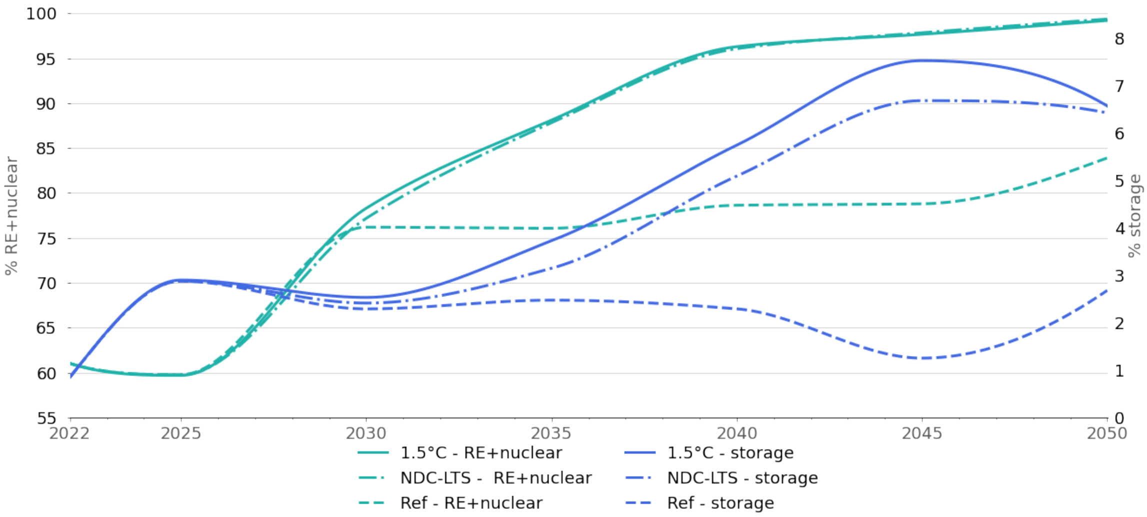
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - United Kingdom



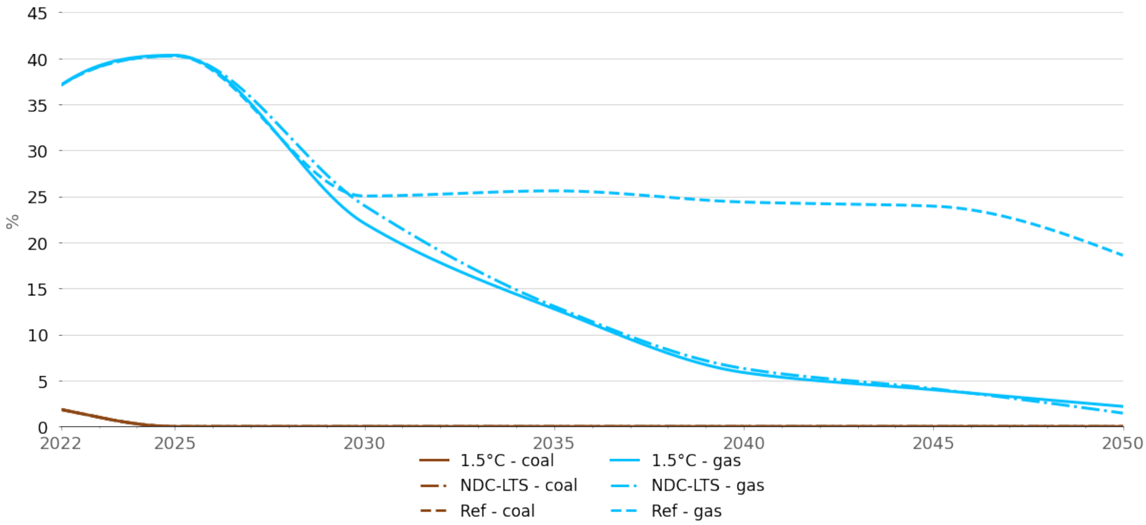
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - United Kingdom



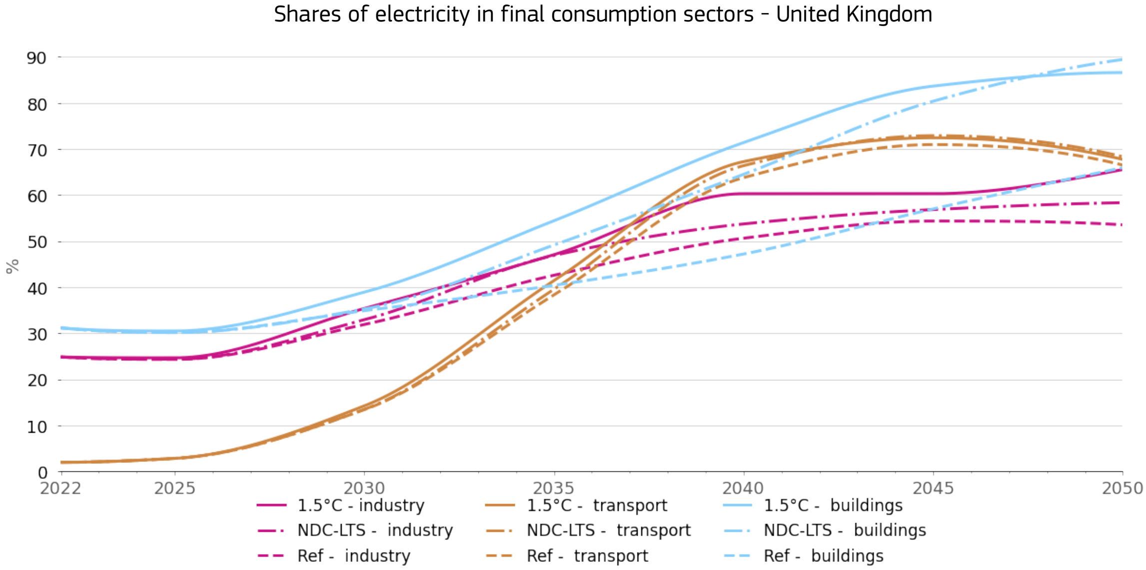
Shares of coal & gas power generation technologies - United Kingdom

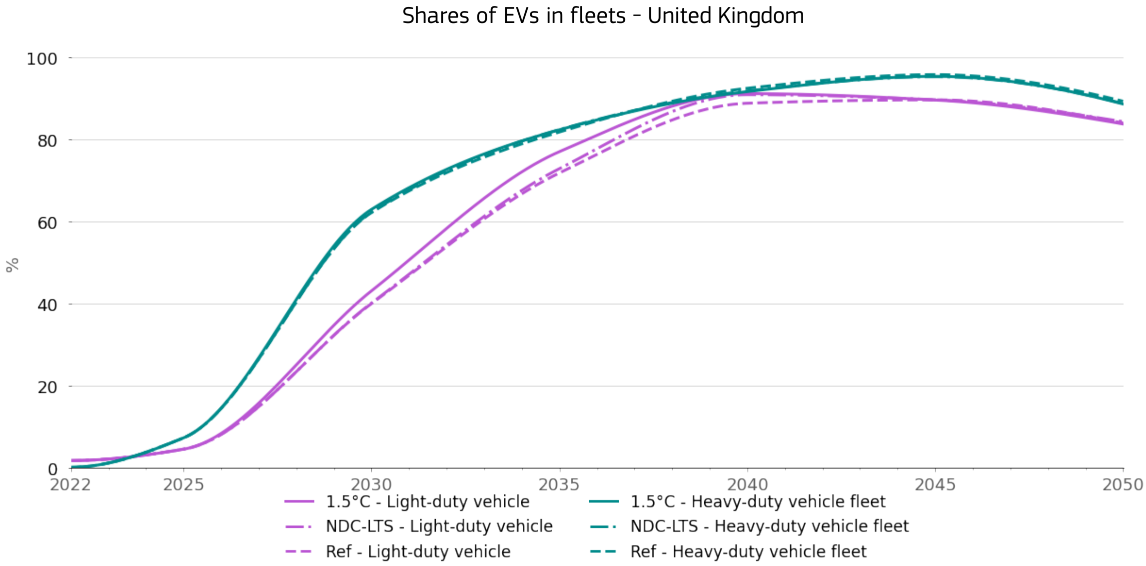


Clean electricity indicators in 1.5ºC scenario - United Kingdom

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	4	10	13	15	15
Wind+solar share of annual additions	%	68%	77%	77%	77%	81%
Annual additions of storage	GW	0.93	0.52	0.92	1.19	1.46
Carbon content of electricity	gCO_2/MWh	154	91	37	-9	-34
Emissions from power sector	$MtCO_2eq$	51	35	18	-5	-20
First year of no unabated coal generation				2025		

Strategy 2 – Electrify end-uses and improve energy efficiency

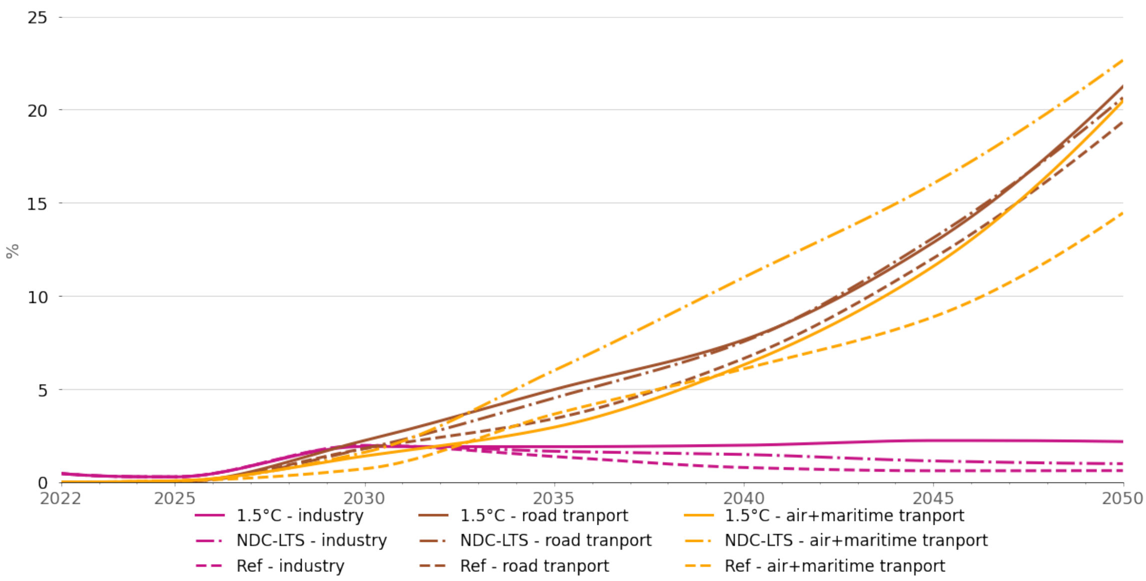


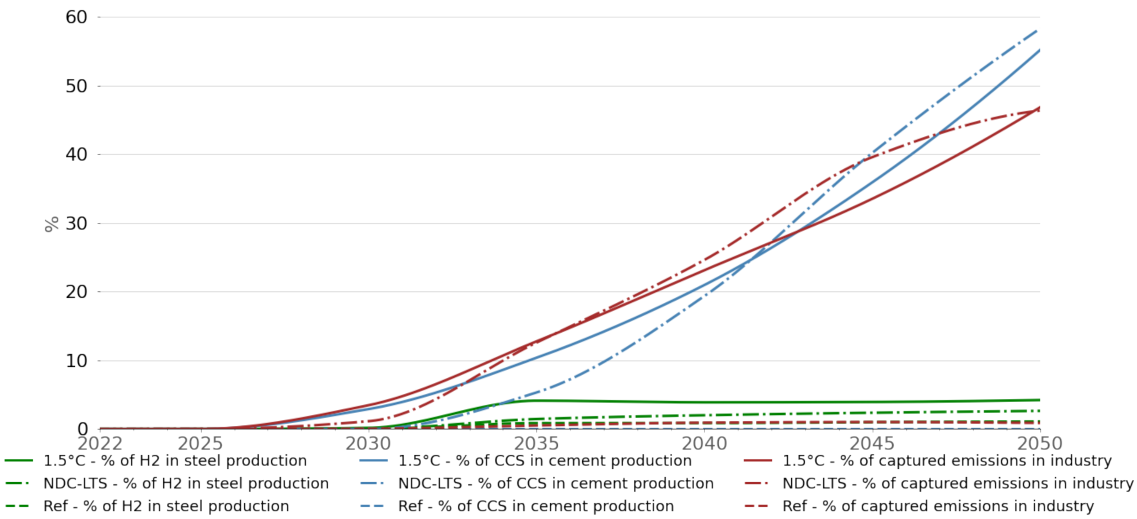


Electrification indicators in 1.5ºC scenario - United Kingdom

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	270	1857	2628	2927	2345
Share of EVs in total car sales	%	9%	63%	97%	86%	75%
Annual sales of EV HDV	thousands	0	1	34	58	88
Share of EVs in total HDV sales	%	0%	1%	39%	62%	85%
Annual sales of small-scale heat pumps in buildings	GW	0	6	17	14	12
Annual sales of large-scale heat pumps in industry	GW	0	14	22	23	25
Share of heat pumps in buildings heating demand	%	0%	8%	18%	35%	59%

Strategy 3 – Decarbonise hard-to-abate sectors



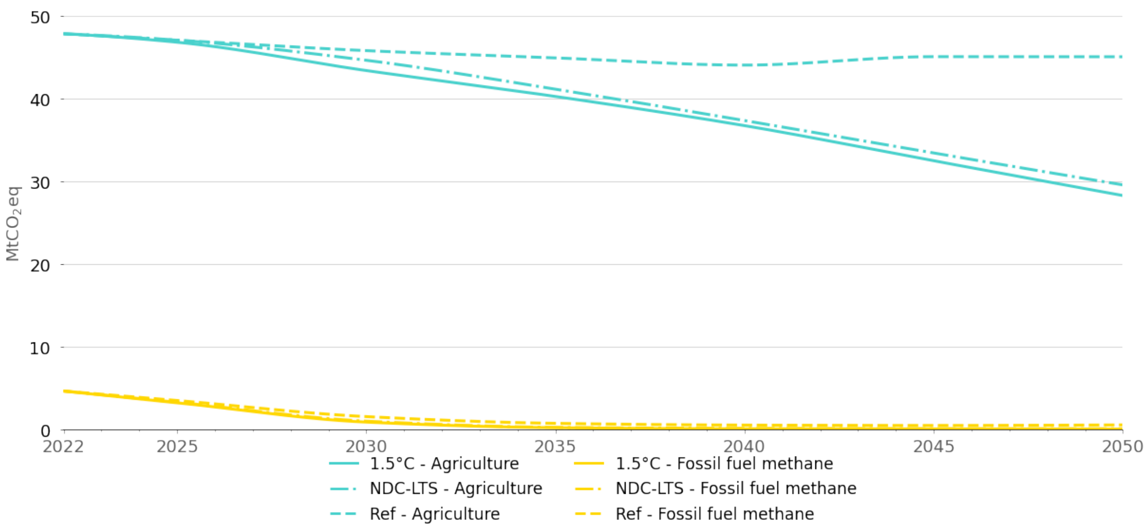


Non-electricity decarbonisation indicators in 1.5°C scenario - United Kingdom

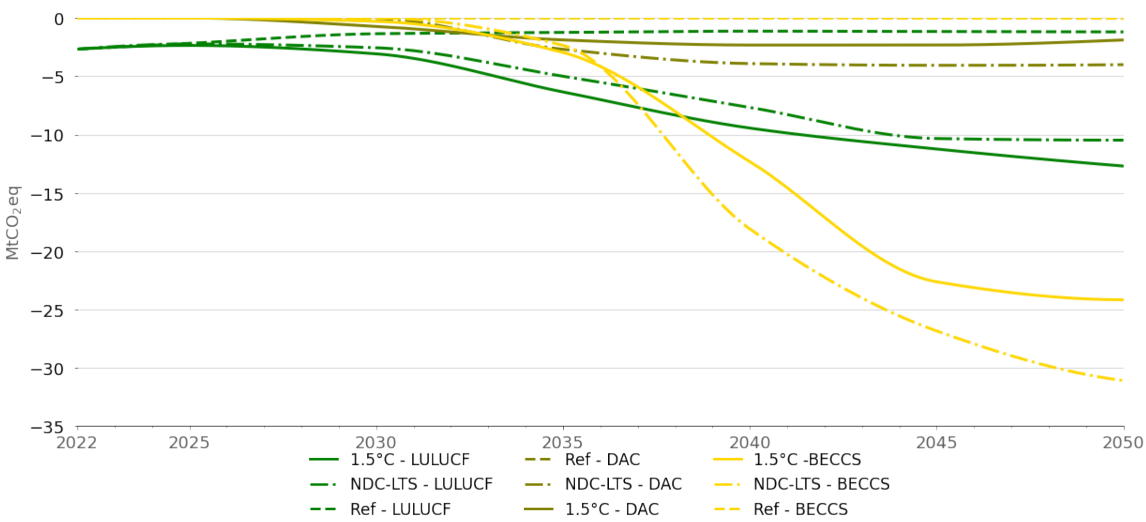
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	128	131	135	315
Domestic production of gaseous e-fuels	bcm	0	0	2	1	2
Domestic production of liquid e-fuels	barrels	0	111	424	335	280
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	2395	2407	2318	5319
Yearly additions of electrolysers	MW	0	161	1	280	1035

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - United Kingdom



LULUCF emissions, DAC and BECCS - United Kingdom



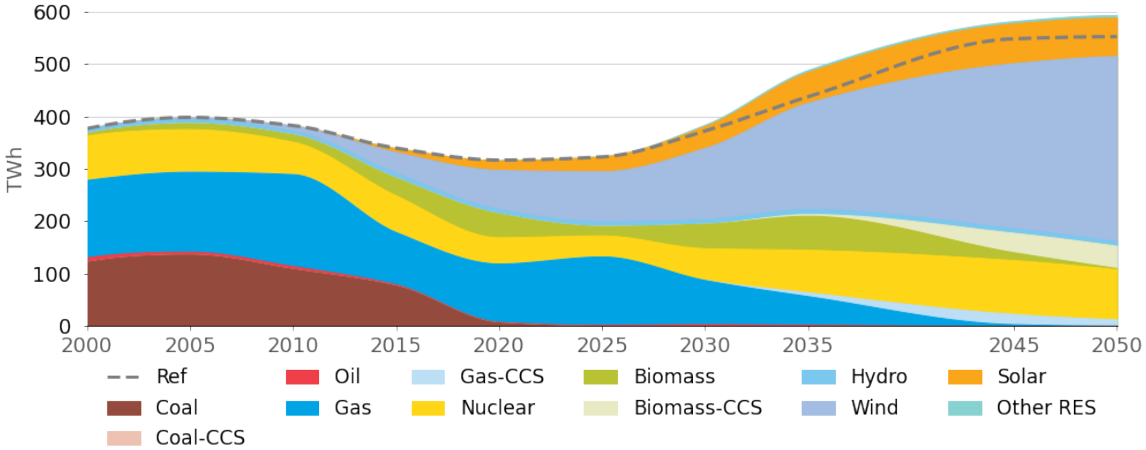
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - United Kingdom

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	1	2	2	2
Biomass emissions captured	$MtCO_2eq$	0	0	3	12	24
LULUCF emissions	$MtCO_2eq$	-3	-3	-6	-9	-13
Agriculture emissions	$MtCO_2eq$	48	43	40	37	28
Methane emissions	$MtCO_2eq$	23	11	5	4	1
Methane emission from fossil fuel production	$MtCO_2eq$	5	1	0	0	0

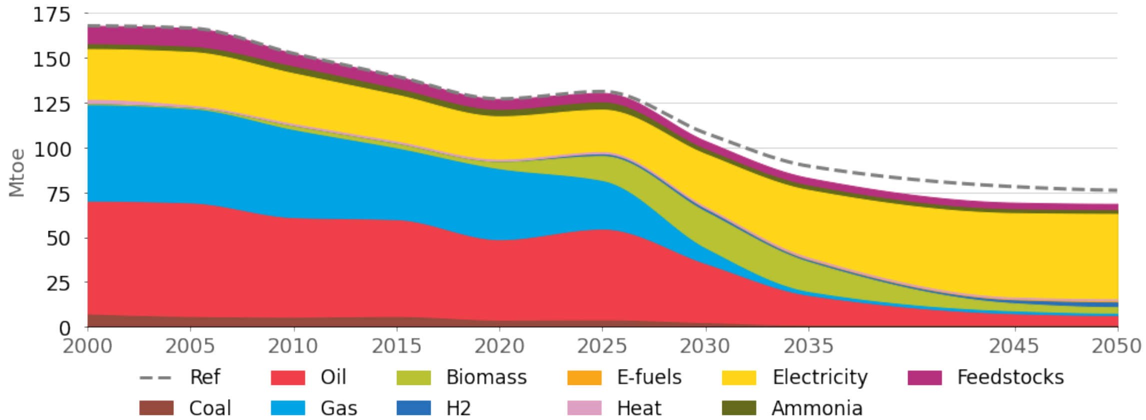
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - United Kingdom



Final energy consumption in the 1.5ºC scenario - United Kingdom



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

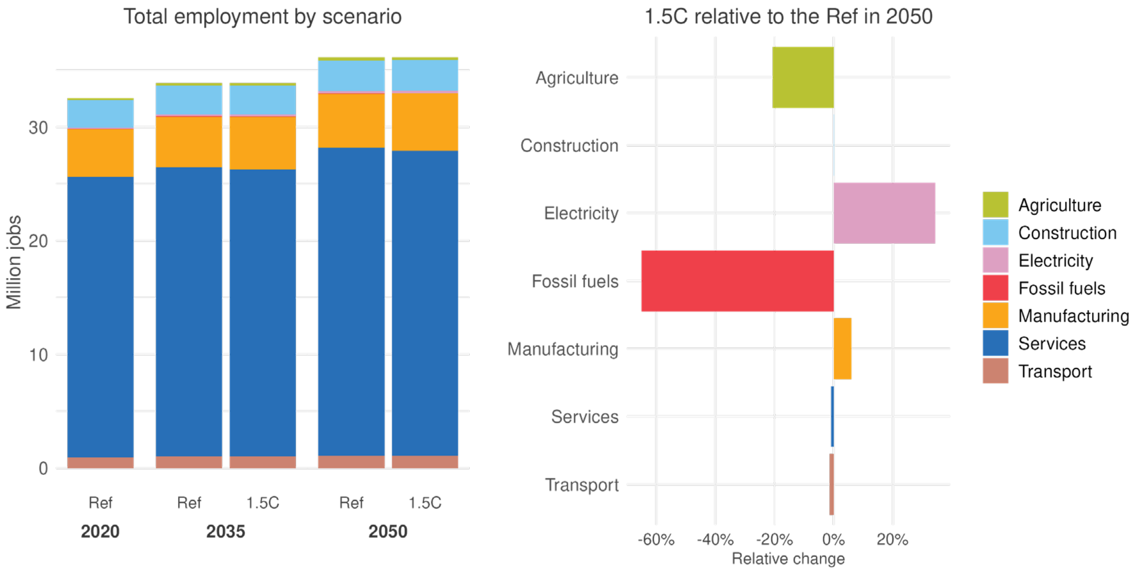
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	40%	32%	23%
Annual energy import bill	billion USD	69	23	17
Air pollution emissions - PM2.5	Mt	88	45	17
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	4	0
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	22%	9%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	2	3
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	63%	95%

Labour market dynamics

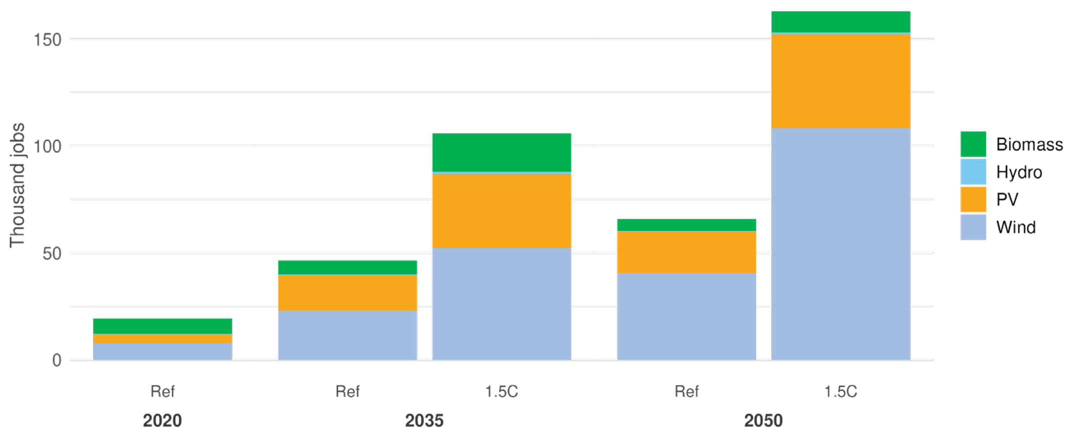
These graphs show the breakdown of employment in United Kingdom, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – United Kingdom



Note: Electricity includes all power generation technologies as well as transmission and distribution.

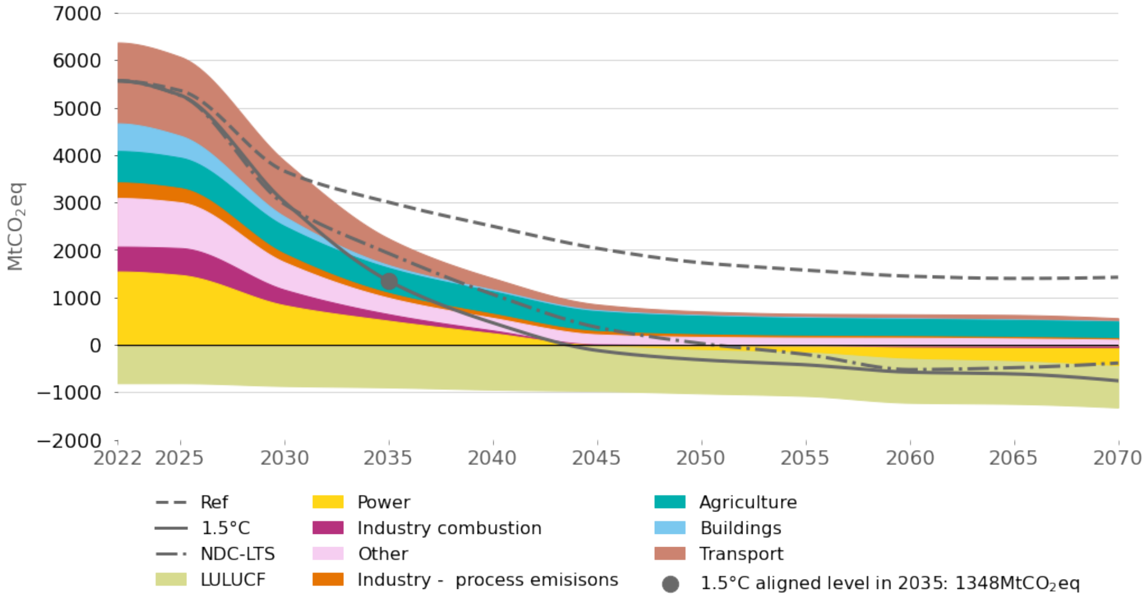
Jobs in renewable technologies by scenario – United Kingdom



United States

United States's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - United States



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows United States's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**5566**	**1348**	**-76%**
Power	1548	509	-67%
Industry	850	240	-72%
Transport	1592	498	-69%
Buildings	558	36	-93%
LULUCF	-809	-896	11%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
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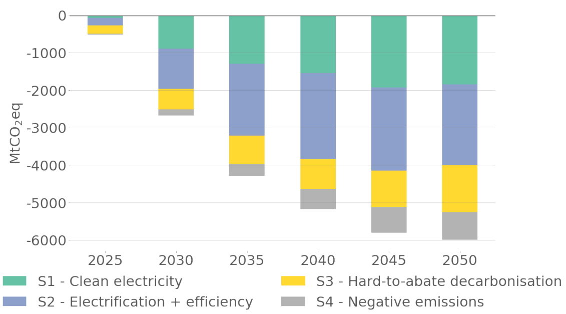
The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - United States



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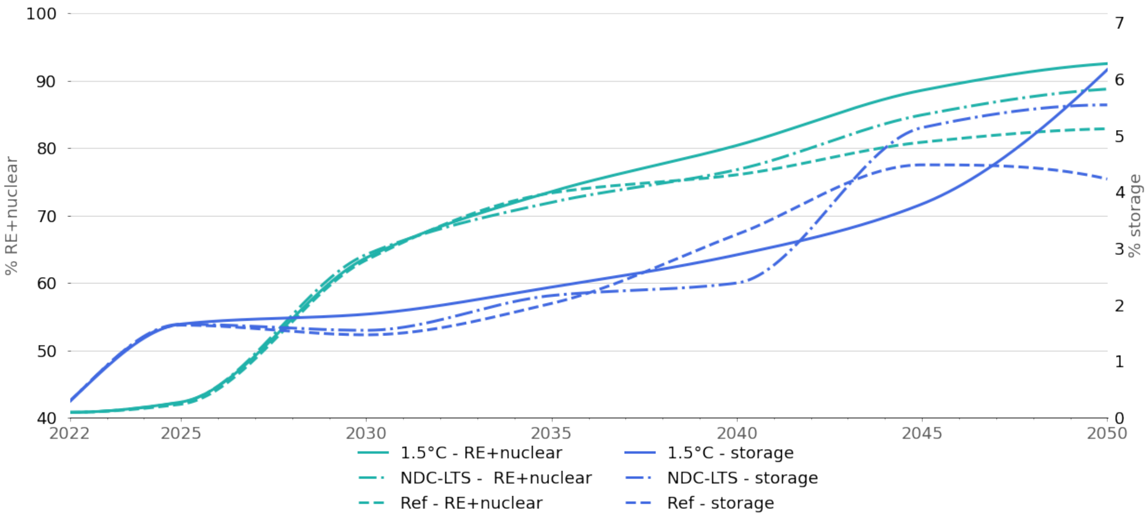
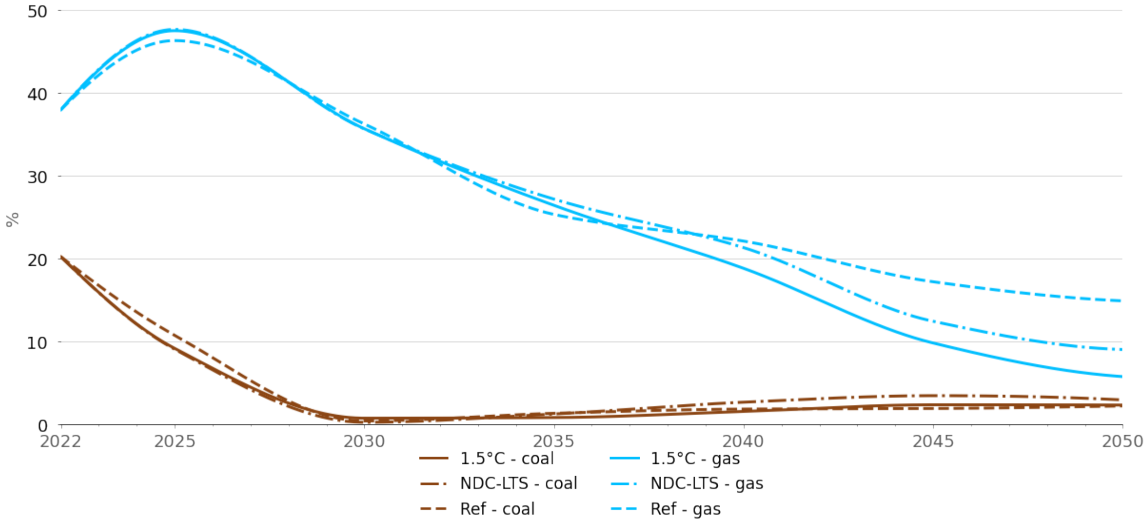
Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - United States



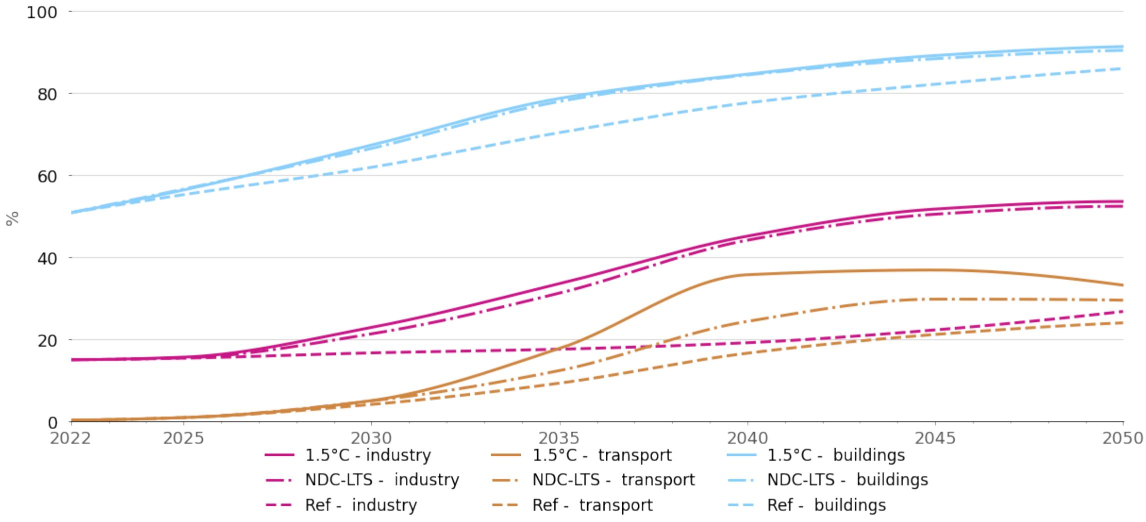
Shares of coal & gas power generation technologies - United States

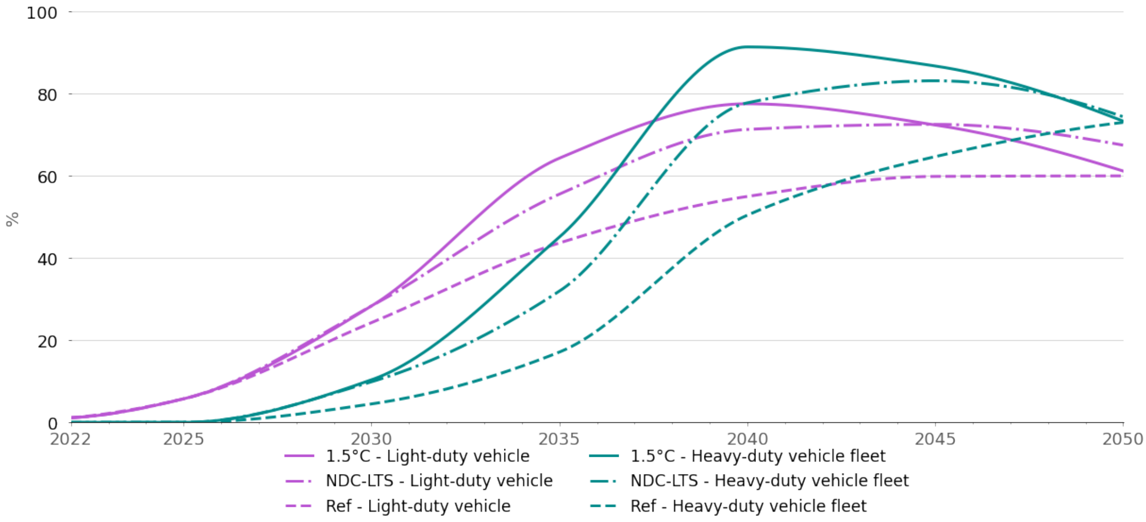


Clean electricity indicators in 1.5ºC scenario - United States

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	28	71	69	75	83
Wind+solar share of annual additions	%	61%	59%	52%	52%	58%
Annual additions of storage	GW	7.47	10.64	19.17	27.54	33.81
Carbon content of electricity	gCO_2/MWh	340	156	84	37	-12
Emissions from power sector	$MtCO_2$eq	1541	832	506	242	-84
First year of no unabated coal generation				2030		

Strategy 2 – Electrify end-uses and improve energy efficiency



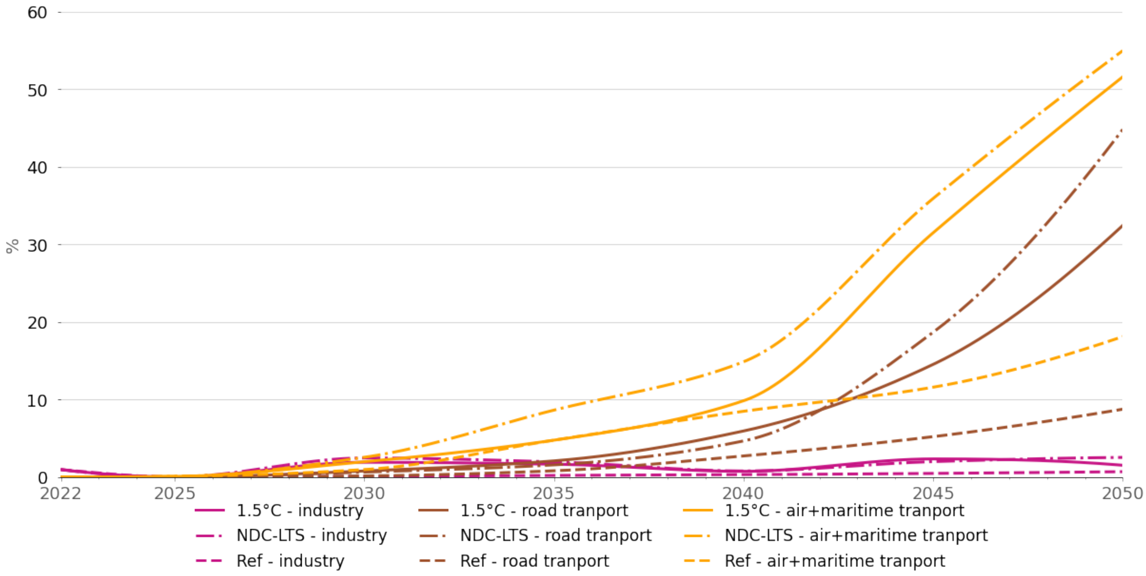


Electrification indicators in 1.5ºC scenario - United States

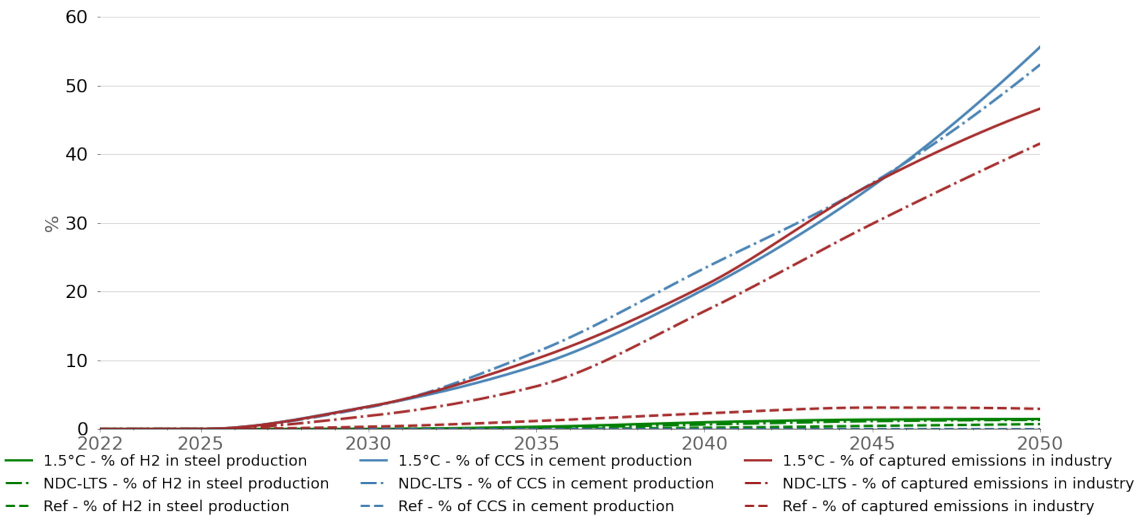
		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	800	10390	16707	16727	13015
Share of EVs in total car sales	%	3%	45%	76%	69%	54%
Annual sales of EV HDV	thousands	0	0	20	185	441
Share of EVs in total HDV sales	%	0%	0%	4%	35%	82%
Annual sales of small-scale heat pumps in buildings	GW	85	128	14	210	1
Annual sales of large-scale heat pumps in industry	GW	0	571	621	484	836
Share of heat pumps in buildings heating demand	%	0%	14%	32%	46%	67%

Strategy 3 – Decarbonise hard-to-abate sectors

Penetration of H_2 & e-fuels in key sectors - United States



Penetration of low-emissions industrial production - United States

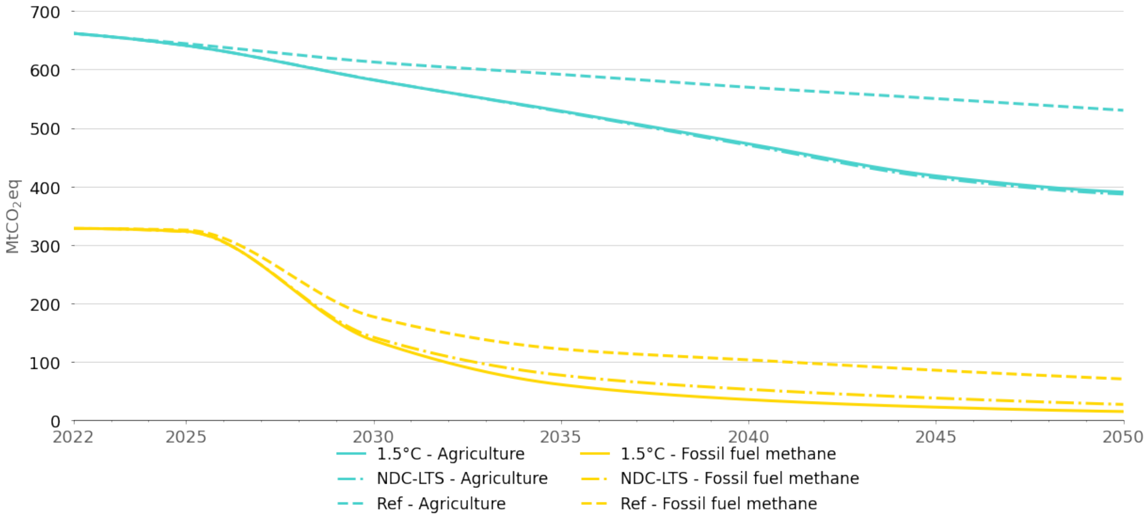


Non-electricity decarbonisation indicators in 1.5ºC scenario - United States

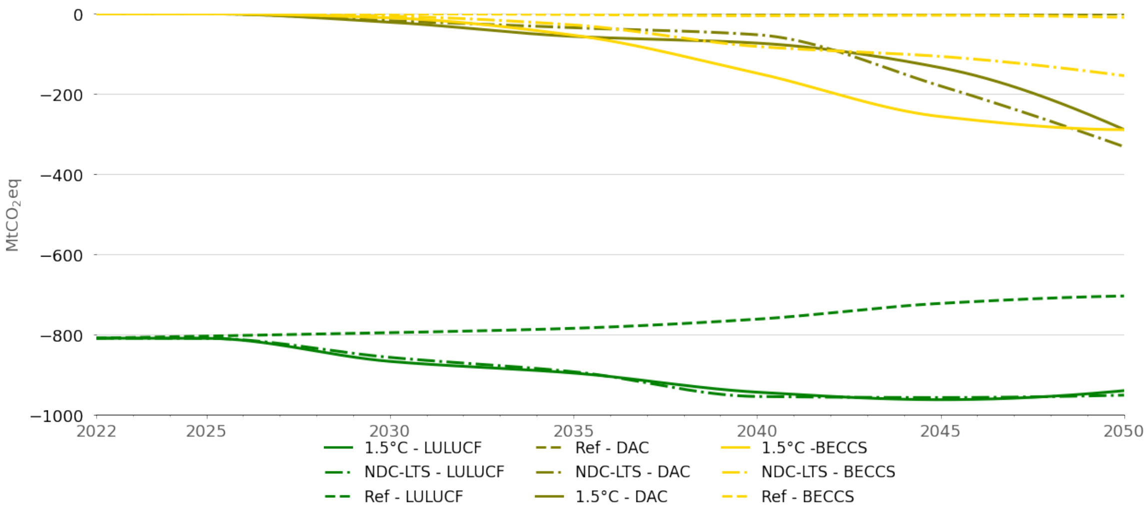
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	2442	2463	3064	37979
Domestic production of gaseous e-fuels	bcm	0	1	0	0	21
Domestic production of liquid e-fuels	barrels	0	18078	21273	21829	406307
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	53791	53839	52429	1096700
Yearly additions of electrolysers	MW	0	3590	2230	60767	100842

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - United States



LULUCF emissions, DAC and BECCS - United States



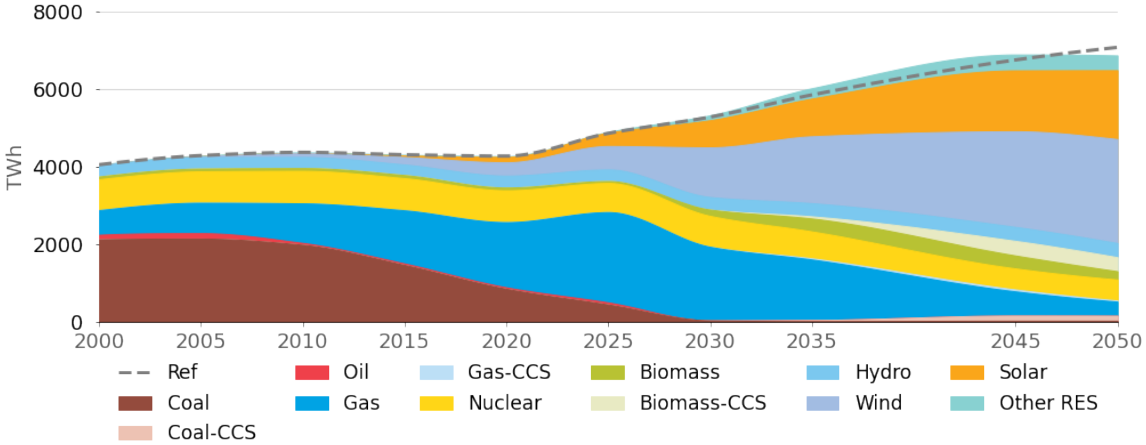
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - United States

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	21	56	73	288
Biomass emissions captured	$MtCO_2eq$	0	10	53	148	289
LULUCF emissions	$MtCO_2eq$	-809	-867	-896	-943	-939
Agriculture emissions	$MtCO_2eq$	662	582	529	473	390
Methane emissions	$MtCO_2eq$	484	236	134	106	74
Methane emission from fossil fuel production	$MtCO_2eq$	328	137	61	35	15

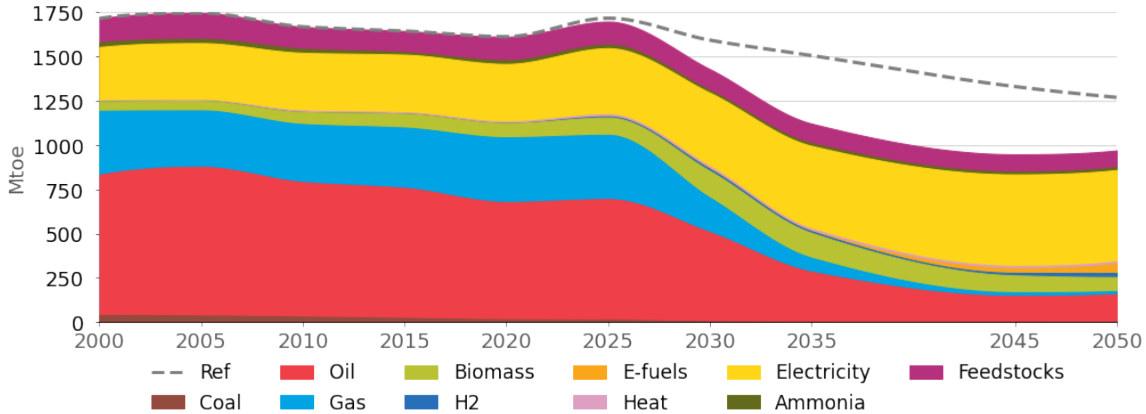
Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.

Power generation in the 1.5ºC scenario - United States



Final energy consumption in the 1.5ºC scenario - United States



Co-benefits and investments related to decarbonisation in the 1.5°C scenario

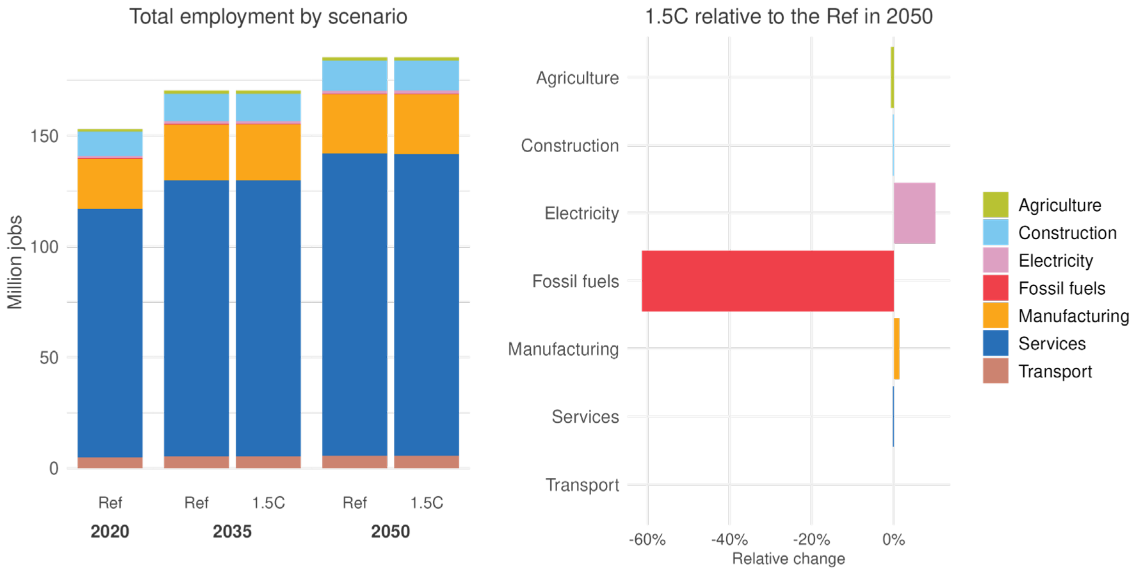
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	6%	11%	13%
Annual energy import bill	billion USD	143	85	85
Air pollution emissions - PM2.5	Mt	1011	716	419
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	29	-3
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	19%	-3%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	42	60
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	61%	88%

Labour market dynamics

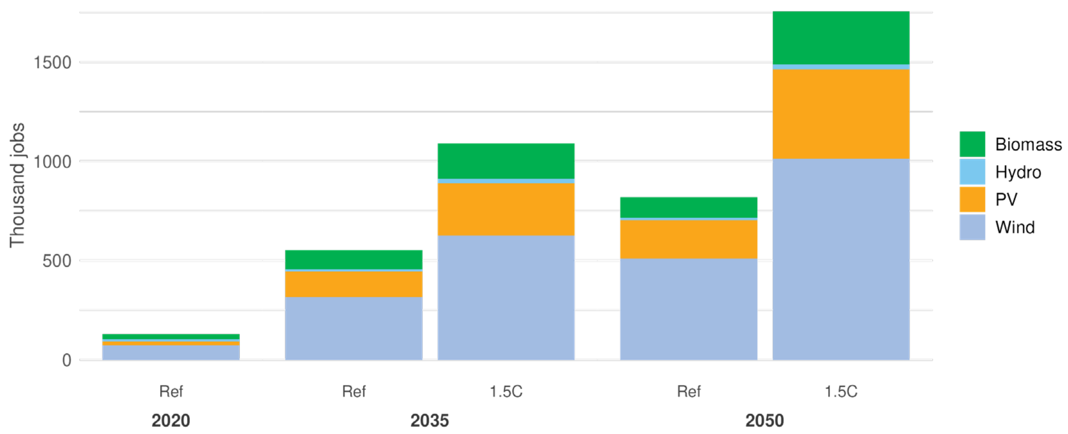
These graphs show the breakdown of employment in United States, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – United States



Note: Electricity includes all power generation technologies as well as transmission and distribution.

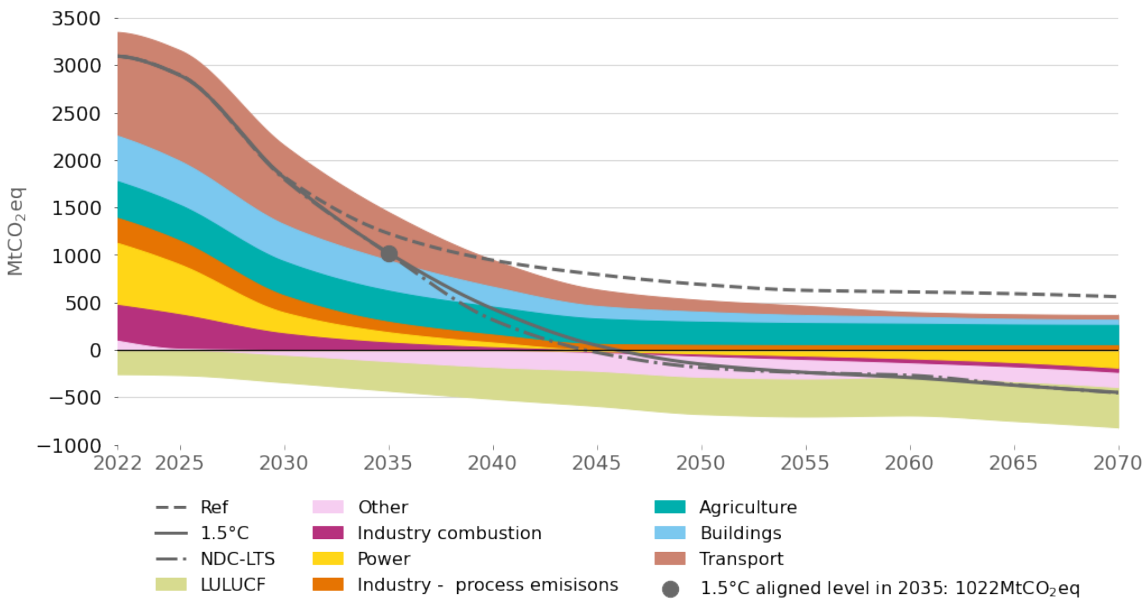
Jobs in renewable technologies by scenario – United States



European Union

European Union's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - European Union



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows European Union's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**3095**	**1023**	**-67%**
Power	653	110	-83%
Industry	641	188	-71%
Transport	799	291	-64%
Buildings	419	270	-36%
LULUCF	-256	-312	22%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

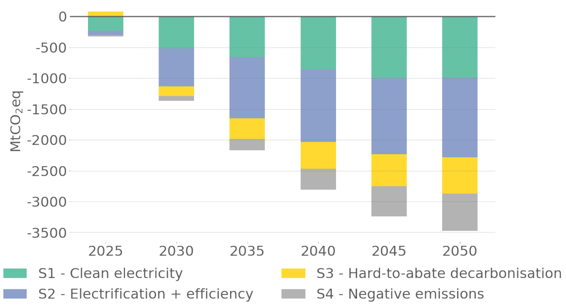
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

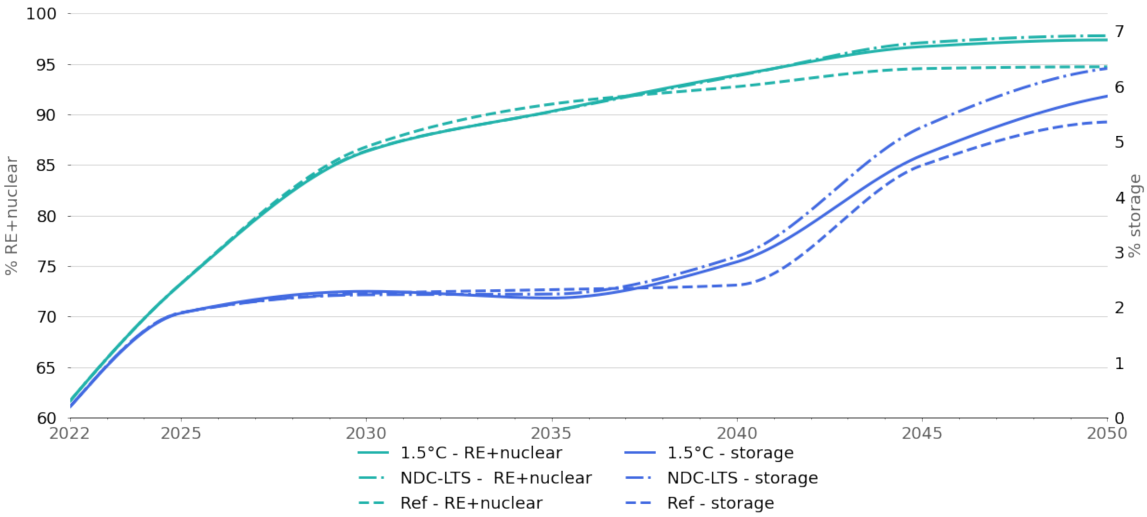
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - European Union



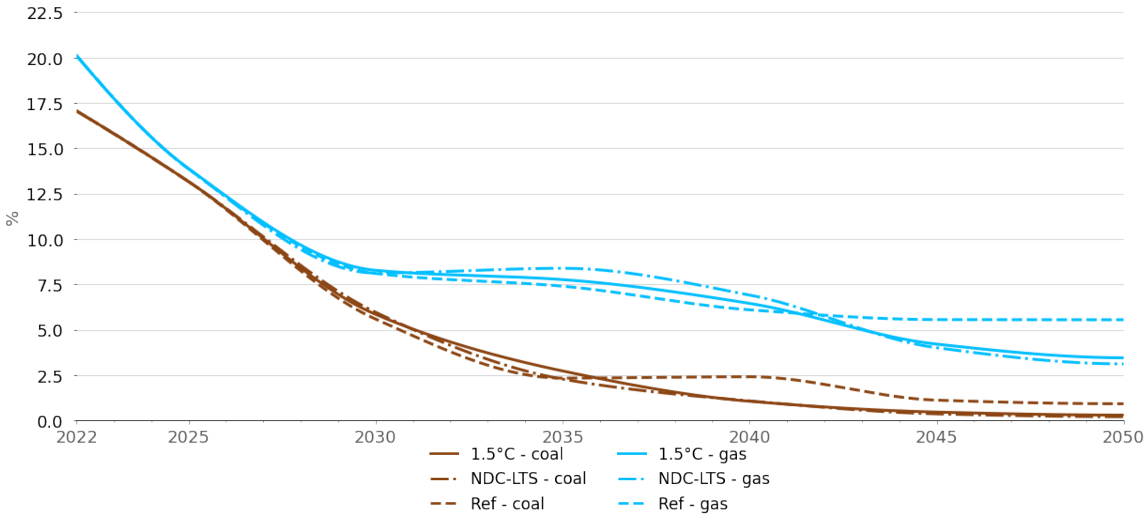
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - European Union



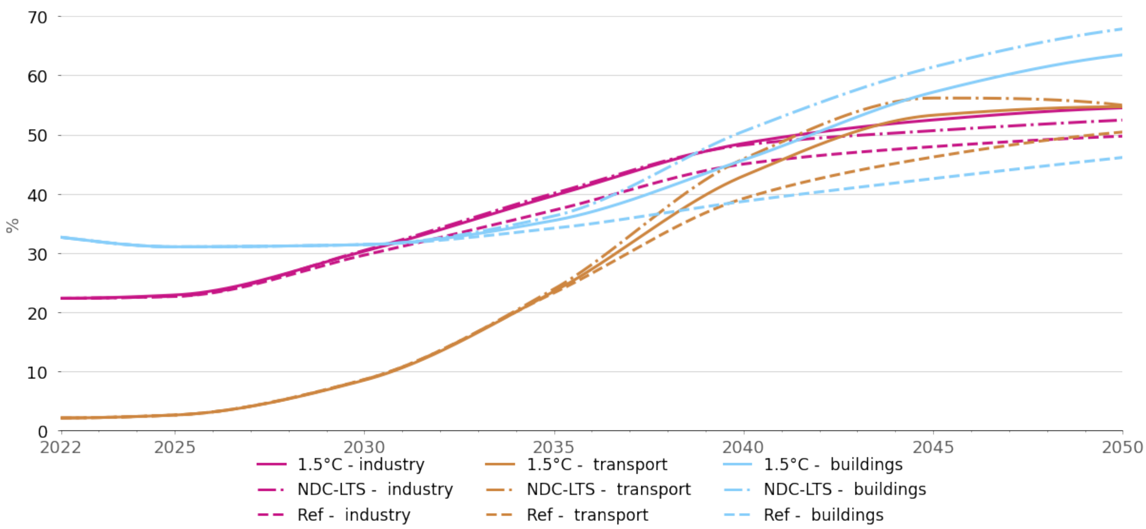
Shares of coal & gas power generation technologies - European Union

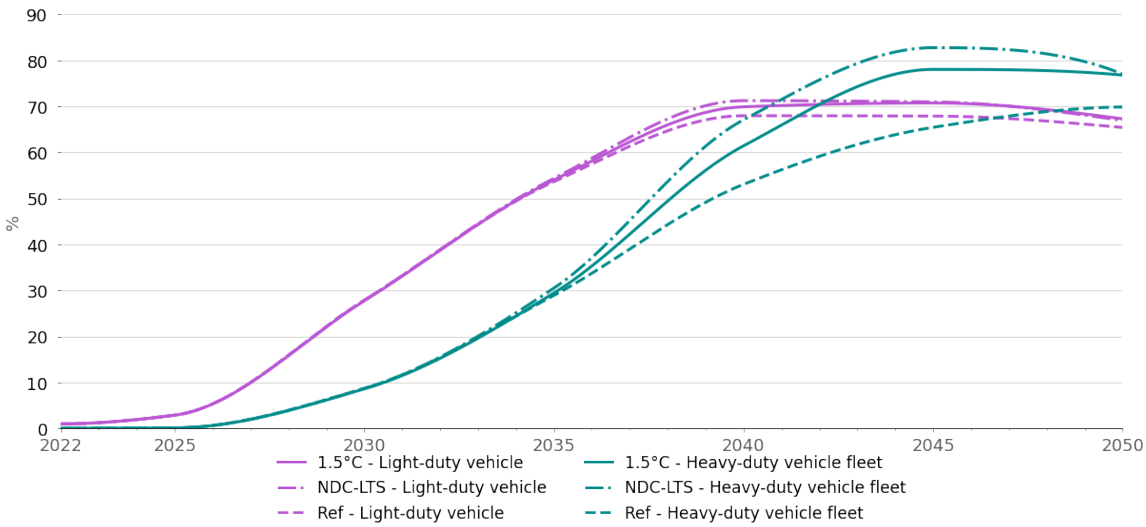


Clean electricity indicators in 1.5ºC scenario - European Union

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	57	64	82	101	97
Wind+solar share of annual additions	%	76%	71%	70%	68%	64%
Annual additions of storage	GW	1.22	4.59	9.17	14.45	17.60
Carbon content of electricity	gCO_2/MWh	230	78	34	13	-8
Emissions from power sector	$MtCO_2eq$	652	220	108	49	-40
First year of no unabated coal generation				2038		

Strategy 2 – Electrify end-uses and improve energy efficiency

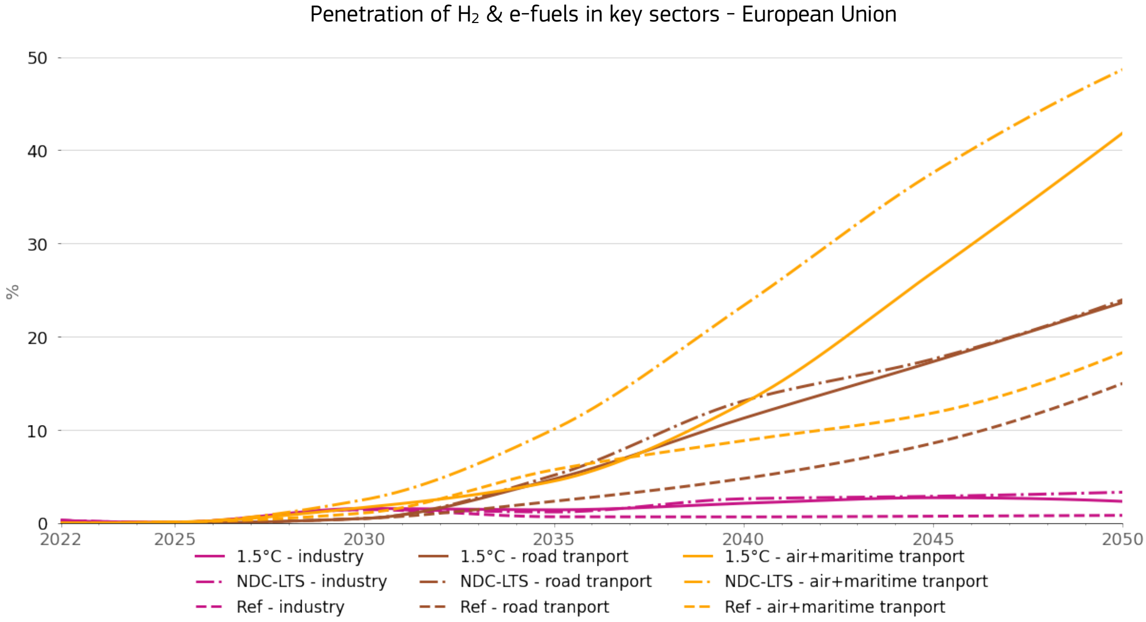


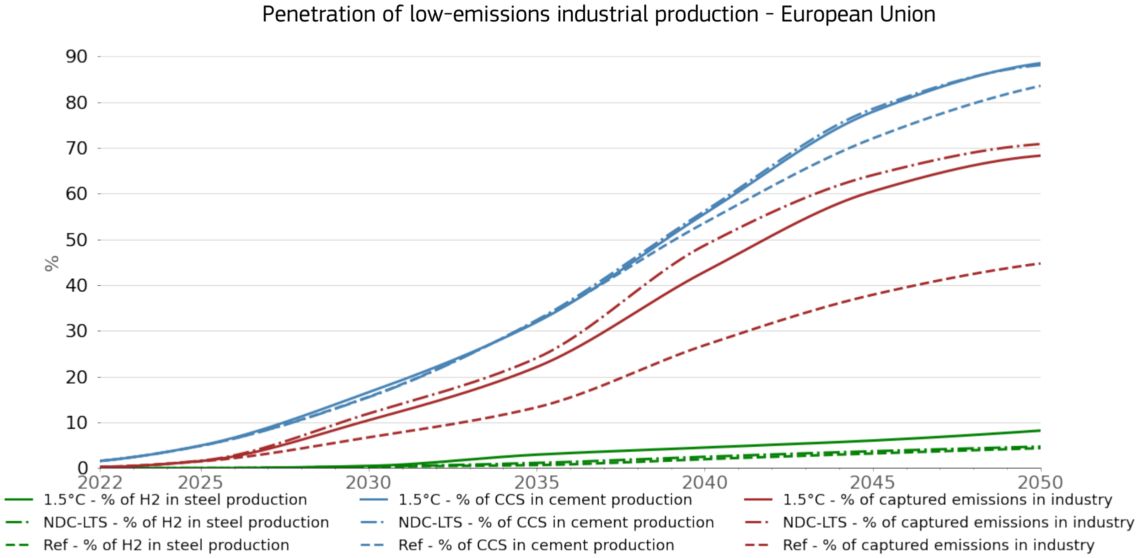


Electrification indicators in 1.5ºC scenario - European Union

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	1151	10913	16518	13776	14013
Share of EVs in total car sales	%	4%	50%	63%	69%	61%
Annual sales of EV HDV	thousands	0	1	42	289	1068
Share of EVs in total HDV sales	%	0%	0%	3%	17%	62%
Annual sales of small-scale heat pumps in buildings	GW	11	19	62	62	54
Annual sales of large-scale heat pumps in industry	GW	0	187	378	55	416
Share of heat pumps in buildings heating demand	%	0%	3%	8%	20%	38%

Strategy 3 – Decarbonise hard-to-abate sectors



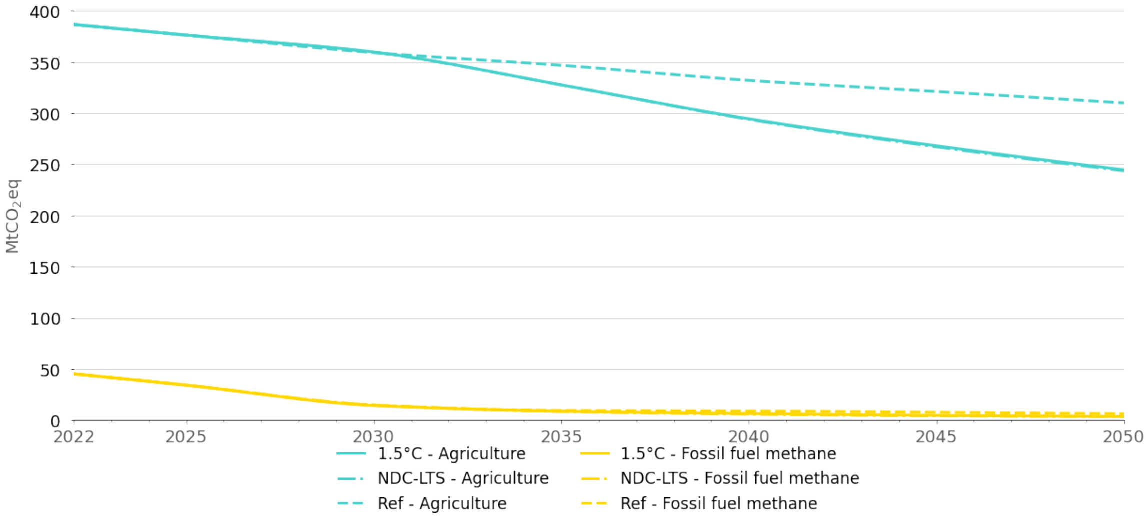


Non-electricity decarbonisation indicators in 1.5ºC scenario - European Union

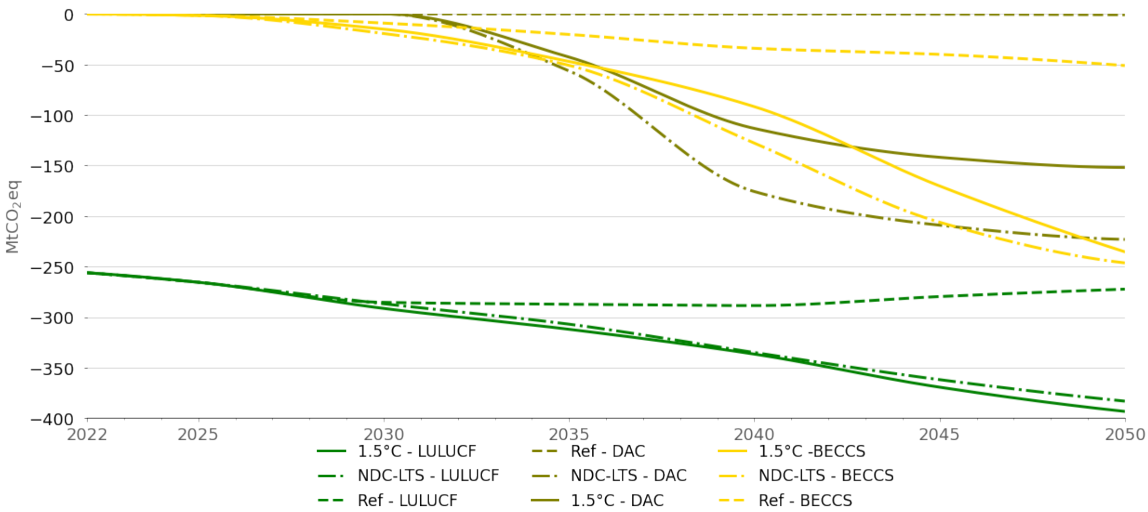
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	6811	8830	12504	28035
Domestic production of gaseous e-fuels	bcm	0	0	11	21	30
Domestic production of liquid e-fuels	barrels	0	0	24456	44174	71484
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	111219	158447	408654	1130630
Yearly additions of electrolysers	MW	0	15005	30408	49813	97690

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - European Union



LULUCF emissions, DAC and BECCS - European Union

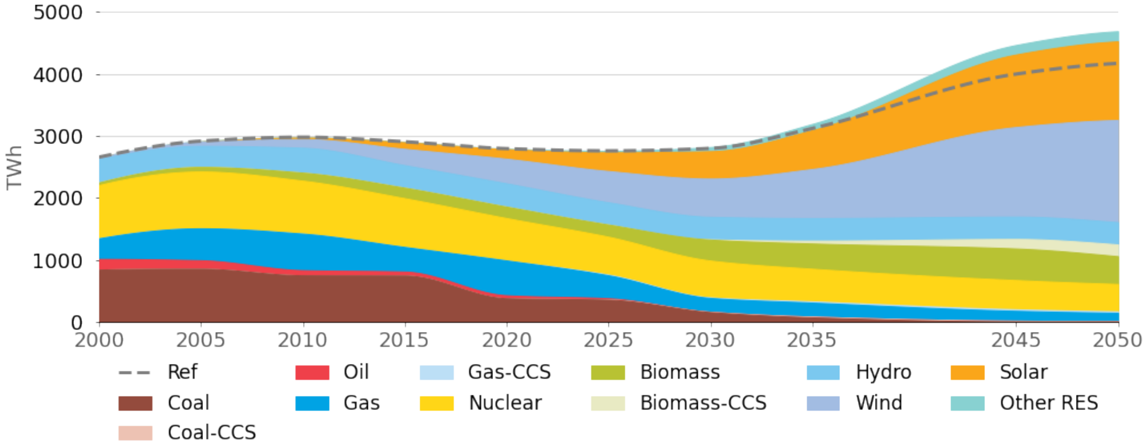


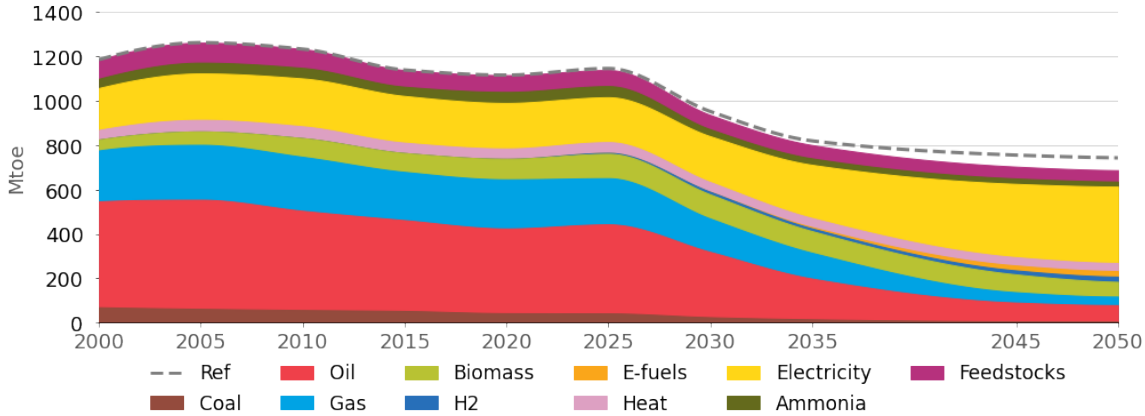
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - European Union

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	0	43	113	152
Biomass emissions captured	$MtCO_2eq$	0	15	47	92	235
LULUCF emissions	$MtCO_2eq$	-256	-291	-312	-337	-393
Agriculture emissions	$MtCO_2eq$	387	360	328	294	245
Methane emissions	$MtCO_2eq$	169	87	44	33	11
Methane emission from fossil fuel production	$MtCO_2eq$	45	14	9	6	4

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

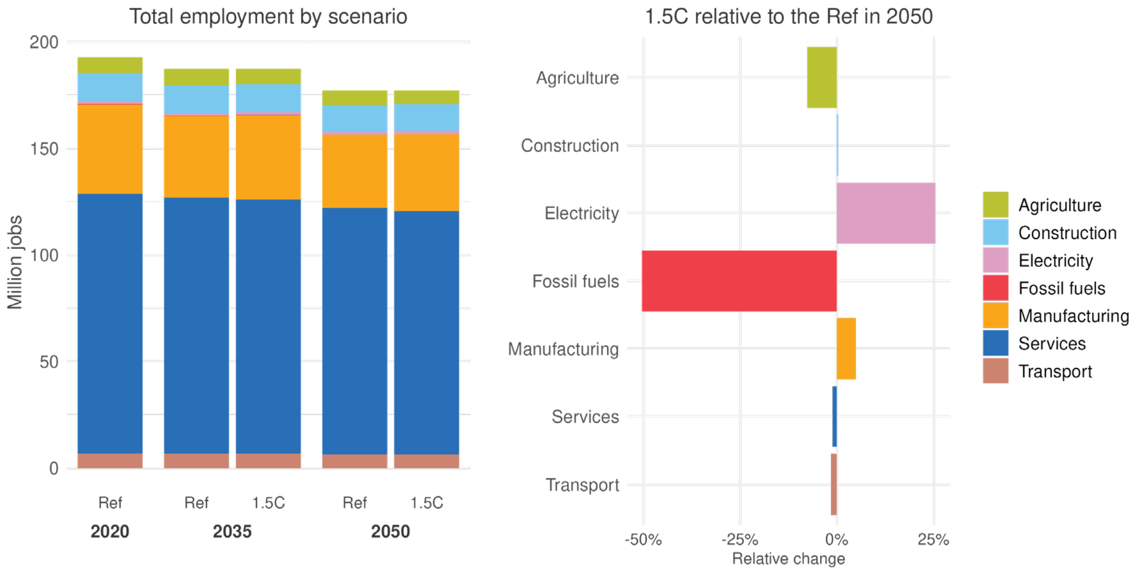
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	61%	39%	20%
Annual energy import bill	billion USD	1259	254	122
Air pollution emissions - PM2.5	Mt	1111	493	240
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	5	20
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	3%	18%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	12	13
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	65%	70%

Labour market dynamics

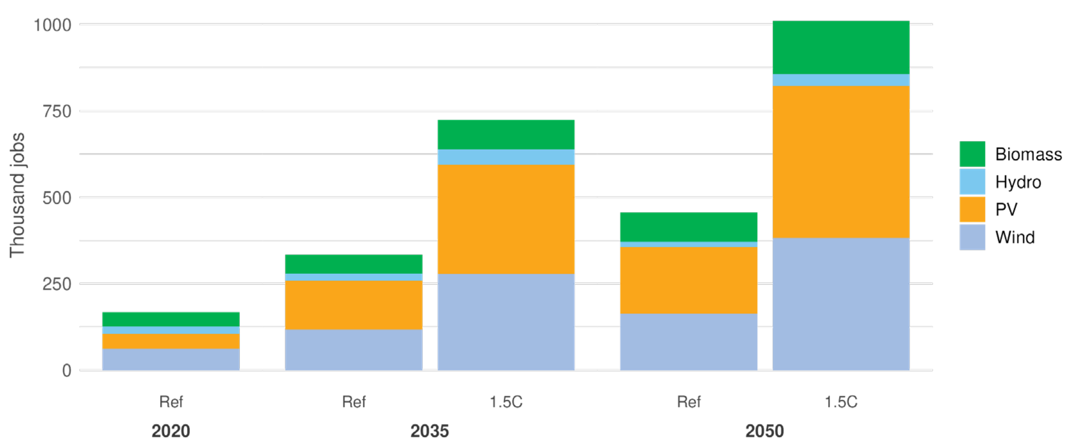
These graphs show the breakdown of employment in European Union, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – European Union



Note: Electricity includes all power generation technologies as well as transmission and distribution.

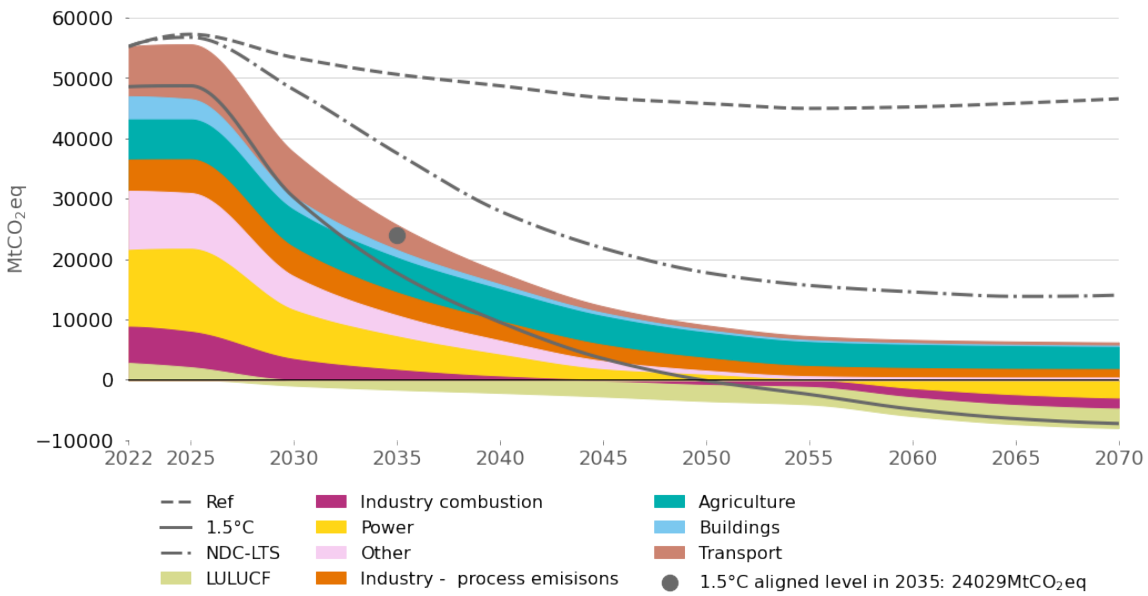
Jobs in renewable technologies by scenario – European Union



World

World's decarbonisation pathways are presented in the figure below, showing economy-wide GHG emissions over time in the 1.5°C scenario (stacked area), as well as in the NDC-LTS and Reference scenarios (dashed lines). The dots show the 1.5°C-compatible 2035 emissions level, as a benchmark for NDC 2035 updated contributions, and the year of reaching net zero in the 1.5C scenario.

Emissions by scenario and sectoral breakdown of 1.5°C scenario - World



Note: the Other category includes non-CO_2 emissions in energy, emissions from other energy transformation (biofuels production, hydrogen and derived fuels production), and the sink from the direct air capture of CO_2.

The following table shows World's emissions in the focus year of the next NDC update, 2035, for key emitting sectors in the 1.5°C scenario ($MtCO_2eq$).

	Historical 2022	1.5°C scenario 2035	% change 2022-2035
Country/region total	**48558**	**17693**	**-64%**
Power	12713	5555	-56%
Industry	11184	5411	-52%
Transport	6915	3129	-55%
Buildings	3411	1039	-70%
LULUCF	2779	-1655	-160%

Note: not all sectors are shown, so the sum of the sectors shown does not equal the country/region total in the top row.

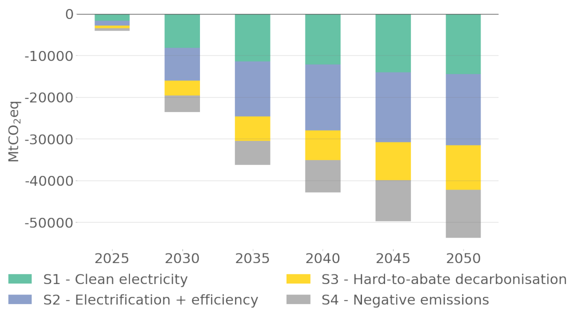
Four decarbonisation strategies

GECO 2024 presents 4 main decarbonisation strategies, common to all countries, which are necessary to reach carbon neutrality:

1. Produce clean electricity.
2. Electrify end-uses and improve energy efficiency.
3. Decarbonise hard-to-abate sectors.
4. Scale-up negative emissions and reduce residual emissions.

The graph on the right shows the emissions reduction by each strategy, compared to 2022, showing the timing and quantity of emissions reductions from each strategy.

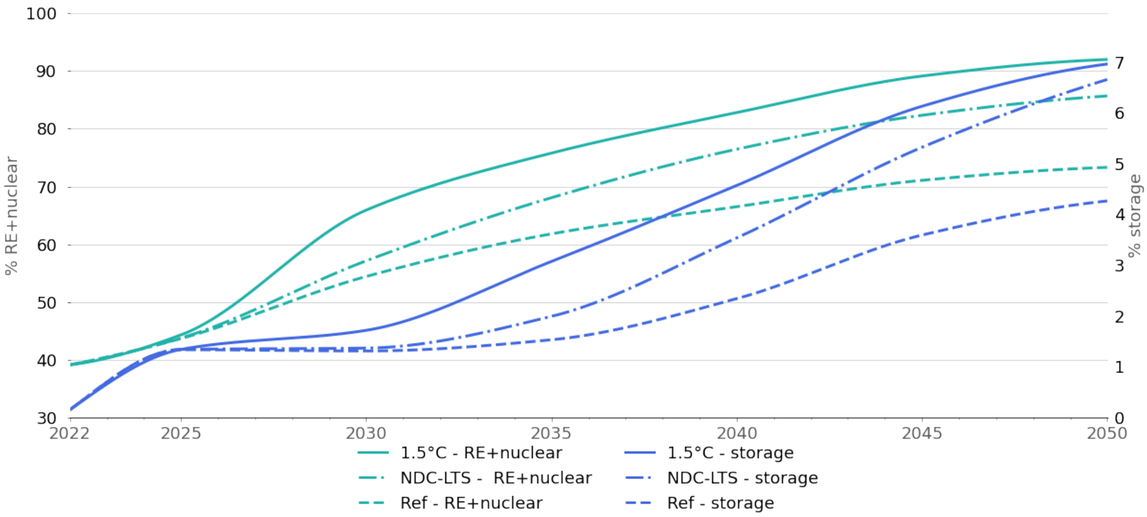
Change in GHG emissions in 1.5°C scenario compared to year 2022 by decarbonisation strategy - World



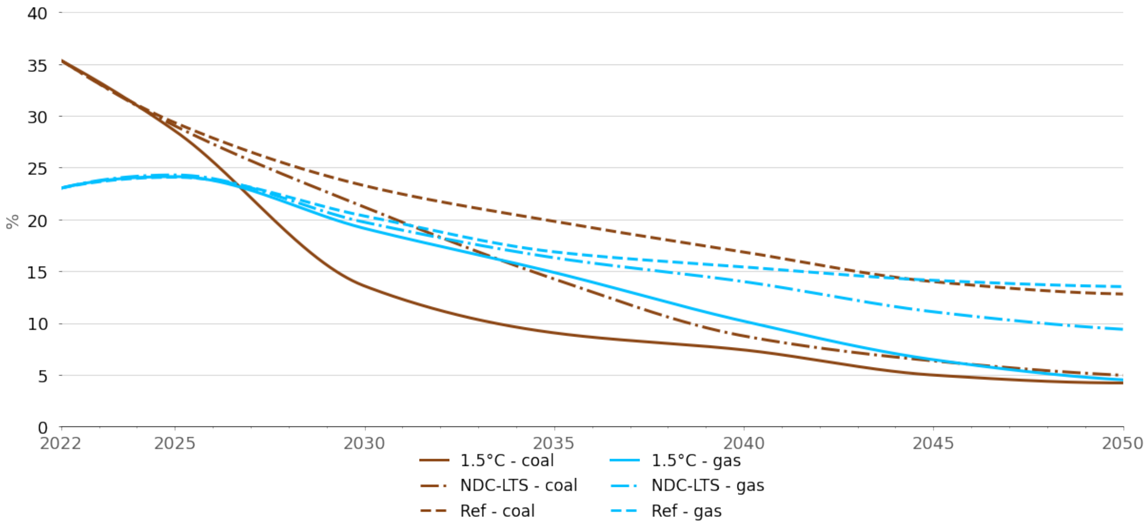
Indicators for NDC-to-1.5°C alignment: the following 4 pages contain 8 graphs and 4 tables which present a selection of key indicators, across the Reference, NDC-LTS and 1.5°C scenarios, grouped by the 4 main strategies to decarbonise. The indicators in the tables quantify how the country can set policies and national contributions to be 1.5°C aligned.

Strategy 1 – Produce clean electricity

Shares of RE+nuclear power generation, and electricity delivered from storage - World



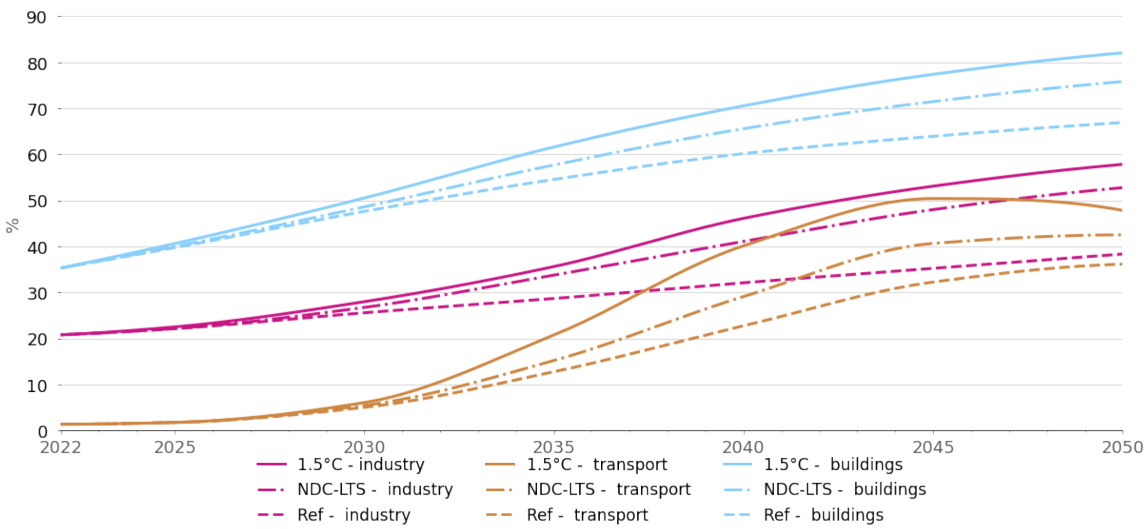
Shares of coal & gas power generation technologies - World

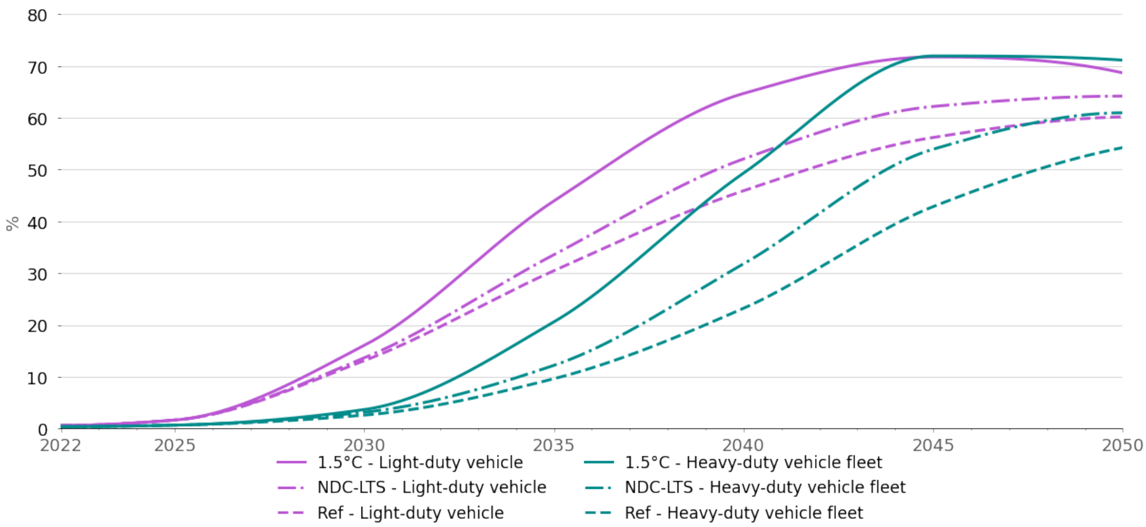


Clean electricity indicators in 1.5ºC scenario - World

		2022	2030	2035	2040	2050
Annual additions of wind+solar	GW	276	867	974	1061	1197
Wind+solar share of annual additions	%	53%	72%	67%	63%	61%
Annual additions of storage	GW	29.94	80.27	170.44	270.31	352.28
Carbon content of electricity	gCO_2/MWh	434	207	116	63	11
Emissions from power sector	$MtCO_2eq$	12591	8044	5506	3580	752
First year of no unabated coal generation				2056		

Strategy 2 – Electrify end-uses and improve energy efficiency

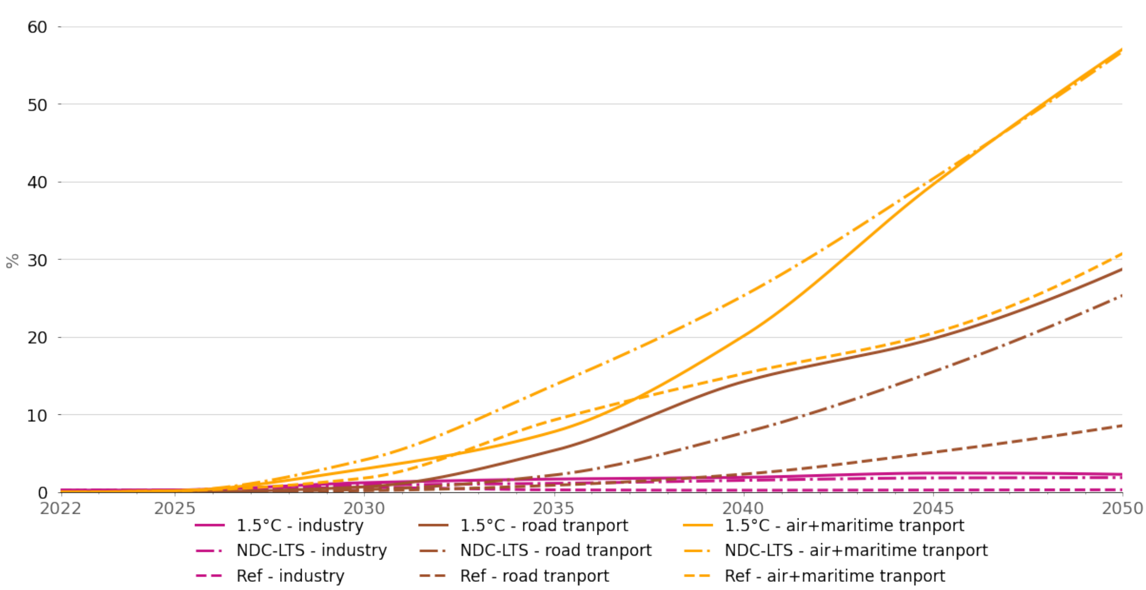


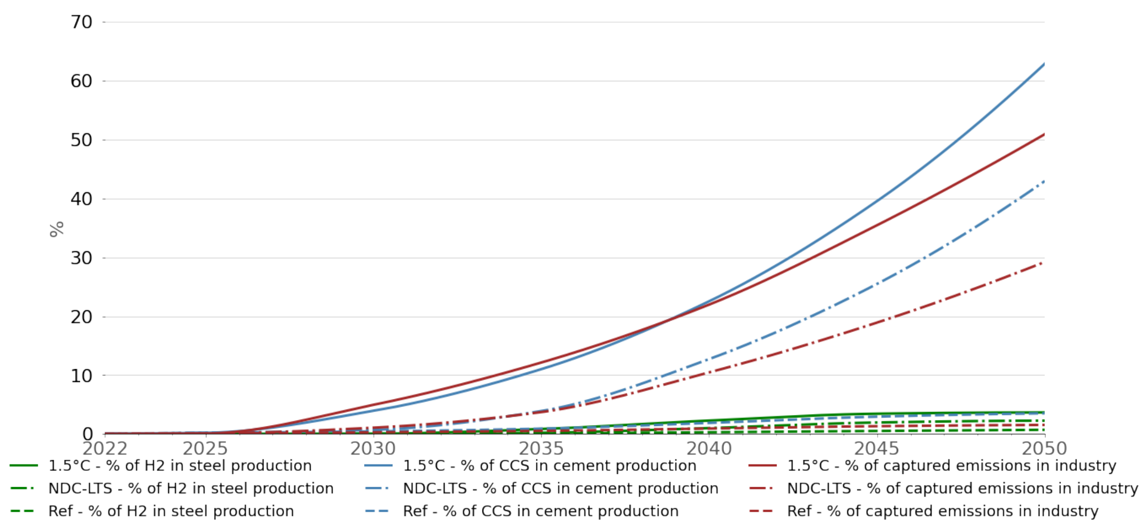


Electrification indicators in 1.5ºC scenario - World

		2022	2030	2035	2040	2050
Annual sales of EV cars	thousands	7244	100332	211438	207602	226899
Share of EVs in total car sales	%	4%	36%	70%	70%	58%
Annual sales of EV HDV	thousands	10	62	246	1909	8739
Share of EVs in total HDV sales	%	0%	0%	2%	11%	54%
Annual sales of small-scale heat pumps in buildings	GW	173	361	223	446	187
Annual sales of large-scale heat pumps in industry	GW	0	2321	3408	4276	6601
Share of heat pumps in buildings heating demand	%	0%	8%	20%	30%	45%

Strategy 3 – Decarbonise hard-to-abate sectors



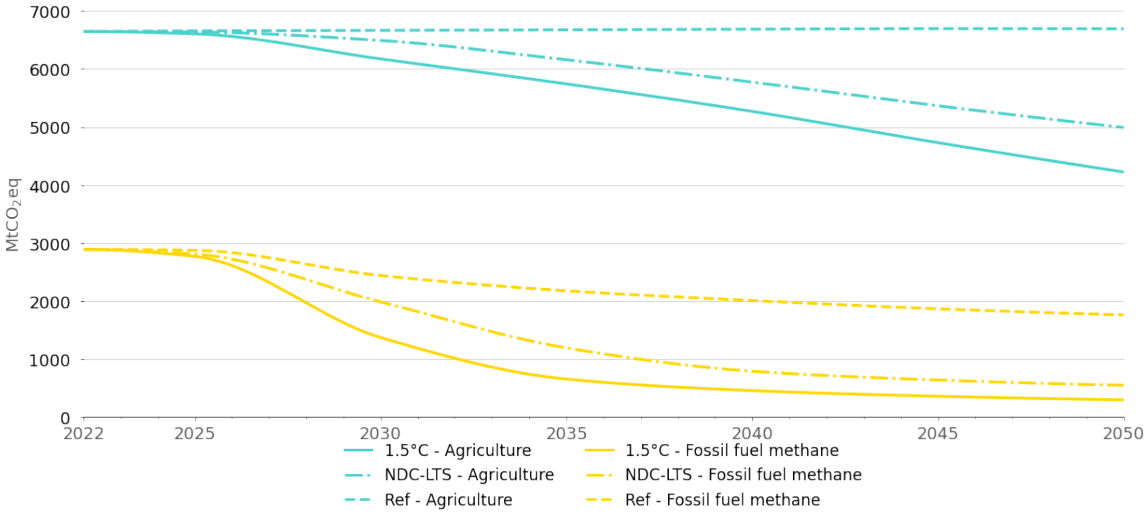


Non-electricity decarbonisation indicators in 1.5ºC scenario - World

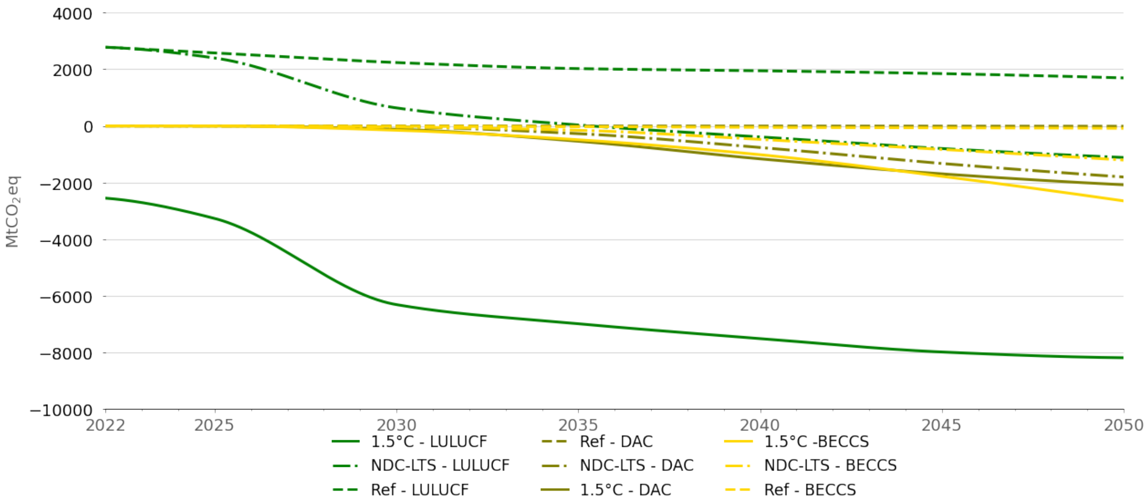
		2022	2030	2035	2040	2050
Domestic production of low-emission H2	kt	0	39745	74995	143619	323005
Domestic production of gaseous e-fuels	bcm	0	10	181	385	570
Domestic production of liquid e-fuels	barrels	0	63347	362176	806905	1802669
Volume of emissions captured	$MtCO_2$	1	212	412	560	1197
Total installed electrolyser capacity	MW	0	960571	2099880	4288850	10121900
Yearly additions of electrolysers	MW	0	197622	317388	493033	802049

Strategy 4 – Scale-up negative emissions and reduce residual emissions

Agriculture and fossil-fuel methane emissions - World



LULUCF emissions, DAC and BECCS - World

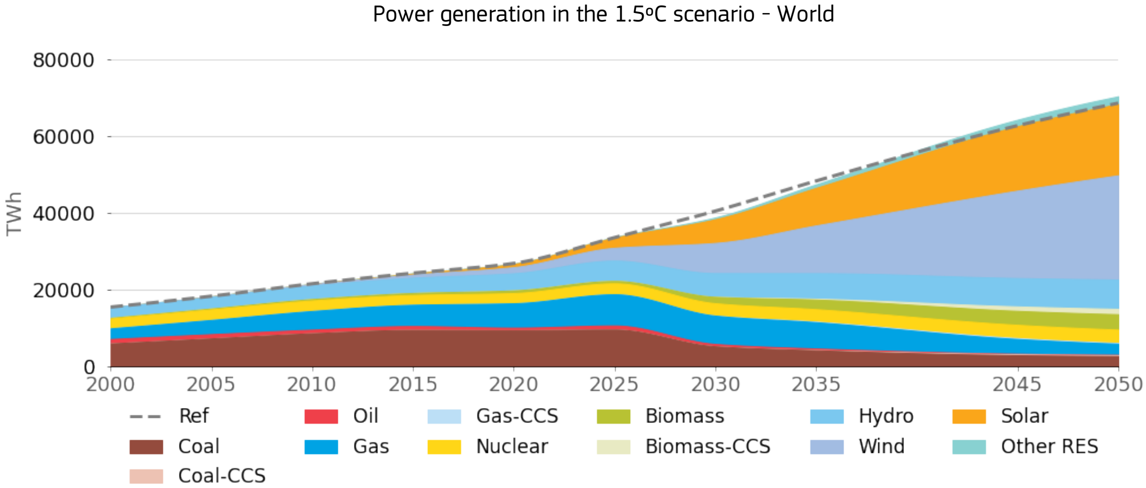


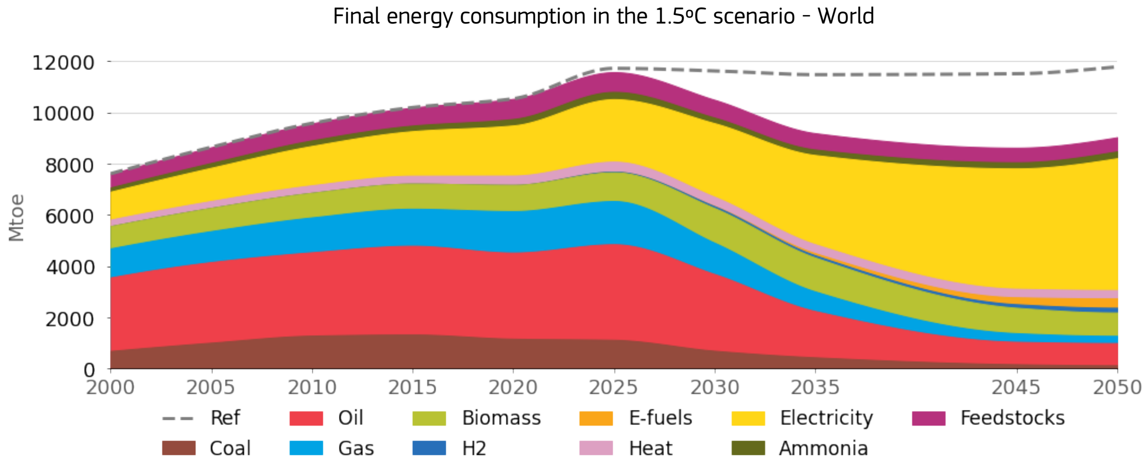
Negative emissions and non-CO_2 indicators in 1.5ºC scenario - World

		2022	2030	2035	2040	2050
Direct air captured	$MtCO_2eq$	0	118	540	1162	2078
Biomass emissions captured	$MtCO_2eq$	0	152	487	1015	2647
LULUCF emissions	$MtCO_2eq$	2779	-980	-1655	-2179	-2857
Agriculture emissions	$MtCO_2eq$	6646	6174	5743	5269	4224
Methane emissions	$MtCO_2eq$	5565	3284	2183	1927	1361
Methane emission from fossil fuel production	$MtCO_2eq$	2891	1372	656	457	297

Energy system transformation

These graphs show the evolution of the power sector and end-use sectors in the 1.5°C scenario, broken down by fuel.





Co-benefits and investments related to decarbonisation in the 1.5°C scenario

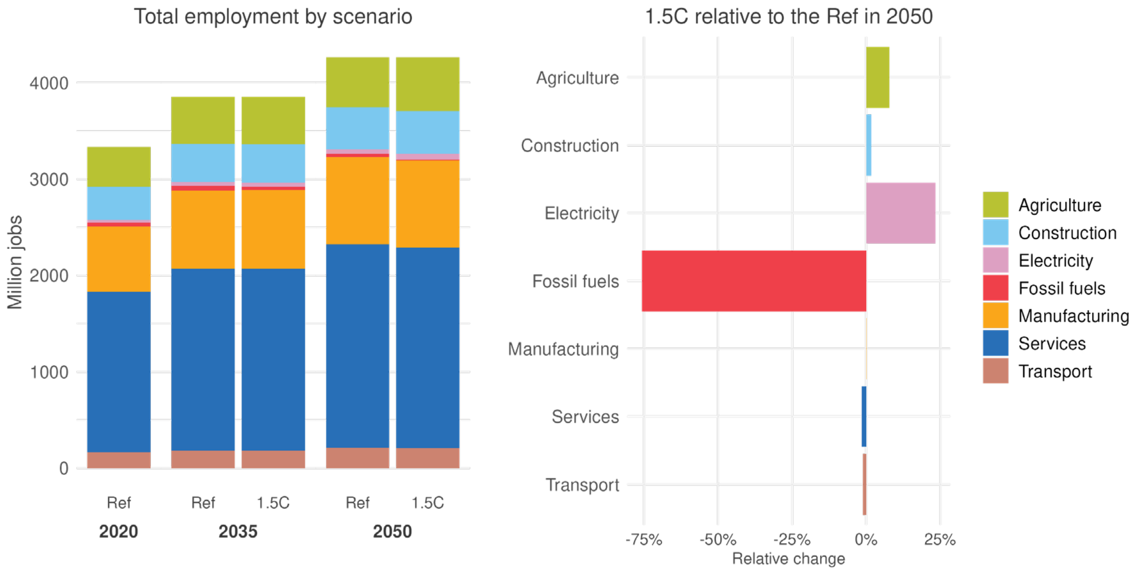
This table gives the evolution of co-benefits, such as energy independence and air pollution, and the changes in investment patterns that accompany decarbonisation.

		2022	2035	2050
Share of energy demand from imports	%	n/a	n/a	n/a
Annual energy import bill	billion USD	n/a	n/a	n/a
Air pollution emissions - PM2.5	Mt	88867	87358	65693
Additional annual investment in power sectors in 1.5°C compared to Ref	billion USD	-	176	431
Increase in annual investment power sectors in 1.5°C compared to Ref	%	0%	13%	37%
Annual reduction in investments on fossil fuel production compared to today in 1.5°C	billion USD	-	219	370
Reduction in investments on fossil fuel production compared to today in 1.5°C	%	-	46%	78%

Labour market dynamics

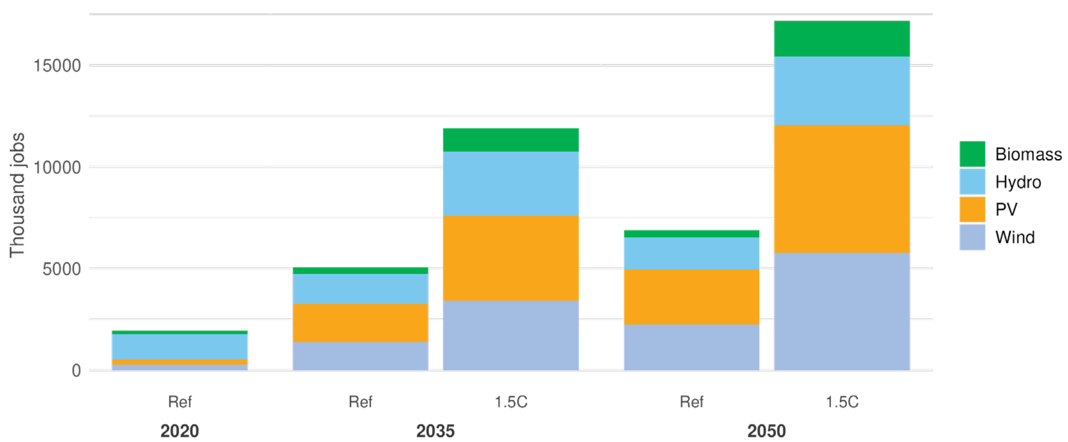
These graphs show the breakdown of employment in World, comparing the Reference and the 1.5°C scenarios. The upper graphs demonstrates total absolute employment by sector as well as the relative change in the 1.5°C scenario compared to the Reference. The lower graph zooms in on the number of jobs related to renewable electricity generation for different technologies.

Sectoral employment – World



Note: Electricity includes all power generation technologies as well as transmission and distribution.

Jobs in renewable technologies by scenario – World



Annex 2: Description of POLES-JRC

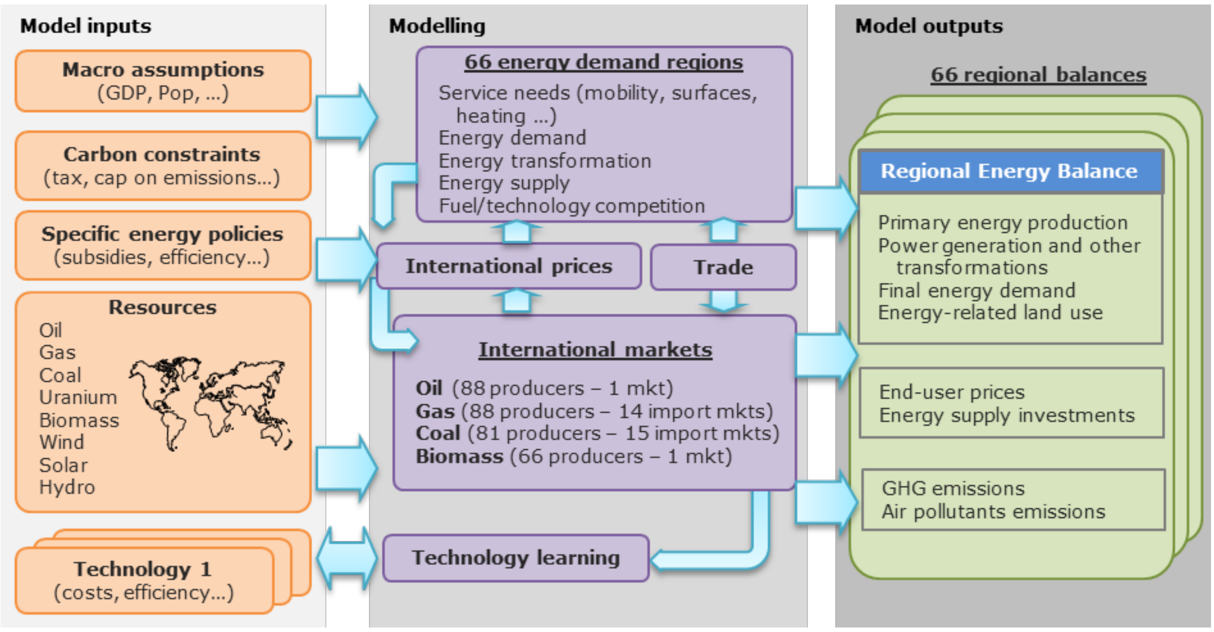
For a more comprehensive description of the model, see (Després et al., 2018).

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 31).

The model provides full energy and emission balances for the EU plus 39 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 most recent POLES-JRC 2024 version as a starting point. This version differs from POLES model versions used in previous GECO reports and POLES model version used by other entities than JRC.

Figure 31.. POLES-JRC model general scheme



Source: POLES-JRC model. "mkt": market. The list of items in each box is not exhaustive.

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 (age structure 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 – Global Forest Model) (Frank et al., 2021). 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. 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.

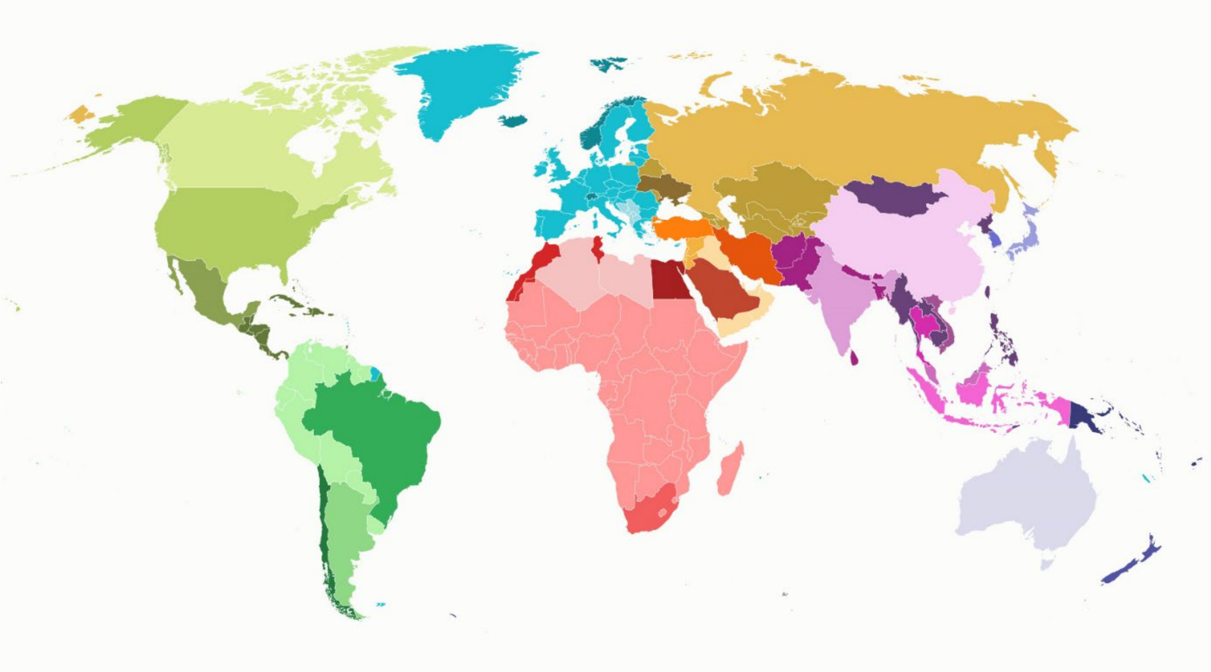
Internationally traded e-fuels can only be produced from renewables ("green hydrogen").

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 the EU, 27 non-EU individual countries and 12 residual regions see Figure 32:, to which international bunkers (air and maritime) are added.

Figure 32.. POLES-JRC model regions (for energy balances)



Source: POLES-JRC model

Table 14. List of non-EU individual countries represented in POLES-JRC (for energy balances)

Argentina	Indonesia	South Africa
Australia	Iran	South Korea
Brazil	Japan	Switzerland
Canada	Malaysia	Thailand

Chile	Mexico	Turkey
China	New Zealand	Ukraine
Egypt	Norway	United Kingdom
Iceland	Russia	United States
India	Saudi Arabia	Vietnam

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

Table 15.. 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 16.. POLES-JRC model historical data and projections

Series		Historical data	GECO Projections
Population		(European Commission: Directorate-General for Economic and Financial Affairs, 2024; Eurostat., 2023; Lutz et al., 2018)	
GDP, GDP growth		(IMF, 2024a, 2024b; World Bank, 2024)	(IMF, 2024a, 2024b; 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 models	
	Hydro	Enerdata	
	Wind, solar	NREL, DLR	
Energy balances	Reserves, production	BP, Enerdata	
	Demand by sector and fuel, transformation (including. power), losses	Enerdata, IEA (multiple years)	
	Power plants	S&P Global Commodity Insights	
Energy prices	International prices, prices to consumer	Enerdata, IEA (multiple years)	POLES-JRC model
GHG emissions	Energy CO_2	Derived from POLES-JRC energy balances	POLES-JRC model
	Other GHG Annex 1 (excl. LULUCF)	UNFCCC (UNFCCC, 2023)	POLES-JRC model, GLOBIOM-G4M models
	Other GHG Non-Annex 1 (excl. LULUCF)	EDGAR v7.0_FT2021_GHG (Crippa et al., 2022)	POLES-JRC model, GLOBIOM-G4M models
	LULUCF	(Grassi et al., 2023)	POLES-JRC model, GLOBIOM-G4M models
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: JRC

Table 17. Historical emissions sources

Energy emissions data is calculated by POLES using emission factors and historical energy consumption data (mostly sourced from Enerdata). Most historical data series are available until 2022, while the remaining mainly go until 2021. Non-energy emissions data until 2021 comes from two sources: EDGAR (Crippa et al., 2022) and UNFCCC (UNFCCC, 2023). LULUCF emissions data until 2020 comes from (Grassi et al., 2023). Energy emissions data come from POLES calculation, mostly based on energy consumption historical data from Enerdata. Most emission data is available until 2022, while the remaining mainly goes until 2021. Non-energy emissions data until 2021 come from two sources: EDGAR and UNFCCC. LULUCF emissions data until 2020 come from Grassi et al. (2023).

Historical emissions	Latest year energy consumption data (Enerdata)	Non-energy emissions source
China	2021	EDGAR
United States	2021	UNFCCC
India	2021	EDGAR
European Union (27)	2021	UNFCCC
Russia	2021	UNFCCC
Indonesia	2021	EDGAR
Brazil	2021	EDGAR
Japan	2021	UNFCCC
Canada	2021	UNFCCC
Saudi Arabia	2021	EDGAR
South Korea	2021	EDGAR
Mexico	2021	EDGAR
Australia	2021	UNFCCC
South Africa	2021	EDGAR
Turkey	2021	UNFCCC
Vietnam	2021	EDGAR
Thailand	2021	EDGAR
United Kingdom	2021	UNFCCC
Argentina	2021	EDGAR

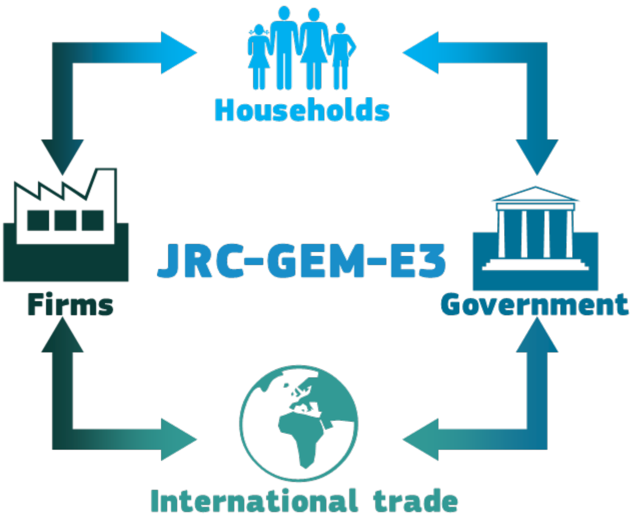
Source: JRC

Annex 3: 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 (Garaffa et al., 2023; Weitzel et al., 2023)[14]. The agents in the model are households, firms and governments (Figure 33:). Households 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 33.:. Schematic overview of the JRC-GEM-E3 model



Source: JRC.

The model version used in GECO 2024 is aggregated into 31 sectors (see Table **18**), 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 Table **19**). Bilateral international trade flows between these regions are modelled following the Armington formulation (Armington, 1969) and linkages between sectors are included based on the GTAP11 power data (Aguiar et al., 2023).

Labour and capital are assumed to be mobile between sectors, but not across regions. Baseline labour supply and unemployment rates are calibrated to the 2024 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.

[14] See also https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases/jrc-gem-e3-model_en

Table 18. 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: JRC.

Table 19. Regional aggregation of the JRC-GEM-E3 model

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

Source JRC.

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 et al., 2019).

The reference year is constructed by generating input-output tables based on GTAP's initial base year (2017). 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).

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 2024 include:

- The input-output tables and the data on bilateral trade flows, which are as derived from the 'Global Trade Analysis Project (GTAP) 11 power database' (Aguiar et al., 2023). We aggregate the GTAP 11 power database to 31 commodities and the regions listed in Table 19.
- GDP growth rates as in the POLES-JRC model. The GDP assumptions are described in Annex 4.
- The International Labour Organisation (ILO) database, which we use 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 2024 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, 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 when 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 fully capture the changes in the energy mix of specific 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 (in private transport and other use, including cooling and 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.

In addition, we implement a carbon tax to harmonize 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).

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 2024 edition we rely on the updated investment matrix to capture the heterogeneity on the delivery of investments across sectors, recently updated to include OECD data for non-EU27 countries (Alsamawi et al., 2020).

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 Labour 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 (Czako, 2020; Pai et al., 2021). 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 4: Socio-economic assumptions and fossil fuel prices

The population assumptions follow Europop (European Commission: Directorate-General for Economic and Financial Affairs, 2024) 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 (EC, 2022). The GDP projections follow numbers of the 2021 Ageing Report for the EU (European Commission: Directorate-General for Economic and Financial Affairs, 2024); for the rest of the world, the sources are IMF World Economic Outlook (IMF, 2024a, 2024b) for the short term and the OECD long-tern baseline projections (OECD, 2021) and Shared Socio-economic Pathway (SSP) 2 (Crespo Cuaresma, 2017) for the long term. Historical GDP levels are taken from the World Bank (World Bank, 2024).

Table 20. 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	9.5	9.7	9.8	9.8	9.7	9.5
GDP (trillion $2015 in purchasing power parity)	65.5	92.6	121.2	168.7	215.7	266.1	325.1	394.8	473.5	561.9	658.9

Source: JRC.

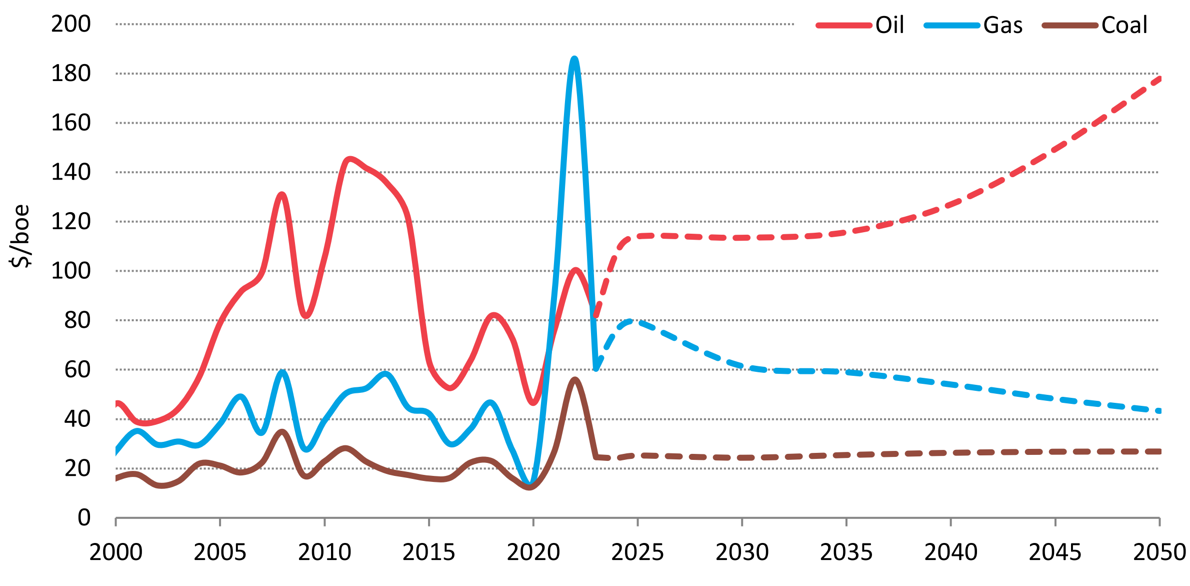
Table 21. GDP assumptions

Group	Historical (to 2022)	2023-2029	2028-2030	2031-2050	2051-2060	2061-2070	2071-2100
EU	WB Apr-2024	ECFIN + Ageing Report 2024			EU Ageing Report 2024	GDP/cap as SSP x Europop	
Large non-EU	WB Apr-2024	IMF Apr-2024	interpolation	GDP OECD 2021 / Pop IIASA-JRC		GDP/cap as SSP x Pop IIASA-JRC	
Rest of World	WB Apr-2024	IMF Apr-2024	interpolation	GDP/cap as SSP x Pop IIASA-JRC			

Source: JRC. 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 34.

Figure 34.. 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 5: Policies considered

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 2025; this price follows a sigmoid curve with an inflection point in 2035.

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 specialised sectoral models.[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 of 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 quantities of emissions; then, the sum of emissions was converted into a target in terms of growth (or decrease) compared to a historical base year (UNFCCC, 2023) 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.

EU refers to the European Union as of the date of publication (27 Member States).

Table 22. Reference scenario – Energy-related policies

Region	Sector	Subsector	Target	Base year	Target year	Objective	Source
Europe							
EU	Transport	New passenger vehicles	Emissions reduction	2021	2030	-37.5%	EU Regulation on light-duty vehicles (2019)
EU	Transport	New heavy-duty vehicles	Emissions reduction	2019-2020	2030	-30%	EU Regulation on heavy-duty vehicles (2019)
EU	Energy	Gross final demand	Share of renewables		2030	>42.5%	EU Renewable Energy Directive (2023)
EU	Energy	Biomethane	Biomethane production (bcm)		2030	35.0	RePowerEU Plan (2022)
EU	Energy	Hydrogen	Hydrogen demand (Mt)		2030	20 (target not reached in the GECO Reference scenario)	RePowerEU Plan (2022)

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

EU	Energy	Final energy demand	Final energy (Mtoe)		2030	763.0	EU Energy Efficiency Directive (2023)
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	RePowerEU Plan (2022)
EU	Power	Power capacity	Wind, offshore (GW)		2030	60.0	EU Strategy for offshore renewable energy (2020)
EU	Power	Power capacity	Wind, offshore (GW)		2050	300.0	EU Strategy for offshore renewable energy (2020)
EU	Power	Power capacity	Ocean (GW)		2030	1.0	EU Strategy for offshore renewable energy (2020)
EU	Power	Power capacity	Ocean (GW)		2050	40.0	EU Strategy for offshore renewable energy (2020)
EU	Energy	Transport demand	Share of renewable fuels		2030	29%	EU Renewable Energy Directive (2023)
EU	Energy	Industry demand	Share of renewable fuels		2021-2030	+15.4%	EU Renewable Energy Directive (2023)
EU	Energy	Buildings demand	Share of renewable fuels		2030	49%	EU Renewable Energy Directive (2023)
United Kingdom	Energy	Final energy demand	Natural gas consumption	2022	2030	-40%	Powering Up Britain (2023)
United Kingdom	Energy	Final energy demand	Gas boilers installation		2035	0.0	British Energy Security Strategy (2022)
United Kingdom	Energy	Hydrogen	Low carbon (green + blue) hydrogen production (GW)		2030	10.0	British Energy Security Strategy (2022)
United Kingdom	Power	Power production	Coal phase-out (does not apply to IGCC, CCS)				Officially closed (2024)
United Kingdom	Power	Power capacity	Offshore wind (GW)		2030	50 (target not reached in the GECO Reference scenario)	Powering Up Britain (2023)
United Kingdom	Power	Power capacity	Nuclear (GW)		2050	24.0	British Energy Security Strategy (2022)
United Kingdom	Power	Installed capacity	Solar (GW)		2035	70.0	British Energy Security Strategy (2022)
United Kingdom	Transport	New passenger vehicles	Zero-emissions cars sales		2030	80%	Powering Up Britain (2023)
United Kingdom	Transport	New passenger vehicles	Zero-emissions cars sales		2035	100%	The Ten Point Plan for a Green Industrial Revolution (2020)
United Kingdom	Transport	New light vehicles	Zero-emissions vans sales		2030	70%	Powering Up Britain (2023)
United Kingdom	Transport	New passenger vehicles	Conventional ICE cars sales		2035	0%	Powering Up Britain (2023)
United Kingdom	Transport	New passenger vehicles	Hybrid cars sales		2035	0%	The Ten Point Plan for a Green Industrial Revolution (2020)
United Kingdom	Transport	New heavy vehicles	Conventional ICE sales		2040	0%	British Energy Security Strategy (2022)

United Kingdom	CCUS	CCUS	Carbon Capture and Storage (MtCO2/y)		2030	20 - 30	Powering Up Britain (2023)
Norway	Transport	New heavy vehicles	Zero-emissions trucks sales		2030	50%	National Transport Plan 2022–2033
Switzerland	Power	Power production	Renewables (TWh)		2035	11.4	Energy Strategy 2050
Switzerland	Power	Power production	Hydro (TWh)		2035	37.4	Energy Strategy 2050
Switzerland	Power	Power production	Hydro (TWh)		2050	38.6	Energy Strategy 2050
North America							
Canada	Power	Power production	Traditional coal-fired plants		2030	0	Pan-Canadian Framework on Clean Growth and Climate Change (2017)
Canada	Power	Power production	Share of renewables		2030	85%	Sustainable Development Goal 7 (2022)
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 capacity	Gas combined cycle (GW)	2023	2027	6.3	National Electric System Development Plan (PRODESEN) 2023-2037 (2023)
Mexico	Power	Power capacity	Gas combined cycle (GW)	2027	2038	5.9	PRODESEN (2023)
Mexico	Power	Power capacity	Gas combined cycle with H_2 (GW)	2027	2038	1.8	PRODESEN (2023)
Mexico	Power	Power capacity	Centralized Solar (GW)	2023	2027	6.2	PRODESEN (2023)
Mexico	Power	Power capacity	Centralized Solar (GW)	2027	2038	16.4	PRODESEN (2023)
Mexico	Power	Power capacity	Decentralized Solar (GW)	2023	2027	1.9	PRODESEN (2023)
Mexico	Power	Power capacity	Decentralized Solar (GW)	2027	2038	6.2	PRODESEN (2023)
Mexico	Power	Power capacity	Wind (GW)	2023	2027	1.9	PRODESEN (2023)
Mexico	Power	Power capacity	Wind (GW)	2027	2038	3.8	PRODESEN (2023)
Mexico	Power	Power capacity	Hydropower (GW)	2023	2027	0.5	PRODESEN (2023)
Mexico	Power	Power capacity	Hydropower (GW)	2027	2038	2.5	PRODESEN (2023)
Mexico	Power	Power capacity	Storage (GW)	2023	2027	2.3	PRODESEN (2023)
Mexico	Power	Power capacity	Storage (GW)	2027	2038	6.2	PRODESEN (2023)
Mexico	Power	Power capacity	Coal (GW)	2023	2027	0.0	PRODESEN (2023)
Mexico	Power	Power capacity	Coal (GW)	2027	2038	0.0	PRODESEN (2023)
Mexico	Power	Power capacity	Nuclear (GW)	2027	2038	0.1	PRODESEN (2023)
Mexico	Power	Power capacity	Total (GW)	2023	2027	20.2	PRODESEN (2023)
Mexico	Power	Power capacity	Total (GW)	2027	2038	44.3	PRODESEN (2023)
United States	Power	Power capacity	Unabated coal (GW)		2035	0.0	
Central & South America							
Brazil	Energy	Primary energy demand	Share of renewables (including biofuels)		2031	48%	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power production	Share of renewables (including biofuels)		2031	85%	Ten-year Energy Expansion Plan (2031)

Brazil	Power	Power capacity	Hydro (GW)		2031	114.1	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Small hydro (GW)		2031	10.2	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Nuclear (GW)		2031	4.4	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Biomass (GW)		2031	16.4	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Wind (GW)		2031	30.3	Ten-year Energy Expansion Plan (2031)
Brazil	Power	Power capacity	Solar (GW)		2031	10.4	Ten-year Energy Expansion Plan (2031)
Brazil	Transport	Transport demand	Share of biodiesel		from 2020	13%	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%	Energy efficiency law (2021)
Chile	Energy	Final energy demand	Energy efficiency	2019	2050	-35%	Energy efficiency law (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 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)
Chile	Transport	New heavy vehicles	Zero-emissions vehicles share		2045	100%	National Electromobility Strategy (2021)
Pacific							
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	56%	States legislation aggregation
Australia	Transport	New passenger vehicles	Electric vehicles share		2030	43%	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)
New Zealand	Energy	Final energy consumption	Share of renewables		2035	50%	Government of New Zealand (2016)
New Zealand	Power	Power production	Share of renewables		2030	100%	Energy in New Zealand 2023 (2022)
South Korea	Energy	Electricity demand	Reduction vs BAU	BAU	2030	-11.0%	10th Basic Energy Plan (2023)
South Korea	Energy	Final energy consumption	Final energy (Mtoe)		2040	170	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			2036	30.6%	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	22.9%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of coal			2030	19.7%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of coal			2030	14.4%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of nuclear			2030	32.4%	10th Basic Energy Plan (2023)
South Korea	Power	Power production	Share of nuclear			2036	34.6%	10th Basic Energy Plan (2023)
South Korea	Power	Power capacity	Renewables (GW)			2030	72.7	10th Basic Energy Plan (2023)
South Korea	Transport	Total passenger vehicles	Electric vehicles (Mveh)			2040	8.5	3rd Energy Master Plan (2019)
South Korea	Transport	Total passenger vehicles	H2 vehicles (Mveh)			2040	2.9	3rd Energy Master Plan (2019)
Indonesia	Energy	Primary energy demand	Share of renewables			2030	34%	JETP (2022)
Indonesia	Energy	Primary energy demand	Share of oil			2050	20%	2015 energy strategy (RUEN / KEN)
Indonesia	Energy	Primary energy demand	Share of coal			2050	25%	2015 energy strategy (RUEN / KEN)
Indonesia	Energy	Primary energy demand	Share of gas			2050	24%	2015 energy strategy (RUEN / KEN)
Indonesia	Power	Power capacity	Coal (GW)			2030	54.0	RUPTL 2021-2030
Indonesia	Power	Power capacity	Additional coal (GW)			post-2030	0.0	JETP (2022)
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	RUPTL 2021-2030
Indonesia	Transport	Total passenger vehicles	Electric vehicles (Mveh)			2030	2	6th ASEAN Energy Outlook - Presidential Regulation 55/2019
Indonesia	Transport	Road transport demand	Share of renewables (liquid biofuels)			2050	31%	National Energy Policy 2014
Asia								
China	Transport	New passenger vehicles	Share of BEV, PHEV and Fuel Cells Vehicles in sales			2027	45%	New Energy Vehicle development plan (2020)
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	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)
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)
Vietnam	Power	Power production	Share of renewables		2030	47%	JETP (2022)
Vietnam	Power	Power production	Share of renewables		2045	25-30%	National Energy Development Strategy (2021)
Vietnam	Power	Power capacity	Coal (GW)		2030	30.0	JETP (2022)
Vietnam	Power	Power capacity	Additional coal (GW)		post-2030	0.0	JETP (2022)
CIS							
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 (target not reached in the GECO Reference scenario)	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)
Russia	Power	Total passenger vehicles	Electric vehicles (million vehicles)		2030	1.4	Ministry of Economic Development (2021)
Ukraine	Energy	Primary energy consumption	Primary energy (ktoe)		2030	72.2	National Energy and Climate Plan (2022)
Ukraine	Energy	Final energy consumption	Final energy (ktoe)		2030	42.2	National Energy and Climate Plan (2022)
Ukraine	Energy	Final energy consumption	Share of renewables		2030	27%	Energy Community Ministerial Council (2022)
Ukraine	Energy	Heat generation	Share of renewables		2035	40%	State policy (2023)
Ukraine	Power	Power production	Share of renewables (including hydro)		2030	25%	Energy Strategy (2017)
Ukraine	Power	Power production	Share of coal		2035	0%	Powering Past Coal Alliance (2023)
Ukraine	Transport	Total vehicles	Share of electricity and renewable fuels		2035	50%	National Transport Strategy of Ukraine (2021)
Middle East							
Turkey	Energy	Primary energy demand	Share of renewables		2035	23.7%	National Energy Plan for 2035 (2023)
Turkey	Power	Power capacity	Nuclear (GW)		2026	2.4	Planned capacity
Turkey	Power	Power capacity	Nuclear (GW)		2027	3.6	Planned capacity
Turkey	Power	Power capacity	Nuclear (GW)		2028	4.8	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	Power	Power capacity	Solar (GW)		2030	3.7	Saudi Green Initiative (2021)
Saudi Arabia	Power	Power production	Share of renewables		2030	50%	Saudi Green Initiative (2021)
Saudi Arabia	Power	Power production	Share of gas		2030	50%	Saudi Green Initiative (2021)
Africa							
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% (target not reached in the GECO Reference scenario)	Post-2015 National Energy Efficiency Strategy (2016)

Source: JRC.

Table 23: Reference scenario – GHG-related policies

Region	Sector	GHG	Subsector	Target	Base year	Target year	Objective	Source
Europe								
EU	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	European Commission, DG Climate Action, Fit For 55 (2023)
EU	ETS sectors	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-61%	European Commission, DG Climate Action (2023)
EU	ETS sectors	All GHGs	Emissions reduction	% reduction in 2040 vs 2005	2005	2040	-90%	European Commission, DG Climate Action (2023)
EU	Non-ETS sectors	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-40%	European Commission, DG Climate Action, Effort Sharing Regulation (2023)
EU	LULUCF	All GHGs	LULUCF	Emissions budget ($MtCO_2eq$)		2030	310	European Commission, DG Climate Action, LULUCF Regulation (2023)
North America								

Canada	Oil & Gas	CH_4	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	-37%	IRA (bottom-up assessment of impacts as per (Bistline et al., 2023))
United States	Power	All GHG	Power production	% reduction in 2030 vs 2005	2005	2030	-68%	IRA (bottom-up assessment of impacts as per (Bistline et al., 2023))
United States	Power	All GHG	Power production	% reduction in 2030 vs 2006	2005	2035	-77%	IRA (bottom-up assessment of impacts as per (Bistline et al., 2023))
Pacific								
Australia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43.0%	NDC (2022)
Japan	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-26%	NDC (2015)
New Zealand	Agriculture	Biogenic CH_4	Emissions reduction	% reduction in 2030 vs 2017	2017	2030	-10%	Climate Change Response (Zero Carbon) Amendment Act 2019 (2021)
New Zealand	Agriculture	Biogenic CH_4	Emissions reduction	% reduction in 2050 vs 2017	2017	2050	-25 to -47%	Climate Change Response (Zero Carbon) Amendment Act 2019 (2021)
Indonesia	Power	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	290	JETP (2023)
Asia								
Vietnam	Power	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	170	JETP (2022)
Africa								
South Africa	All (incl. LULUCF)	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	350	JETP (2022)

Source: JRC.

Table 24. NDC-LTS scenario – Energy-related policies

Region	Sector	Subsector	Target	Base year	Target year	Objective	Source
Europe							
Iceland	Energy	Primary energy demand	Share of fossil fuels		2050	0%	Government of Iceland (2021)
Iceland	Transport	All transport	Share of fossil fuels	2016	2030	-50%	Government of Iceland (2021)
Central & South America							
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)
Pacific							

South Korea	Power	Power production	Coal phase-out		2050	0	Third Energy Master Plan (2019)
Asia							
China	Energy	Primary energy demand	Share of non-fossil		2030	25%	NDC (2021)
China	Power	Power capacity	Wind and solar (GW)		2030	1.2	NDC (2021)
India	Transport	Total passenger vehicles	Electric vehicles share		2030	30% (not reached)	EV30@30 initiative (2022)
Thailand	Power	Power capacity	Share of renewables		2050	50%	LTS (2021)
Thailand	Transport	New passenger vehicles	Electric vehicles share		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)
CIS							
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)
Middle East							
Saudi Arabia	Energy	Hydrogen	Hydrogen production (green and blue)		2030	4	NDC (2021)
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)
Africa							
South Africa	Transport	Total passenger vehicles	Electric vehicles (thousand vehicles)	2016	2050	15	NDC (2016)
Bunkers							
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		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 H_2 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 CO_2 emissions per ton-kilometre	2008	2030	-40%	IMO (2018)
Maritime	Maritime	Carbon intensity reduction	% reduction of CO_2 emissions per ton-kilometre	2008	2050	-70%	IMO (2018)

Source: JRC.

Table 25. NDC-LTS scenario – GHG-related policies

Region	Sector	GHG	Subsector	Target	Base year	Target year	Objective	Source
Europe								
EU	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	LTS (2020)
EU	Transport	All GHGs	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-90%	European Green Deal (2019)
United Kingdom	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-68%	NDC (2020)
United Kingdom	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Switzerland	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-50%	NDC (2020)
Switzerland	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Norway	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	NDC (2020)
Norway	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-95%	LTS (2019)
Iceland	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	NDC (2021)
Iceland	All incl LULUCF	All GHGs	Emissions reduction	Emissions 2050		2040	0	Climate Action Plan (2020)
North America								
Canada	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	NDC (2021)
Canada	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
Mexico	All (incl. LULUCF, excl. absorption)	All GHGs	Emissions reduction vs BAU	% reduction in 2030 vs BAU		BAU 2030	-36%	NDC (2020)
Mexico	All (incl. LULUCF, excl. absorption)	All GHGs	Emissions peak year	Peak before		2026		NDC (2020)
Mexico	All (incl. LULUCF, excl. absorption)	All GHGs	Emissions intensity per GDP	% reduction in 2030 vs 2013	2013	2030	-40%	NDC (2020)
Mexico	All (incl. LULUCF, excl. absorption)	All GHGs	Emissions reduction	% reduction in 2050 vs 2000	2000	2050	-50%	NDC (2015)

United States	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-52%	NDC (2021)
United States	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
Central & South America								
Argentina	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2007	2007	2030	-19%	NDC (2020)
Argentina	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-2%	NDC (2020)
Argentina	All (incl. LULUCF)	CO_2	Net-zero emissions	Emissions 2050	1990	2050	0	NDC (2021)
Brazil	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-53%	NDC (2021)
Brazil	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	Brazilian Administration (2021)
Chile	All (excl. LULUCF)	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	95	NDC (2020)
Chile	All (excl. LULUCF)	All GHGs	Emissions budget	Budget over 2020-2030 ($MtCO_2eq$)	2020	2030	1,100	NDC (2020)
Chile	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2016	2016	2030	-45%	NDC (2020)
Chile	All (incl. LULUCF)	All GHGs	Black carbon emissions	% reduction in 2030 vs 2016	2016	2030	-25%	NDC (2020)
Chile	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	NDC (2020)
Chile	AFOLU	All GHGs	Emissions reduction	% reduction in 2030 vs average 2001-2013	av. 2001-2013	2030	-25%	NDC (2020)
Rest of Central America	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	9%	NDC (2017-2021)
Rest of South America	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	8%	NDC (2017-2021)
Pacific								
Australia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	NDC (2022)
Australia	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050	1990	2050	0	LTS (2021)
New-Zealand	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-50%	NDC (2021)
New-Zealand	All (incl. LULUCF)	All GHGs, excl. CH_4	Net-zero emissions	Emissions 2050		2050	0	LTS (2021)
New-Zealand	All (incl. LULUCF)	CH_4	Emissions reduction	% reduction in 2050 vs 2017	2017	2050	-47%	NDC (2021)
Japan	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-46%	NDC (2021)
Japan	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
Japan	Energy	CO_2	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-45.2%	NDC (2021)
Japan	Non-energy	CO_2	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-14.9%	NDC (2021)

Japan	All (incl. LULUCF)	CH_4	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-11%	NDC (2021)
Japan	All (incl. LULUCF)	N_2O	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-16.8%	NDC (2021)
Japan	All (incl. LULUCF)	F-gases	Emissions reduction	% reduction in 2030 vs 2013	2013	2030	-27%	NDC (2021)
South Korea	All (incl. LULUCF)	All GHGs, excl. NF_3	Emissions reduction	% reduction in 2030 vs 2018	2018	2030	-40%	NDC (2021)
South Korea	All (incl. LULUCF)	All GHGs, excl NF_3	Net-zero emissions	Emissions 2050		2050	0	LTS (2020)
Indonesia	All (incl. LULUCF)	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	1,630	JETP (2022)
Indonesia	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2060		2060	0	LTS (2021)
Indonesia	Power	All GHGs	Emissions peak year	Peak before, with budget ($MtCO_2eq$)		2030	290	JETP (2022)
Rest of Pacific	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	130%	NDC (2020)
Asia								
China	All (excl. non-CO_2 sectors)	CO_2	Emissions per unit of GDP reduction	% reduction in 2030 vs 2005	2005	2030	-65%	NDC (2020)
China	All (excl. non-CO_2 sectors)	CO_2	Emissions peak	Peak before		2030		NDC (2020)
China	All (incl. LULUCF)	CO_2	Net-zero emissions	Emissions 2060		2060	0	LTS (2021)
India	All (incl. LULUCF)	All GHGs	Emissions per unit of GDP reduction	% reduction in 2030 vs 2005	2005	2030	-45%	NDC (2022)
India	All (incl. LULUCF)	All GHGs	Carbon neutrality	Emissions 2070		2070	0	NDC (2022)
India	Absorption	All GHGs, excl. CH_4	Emissions budget	Over 2020-2030 ($GtCO_2eq$)	2020	2030	2.5-3	NDC (2016)
Vietnam	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs BAU	BAU	2030	-27%	NDC (2020)
Vietnam	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs BAU		2030	-43.5%	NDC (2022)
Vietnam	All (incl. LULUCF)	All GHGs	Emissions peak year	Peak before		2035		National Climate Change Strategy to 2050 (2022)
Vietnam	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2050		2050	0	National Climate Change Strategy to 2050 (2022)
Vietnam	Energy	All GHGs	Emissions reduction	% reduction in 2030 vs BAU		2030	-24.4%	NDC (2022)
Vietnam	Power	All GHGs	Emissions peak year	Peak before, with budget ($MtCO_2eq$)		2030	170	NDC (2022)
Thailand	All (excl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2022	2022	2030	-40%	NDC (2022)
Thailand	All (incl. LULUCF)	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2050	200	LTS (2021)

Thailand	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2065		2065	0	LTS (2021)
Malaysia	All (incl. LULUCF)	All GHGs	Emissions intensity reduction	% reduction vs GDP	2005	2030	-45%	NDC (2021)
Rest of South Asia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	97%	NDC (2016-2021)
Rest of South-East Asia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-11%	NDC (2015-2021)
CIS								
Russia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-30%	NDC (2020)
Russia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2050 vs 1990	1990	2050	-80%	NDC (2021)
Russia	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2060		2060	0	NDC (2021)
Ukraine	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-65%	NDC (2021)
Ukraine	Energy	All GHGs	Net-zero emissions	Emissions 2050		2050	0	Energy Strategy of Ukraine until 2050 (2023)
Ukraine	All (incl. LULUCF)	All GHGs	Net-zero emissions	Emissions 2060		2060	0	NDC (2021)
Rest of Central Europe	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	31%	NDC (2016-2021)
Rest of CIS	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	12%	NDC (2016-2021)
Middle East								
Saudi Arabia	All (excl. LULUCF)	All GHGs	Emissions reduction	Reduction vs BAU ($MtCO_2eq$)	2019	2030	-278	NDC (2021)
Saudi Arabia	All (incl. LULUCF)	All GHGs, excl. CH_4	Net-zero emissions	Emissions 2060	1990	2060	0	NDC (2021)
Saudi Arabia	All (excl. LULUCF)	CO_2	CCS	CO2 captured ($MtCO_2eq$)		2030	44 (not reached)	NDC (2021)
Saudi Arabia	All (incl. LULUCF)	CH_4	Emissions reduction	% reduction in 2030 vs 2020	2020	2030	-30%	NDC (2021)
Turkey	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs BAU	BAU	2030	-41%	NDC (2023)
Turkey	All (incl. LULUCF)	All GHGs, excl. CH_4	Net-zero emissions	Emissions 2053	1990	2053	0	NDC (2021)
Mediterranean Middle East	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	0%	NDC (2016-2021)
Rest of Persian Gulf	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	44%	NDC (2015-2021)
Africa								
Egypt	Power	All GHGs	Power	Emissions budget ($MtCO_2eq$)		2030	144.8	NDC (2022)
Egypt	Transport	All GHGs	Transport	Emissions budget ($MtCO_2eq$)		2030	115.4	NDC (2022)
Egypt	Oil & Gas	All GHGs	Oil & Gas	Emissions budget ($MtCO_2eq$)		2030	0.89	NDC (2022)

South Africa	All (incl. LULUCF)	All GHGs	Emissions budget	Emissions budget ($MtCO_2eq$)		2030	350	NDC (2021)
South Africa	All (incl. LULUCF)	All GHGs, excl. SF_6 and NF_3	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
South Africa	Power	CO_2	Net-zero emissions	Emissions 2050		2050	0	NDC (2021)
South Africa	Coal to liquids	CO_2	CCS from coal-to-liquid plant	CO2 captured ($MtCO_2eq$)		2030	23 (not reached)	NDC (2021)
Algeria and Libya	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-19%	NDC (2016)
Morocco and Tunisia	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-3%	NDC (2021)
Rest of Sub-Saharan Africa	All (incl. LULUCF)	All GHGs	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	4%	NDC (2021)
Bunkers								
Aviation	Aviation	CO_2	Emissions reduction	Emissions 2050		2050	0 (not reached)	ICAO (2021)
Maritime	Maritime	All GHGs	Emissions reduction	% reduction in 2050 vs 2008	2008	2030	-30%	IMO (2023)
Maritime	Maritime	All GHGs	Emissions reduction	% reduction in 2050 vs 2008	2008	2040	-80%	IMO (2023)
Maritime	Maritime	All GHGs	Emissions reduction	% reduction in 2050 vs 2008	2008	2050	-100%	IMO (2023)

Source: JRC.

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