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Global Energy and Climate Outlook 2021: Advancing towards climate neutrality

Taking stock of climate policy pledges after COP26 and the corresponding energy-economy implications

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Contents

Abstract

This edition of the Global Energy and Climate Outlook (GECO 2021) takes stock of recent updates in nationally determined contributions (NDCs) and long-term net zero emission targets (LTS) announced leading up to and during the Conference of the Parties (COP 26) in November 2021. GECO 2021 finds that the NDC and LTS pledges stop global emissions growth over the next decades and lead to declining emissions until 2050. While delivering on these aims results in an increase of global mean temperature of 1.8°C (current policies in excess of 3°C), substantial further actions are needed to limit global warming to the Paris Agreement targets, to well below 2°C and pursue efforts to 1.5°C above preindustrial levels. To achieve this objective, net-zero greenhouse gas emissions has to be reached around the 2070s at the global level. Nevertheless, the announced LTS pledges could be a major step towards filling this gap, since an NDC-only scenario sees average temperature increases of 2.6°C at the end of the century.

In this report, we focus on the transition of G20 countries, which accounted for nearly 75% of global Greenhouse Gas (GHG) emissions. For each of them, we assess emissions under three different scenarios: current policies, announced domestic targets (NDC-LTS) and under two 1.5°C-compatible pathways. We analyse decarbonisation drivers and transformation metrics within each scenario, highlighting the policy options to bring emissions in line with ambitious climate targets.

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This report was mainly written by Kimon Keramidas, Ana Diaz Vazquez, Paul Dowling, Florian Fosse, Rafael Garaffa, Toon Vandyck, and Matthias Weitzel.

The energy and greenhouse gas (GHG) emissions modelling was carried out by Florian Fosse, Andreas Schmitz, Kimon Keramidas, Jacques Després, Burkhard Schade, and Stéphane Tchung-Ming.

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Executive summary

As the signatories of the Paris Agreement updated their nationally determined contributions (NDCs) and as several large emitters announced net-zero emission targets ahead of and during the 2021 United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) in Glasgow, this year's Global Energy and Climate Outlook (GECO) takes stock of the energy, emission and climate implications of these policy updates. We analyse the critical role of NDCs and long-term strategies (LTSs) in advancing towards limiting the global temperature to well below 2°C and preferably towards 1.5°C by 2100 as stipulated by the Paris Agreement.

In this edition, we focus on the transition of G20 countries, which have accounted for 75% of GHGs emitted since 1990. In particular, we assess the role of different abatement options that bring emissions from current policy pathways to the announced targets, but also what further changes are needed to achieve the global 1.5°C target. We highlight 2 major gaps in global climate action: the implementation gap between the currently announced policies and the pledges of the NDC and LTS announcements, where more policy action is needed, and the ambition gap between NDC and LTS pledges and the 1.5°C target, where greater ambition is required.

Policy context

The 2015 Paris Agreement establishes a policy framework in which countries submit their domestic emission reduction objectives to the UNFCCC. Importantly, parties (countries) were invited to revisit these targets every 5 years – with the aim of ratcheting up the level of emission reductions. The first update of NDCs was scheduled ahead of COP 26 in Glasgow and many countries have updated their NDCs, although not all of the updates have increased ambition; submissions up to 5 November 2021 and pledges made in COP26 are included in this report[1].

The Paris Agreement further invites parties to submit long-term low GHG emission development strategies. In its long-term strategy of 2018 ("A clean planet for all"), the EU announced the target to become climate neutral by 2050. Since then, several other large economies have followed and announced own net-zero emission targets for mid-century and beyond.

The results presented in this report are also relevant for the first "global stocktake" under the Paris Agreement, scheduled for 2023. This aggregation of individual targets serves to assess the collective progress towards achieving the long-term objective of the Paris Agreement.

Key conclusions

The announced targets for the short term (2030) and long term (mid-century) see a clear departure from historic trends and current policies. While current policies lead to climate change in excess of 3°C, the implied temperature change from announced targets amounts to about 1.8°C by 2100. This is significantly lower than assessed in previous GECO editions, as for the first time we include announced long-term targets. Achieving them will however require policy measures to be implemented, as current policies are merely sufficient to stabilise global emissions by 2035-2040.

Further, to limit global warming to 1.5°C, more ambitious action is needed, both in the short term for achieving a stronger decline of emissions towards 2030, as well as in the long term as some countries have not yet embraced a net zero target.

Main findings

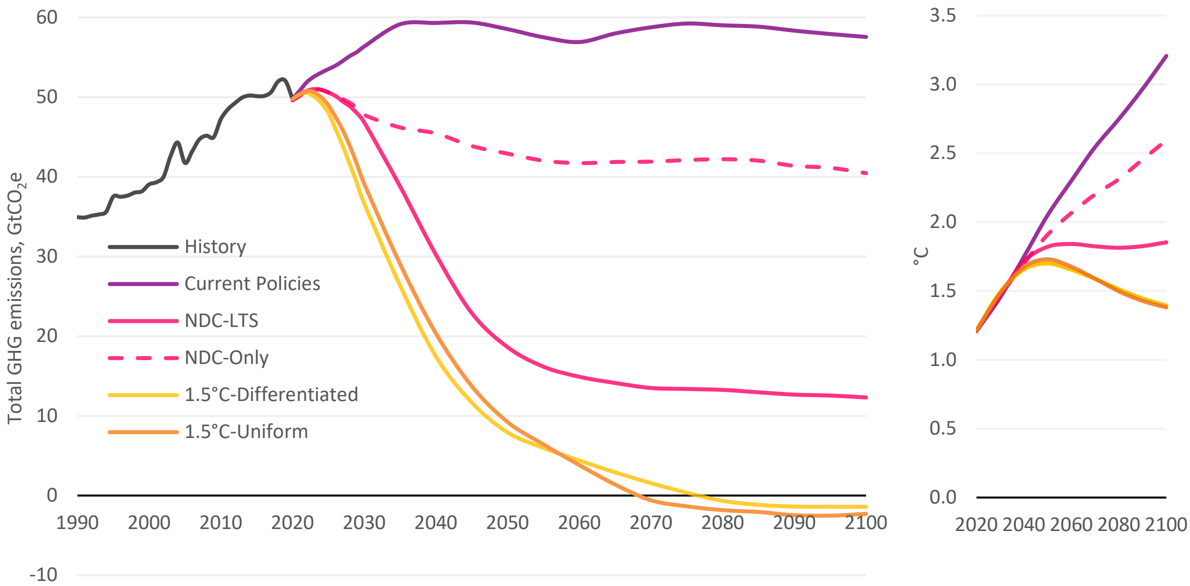
GECO 2021 analyses different plausible policy pathways and assesses their GHG emission and temperature implications[2] (Figure 1). Current policies stabilise emissions, however only around 2040; hence, additional policies are needed to achieve the targets of the NDC-LTS pathway, which include the stated Nationally Determined Contributions and the Long-Term Climate Strategies announced by the UNFCCC parties. In the NDC-LTS pathway, emissions peak as early as 2023 and then stabilise by mid-century. Emission reductions in the power sector can contribute most towards realising the emission targets, especially by reducing generation based on coal.

Considering the set of assumptions behind each scenario, a common interesting feature is that all of them show stabilised emissions in the long-term, without any perceptible, growth-induced rebound. This suggests

[1] https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx
[2] based on GHG and air pollutant emissions projections from POLES-JRC

that these storylines genuinely entail structural changes where economic growth is decoupled from emission growth thanks to different levels of investment and capital stock turnover. Accordingly, the global economy can grow with constant levels of GHG emissions that reach zero between 2070-2080 in the 1.5°C scenarios.

Figure 1: Global GHG emissions (left) and global mean temperature increase (right)



Note: The 1.5°C scenarios were designed with differing carbon prices and a 50% probability to not exceed their temperature change at the end of the century. NDC-Only includes Nationally Determined Contributions, NDC-LTS includes Nationally Determined Contributions and the Long-Term Climate Strategies.
Source: POLES-JRC model and liveMAGICC

Compared to the assessment of NDC scenarios carried out in GECO 2019 (Keramidas, et al., 2020), global emissions in 2030 are about 6.4 $GtCO_2e$ lower in GECO 2021. This is partly due to changes in the expected evolution of technologies, partly due to post-Covid updated macroeconomic projections, and partly due to new and updated NDCs[3]. This reduction closes the gap towards 1.5°C-compatible emissions pathways. The NDC-LTS scenario is 36.0 $GtCO_2e$ lower in 2050 than the NDC scenario of GECO 2019, which did not explicitly include net-zero targets. In terms of temperature change, previous analysis of NDCs led to a stabilisation of global emissions and temperature change to around 2.9°C (Keramidas, et al., 2020); GECO 2021's NDC-only case sees temperature increases of about 2.6°C at the end of the century, while the updated NDC-LTS scenario reduces that temperature change to about 1.8°C.

To reach the 1.5°C target additional effort is needed, both in the near and in the long term. The transition to a low-carbon economy compatible with the 1.5°C temperature target requires global GHG emissions to drop quickly in the next decades and to reach net-zero early in the second half of the century – with net CO_2 emissions being negative thereafter. The NDCs cover some 44-55% of the ambition gap to 1.5°C in 2030 (depending on the 1.5°C scenario considered).

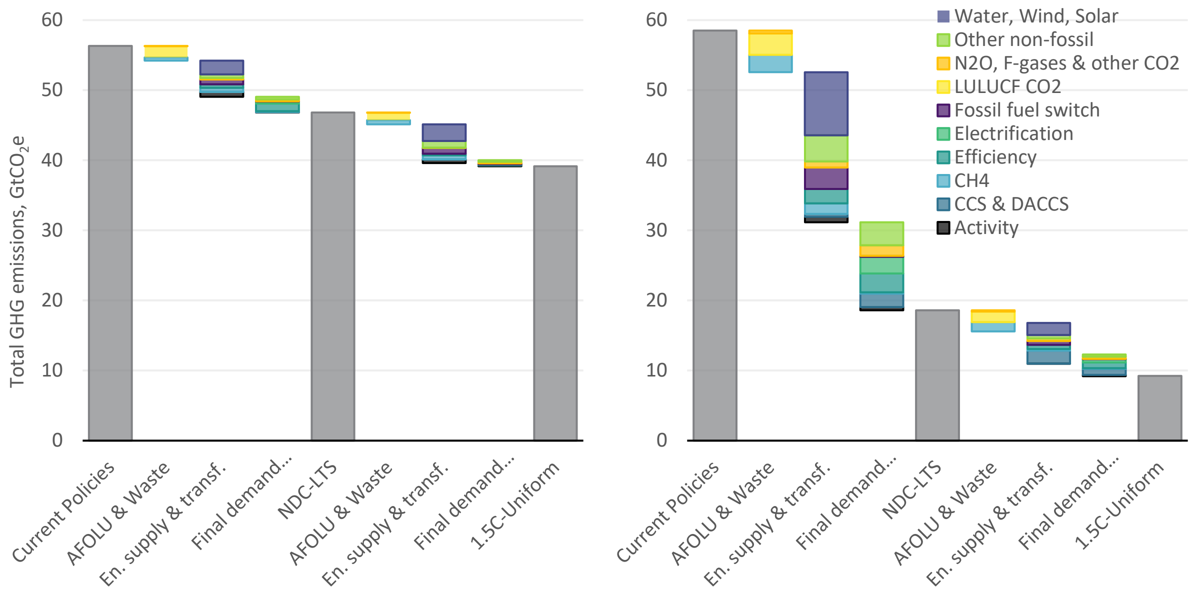
Coal combustion reduction is the most important change of primary energy use when moving from the current policies to the NDC-LTS scenario while the largest difference in primary energy when going from the NDC-LTS scenario to the 1.5°C scenario comes from gas in 2050. This implies that a reduction of all fossil fuels is needed to achieve the 1.5°C target. Up to 2030, a robust transition towards a low-carbon economy relies primarily on the energy supply and transformation sector; this includes a shift to low-carbon sources, mainly wind, solar and nuclear, followed by increase in energy efficiency. Beyond 2030 and moving towards the 1.5°C target, emission reduction needs to mobilize in the land sector and in final demand sectors as well, including increased demand side efficiency and electrification, see Figure 2.

The transition to a low carbon economy requires substantial structural change in the capital stock of the world economy. Global aggregated investment grows under both scenarios (+0.6% under the NDC-LTS and +1.0% under the 1.5°C scenarios, in 2030, as compared to the Current Policies scenario), with sectors related to clean power technologies standing out as the prime driver of this transition. Consequently, employment levels

[3]An update in historical data has resulted in 2017 emissions being 2.2 $GtCO_2e$ lower in GECO 2021 than in GECO 2019; net of this change, the GECO 2021 and GECO 2019 difference in 2030 is of 4.2 $GtCO_2e$.

increase in many sectors, while the overall negative employment impact remains concentrated in the few sectors directly related to fossil fuel extraction and processing.

Figure 2: Mitigation options in 2030 (left) and 2050 (right) for three scenarios



Note: The NDC-LTS scenario includes Nationally Determined Contributions and the Long-Term Climate Strategies, En. supply & transf. stands for energy supply and transformation, the 1.5°C-Uniform scenario applies a single global carbon price for all regions to reach the temperature target.
Source: POLES-JRC model

Fortunately, those sectors facing the strongest decrease in employment levels, such as the fossil fuel industry, represent only a small share of the global labour market. As the decarbonisation of the economy advances, bioenergy and electrification lead to increasing employment opportunities. We also note that additional investments associated to energy-saving activities positively affect the employment levels in the construction sector. Increased efficiency in the energy system and enhanced electrification also foster employment in manufacturing and in the transport sectors at global level.

When zooming in from the global picture to individual countries and regions, some countries appear on track for the emission reductions implied by a cost-efficient 1.5°C pathway, especially those with net zero emission targets by mid-century. On the other end of the scale are countries with a non-binding NDC target in the short term and no announced plan for deep emission reductions in the long term.

Considering the 1.5°C target, all countries reduce the use of fossil fuels, especially coal, to decarbonise electricity generation, along with improving energy efficiency, advancing electrification and reducing emissions from land use. However, abatement options vary between countries: in terms of overall contribution towards decarbonisation: the main mitigation options for developed countries are renewables for power generation and demand-side efficiency, while for developing countries the reduction of emissions from agriculture, forestry and land-use (AFOLU) plays an important role.

Related and future JRC work

This report is the seventh edition of the Global Energy and Climate Outlook (GECO). It contributes to the JRC work in the context of the UNFCCC policy process and IPCC assessment reports. This release offers a global view of decarbonisation scenarios, as well as regional views for G20 countries.

Quick guide

This report uses quantitative energy-economy modelling to build several scenarios differing on the ambition of climate policies implemented, with a particular focus on G20 countries, allowing to compare the gap between the latest pledges with several scenarios configurations of the 1.5°C target. Section 2 presents these scenarios. Section 3 provides an in-depth analysis of global energy and GHG emission trends. Section 4 provides details on individual G20 countries and international transport.

1. Introduction

The Sixth Assessment Report (AR6) of the IPCC (IPCC, 2021), published in August 2021, repeats the key messages of previous reports and further strengthens the scientific basis of climate science: it states that the climate crisis is unequivocally caused by human activities and that it is being felt in all parts of the planet today. In an unprecedented call for urgent coordinated global action, it concludes that only drastic reductions in GHG emissions this decade can prevent global temperatures rising above a level beyond which the consequences could become excessively costly and unpredictable. The 2018 IPCC Special Report on 1.5°C concluded that global GHG emissions must be cut significantly by 2030 and reach net-zero soon after 2050 in order to reach the 1.5°C objective (IPCC, 2018).

To avoid dangerous climate change, the Paris Agreement aims at limiting the increase in global average temperature to well below 2°C by 2100 and points towards a 1.5°C increase above pre-industrial levels. As the core mechanism of the Paris Agreement, nationally determined contributions (NDCs)[4] represent each country's short-term (2030) effort to reduce national GHG emissions and adapt to the impact of climate change. NDCs are required to be communicated and maintained with updated submissions every five years (2020, 2025, and 2030) regardless of their respective implementation periods. Additionally, all countries were further invited to communicate their long-term low GHG emissions development strategies (LTSs).

By the Conference of the Parties (COP 26) in Glasgow, out of the 196 parties that have adopted the Paris Agreement[5], 194 parties have submitted their first NDCs and 13 have submitted their second NDCs; many countries also submitted intermediate updates of their first NDC since the beginning of the procedure in 2016[6]. Furthermore, 48 parties have communicated their long-term low GHG emission development strategies (November 2021[7]). During the COP 26, several other important pledges from large emitters were announced.

This year, the Global Energy and Climate Outlook (GECO 2021) focuses on climate action spurred by the latest pledges under the Paris Agreement and how the recent announcements of long-term net-zero emissions targets by major world economies might impact the global effort for the low-carbon transition in the coming decades.

The modelling work underlying this report includes these updated short-term and long-term targets in a unique scenario labelled as NDC-LTS. Two possible 1.5°C-compatible pathways are also showed in the results, 1.5°C-Uniform and 1.5°C-Differentiated, both targeting a long-term stabilisation to this warming level, with different implementation assumptions on international carbon price regime.

This GECO edition presents a focus on G20 countries. Since 1990, the G20 countries have accounted for about than 75% of global GHG emissions. Emissions and energy system indicators are presented for each of the G20 countries, along with detailed analysis of how each country can achieve its climate goals.

Box 1: Differences with GECO 2020

The latest historical data has been updated. Technologies costs were updated with recent literature. Fuel/technology preference factors were revised to reflect the updated data. The reactivity to carbon pricing was revised by accounting for the perceived risk premium of a consistently increasing carbon price in the decision-making process.

The work done in GECO 2020 to represent the effects of the Covid-19 pandemic was repeated with more recent data on 2020 and the expected effects in 2021 and following years.

Current policies especially in G20 countries were reviewed and updated. The NDC scenario from GECO 2019 was updated with new NDCs and now includes LTS pledges as well.

The modelling period extends over the entire 21st century; results are displayed to 2070.

[4] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs

[5] https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en

[6] https://www4.unfccc.int/sites/NDCStaging/Pages/LatestSubmissions.aspx

[7] https://unfccc.int/process/the-paris-agreement/long-term-strategies

2. Scenarios

This section provides a stylised description of the assumptions made for the set of projections presented in this report. The following scenarios were modelled[8]:

CurPol: this scenario corresponds to a world where currently existing policies related to GHG emissions, renewables deployment and energy efficiency are enacted, and where no additional policies are implemented compared to what had been legislated as of 2019. Exogenous macroeconomic projections (GDP and population), and endogenously calculated energy prices and technological development specific to the POLES model, combine with the effect of enacted policies to calculate projections of the energy system and CO_2 emissions. As a consequence, this scenario may differ from energy and emissions projections from official national sources and international organisations. See Annex 1 for the list of policies considered.

This scenario does not aim to reach stated policies that have not been translated into law and accompanied by concrete action plans, nor does it consider the objectives put forward in countries' NDCs if there are no policies in place. It does not attempt the deep structural decarbonisation process needed for a 1.5°C emissions trajectory. See Annex 2 for more on the functioning of the modelling.

Building on work conducted in GECO 2020, the effect of the Covid-19 pandemic on the energy system has been considered on three sets of parameters: adapted macroeconomic figures (annual GDP growth revised for 2020-2027, traffic by transport mode estimated and revised for 2020-2023); decreased rate of renewal of stock (for 2020-2022); and structural changes in passenger mobility induced by the pandemic (e.g., progressive phase-in of changes in mobility per mode compared to earlier behaviour). This CurPol scenario is derived from the GECO 2020 Base_C19+TC scenario; see Annex 6 and GECO 2020 for more detail.

NDC-LTS: this scenario considers the policies of NDCs in the medium term and the LTSs in the longer term. This scenario assumes that the objectives in the NDCs (including conditional objectives) are reached in 2025-2030. To this end, carbon values and other regulatory instruments are put in place on top of the existing, legislated measures of the CurPol scenario. Beyond 2030, the objectives of the countries' LTS, where they exist, are pursued; if the country has not announced an LTS, it is assumed that no additional effort is made, and carbon values kept constant to their 2030 level. See Annex 1 for a list of NDC and LTS objectives included in this scenario[9]. The NDC-LTS scenario also considers decarbonisation proposals related to international aviation and maritime transport fuels (international bunker fuels).

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

Two 1.5°C scenarios are modelled varying by the way the carbon price is implemented. The 1.5°C scenarios assume a global GHG trajectory consistent with a likely chance of meeting the Paris Agreement long-term goal of a temperature rise over pre-industrial times of well below 2°C at the end of the century. They were designed with a global carbon budget of approximately 500 $GtCO_2$ cumulated net emissions over 2018-2100 and a 50% probability of not exceeding 1.5°C of warming[10,11].

1.5°C-Uniform: A single global carbon price for all regions is used in this scenario starting immediately (2021) and strongly increasing. Bottom-up policy drivers (such as capacity targets) from the NDC-LTS scenario are not included here, as this scenario is constructed on the basis of the CurPol scenario. The global carbon price is the sole policy driver in the model. This scenario is therefore a stylized representation of an economically efficient pathway to the 1.5°C climate target, as the uniform global carbon price ensures that emissions are reduced where abatement costs are lowest. This scenario does not consider financial transfer between countries to implement mitigation measures. The use of negative emissions technologies is relatively limited (<14 $GtCO_2$/year in 2100); combustion CO_2 capture and CO_2 direct air capture technologies are made available progressively beyond 2030 (<7 $GtCO_2$/year in 2050). The mobilisation of biomass as an energy resource is

[8] A description of the POLES-JRC model used in GECO 2021 can be found in Annex 2. In addition, detail on socio-economic assumptions and fossil fuel prices are in Annex 6.

[9] Information supplied from a working version of the GECO 2021 scenarios to the UNEP Emissions Gap Report 2021 (United Nations Environment Programme, 2021a) did not include the implementation of NDC and LTS objectives announced at COP 26, which are taken into account in the NDC-LTS scenario of this report. However, this does not imply changes to the multi-model estimate of global 2030 GHG emissions of conditional and unconditional NDCs and associated results presented in that report.

[10] Characterised as 1.5°C with low overshoot according to UNEP Gap Report (United Nations Environment Programme, 2021a), IPCC SR 1.5°C (IPCC, 2018) (IPCC, 2018)

[11] Obtained with the online tool liveMAGICC, based on GHG and air pollutant emissions projections from POLES-JRC: http://live.magicc.org/

relatively limited (remains below 170 EJ/year for all years), in order to reflect the use of only sustainably-grown biomass [12]. Within the above economic and technological constraints, the overshoot of the temperature target was kept low (at slightly above 1.7°C in 2050[13]).

1.5°C-Differentiated: A global GHG pathway consistent with the same temperature target, differing from the 1.5°C-Uniform scenario above in the regional allocation and, to some extent, in the temporal allocation, of mitigation effort. The carbon price is differentiated across regions according to their per-capita income, with richer regions having a higher carbon price and poorer regions progressively catching up to that price; this was done according to the schedule described in Annex 1. The differentiation attempts to reflect a possible staged implementation of climate policies in order to account for each country's financial capacity and response flexibility. The rest of the technological constraint assumptions are kept the same as the 1.5°C-Uniform scenario.

[12] 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, F. et al., 2015)

[13] Obtained with the online tool liveMAGICC, based on GHG and air pollutant emissions projections from POLES-JRC: http://live.magicc.org/

3. Global trends

This chapter reports the main historical trends on GHG emissions and the corresponding future projections for the four scenarios defined in section 2. In order to achieve the climate targets of the Paris Agreement, all anthropogenic GHG emissions need to be reduced. This includes primarily emissions coming from burning fossil fuels for energy uses, but also from the fossil fuels processed in industry, as well as land use emissions.

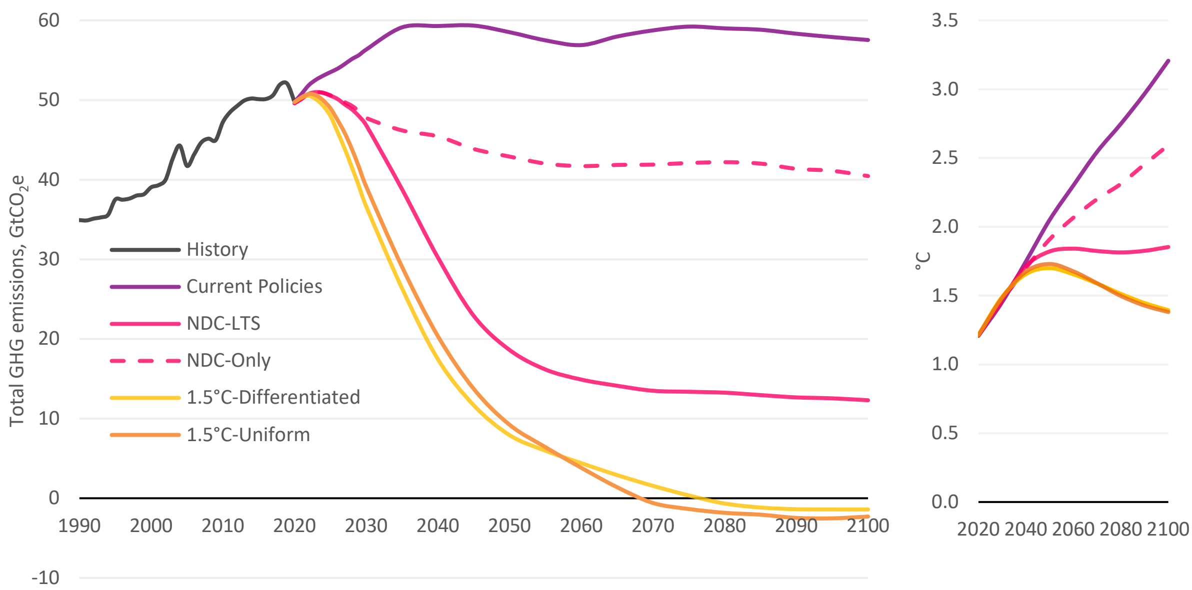
The biggest contribution at the global level have to come from reducing CO_2 emissions from burning fossil fuels which in 2019 represented an estimated 67%. Furthermore, as acknowledged in the IPCC 5th assessment report (IPCC, 2014), AFOLU sector is already responsible for 23% of anthropogenic GHG emissions. This reemphasises the importance of the existing efforts to mitigate climate change through land use activities.

Accordingly, section 3.1 presents the emission pathways and temperature implications of the scenarios; section 3.2 shows the mitigation GHG emission drivers between scenarios, with section 3.3 providing additional insights on the relative importance of the NDC and net-zero targets. In section 3.4 we analyse several major multi-lateral pledges made at COP26. Sections 3.5 and 3.6 present the scenarios' projections of global primary energy supply and global final energy, respectively, while section 3.7 highlights the economic implications of the decarbonisation pathways.

3.1. GHG emissions and temperature change

GHG emissions have continuously increased since the industrial revolution, and have accelerated dramatically in the second half of the 20th century. This section compares GHG emissions projections under Current Policies (CurPol scenario), and those under the combined 2030 NDC mitigation targets together with the submitted LTSs (NDC-LTS scenario). These two scenarios are not on track to meet the objective of the Paris Agreement, to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. The Paris Agreement ambition is therefore represented in the 1.5°C-Uniform and 1.5°C-Differentiated scenarios.

Figure 3: Global GHG emissions and global mean temperature change in the GECO2021 scenarios



Source: POLES-JRC model, liveMAGICC.

Figure 3 shows the GHG emissions pathways of the projected scenarios and the associated global mean temperature change profiles. In the CurPol scenario, from 52.0 Gt CO_2e in 2019 and despite a 4.4% drop in 2020 due to the COVID-19 pandemic, GHG emissions grow again to 56.3 Gt CO_2e in 2030 and keep increasing before plateauing around 2035 and remain roughly constant thereafter at around 59 $GtCO_2e$. Temperatures increase to in excess of 3°C (50% probability) above pre-industrial levels at the end of the century in this scenario[14]. Emissions growth is stopped, partially through existing policies, and partially through market forces and technology developments as costs for key low-carbon technologies continue to decline.

[14] Obtained with the online tool liveMAGICC, based on GHG and air pollutant emissions projections from POLES-JRC: http://live.magicc.org/

Implementing the announced targets of the NDCs leads to a peak in global emissions in 2023 with 51.0 Gt CO_2e and limit GHG emissions to 46.8 Gt CO_2e in 2030. Beyond 2030, the pursuit of LTSs leads to 18.6 $GtCO_2e$ globally in 2050. This results in a temperature increase of approximately 1.8°C (50% probability) at the end of the century. The difference between CurPol and pledges announced in the NDCs suggests an implementation gap of 9.5 Gt CO_2e in 2030 that will need to be bridged.

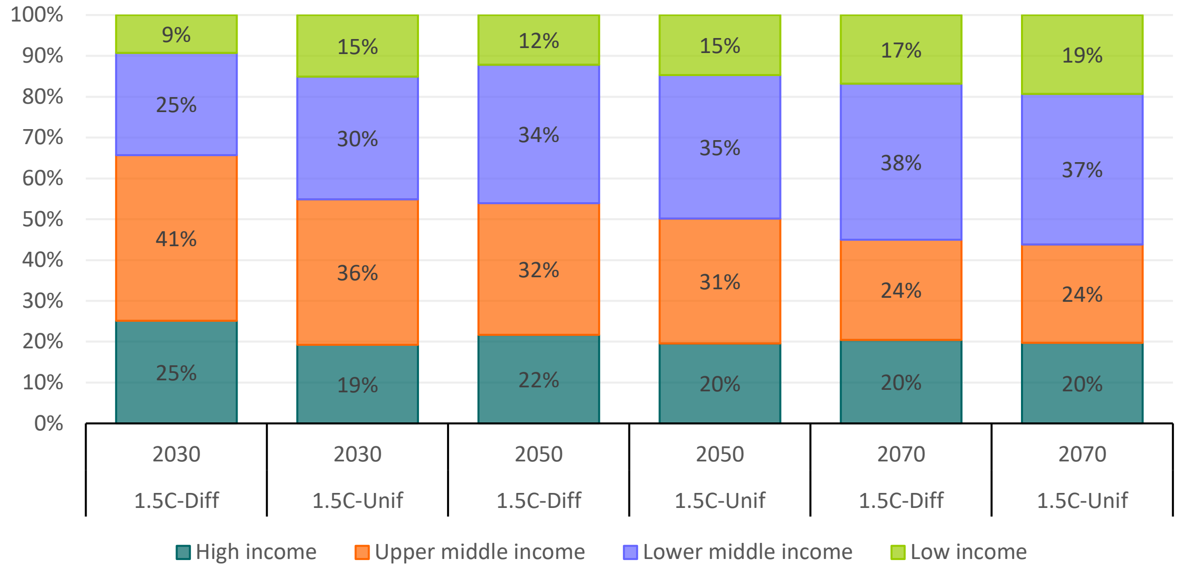
Compared to the last assessment of NDC scenarios in GECO 2019 (Keramidas, et al., 2020) global emissions in 2030 are now about 6.4 $GtCO_2e$ lower – partly due to changes in the expected evolution of technologies, partly due to post-Covid updated macroeconomic projections, and partly due to new and updated NDC policies (of which, 2.2 $GtCO_2e$ in the year 2017 are due to historical statistics updates). This reduction closed the gap towards the 1.5°C-compatible emissions pathways. The present NDC-LTS scenario is 36.0 $GtCO_2e$ lower in 2050 than the NDC scenario of GECO 2019, which did not explicitly include net-zero targets. In terms of temperature change, previous analysis of NDCs led to roughly a stabilisation of global emissions and temperature change of around 3°C (GECO 2019); the updated NDC-LTS scenario reduces that temperature change to about 1.8°C.

To limit global temperature change to 1.5°C at the end of the century, additional efforts beyond the NDC and announced LTSs are necessary. Global GHG emissions peak even earlier (2022) in the 1.5°C-Uniform scenario and decline faster to reach 39.1 Gt CO_2e in 2030 and 9.2 Gt CO_2e in 2050. This suggests an ambition gap of 17.2 Gt CO_2e in 2030 compared to CurPol (7.7 Gt CO_2e compared to NDC-LTS).

Considering the set of assumptions behind each scenario, a common interesting feature is that all of them show stabilised emissions in the long-term, without any perceptible, growth-induced rebound. This suggests that these storylines genuinely entail structural changes where economic growth is decoupled from emission growth thanks to different levels of investment and capital stock turnover. Accordingly, the global economy can grow with constant levels of GHG emissions that reach zero between 2070-2080 in the 1.5°C scenario.

In the 1.5°C-Differentiated scenario, the income-based carbon price disparity across countries results in developed countries experiencing a higher carbon price and contributing with additional effort compared to the 1.5°C-Uniform scenario (both geographical and intertemporal redistribution occur), while lower-income countries contribute with comparatively less mitigation, see Figure 4. The two scenarios also differ on the timing of mitigation: globally, more mitigation is done in the 1.5°C-Differentiated in the first half of the century and, conversely, less in the second half of the century, while maintaining the 1.5°C temperature target at the end of the century. Given that these two scenarios have equivalent CO_2 budgets (~500 $GtCO_2$ for 2020-2100), their median temperature changes are very similar, around 1.5°C in 2100, and only differ slightly in the overshoot in 2050 at around 1.7°C.

Figure 4: Contributions to emissions reductions compared to Current Policies, in the 1.5°C-Differentiated scenario and the 1.5°C-Uniform scenario, by income group, in 2030, 2050 and 2070



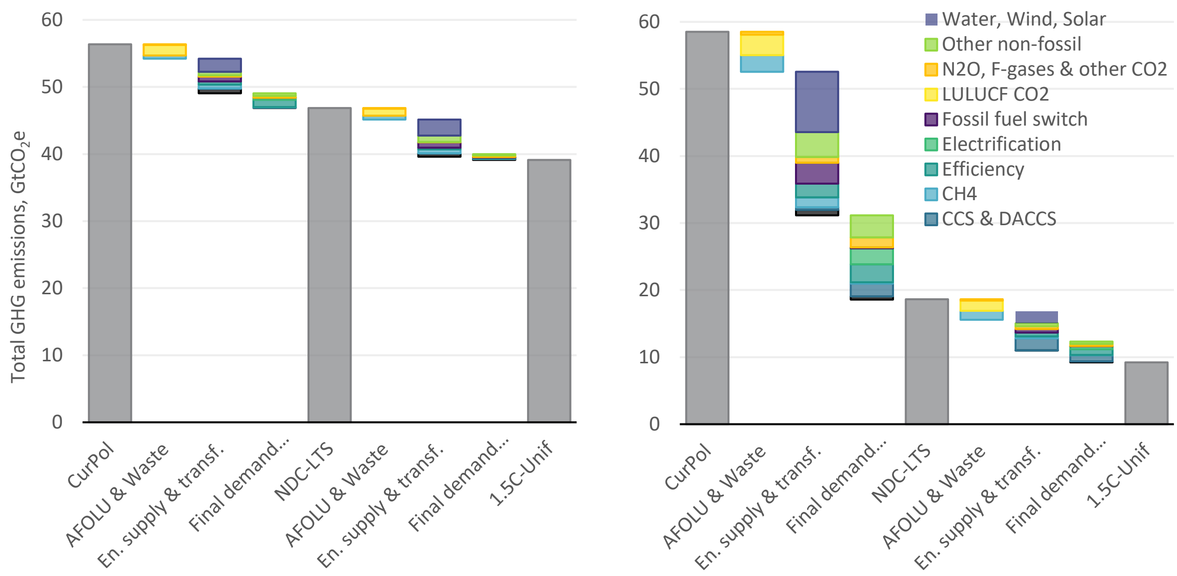
Source: POLES-JRC model

3.2. GHG emissions – drivers and mitigation options

The deviations in GHG emissions between the three main scenarios in 2030 and 2050 are displayed in Figure 5. The difference between the current policy scenario and the NDC-LTS scenario could be interpreted as an implementation gap, while the difference between the NDC-LTS scenario and the 1.5°C scenario could be interpreted as ambition gap (Roelfsema, et al., 2020). In 2030, the GHG emissions reduction between CurPol and NDC-LTS scenarios is around 9.5 $GtCO_2e$, almost evenly split in the implementation and ambition gaps. Emissions reductions in the NDC-LTS and 1.5°C-Uniform scenario make extensive use of already mature low-hanging-fruit mitigation options related to energy supply and transformation. Significant contribution is provided by the power sector, mainly from renewable power, basically wind and solar PV, a switch from coal to gas, as well as nuclear. AFOLU and final energy demand sectors provide comparatively smaller mitigation potential due to the relative higher organizational complexity in implementing wide-ranging changes in these sectors.

In 2050, the NDC-LTS scenario already achieves 81% of the mitigation necessary to reach the 1.5°C emission levels. The volume of mitigated emissions is large, around 40 Gt CO_2e, narrowing the gap to the 1.5°C scenario, with the effort involving all energy related and non-energy related contributions. The largest contribution is still provided by energy supply and transformation sectors, with a massive contribution from renewables, followed by switching to less carbon-intensive fossil fuels, nuclear and efficiency. The need for additional mitigation increases the contribution of AFOLU, mainly via forest management and reducing deforestation. Final demand sectors increase their emission reduction contribution in 2050, via the use of synthetic fuels, electrification, efficiency and CCS.

Figure 5: Drivers of GHG emission growth and mitigations options in 2030 (left) and in 2050 (right) for the three analysed scenarios



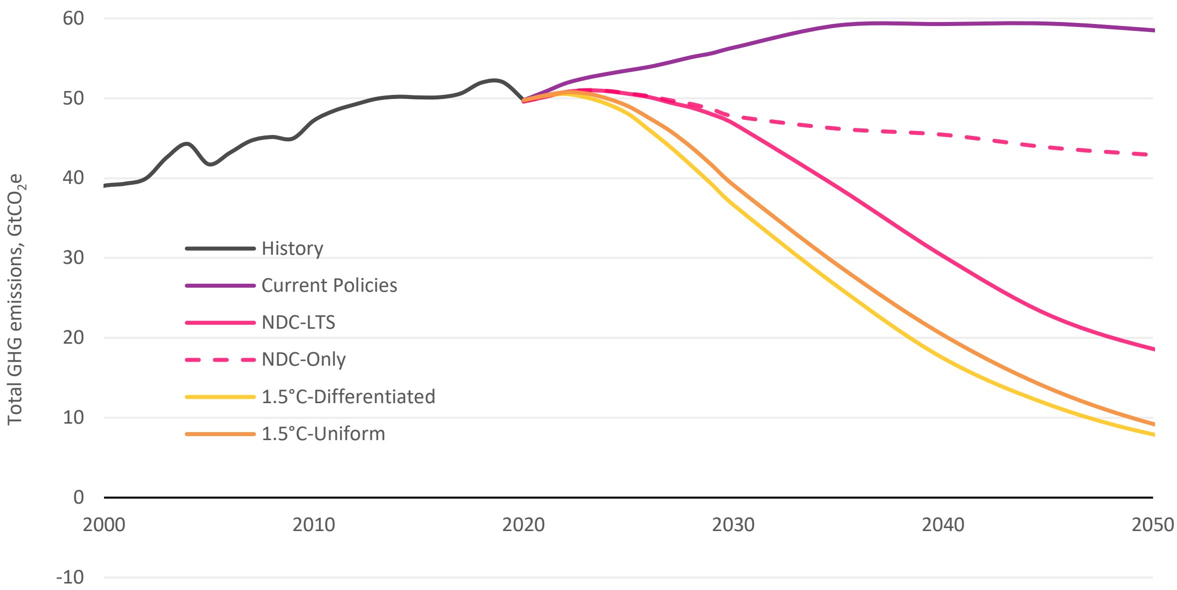
Source: POLES-JRC model

3.3. NDCs and LTS impacts

The Paris Agreement proposes two mechanisms for countries to signal and align their decarbonisation efforts: Nationally Determined Contributions and Long-Term Strategies. Countries have been progressively submitting pledges and targets to both mechanisms, often separately.

GECO 2021 has taken the combination of both the available NDC and LTS together to produce the NDC-LTS scenario as shown in Figure 6. These two pledges represent different and specific points in time, typically 2030 for the NDC and 2050-2070 for the LTS, hence it is logical to combine both into one future pathway for emissions. However, separating out the contribution of each is insightful, for instance because the longer-term target may be subject to more political uncertainty. To analyse their individual contributions to global mitigation, the NDC-only case in Figure 6 represents a policy pathway in which no further action is implemented beyond the NDC. In modelling terms, this is represented by fixing carbon prices at 2030 levels as implied by the NDC. This NDC-only case would lead to a temperature change of about 2.6°C at the end of the century, in line with projections of the UNEP Emission Gap Report (United Nations Environment Programme, 2021a)[15].

Figure 6: Global GHG emissions per GECO2021 scenario, and NDC-only analysis



Source: POLES-JRC mode

The comparison between NDC-only and NDC-LTS may shed some light on the role of early structural changes to attain climate neutrality. By 2050, the LTS targets contribute most (61%) of the emissions reduction between the Current Policies scenario and the NDC-LTS scenario. When considering the challenge of reaching a 1.5°C pathway, the effect of the NDCs alone only account for 32% of the required emissions reduction in 2050, while the LTSs narrow the emissions gap between current policies and a 1.5°C trajectory to 81%.

Crucially, in the coming decade, the NDCs move the world from the continuing upwards emissions trend of the Current Policy scenario to the decreasing emissions trajectory of the NDC-LTS scenario by 2030. While more action is required of the NDCs to put the world on a 1.5°C pathway by 2030, in the period 2030-2050 the role of the LTS in building upon the NDC efforts is equally essential in moving the world towards the 1.5°C target. Efforts by policymakers are required to improve the commitment level of NDC pledges and simultaneously extend the policy planning time horizon with more (and more ambitious) LTSs.

3.4. COP26 methane, deforestation and coal pledges

Alongside the NDC and LTS general emission reduction pledges announced before and at COP26, there have been several prominent multi-lateral pledges addressing methane emissions, halting deforestation, and new unabated coal plants. These pledges have not been explicitly modelled in the GECO scenarios presented here, as such countries that have joined these pledges could have also included these pledges and targets in their announced NDCs and LTSs. The following section compares an interpretation of the target of each pledge with the results of the NDC-LTS scenario and the 1.5°C-Uniform scenario, to indicate the role the pledge could play in deep decarbonisation scenarios.

The global methane pledge

Methane is a potent GHG and accounts for about half of the 1°C net rise in global average temperature since the pre-industrial era[16]. Rapidly reducing methane emissions is complementary to action on carbon dioxide and other greenhouse gases, and is regarded as the single most effective strategy to reduce global warming in the near term and keep the goal of limiting warming to 1.5 degrees Celsius within reach[17]. Importantly, reducing methane emissions can also contribute to reducing the peak temperature in scenarios where temperature peaks

[15] The UNEP Emission Gap Report reports a 66% chance of remaining below 2.7°C for the unconditional NDC pledges and 2.6°C for conditional NDC pledges. The values are close to our estimates despite using a different extrapolation method beyond 2030. An update to also include pledges up to COP 26 (United Nations Environment Programme, 2021b) did little to change these values as most updated pledges were related to mid-century pledges, leading to temperature projections of 2.7°C and 2.5°C, respectively.

[16] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_4785

[17] https://link.springer.com/article/10.1007/s10584-019-02437-2

and then decline due to negative emissions. Major sources of anthropogenic methane emissions include the processing of oil and gas, coal, the agriculture sector, and landfills.

Countries joining the Global Methane Pledge commit to a collective goal of reducing global methane emissions by at least 30% from 2020 levels by 2030. A total of over 100 countries representing 70% of the global economy and nearly half of anthropogenic methane emissions have signed onto the pledge as of 18 November 2021[18].

While the EU produces 5% of global methane emissions domestically, it encourages international action as the largest global importer of energy and as a strong player in the agriculture and waste sectors.

The 1.5°C-Uniform scenario shows global methane emissions decrease by 28% from 2019 to 2030, suggesting that full global participation in the Global Methane Pledge would be aligned with a 1.5°C trajectory. The NDC-LTS scenario shows a decrease in global methane emissions of 14% between 2020 to 2030, suggesting that the targets and pledges already announced fall short of meeting the 30% reduction; therefore, additional policymaking effort is required to reach the Global Methane Pledge's goal.

Sustainable land use transition

Forests play a critical role in reaching 1.5°C targets by the removal of CO_2, becoming sinks for atmospheric carbon dioxide. Optimal forest management will allow buying time for technological progress to deliver cost-effective abatement, especially those economic sectors that are harder to decarbonise. Due to the speed with which changes in forestry management can impact emissions, the lower the temperature target the greater role forests play in keeping to those objectives.

In recognition of this, leaders at the COP26 committed to working collectively to halt and reverse forest loss and land degradation by 2030[19]. 135 countries have endorsed the commitment, covering over 90% of the world's forests.

The NDC-LTS scenario sees emissions from deforestation reduced by 37% in 2030 relative to 2019, and the 1.5°C-Uniform scenario sees a reduction of 53% over the same period. This highlights both the ambition of the pledge, and points to the co-benefits that stringent targets for deforestation have beyond emissions, including for example biodiversity[20].

The global coal-to-clean-power transition statement

Coal power generation is the single largest cause of global temperature increases. Eliminating new unabated coal power plants and reducing the output from currently operating unabated coal-firing stations are both required to put the world on a 1.5°C trajectory. Transitioning out of coal is a relatively cheap abatement option, as economic alternatives are available.

The global coal-to-clean-power transition statement that was released at COP26 commits to "a transition away from unabated coal power generation in the 2030s (or as soon as possible thereafter) for major economies and in the 2040s (or as soon as possible thereafter) globally[21]."

Power generation from unabated coal plants reaches zero in 2040 in G20 countries and zero in 2050 globally in the GECO 2021 1.5°C Uniform scenario, showing that the achievement of the coal-to–clean-power transition statement is aligned with a 1.5°C trajectory. However, current NDC and LTS pledges and targets do not achieve this complete elimination of unabated coal. The NDC-LTS scenario sees an 88% reduction in power generation from unabated coal plants in 2040 in G20 countries, and a 89% reduction globally in 2050, highlighting the need for more efforts in relation to unabated coal.

3.5. Primary energy supply

Total primary energy supply is the sum of final energy demand and the energy used in the transformation into final fuels (power generation, synthetic liquids and gases), including losses. In 2019, total primary energy demand worldwide reached 14.3 Gtoe. Due to the impacts of the Covid-19 pandemic, total primary energy supply suffered an unprecedented drop of 5.7% in 2020, much larger than in the 2008-2009 financial crisis (-0.8%). However, in the CurPol scenario, energy demand is projected to grow continuously at an average rate of 0.8%/year, from 2019 throughout the middle of the century. This is slower than past decades, having observed

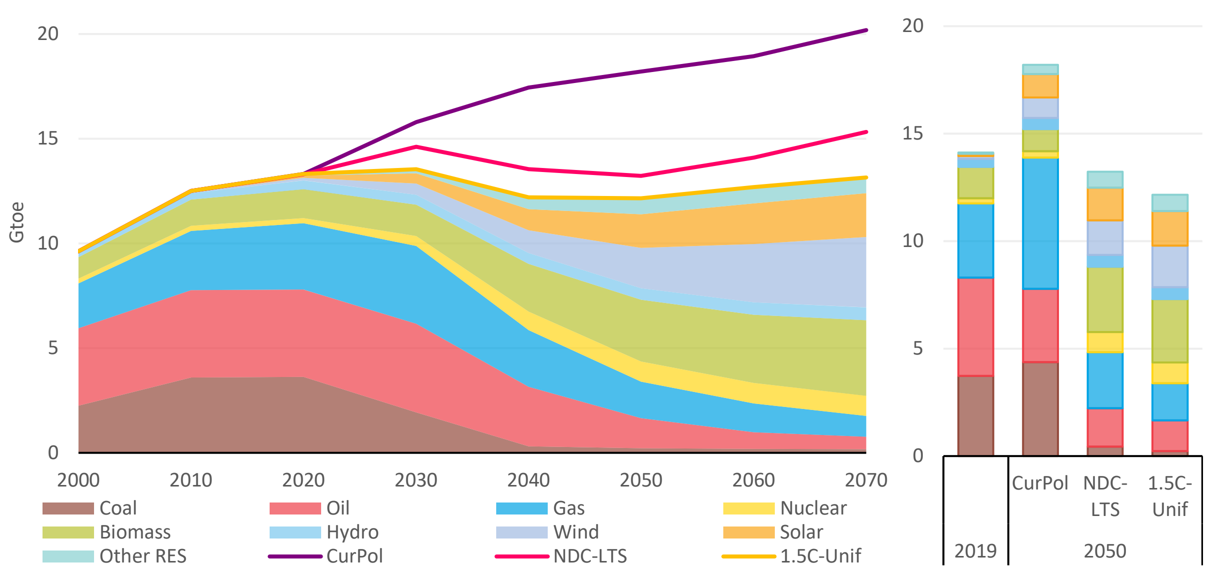
[18] https://ec.europa.eu/commission/presscorner/detail/en/statement_21_5766
[19] https://ukcop26.org/glasgow-leaders-declaration-on-forests-and-land-use/
[20] See Annex 2 for a description of POLES forestry and land use data sources.
[21] https://ukcop26.org/global-coal-to-clean-power-transition-statement/

an average annual growth of 2.0%/year in the 2000-2019 period. Implementing the targets of the submitted NDCs and LTSs stabilises global energy supply around 2030 at 14.7 Gtoe while under the 1.5°C-Uniform scenario total primary energy supply peaks in 2024 at 14.5 Gtoe (the peak occurs in 2023 at 14.3 Gtoe in the 1.5°C-Differentiated scenario, at about the same level as 2019), see Figure 7.

In 2019 more than three quarters (83%) of global energy demand was still met by fossil fuels, despite the significant growth of renewable energy over the previous decade. In the CurPol scenario this number declines only to 76% in 2050, while it represents 37% and 29% in the NDC-LTS and 1.5°C-Uniform scenarios in 2050, respectively.

Strong climate policy scenarios see the fastest increase in the participation of renewable energy sources (hydro, biomass, solar, wind, geothermal and ocean). Renewables' share in primary energy demand increases from 15% in 2019 to 56% and 63% by 2050 for the NDC-LTS and the 1.5°C-Uniform scenarios, respectively. Nuclear's contribution in 2019 is 1.7%, and increases to 7.8% in 2050 in the 1.5°C-Uniform scenario.

Figure 7: World primary energy supply by fuel, 1.5°C-Uniform scenario



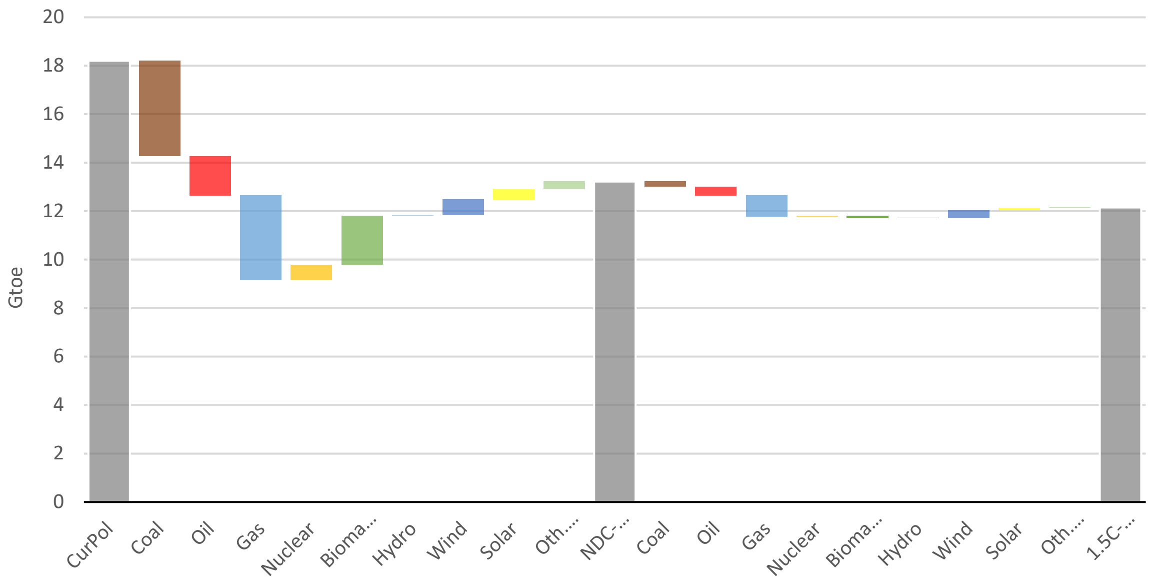
Source: POLES-JRC model

Coal demand is the most strongly and quickly impacted by climate-protecting policies, including in the NDC-LTS scenario. It is almost completely phased out in the 1.5°C-Uniform scenario, it peaks in 2020 and declines at -7.9%/year over 2020–2050; and by 2050 it only represents 2.5% of total primary energy demand, the lowest share it has had since the beginning of the industrial revolution, see Figure 8.

Oil is decreasing for all the scenarios during the 2020-2050 period, reaching as much as -3.4%/year for the 1.5°C-Uniform scenario; however, it peaks in absolute terms only in 2023 (4.7 Gtoe) in the 1.5°C-Uniform scenario. These trends are accompanied by a progressive decarbonisation and electrification of transport modes, at different speeds and with different intensities depending on the corresponding policy mix.

The share of gas decreases beyond 2035 in the NDC-LTS and 1.5°C-Uniform scenarios; however, its absolute demand level peaks in 2030 (3.7 Gtoe) in the 1.5°C-Uniform scenario. Gas has the lowest annual decline of the fossil fuels for the 2020-2050 period (-2.0%/year in 1.5°C-Uniform); however, its absolute decrease in volume from CurPol to 1.5 ˚C-Uniform in 2050 is comparable to that of coal.

Figure 8: Changes in primary energy supply between scenarios in 2050.



Source: POLES-JRC model

Figure 8 shows the fuel mix variation across scenarios in 2050 to meet primary energy supply from CurPol to NDC-LTS and to the 1.5°C-Uniform scenario. We observe a major reduction of fossil fuels around 9.1 Gtoe from CurPol to NDC-LTS, dominated by coal, followed by gas and oil. The reduction in fossil fuels sources is partially offset by an increase of renewable sources, highlighting the importance of biomass in the transition from the CurPol to NDC-LTS scenarios. Additionally, to reach the 1.5°C-Uniform scenario primary energy supply, fossil fuels continue to drop by around 1.4 Gtoe more, but this time with gas reduction as the major contributor. This shows how oil, despite its relatively high carbon content, is the most resistant fossil fuel to be substituted, as a specialised fuel for transport sectors and highly relevant in many industrial processes.

3.6. Power generation

The global power generation sector is set for a dramatic transformation over the coming decades, driven both by decided policy support and rapid cost decreases in renewables. However, despite the rapid growth of renewables in recent years, in 2019 fossil fuel generation still accounted for 63% of global power generation. Coal was the largest fuel source with 36%, followed by renewables consisting of mostly hydro but with increasing contributions from wind and solar with 27%, gas accounted for 23% and nuclear 10%.

Rapid cost decreases in wind and solar generation in recent years have led to the power generation sector having cost-competitive decarbonisation options available today, and as such it is the first sector that moves to rapid deployment of low-emission options in a 1.5°C trajectory.

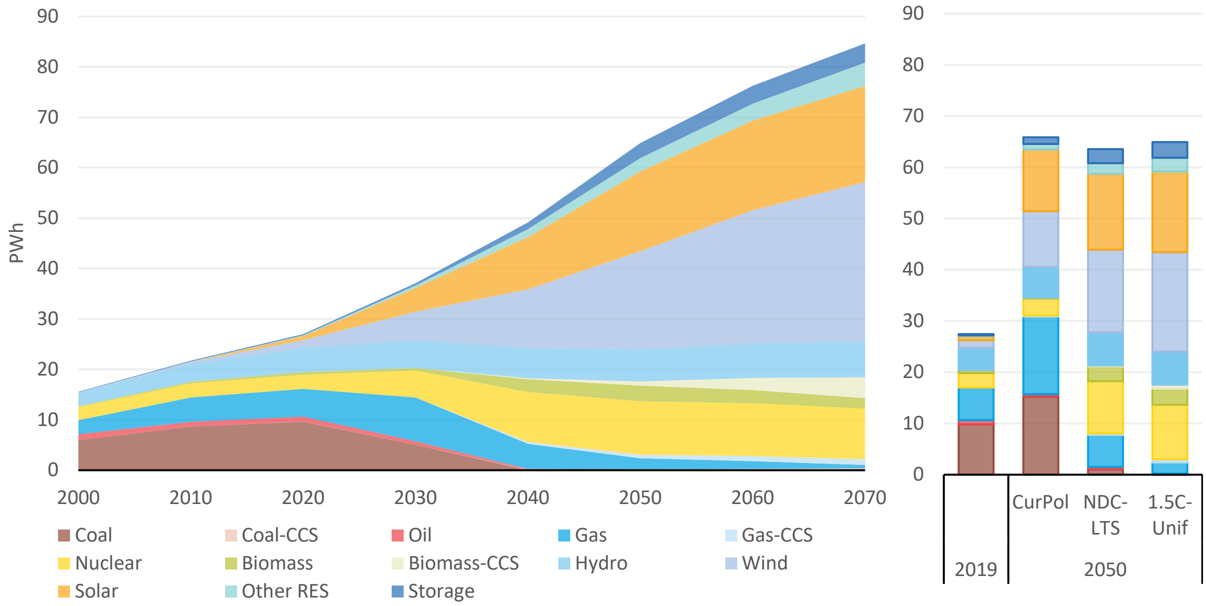
Figure 9 shows the evolution of the global power sector in the 1.5°C-Uniform scenario. In 2050 in this scenario renewables account already for 78% of global power generation, mostly wind (31%) and solar (25%). The other important low-emission generation source is nuclear, which sees its share increase to 17% in 2050. As a result of the increasing shares of these low-emission technologies, the share of fossil fuel generation contracts to 5%, mostly from gas-fired power plants as generation from coal is completely phased out.

Plants fitted with CCS contribute with 3% of total generation, as renewables generally provide a lower-cost decarbonisation option in the power sector. Various forms of storage account for 5% of total generation, which allows the power system to balance supply and demand at lower costs.

The fuel switching from fossil fuels to electricity in end use sectors sees total power generation increase in all scenarios in 2050. The 1.5°C-Uniform scenario reaches 62 PWh in 2050, more than double the 27 PWh of global power generation in 2019[22].

[22] GECO 2018 explored the impacts of decarbonisation on the power sector, while GECO 2019 explored the impacts of electrification on final demand sectors.

Figure 9: World power generation by technology, 1.5°C-Uniform scenario



Source: POLES-JRC model

3.7. Final energy demand

Final energy demand has steadily grown since the industrial revolution[23] with only minor disruptions due to economic recessions, pandemics and wars. In 2019, global total final energy consumption reached 9.6 Gtoe, with an average growth of 1.9%/year since 2000.

Global final energy demand continues to rise in the CurPol scenario at an average of 1.1%/year for the period 2020-2030. In the CurPol scenario developed countries decrease their energy consumption slightly while demand increases in developing countries. Demand only slows down beyond 2030 with an average annual growth of 0.5%/year over 2030-2050.

In the NDC-LTS and 1.5°C-Uniform scenarios, ambitious climate policies result in a decelerating growth of final energy consumption beyond 2020, see Figure 10. For the decade 2020-2030 the annual average growth rate is respectively 0.6%/year and 0.3%/year. For the period 2030-2050, the deceleration intensifies, reaching negative growth rates, -0.5%/year and -0.8%/year, for both scenarios respectively, to reach 8.8 Gtoe and 8.1 Gtoe in 2050.

Beyond 2050 the NDC-LTS scenario shows global final energy demand rising again if no further climate policies are put in place, as mitigation once LTS targets are reached is outpaced by increasing economic growth.

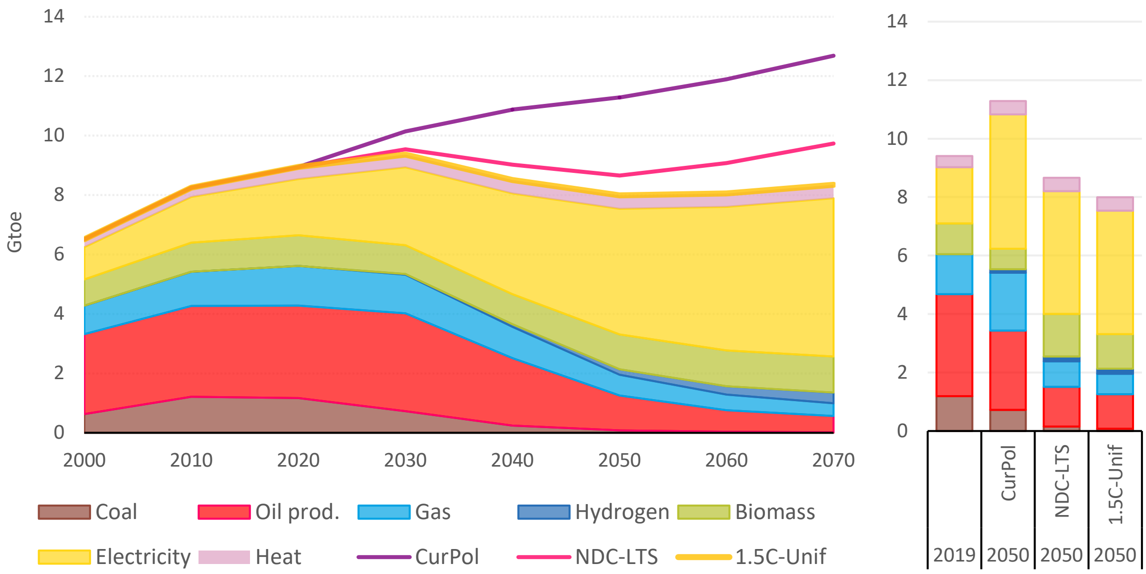
In the 1.5°C-Uniform scenario, consumption remains stable after 2050, despite a growing global economy, stabilising over 2050-2070 with an average growth of 0.2%/year, to reach 8.4 Gtoe in 2070.

Electricity evolves rapidly into the largest share in the fuel mix, in a generalised framework of demand electrification. The increasing dominance of electricity is the result of declining technological costs, change in end-use equipment and favourable policies. Electricity already accounted for around 20% of final global energy demand in 2019 and is projected to reach 52% in 2050 in the 1.5°C-Uniform scenario. The share of e-fuels and hydrogen reach a mere 5.0% in the 1.5°C-Uniform scenario in 2050, 2.8% in the NDC-LTS scenario, and at a marginal share in the CurPol of 1.1%.

As expected, fossil fuels are projected to reduce their share in 2050 in all scenarios. Oil represented 38% in 2019, and it decreases its share in all scenarios, even in the CurPol scenario to 24% in 2050. This share is further reduced to 14% in the 1.5°C-Uniform scenario. Biomass (solids and liquids) increases its share in the final energy mix in the NDC-LTS and 1.5°C scenarios, reaching 13% in 2050 in the 1.5°C scenarios, up from 11% in 2019.

[23] https://ourworldindata.org/energy-production-consumption

Figure 10: World total final energy demand by fuels, 1.5°C-Uniform scenario



Source: POLES-JRC model

3.8. Economics of transition

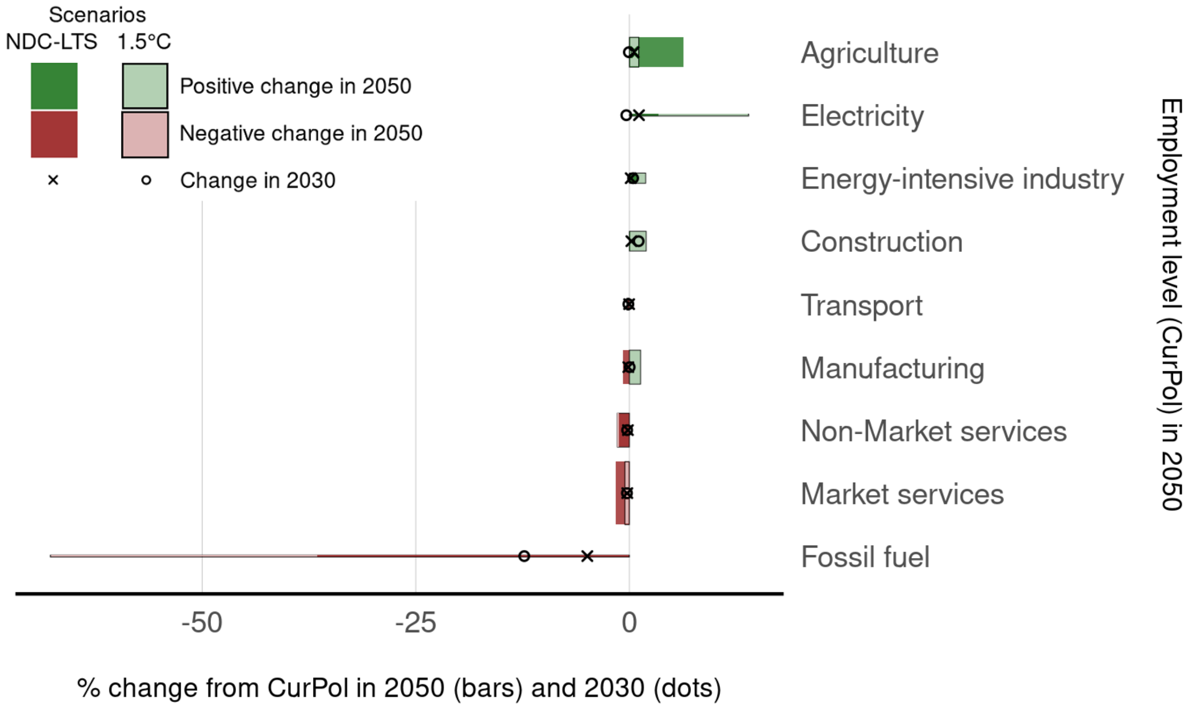
The preliminary work for the economic analysis is carried out using the PIRAMID modelling system (Wojtowicz, et al., 2019) to project input-output tables forward in time. Within the PIRAMID framework, macroeconomic projections and results from POLES-JRC are taken as constraints to provide a consistent baseline and produce a time series of regional input-output tables. Then, the computable general equilibrium (CGE) model JRC-GEM-E3 (Capros, et al., 2013) uses them to assess the macroeconomic effects of NDC-LTS pledges and 1.5°C scenarios in contrast to the projected baseline. Annex 3 provides a description of the JRC-GEM-E3 and a technical discussion of the soft-link between POLES-JRC and the overall economic modelling framework.

The transformation of the energy system described in the previous sections requires significant additional investment to expand the capital stock in clean energy sectors. Investment in the overall economy globally increases under both scenarios (+0.6% under the NDC-LTS and +1.0% under the 1.5°C scenarios, in 2030), with the investment in power technologies standing out as the prime driver of the transition. Under the Current Policies scenario, GDP is projected to grow 2.54% per annum over 2020-2050, whereas under the NDC-LTS and 1.5°C scenarios, GDP growth is projected to be 2.50% per annum. This means that global GDP costs of the decarbonisation transition are less than one percent in 2050, as compared to the Current Polices scenario, mainly driven by a decrease in consumption of -2.0% under both scenarios.

The investment expansion positively affects the employment levels in several sectors. Figure 11 reports the projected changes in global labour demand in 2030 and 2050 by scenario, with the two 1.5°C scenarios merged together. The horizontal axis in Figure 11 presents the change in sectoral employment relative to the Current Policies and the width of the bar represents that sector's level of employment in Current Policies scenario in year 2050. The area of a bar thus corresponds to volume of jobs subject to transition to/from a sector. In our long-term modelling setup, we assume that aggregate employment is stable in the long run, i.e. a perfect labour market with adjustments of wages. In other words, the determinants of unemployment in the long-run are not affected by the climate policy and the net effect on overall employment is zero. Carbon pricing revenues are assumed to be directly recycled by governments to households through lump-sum transfers, as opposed to other recycling options that could potentially affect the labour market (e.g., lowering of labour taxes). Effects of the energy transition within sectors – e.g., structural changes in supply chains, such as those in the production of ICE vehicles to EVs as analysed in GECO 2019 (Keramidas, et al., 2020) – are not captured in the current model structure.

In line with previous work (Vandyck, Keramidas, Saveyn, Kitous, & Vrontisi, 2016), the results in Figure 11 show that sectors facing the strongest decrease in employment represent only a relatively small share of the overall labour market. A global transition of jobs from fossil-fuel sectors to low-carbon oriented sectors is expected, in which the fossil fuel industry experience the greatest losses as compared to the Current Policies scenario, particularly due to the strong activity reduction of the coal sector.

Figure 11: Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios



Source: JRC-GEM-E3 model

As the decarbonisation of the economy advances, electrification and bioenergy offer increasing employment opportunities, particularly in the electricity production and agriculture sectors. Agriculture, as a labour-intensive sector, benefits from employment growth under both scenarios in 2050, led by increased use of bioenergy as an important mitigation option. The deployment of renewable energy systems, along with increased efficiency in the energy systems and enhanced electrification, fosters employment in energy-intensive industry, manufacturing and in the transport sector. As a consequence of the transition in the power sector, green investment positively drives employment levels also in the construction sector, particularly due to the infrastructure expansion required in the energy transition. Service-oriented sectors face growing labour demand under both scenarios, but such growth is slightly lower than projected in our Current Policies scenario. In this respect, the NDC-LTS and 1.5°C scenarios variants represent a certain reindustrialisation of the global economy driven by significant investments and structural changes prompted by the energy transition. Finally, the interpretation of the economic results should account for the caveat that they do not include the benefits of climate policy in the form of avoided climate damages or co-benefits such cleaner air and/or biodiversity preservation.

In terms of changes within global energy supply chains, the analysis of trade flows reveals an increasing concentration in the LNG market into a few exporting countries (e.g. Gulf area and Australia). A similar trend appears in the crude oil market, as exports from Gulf countries and Russia remain relatively stable under the NDC-LTS scenario, while other players (e.g., African countries, Canada and Mexico) lose market share. Global trade of oil products decreases, particularly from main exporters (e.g. exports from the USA decrease avg. -3.4% per annum and from the EU27 -1% per annum over 2020-2050), but the decrease in trade is even stronger for coal, with an average drop of -4.8% per annum under in the 1.5°C scenarios between 2020 and 2050.

4. Regional results

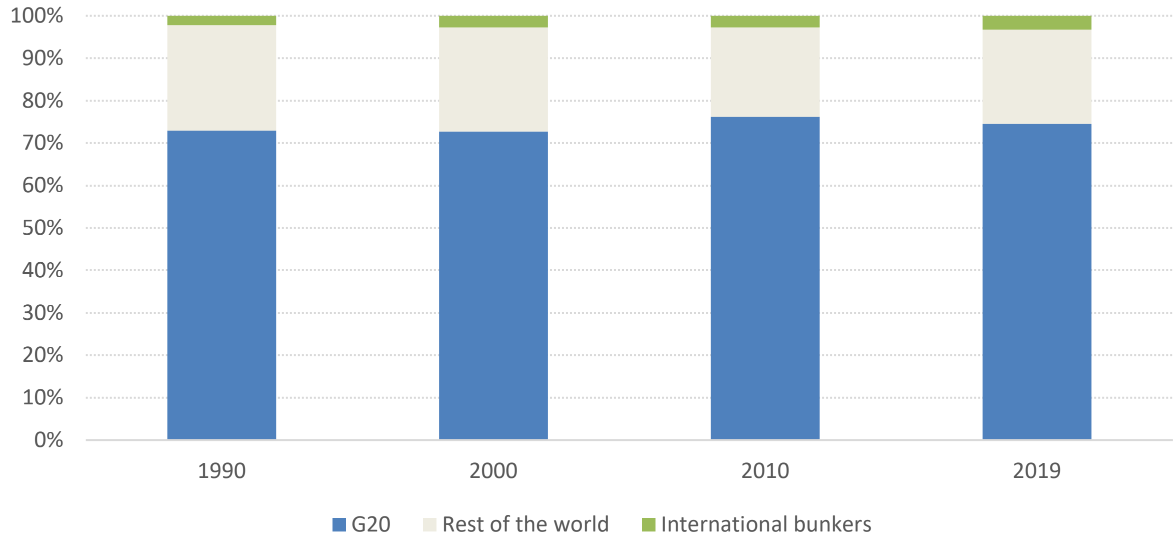
This chapter presents a special focus on the G20 group of countries including 16 countries, the EU with its 27 Member States and the International maritime and aviation bunkers, as listed in Table 1, accounting for around 75% of global GHG emissions, see Figure 12.

Table 1: State of the art analysis of the NDCs and LTSs in G20 countries/regions and international bunkers, ranked by size of emissions

G20 countries	% of world CO_2 emissions, 2019 (excl. LULUCF)	Updated NDC	LTS	Net-zero target
China	31.3%	Strengthened targets	LTS submitted	2060 (CO_2-only)
USA	13.5%	New target for 2030	2016, new 2050 target announced April 2021	2050
EU	8.1%	December 2020 - Strengthened targets	Submitted March 2020	2050
India	6.8%	announced COP26 - Strengthened targets	Announced COP 26	2070
International bunkers	4.3%	n/a	2018 (IMO initial strategy), 2016 (ICAO CORSIA)	
Russia	4.2%	November 2020 - Similar targets	Announced COP 26	2060
Japan	3.2%	October 2021 - Strengthened targets	2016; net zero target announced Oct. 2020	2050
South Korea	1.7%	October 2021 - Strengthened targets	Ratified September 2021	2050
Canada	1.5%	July 2021 - Strengthened targets	2016, new 2050 target announced 2021	2050
Saudi Arabia	1.5%	November 2021 Strengthened targets	Announced COP 26	2060
Indonesia	1.3%	July 2021 - Strengthened LULUCF	Announced October 2021	2060
Mexico	1.3%	December 2020 - Similar targets	2016	50% reduction by 2050 from 2000 levels
Brazil	1.2%	Announced at UN summit - Strengthened targets	Climate neutrality announced	2050 (all GHG)
Turkey	1.1%	2016 submission only	October 2021	2053
South Africa	1.1%	2016 submission only	September 2020	2050 (CO_2 only)
Australia	1.0%	December 2020 - Similar targets	October 2021	2050
UK	1.0%	December 2020 - Strengthened targets	April 2018	2050
Argentina	0.5%	December 2020 - Strengthened targets	Announced December 2020	2050 (CO_2 only)

Source: United Nations Climate change

Figure 12: Share of the G20 and international bunkers in global GHG emissions for the period 1990-2019



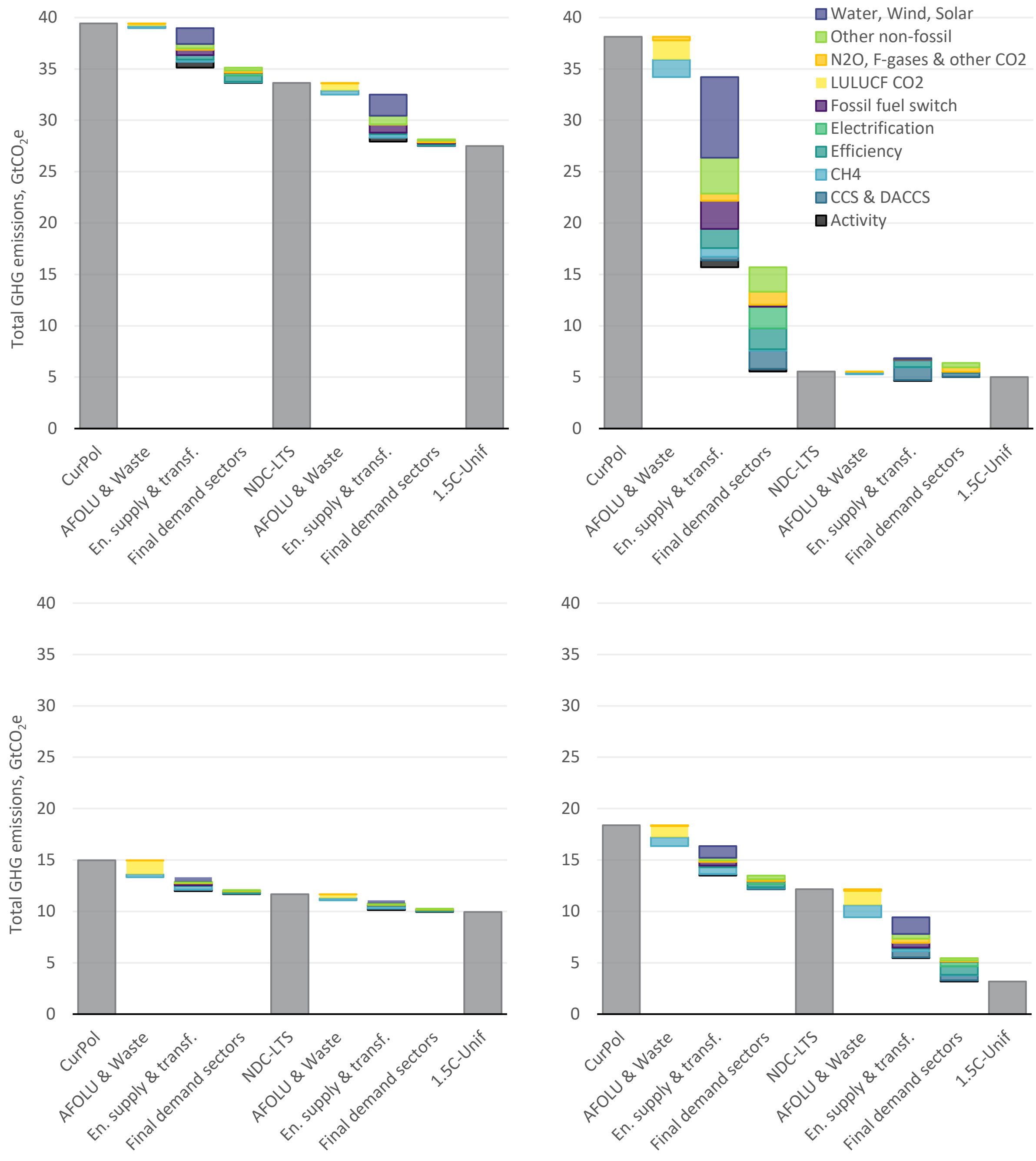
Source: POLES-JRC model

The analysis of the mitigation effort required to move away from the Current Policies pathway to the NDC-LTS, and then to a 1.5°C compatible pathway, reveals interesting patterns when assessed at the regional level. In Figure 13, the available options in 2030 and 2050 are presented, separating G20 countries from non-G20 countries.

In terms of global emissions, G20 countries reduce total emissions in 2030 with respect to CurPol scenario by 15% to reach their NDCs, and an additional 16% compared to CurPol to aim at a 1.5°C trajectory; at the same time, non-G20 countries reduce emissions by 22% and 12% respectively. These relative efforts, although quite similar, reveal very different strategies. In the G20 countries, most of the reduction is achieved by mobilising potential in the energy sector itself: energy supply and demand. The main drivers for this are an important increase in energy efficiency, which triggers a reduction of energy needs, which comes along with a strong penetration of renewables for power generation (Figure 13 top left graph). In non-G20 countries, 50% of the reduction relies on AFOLU (Figure 13 bottom left graph) - more specifically, reduced deforestation. To move ahead towards a 1.5°C pathway in 2030, both G20 and non-G20 regions rely on supply-side mitigation options, strongly based on renewables.

2050 brings in a very different picture. While the global effort in non-G20 countries is still "moderate" to reach the NDC-LTS pathway, up to 34% (Figure 13 bottom right graph), G20 countries achieve reductions up to 85% (top right graph). This is the effect of the implementation of net-zero emissions targets in many of these countries. In our projections, energy supply still provides more than half of the reduced emissions; energy demand-side measures also provide more than one third of the mitigation, with a well-balanced portfolio of switching to less carbon-intensive fossil fuels, alternative transport fuels, electrification, efficiency and CCS in industry. This reflects the diversity of options on the demand-side, across sectors and regions. To be on track with 1.5°C, AFOLU/waste and supply-side options play a relatively bigger role; requiring an additional 10% of emissions reductions compared to the NDC in G20 countries. In non-G20 regions though, a more substantial effort is required to align emissions with a 1.5°C scenario (-74% compared to the NDC-LTS scenario); the main options are AFOLU, renewables for power generation, and demand-side efficiency.

Figure 13: GHG emission growth and mitigations options drivers for G20 countries (above), and non-G20 countries (below) in 2030 (left) 2050 (right) for the 3 analysed scenarios

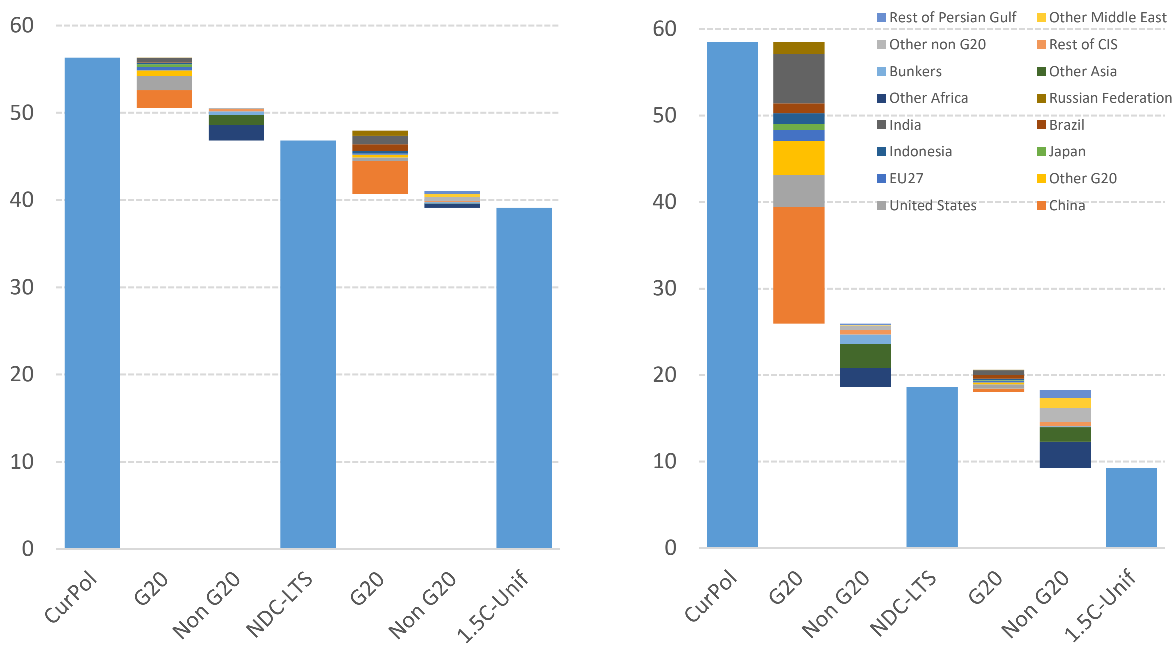


Source: POLES-JRC model

Figure 14 shows the same emission reductions in finer regional detail. In 2030, China and the USA as the largest emitters, also show up as important players in absolute numbers to fill the implementation gap between current policies and announced NDC targets. However, in the 1.5°C scenario, China abates more in the 1.5°C-Uniform scenario. Countries for which the NDC target is not binding (e.g. Russia, India, and Brazil) also do more mitigation in the 1.5°C scenario.

In 2050, several large economies (including China, the USA, the EU, and Japan) that have announced net-zero emission targets for mid-century show large emissions reductions in the NDC-LTS scenario; however, further emission reductions are required from these countries when moving to the 1.5°C-Uniform scenario. For non-G20 countries, there is a stark divide between countries having either an implementation gap or an ambition gap, showing that there is strong heterogeneity on the country level depending on whether ambitious long term targets have been announced.

Figure 14: GHG emission reduction by regions in 2030 (left) 2050 (right) for the 3 analysed scenarios

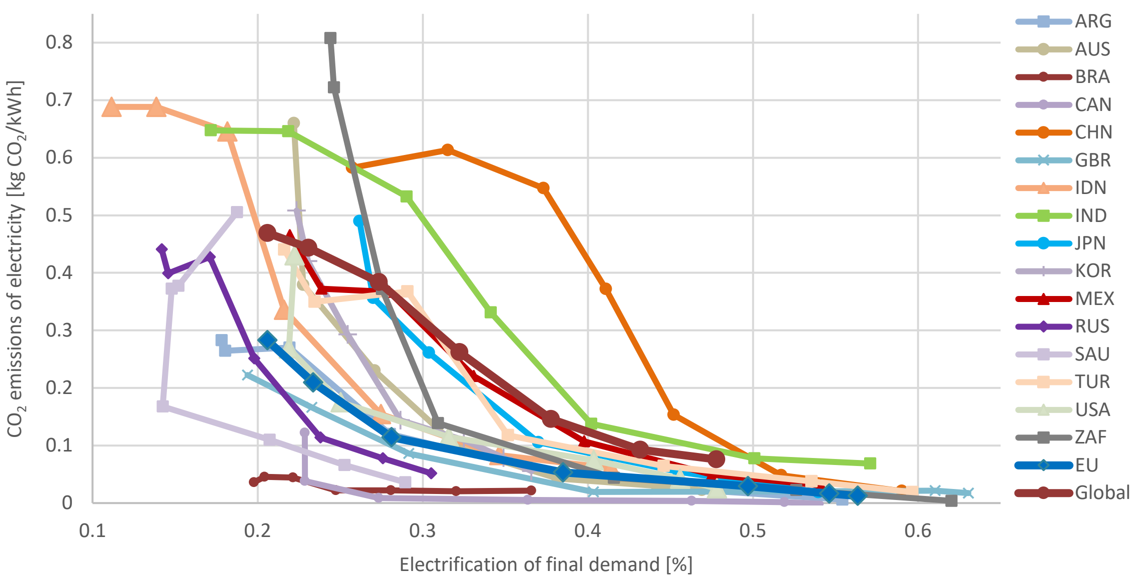


Source: POLES-JRC model

One of the crucial decarbonisation pathways is to substitute fossil fuels in final energy demand with electricity, while simultaneously decarbonize power generation. Currently, countries vary in how they are pursuing these policy measures and the emphasis between these two important transformations over time, see Figure 15 and Figure 16 for the NDC-LTS and 1.5°C scenarios, respectively.

The x-axis shows the electricity share in final demand, whereas the y-axis shows the CO_2-emission intensity of electricity. The top left dot on each line represents 2020, with each dot representing a 5-year time-step progressing towards 2050 in the bottom right corner.

Figure 15: Pathways of decarbonisation in the NDC-LTS scenario



Source: POLES-JRC model

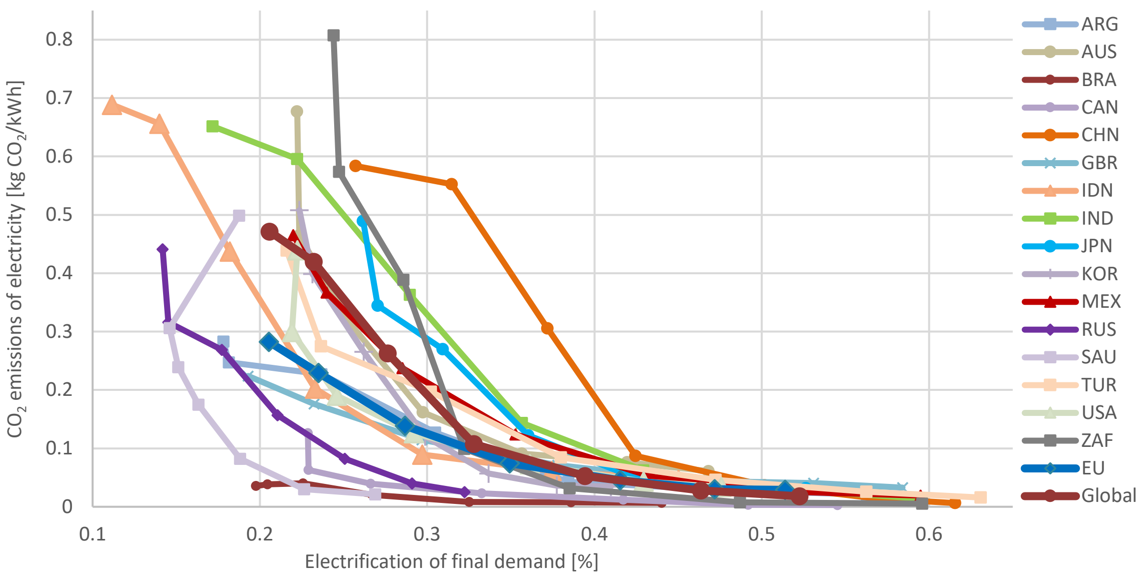
The global evolution of decarbonisation pathways has a reversed S-shape, which is a result of the implementation of NDC pledges and LTS targets. Driven by NDC pledges the global evolution of decarbonisation pathways sees in a high increase of electrification in final demand between 2020 and 2030, while at the same time decarbonisation of electricity takes place at a slower pace. The global decarbonisation pathway fundamentally changes after 2030 when – driven by more stringent climate policies due the LTS targets – the decarbonisation of electricity increases strongly, while electrification of final demand increases at a slower rate. After 2040 the speed of decarbonisation of electricity is slows, while the share of electrification of final demand increases by the same amount as in the decade before.

The comparison between countries on this transition path from 2020 to 2050 in the NDC-LTS scenario shows differing approaches to decarbonisation based on submitted NDCs pledges and LTS targets, as well as on specifics relating to domestic technology costs and fuel prices:

- A high number of – mostly developed - countries differ from the global evolution to a certain extent. They are starting the transition putting more emphasis on reducing CO_2 emissions from electricity between 2020 and 2030, and then accelerated electrification of final demand in the period from 2030 to 2050. This group includes the USA, EU, Japan, Mexico, Great Britain and South Korea.
- On the contrary, China, India, Indonesia and Turkey – and to a certain extent also Russia and Argentina - see a significant increase of electrification in final demand in the coming decade and shifts its focus on reducing the CO_2 emission intensity of electricity in the following years. The evolution of their decarbonisations pathways is more similar to the global evolution. In these countries, while progress is made on reducing CO_2 emissions from power generation by 2050, decarbonisation is also achieved outside of the energy sector, i.e. via land-use and reduction in non-CO_2 gases.
- Brazil and Canada have a low CO_2-emission intensity of their electricity mix already today, and would see a drive of increasing electrification of final demand as the main lever of decarbonisation by 2050.
- Coal oriented countries like South Africa and Australia put very strong focus on reducing CO_2 emissions from power generation in the coming decade and initiate a shift towards electrification of final demand in the period 2030 to 2050.
- Saudi Arabia focuses mainly on reducing CO_2 emissions in the electricity mix.
- While the trajectory of the EU is very similar to the one of USA it might differ among the Member States, depending on their power generation structure, e.g. France follows the trends of Brazil and Canada due to its high levels of nuclear in electricity production.

The comparison between countries in the 1.5°C scenario in Figure 16 shows that the development of the pathways is much more harmonised: the stringency of the 1.5°C scenario requires all countries to pursue both renewables and electrification with increasingly ambitious targets and at similar, harmonised rates.

Figure 16: Pathways of decarbonisation in the 1.5°C-Uniform scenario

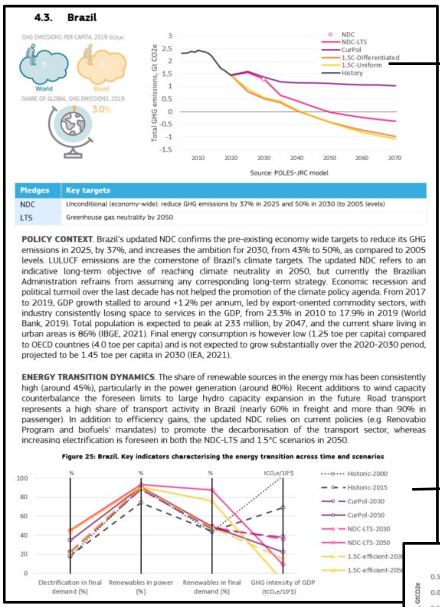


Source: POLES-JRC model

The S-shape of the global evolution pathways and the appearance of country groups with differing decarbonisation approaches vanishes in the pursuit of the 1.5°C target, as all countries first push to reduce the CO_2-emission intensity of the electricity mix in the period from 2020 to 2035, with most countries achieving a largely decarbonised electricity mix between 2030 to 2040. Simultaneously, effort is required over the whole projection period, from 2020 to 2050, to increase electrification in final demand. Measured rates on the two processes are needed, as a quick electrification without a matching acceleration of power decarbonisation would produce incentives to turning back again to fossil fuelled power plants, a much undesirable effect.

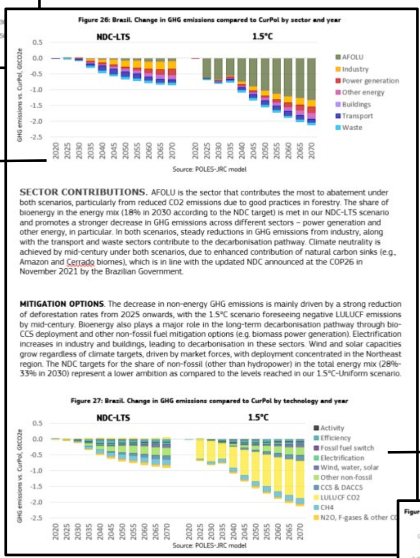
The remainder of the Regional results section goes into more detail of individual G20 members. The profiles by country/region provide specific policy context, indicators and economic information. They also include the GHG emissions projections by country/region according to the CurPol, NDC-LTS, and 1.5°C scenarios. Moreover, sectoral contributions and mitigation options based on country-specific indicators are highlighted by comparing the NDC-LTS, and 1.5°C scenarios to the CurPol scenario. The definitions of the sectoral and technological options in mitigation displayed in the country sheets are provided in Annex 4 and Annex 5 guide on how to read the country sections is provided on the next page.

Figure 17: How to read the country sheets



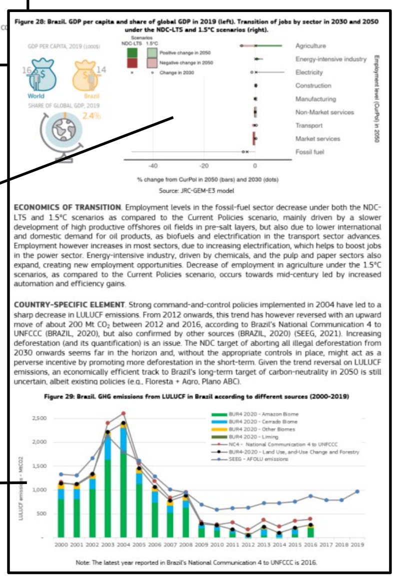
Greenhouse gas emission projections through to 2070 by scenario.#

Key decarbonisation indicators along 4 vertical axes. The first axis gives the share of final demand met by electricity, the second axis shows the share of power generation that is renewable. The third axis sums both the share of renewables in final demand and the share of final demand that is met by renewable electricity, providing an indication of overall renewables contribution to final demand. The fourth axis gives the GHG intensity of GDP. This representation allows a comparison between the role of the first 3 decarbonisation levers between scenarios and over the time period.



A discussion of results broken down by sector, aided with a 'wedges' chart showing the relative contribution of emissions reductions in the NDC-LTS and 1.5°C-Uniform scenarios compared to the Current Policies scenario.*

A discussion and 'wedges' chart presenting the emissions reductions in the NDC-LTS and 1.5°C scenarios relative to the Current Policies scenario, broken down by mitigation options, highlighting, for instance, the role of non-CO_2 gases.**



The results of the emissions scenarios on employment and the economy, showing the change in employment level relative to the Current Policies scenario (horizontal axis) in main economic sectors, where the width of the bar represents that sector's level of employment in Current Policies scenario in 2050. The area of a bar corresponds to employment subject to transition to/from a sector.

Where relevant, the country sections finish with a discussion of important country-specific issues with additional ex-model analysis.

LULUCF emissions refer from 1990 - 2004 to GHG inventories (historic); from 2005 onwards they are derived from the specialized GLOBIOM model (soft-link to POLES-JRC). Major mismatches in LULUCF emissions (globally about 5.5 $GtCO_2\,yr^{-1}$ for 2005–2015) exist between GHG inventories and global land-use carbon flux models (such as GLOBIOM) which can be attributed to methodological and perimeter differences in establishing emissions and sinks estimates (Grassi, et al., 2021; Grassi, et al., 2018). Due to these differences, the LULUCF and total emissions by country displayed here may be different compared to GHG inventory data from 2005-2019.

* AFOLU = Agriculture, Forestry and Other Land Use. Includes emissions from agriculture (CH_4, N_2O) and LULUCF (CO_2)

** A detailed description of what is included in the sectors and mitigation options are available in Annex 4 and Annex 5 Other non-fossil includes nuclear, biomass, geothermal, and hydrogen.

4.1. Argentina

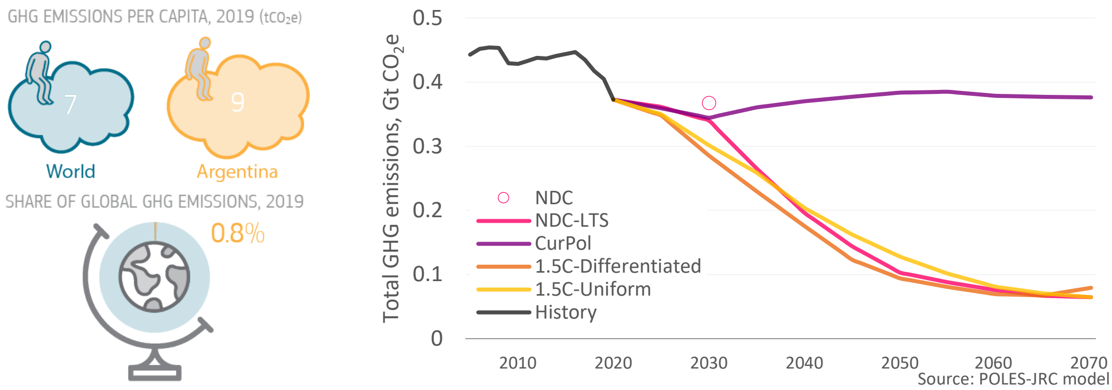


Figure 18: Argentina. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Economy-wide target to reduce GHG by 19% below 2007 levels by 2030
LTS	CO_2 neutral by 2050

POLICY CONTEXT. In 2017, Argentina had 300MW of wind and solar capacity, which increased to 2GW in 2019. Despite this strong growth, Argentina is still far from its target of 16% renewables in final energy consumption by 2021 (9% in 2020). In April 2021, Argentina announced its goal of reaching 25% of renewable electricity by 2030. In December 2020 Argentina updated its NDC targets, with stronger GHG reduction pledges (an absolute, economy-wide target of reducing GHG emissions by 19% in 2030 relative to 2007 levels). The increased mitigation ambition also represents a 26% emission reduction compared to Argentina's previous 2030 emission target. However, the new emission target for 2030 is on par with the most recent GHG inventory data (364 $MtCO_2e$ in 2016). In April 2021, Argentina signalled its intention to enhance by an extra 2% the mitigation ambition, which would amount to a 27.7% reduction of emissions compared with the previous NDC. Argentina was expected to present its LTS to achieve carbon neutrality in 2050 at the COP26 in November 2021, but although this has been postponed to 2022, its pledges have been included in this report at the NDC-LTS scenario.

ENERGY TRANSITION DYNAMICS. Meeting Argentina's emission reduction target in 2030 requires minimal effort. The relatively modest emission reduction targets by 2030 leave a large gap for meeting 1.5°C target in 2050, where significant transformation is needed on electrification and on increasing the share of renewables in the power sector and in final demand (around 60%) to achieve 1.5°C target, see Figure 19. Gas, that has dominated the power sector, peaks in 2030, and is almost phased-out in 2050 for all the climate policy scenarios. From 2030 onwards, the share of fossil fuels continues its decline in all scenarios – allowing for a higher share of renewables and a boom in nuclear.

Figure 19: Argentina. Key indicators characterising the energy transition across time and scenarios

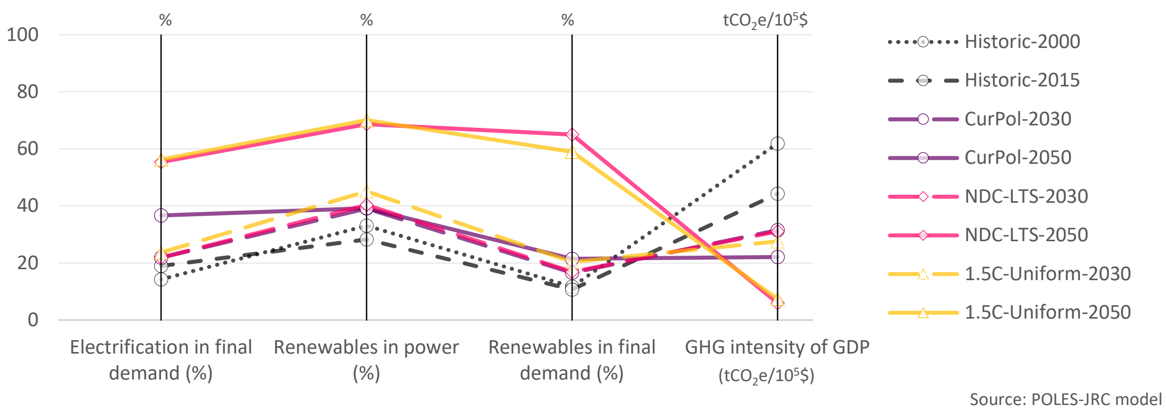
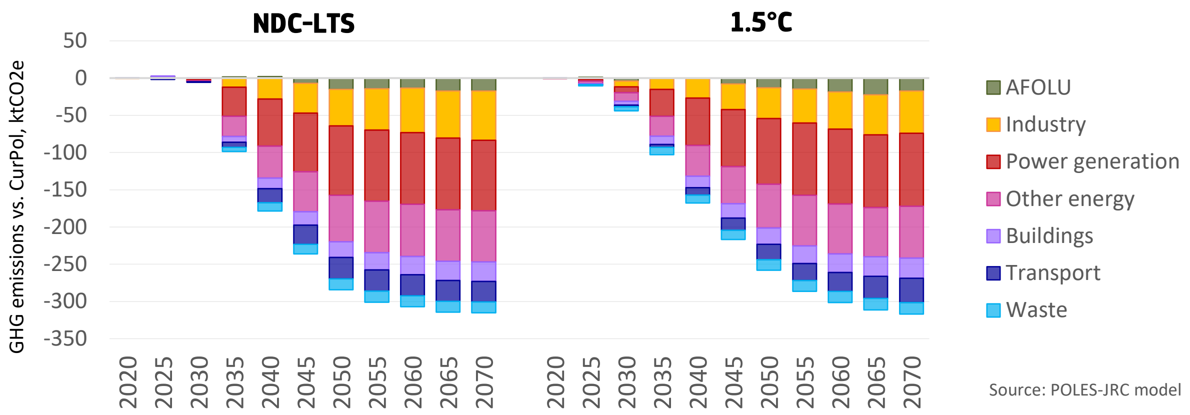


Figure 20: Argentina. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. Meeting Argentina's NDC target in 2030 does not require significant effort by any sector. The second NDC updated in 2020 proposed 35-adaptation measures, divided into crosscutting and sectoral measures. These measures include structural changes for a sustainable transformation in agriculture, industry and services. During COP26 Argentina announced its LTS targets, zero carbon by 2050. Therefore, the NDC-LTS scenario is aligned with the Paris Agreement objectives of maintaining the temperature below the 2°C by the end of the century. Reaching this emission reduction relies, especially in the short term, on the power sector, and from 2040 it involves the contribution of the other economic sectors. The pathways outlined included spurring renewable power, using energy more efficiently, transforming the country's giant agriculture sector (cattle farming accounts for about 22% of emissions in 2018 (FAO & New Zealand Agricultural Greenhouse Gas Research Centre, 2017), and promoting forestry, see Figure 20.

MITIGATION OPTIONS. The increasing use of renewable sources is the main mitigation driver for emissions reduction in the energy and industrial sector. Followed by electrification of the final energy demand, energy efficiency measures. The reduction of non-CO_2 GHG with high global warming potentials, such as HFCs, CH_4 and N_2O are also exploited in the climate policy scenarios. Argentina is part of the Global Methane Pledge, a coordinated international effort to cut methane emissions by 30% by 2030, compared with 2020 levels. Argentina has the potential for large methane emission reductions in the hydrocarbons sector. Furthermore, the fossil-fuel dominated power sector sees a shift to renewable and nuclear sources being the main driver for the decarbonisation, Figure 21.

Figure 21: Argentina. Change in GHG emissions compared to CurPol by technology and year

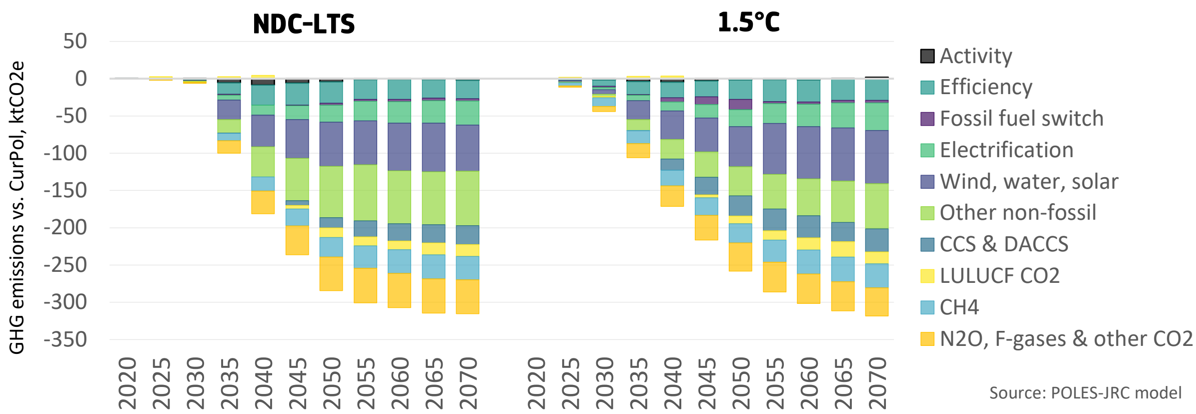
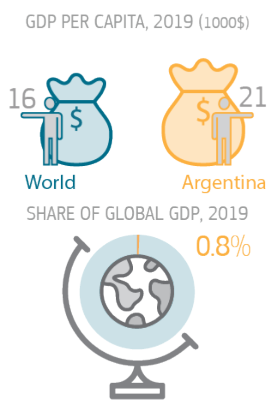
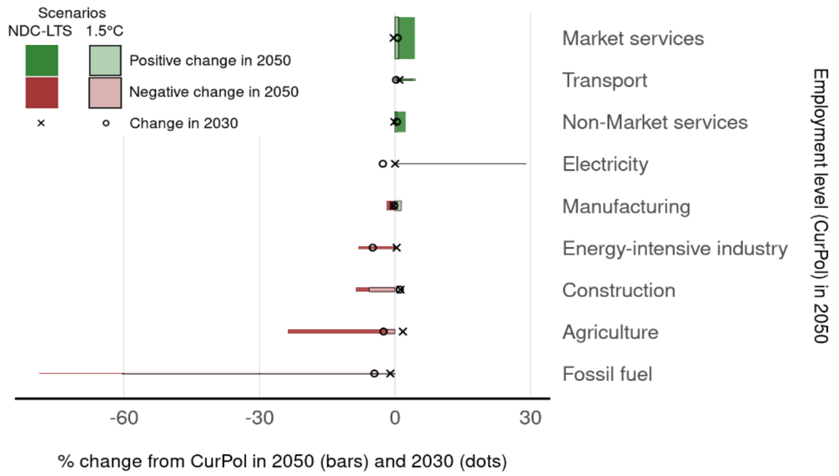


Figure 22: Argentina. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).





Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. In the Current Policies scenario, an increasing production of shale gas (e.g. Vaca Muerta field) still attracts workers from other sectors to the oil industry. However, especially under the 1.5°C scenarios, the employment levels in the fossil-fuel sector decrease, mainly driven by the constrained development of the shale gas prospects. Substantial changes are observed in the employment level of the natural gas sector with a decrease of 68% as compared to CurPol. The lower activity in the fossil fuel industry under the 1.5°C scenarios also affects the construction sector and has substantial impact on the service-oriented sectors, which see activity growth. Export-oriented production of crops (e.g., wheat, soybeans, corn) grow (+2% as compared to CurPol under the 1.5°C scenario in 2050), meeting increasing international demand and promoting employment, but not enough to counterbalance the decrease in demand from the livestock sector, which leads to an overall reduction of employment levels in agriculture. Also, investment in renewable energy systems and increased electrification contribute to greater employment levels in the related sectors.

ARGENTINA: BETWEEN SHALE GAS AND CLIMATE GOALS. Since the Paris Agreement 2015, fracking has been one of the hotly debated topic for oil and gas producing countries. Argentina continues to tap the world's second-biggest shale gas reserves in Vaca Muerta. Oil and gas production, which declined during the pandemic, has rebounded, reaching a record high of 200 thousand oil barrels per day in July 2021 according to the Ministerio de Energia y Recursos Naturales de Neuquén, with a target of 230 thousand barrels per day for December 2021. On this trend, Argentina's energy plans foresee doubling the production of oil and gas in 5 years, despite Argentina's Paris Agreement target of cutting emissions by 19% from 2007 levels by the end of the decade.

On the other side, Argentina's updated NDC (November 2021) means an opportunity to transform the Argentinian energy system. The deployment of renewable energy has been supported since 2016 by the government, via an auction system known as RENOVAR. Through this programme, mainly large wind farms and solar PV parks flourished in some of the best wind and solar locations in the world: (the southern coastal regions for wind power, and to the north, the Atacama Desert, which has some of the world's best solar irradiation sites), helping make wind and solar the country's cheapest unsubsidised sources of energy. This has made Argentina one of the most promising renewable energy markets in the world; an opportunity that can open the door to significant renewable investments. Similar to many countries, Argentina is facing the debate between further profiting from carbon intensive industries or addressing climate change targets and accelerating its transition to renewable energy.

4.2. Australia

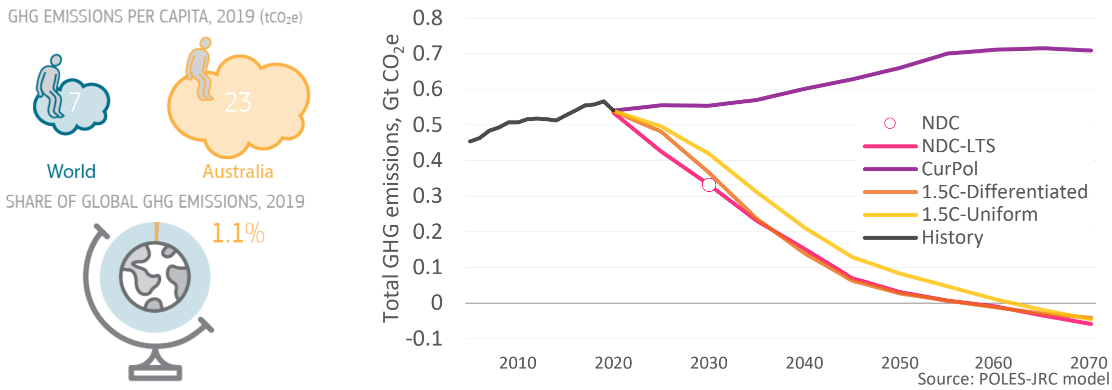


Figure 23: Australia. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Economy-wide target to reduce GHG by 26/28% below 2005 levels by 2030
LTS	Net zero GHG emissions by 2050 (announced in October 2021, included in this report)

POLICY CONTEXT. Australia, one of the world's largest exporters of coal, natural gas and uranium, relies extensively on fossil fuels to satisfy its energy needs. In 2019, oil accounted for the largest share of the primary energy mix (39%), followed by coal (29%) and natural gas (26%), while renewables had a modest share (6%). Fossil fuels also account for a significant share in power generation (79% in 2019). Emissions have modestly declined between 1990 and 2019 (-16%), driven by a substantial reduction from LULUCF activities (-113%), reflecting improvements in deforestation compared to past trends. However, when LULUCF emissions are excluded, total emissions rose by 27%. This is primarily driven by a substantial increase in emissions from the energy sector (46%), reflecting the high carbon content of the energy mix. The country first communicated its NDC under the COP21, committing to an economy-wide target to reduce GHG emissions by 26-28% below 2005 levels by 2030. A net-zero by 2050 LTS was announced at COP26. The analysis presented here indicates that beyond current policies on renewables and deployment of clean technology, quick and major action is required to reach the emissions reduction goals.

ENERGY TRANSITION DYNAMICS. Meeting the country's 2030 target requires the share of renewables in final demand and power generation to rise considerably. Despite the substantial improvements of recent years, the current share of renewables in power generation (21%) is low compared with Australia's significant wind and solar resources. A decarbonised power system, combined with increased electrification of final demand can lower the emission intensity of final demand sectors that are highly dependent on electricity, such as the aluminium industry. According to the GECO 2021 scenarios, the industry sector sees a strong push for electrification, followed by the building and transport sectors.

Figure 24: Australia. Key indicators characterising the energy transition across time and scenarios

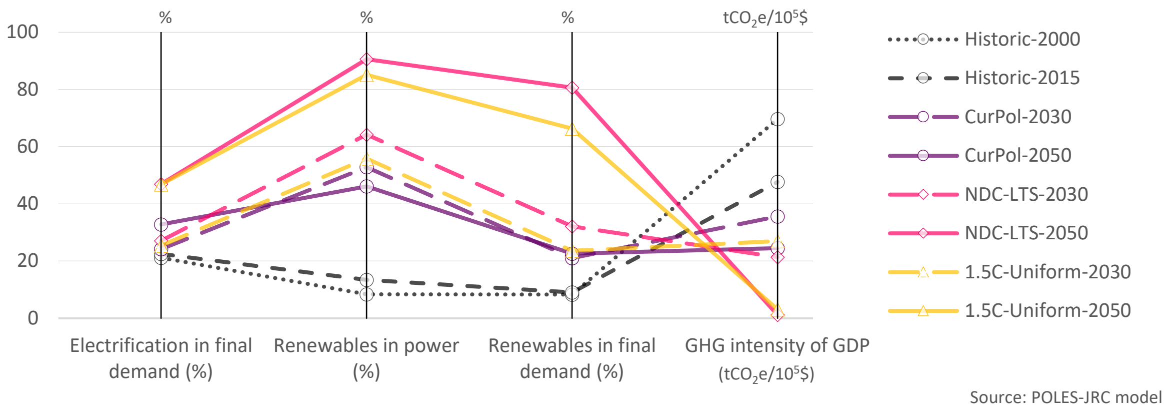
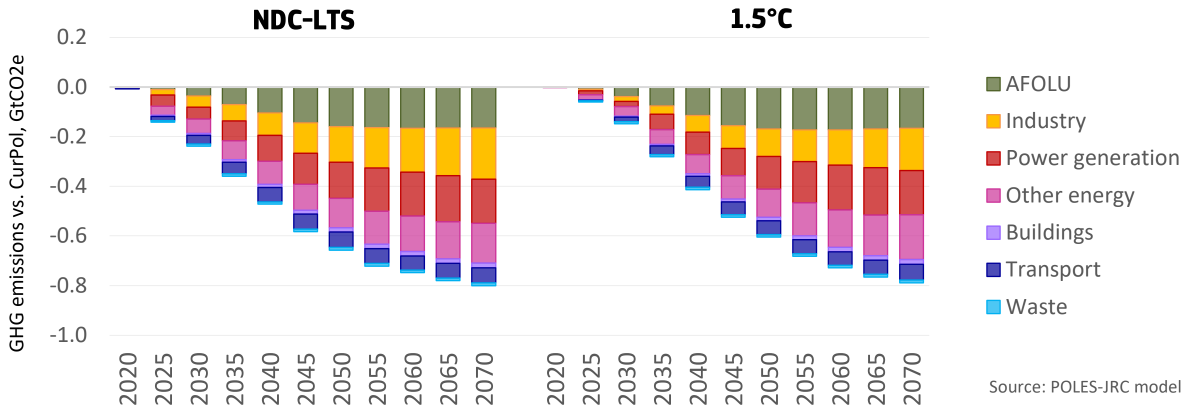


Figure 25: Australia. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. The energy sector, which is the most significant contributor to GHG emissions, represents the country's highest potential for emission reductions. Particularly, the power generation sector, which has witnessed decreasing coal use in the past decade (-18%), requires further decarbonisation efforts. Although the role of coal in the overall energy supply has declined in the past decade, this major coal producer and world-leading exporter also has potential for emission reductions in processes such as coal mining (underground and surface), fugitive emissions and, in general, in primary energy transformation processes. Beyond the substantial opportunities provided from decarbonising the energy sector, other emissions reduction opportunities exist in the industry, AFOLU and transport sectors. Avoided deforestation remains the major driver for emissions reductions in the AFOLU sector, and, the road (light and heavy vehicles) and maritime segments are key for transport.

MITIGATION OPTIONS. The diversification of power generation entails coal being replaced by renewable sources (mainly wind and solar), whose penetration pace speeds up compared to recent years. The share of renewables in the generation mix grew from 9% to 21% between 2009 and 2019, driven by the Renewable Energy Target Scheme which required delivering 33 TWh of large-scale renewable energy by 2020 (met in January 2021). For the AFOLU sector, improved forest management is the major mitigation option. Regarding the industry and transport sectors, energy efficiency is the primary driver for emission reductions. Furthermore, in transport, electrification and a switch to lower-emission fuels such as biofuels, e-fuels, and hydrogen are crucial in the long term, particularly regarding the road (light and heavy vehicles) and maritime segments. Concerning the deployment of emerging low-emissions technologies, the country's Technology Investment Roadmap prioritises investments towards key emerging technologies, including clean hydrogen, energy storage, and carbon capture and storage.

Figure 26: Australia. Change in GHG emissions compared to CurPol by technology and yea

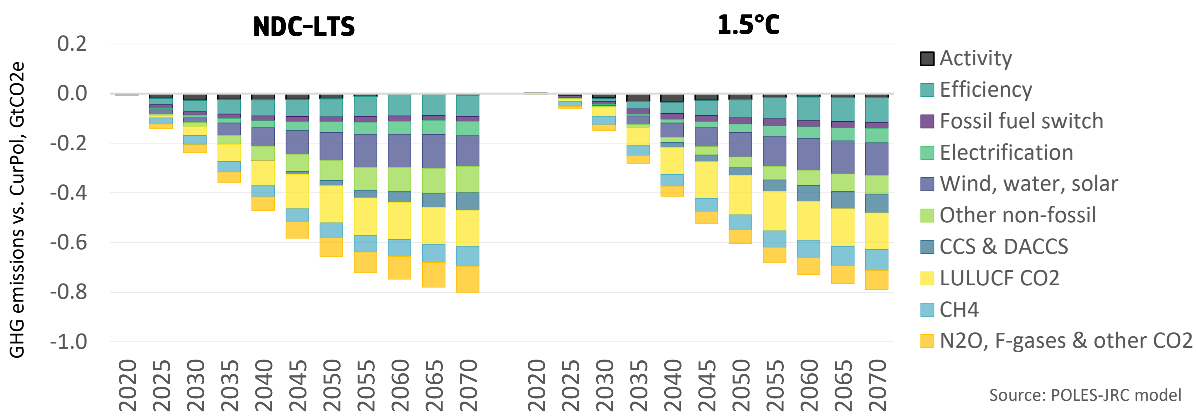
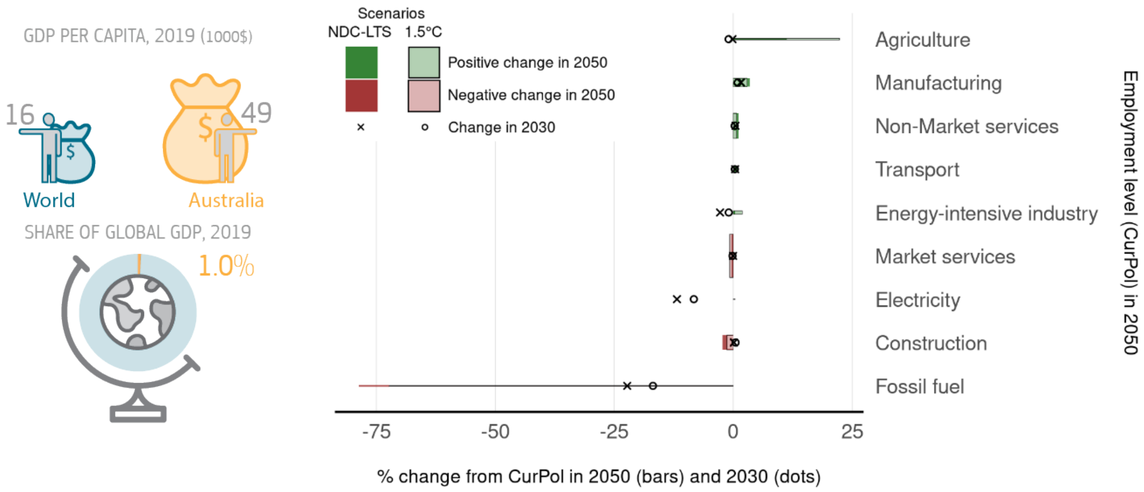


Figure 27: Australia. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Australia experienced a decrease in employment in the fossil fuel industry in the 2012-2018 period, driven by the coal-mining sector (ABS, 2021). However, as the economy decarbonises, a strong decrease in the number of jobs in the coal sector is foreseen under both the NDC-LTS and the 1.5°C scenarios. In the natural gas sector, employment levels remain relatively stable until 2040, in line with the role that natural gas plays in the mid- and long-run, while a steeper reduction occurs after 2040.

Agriculture and manufacturing stand out as the main sectors absorbing jobs from the fossil fuel industry as the economy moves towards decarbonisation. Crop exports (e.g., wheat, wool) face an average increase of +6.5% under both scenarios as compared to CurPol in 2030. The non-market services and the transport sectors also contribute by covering some job losses from construction and, to a lesser degree, from market services, particularly under the 1.5°C scenarios.

4.3. Brazil

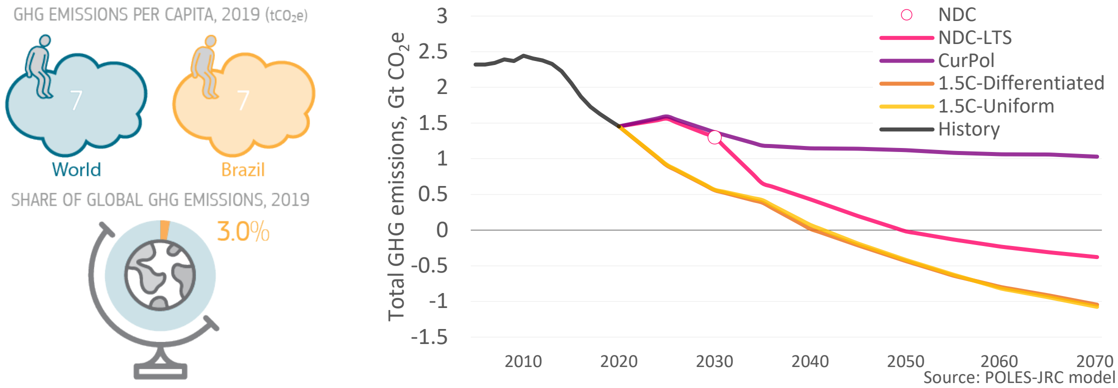


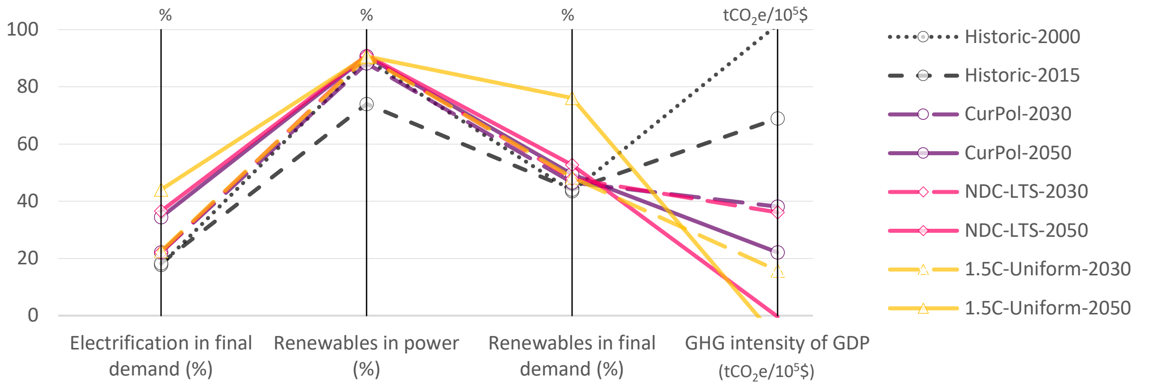
Figure 28: Brazil. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Unconditional (economy-wide): reduce GHG emissions by 37% in 2025 and 50% in 2030 (to 2005 levels)
LTS	GHG neutrality by 2050

POLICY CONTEXT. Brazil's updated NDC confirms the pre-existing economy wide targets to reduce its GHG emissions in 2025, by 37%, and increases the ambition for 2030, from 43% to 50%, as compared to 2005 levels. LULUCF emissions are the cornerstone of Brazil's climate targets. The updated NDC refers to an indicative long-term objective of reaching climate neutrality in 2050, but refrains from proposing any corresponding long-term strategy. Economic recession and political turmoil over the last decade has not helped the promotion of the climate policy agenda. From 2017 to 2019, GDP growth stalled to around +1.2% per annum, led by export-oriented commodity sectors, with industry consistently losing space to services in the GDP, from 23.3% in 2010 to 17.9% in 2019 (World Bank, 2019). Total population is expected to peak at 233 million, by 2047, and the current share living in urban areas is 86% (IBGE, 2021). Final energy consumption is however low (1.25 toe per capita) compared to OECD countries (4.0 toe per capita).

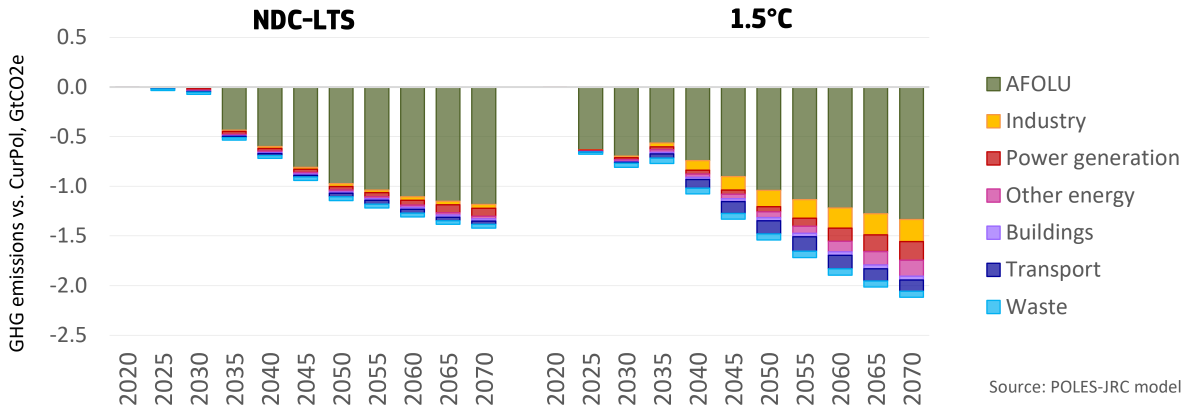
ENERGY TRANSITION DYNAMICS. The share of renewable sources in the energy mix has been consistently high (around 45%), particularly in power generation (around 80%). Recent additions to wind capacity counterbalance the foreseen limits to large hydro capacity expansion in the future. Road transport represents a high share of transport activity in Brazil (nearly 60% in freight and more than 90% in passenger). In addition to efficiency gains, the updated NDC relies on current policies (e.g. Renovabio Program and biofuels' mandates) to promote the decarbonisation of the transport sector, whereas increasing electrification is foreseen in both the NDC-LTS and 1.5°C scenarios in 2050.

Figure 29: Brazil. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 30: Brazil. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. AFOLU is the sector that contributes the most to abatement under both scenarios, particularly from reduced CO_2 emissions due to improved forestry practices. The share of bioenergy in the energy mix (18% in 2030 according to the NDC target) is met in our NDC-LTS scenario and promotes a stronger decrease in GHG emissions across different sectors – power generation and other energy, in particular. In both scenarios, steady reductions in GHG emissions from industry, along with the transport and waste sectors contribute to the decarbonisation pathway. Climate neutrality is achieved by mid-century under both scenarios, which is in line with the updated NDC announced at the COP26 in November 2021 by the Brazilian Government, especially due to enhanced contribution of natural carbon sinks (e.g., Amazon and Cerrado biomes).

MITIGATION OPTIONS. The decrease in non-energy GHG emissions is mainly driven by a strong reduction of deforestation rates from 2025 onwards, with the 1.5°C scenario seeing negative LULUCF emissions by mid-century. Bioenergy also plays a major role in the long-term decarbonisation pathway through bio-CCS deployment and other non-fossil fuel mitigation options (e.g. biomass power generation). Electrification increases in industry and buildings, leading to decarbonisation in these sectors. Wind and solar capacities grow regardless of climate targets, driven by market forces, with deployment concentrated in the Northeast region. The NDC targets for the share of non-fossil (other than hydropower) in the total energy mix (28%-33% in 2030) represent a lower ambition compared to the levels reached in our 1.5°C-Uniform scenario.

Figure 31: Brazil. Change in GHG emissions compared to CurPol by technology and year

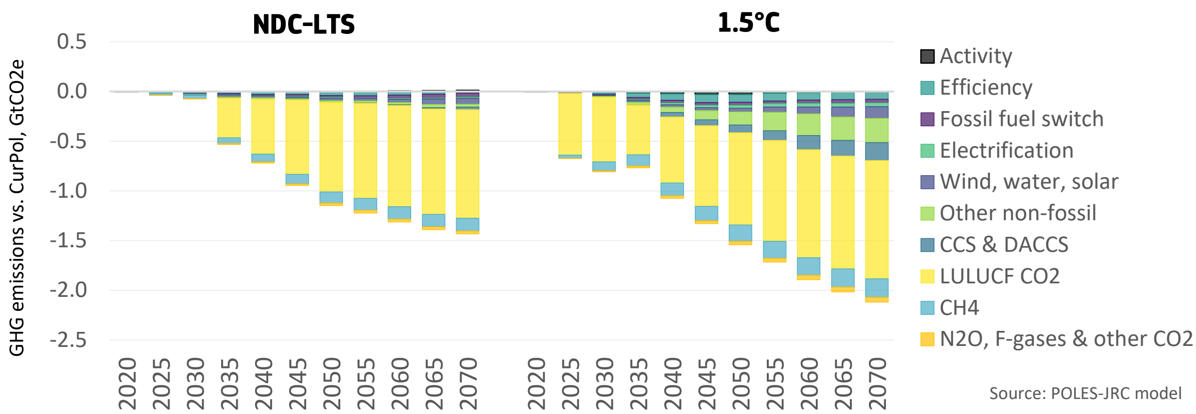
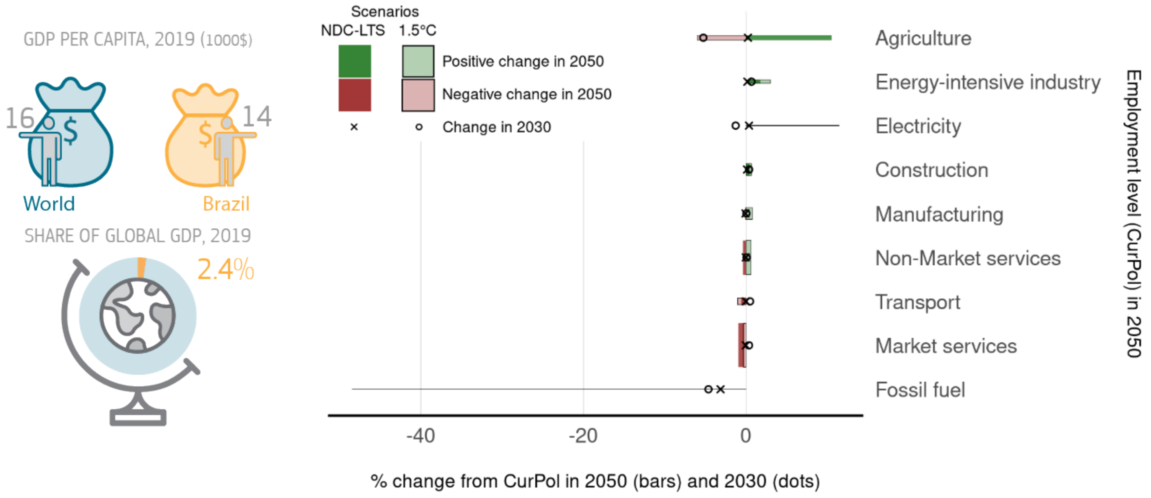


Figure 32: Brazil. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).

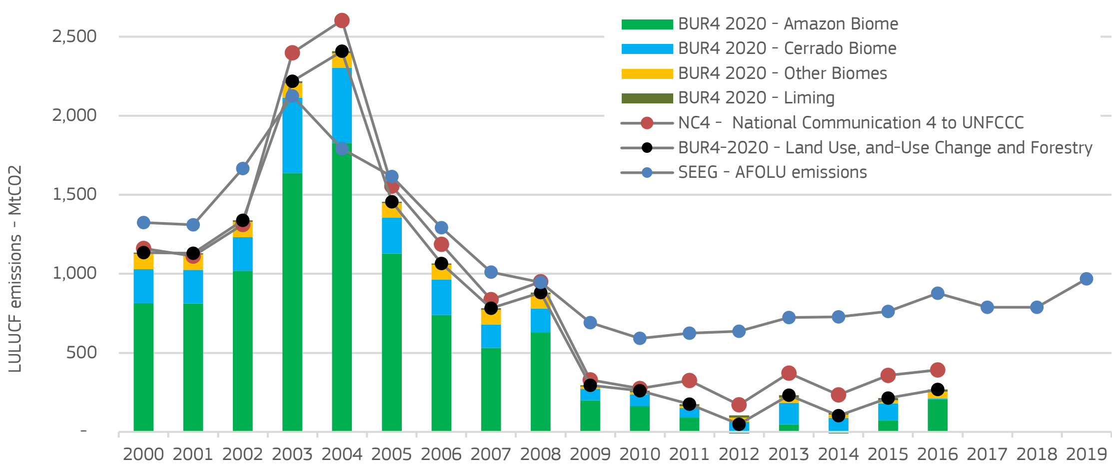


Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Employment levels in the fossil-fuel sector decrease under both the NDC-LTS and 1.5°C scenarios as compared to the Current Policies scenario, mainly driven by a slower development of offshores oil fields in pre-salt layers, but also due to lower international and domestic demand for oil products, as biofuels and electrification in the transport sector advances. Employment however increases in most sectors, due to increasing electrification, which helps to boost jobs in the power sector. Energy-intensive industry (driven by chemicals) and the pulp and paper sectors also expand, creating new employment opportunities. A decrease of employment in agriculture under the 1.5°C scenarios, as compared to the Current Policies scenario, occurs towards mid-century led by increased automation and efficiency gains.

COUNTRY-SPECIFIC ELEMENT. Strong command-and-control policies implemented in 2004 have led to a sharp decrease in LULUCF emissions. From 2012 onwards, this trend has however reversed with an upward move of about 200 Mt CO_2 between 2012 and 2016, according to Brazil's National Communication 4 to UNFCCC (BRAZIL, 2020), but also confirmed by other sources (BRAZIL, 2020) (SEEG, 2021). Increasing deforestation (and its quantification) is an issue. The NDC target of aborting all illegal deforestation from 2030 onwards seems far in the horizon and, without the appropriate controls in place, might act as a perverse incentive by promoting more deforestation in the short-term. Given the trend reversal on LULUCF emissions, an economically efficient track to Brazil's long-term target of carbon-neutrality in 2050 is still uncertain, in spite of existing policies (e.g., Floresta + Agro, Plano ABC).

Figure 33: Brazil. GHG emissions from LULUCF in Brazil according to different sources (2000-2019)



Note: The latest year reported in Brazil's National Communication 4 to UNFCCC is 2016.

4.4. Canada

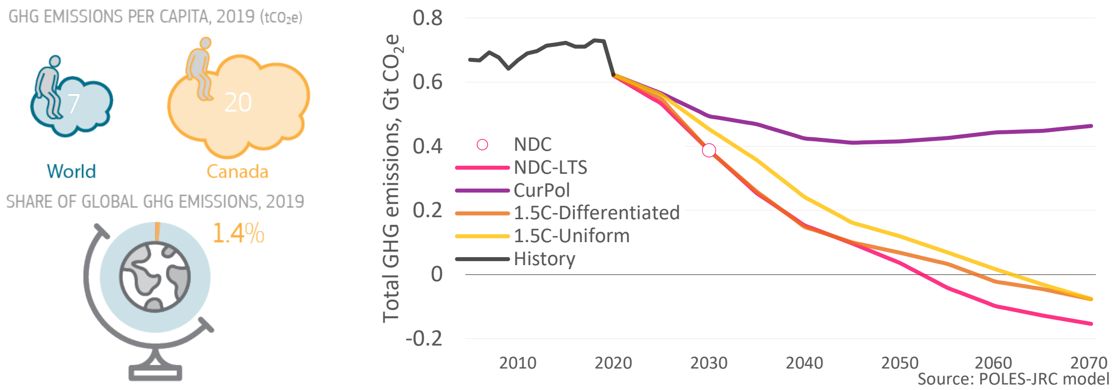


Figure 34: Canada. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Unconditional: -40/45% GHG compared to 2005
LTS	Climate neutral by 2050

POLICY CONTEXT. Canada is an important oil and gas producer, ranking 5th and 4th worldwide in each market. Despite its vast fossil fuel endowment, the Canadian power generation mix is rather climate-friendly. More than half of the electricity generation is based on hydro and, together with nuclear and other renewables; more than 80% of the electricity produced is low-carbon. The country has exhibited a declining GDP-emission-intensity trend in the last decades attributable to various macroeconomic and technological factors. The main drivers for rising GHG emissions are the oil and gas and transport sectors, whereas the industry and power generation sectors have contributed to substantial emission reductions. Canada submitted its NDC in 2016, committing to an unconditional economy-wide target of reducing GHG emissions by 30% in 2030 compared to 2005. The Pan-Canadian Framework on Clean Growth and Climate Change, adopted in 2016, sketches key actions for achieving the 2030 objectives and paves the way towards a climate-neutral economy by 2050. Recently, the government announced its willingness to commit to increasing its ambition for 2030 to reduce emissions by 40/45% compared to 2005 reaffirming its LTS.

ENERGY TRANSITION DYNAMICS. The present share of renewables in the power mix is relatively high (around two-thirds), extensively relying on hydropower, with only limited wind and solar shares. Nevertheless, increasing this share with a more diversified portfolio of renewable sources would be crucial to reach the strengthened, more ambitious 2030 target. Renewables in final demand play an essential role in the ongoing transition towards carbon-neutrality. It is perhaps in this aspect where significant efforts are required to close the gap. According to the GECO 2021 results, increasing electrification in final demand in industry plays a significant role in reaching the targets. The buildings (mainly space and water heating) and transport (mainly heavy vehicles) sectors also benefit from electrification.

Figure 35: Canada. Key indicators characterising the energy transition across time and scenarios

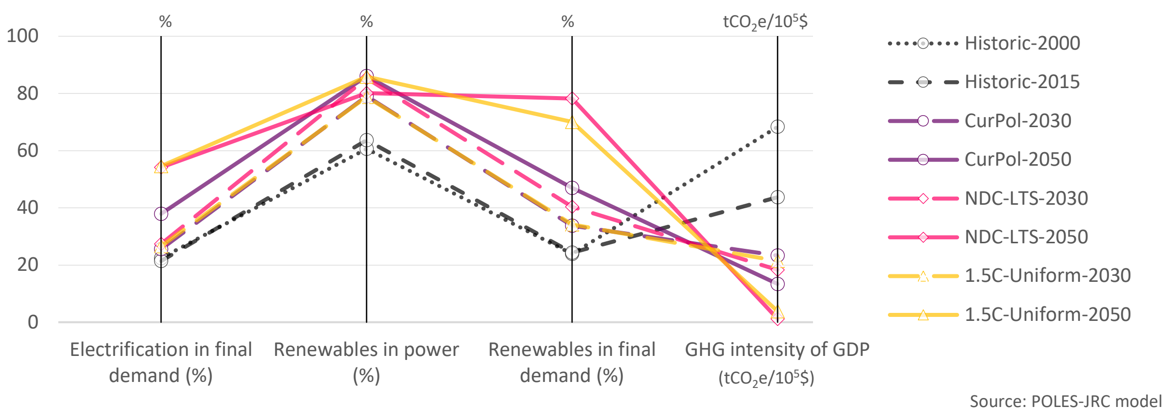
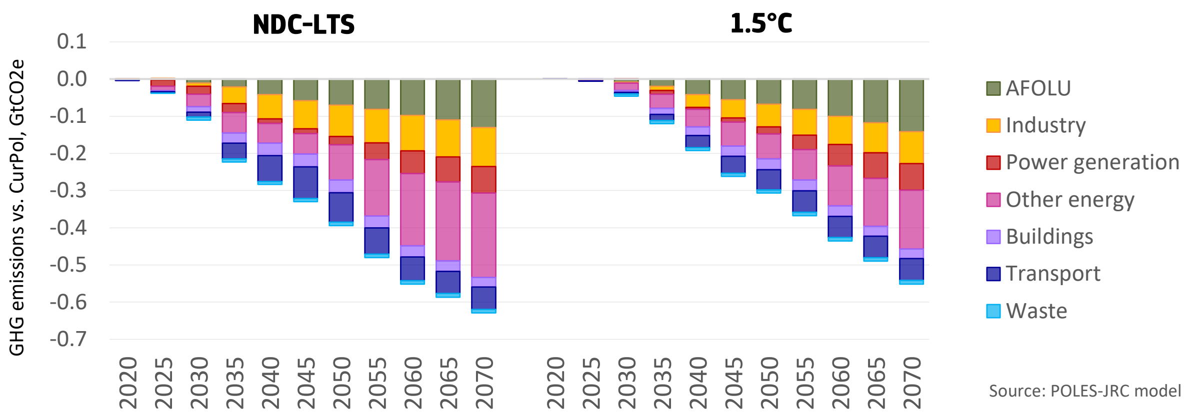


Figure 36: Canada. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. Most of Canada's GHG emissions come from the energy extraction and transformation sectors (other than power generation), with oil and gas accounting for a quarter of total emissions. Hence, drilling and fossil fuel processing represents an essential opportunity for emission reductions (key is the oil-sands industry, which is highly energy-intensive). Contrary to the majority of countries analysed, the already low-carbon content of the Canadian electricity mix sees initial emission reductions efforts focussed on other sectors. Nevertheless, the target of phasing out coal power by 2030 together with increased electrification in final demand call for a more significant penetration of renewables other than hydro. These options currently play only a minor role in the power sector. The AFOLU sector offers opportunities mainly in the form of improved forest management and, to a lesser extent, from agriculture, deforestation and other land-use changes. Finally, the industry (mainly light industries, e.g. machine and equipment manufacturing) and transport (mainly road heavy vehicles) sectors provide further opportunities for emission reductions via fuel substitution and optimisation of processes.

MITIGATION OPTIONS. Regarding emission reductions in the extraction and processing of energy, the scenarios studied indicate a good potential for the use of direct air capture technologies in the long term, exploiting the sequestration opportunities in depleted gas fields. Regulations to reduce methane emissions from oil and gas by 40% to 45% by 2025 compared to 2012 levels went into effect in 2020 (the release of the final text is expected in late 2021). For power generation, wind and solar play an important role in diversifying the power mix in the short term, due to the large deployment potential for these two technologies. Biomass combined with carbon capture and storage follows in the long term. Among the mitigation options, the LULUCF CO_2 component comprises measures to reduce CO_2 emissions primary related to avoided deforestation and improved forest management.

Figure 37: Canada. Change in GHG emissions compared to CurPol by technology and year

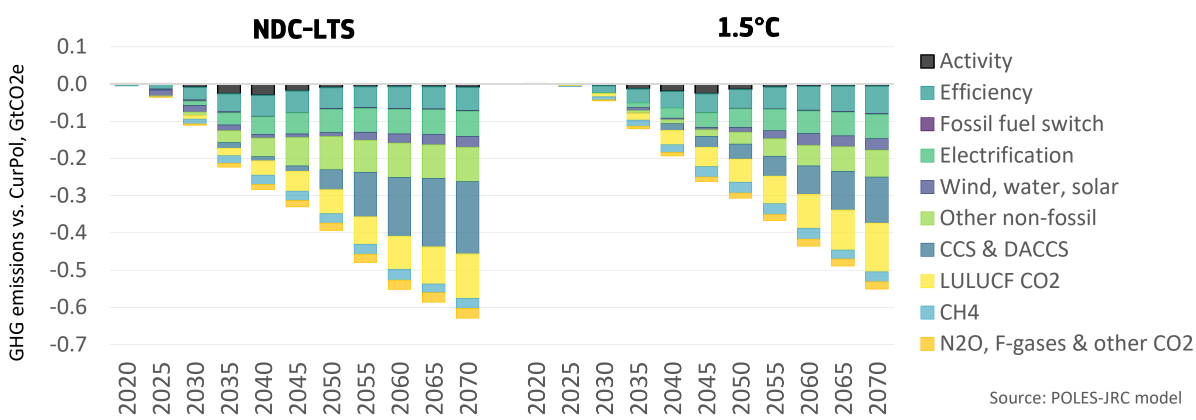
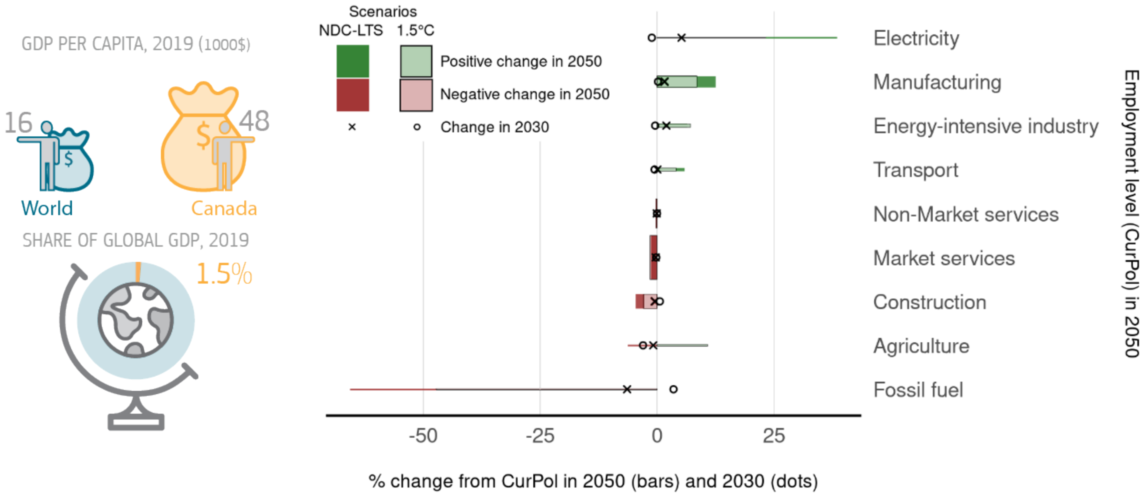


Figure 38: Canada. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. The expected growth of the fossil fuel sectors in the Current Policies scenario due to the development of oil fields (e.g., tar sands) does not occur in both the NDC-LTS and 1.5°C scenarios. This leads to employment losses in the oil and gas sector, and also affects the construction sector. As electrification advances, employment in the electricity, manufacturing and transport sectors see growth, with energy-intensive industry seeing increasing opportunities, led by innovative processes coming from the non-ferrous metals sector (e.g. aluminium). Under the 1.5°C scenario, the employment levels in agriculture also increase, as compared to the Current Policies scenario in 2050, propelled by the announced policies in the LTS promoting biomass production from dedicated forestry in the long run.

4.5. China

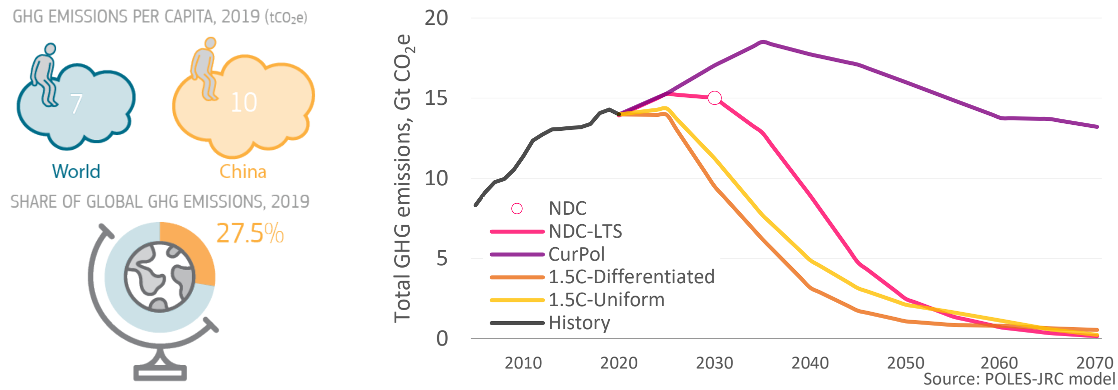


Figure 39: China. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

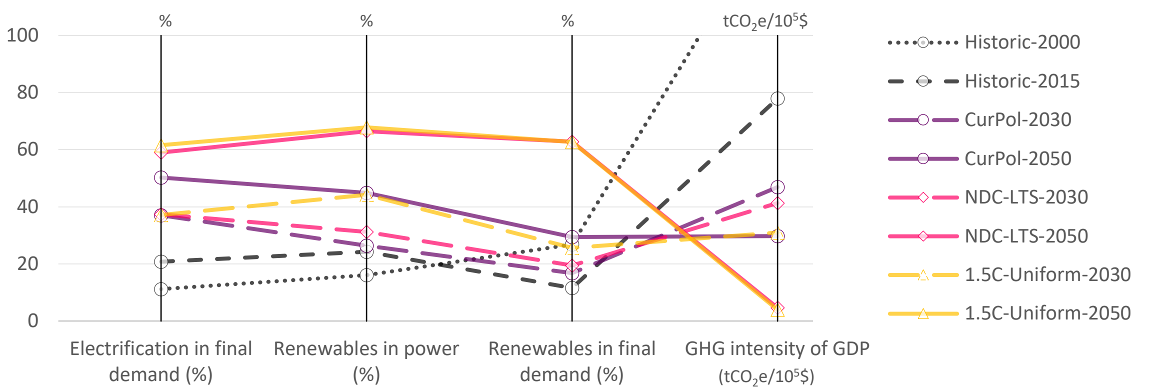
Pledges	Key targets
NDC	Peak CO_2 emissions before 2030; 65+% lower carbon intensity in 2030 relative to 2005; around 25% non-fossil primary energy use
LTS	CO_2 neutrality by 2060

POLICY CONTEXT. Rapid economic growth combined with a coal-heavy energy system (including 66% of electricity generation in 2019) has led to a strong emission growth in China since the beginning of the century. Just prior to the COVID-19 pandemic, China accounted for more than a quarter of emissions globally. Despite new policies in the 14th Five Year Plan (2021-2025) like increasing the share of non-fossil energy to 20% (2019: 15%), adding nuclear capacity and reducing emissions intensity of GDP by 18% over the Plan's period, emissions may still rise due to increasing economic activity and new coal plants being added to the grid. Further, a national emission trading system was launched in 2021, replacing sub-national pilot schemes.

In September 2020, Chinese president Xi Jinping announced an emission peak "before 2030" and carbon neutrality by 2060. Further policy announcements (25% of non-fossil in primary energy by 2030, phasing down coal during 2025-2030, 1200 GW capacity of wind/solar in 2030, increase of forest stock by 6bn m^3 relative to 2005) were added. A formal submission of the updated NDC and LTS occurred only on 28 October 2021, these targets are included in the NDC-LTS scenario as they confirmed these earlier announcements.

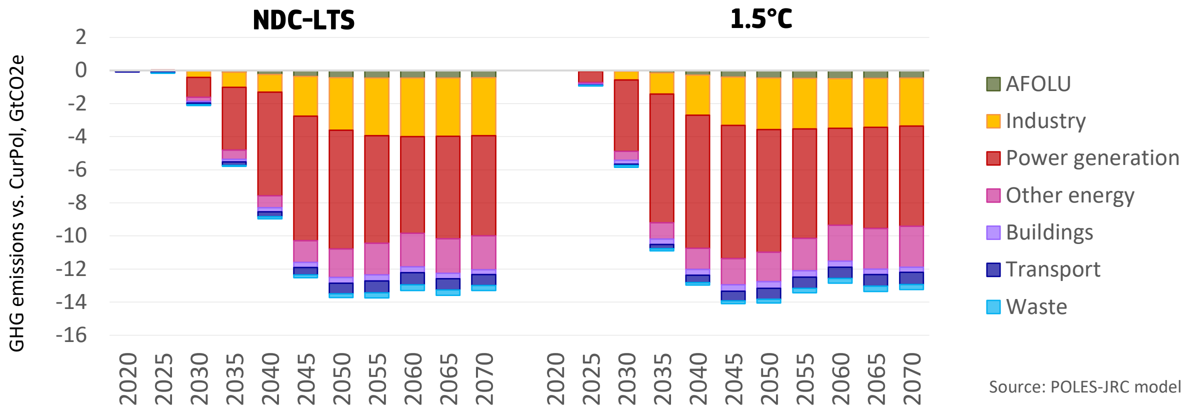
ENERGY TRANSITION DYNAMICS. Historically, emission intensity improvements have offset some pressure on emissions from increases in economic activity in China. This trend is expected to continue in the future, especially when moving to more stringent emission targets. The share of fossil fuels, especially coal, is set to continue its decline in all scenarios – allowing for a higher share of renewables and nuclear which in turn also helps emission reductions through demand electrification in rapidly growing sectors.

Figure 40: China. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 41: China. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. Presently, coal represents two thirds of China's power generation mix. The coal-dominated power sector accounts for about a third of Chinese GHG emissions – it therefore offers plenty of opportunities for emission reductions by using less coal-fired electricity, especially in the next decade. Switching from coal-powered electricity to renewables, nuclear and even gas provides the largest share of the mitigation required for the NDC-LTS pathway and the 1.5°C scenario. In both policy scenarios, emissions from the power sector peak within the next 2-5 years and the power sector is practically emissions-free by 2050.

The other energy transformation sector provides further reduction potential, notably with a shift from coal to biomass for plants producing heat. Emissions from industry are almost as high as for power. However, the potential for abatement is smaller than in the power sector where low carbon alternatives exist more readily. Within industry, energy efficiency, electrification and structural changes contribute most to reductions.

MITIGATION OPTIONS. As described above, the power sector is key to reducing emissions in China. Even under current policies, renewable and nuclear capacities expand rapidly and almost meet the 1200 GW target of wind and solar in 2030 (relative to about 415 GW in 2019). In the 1.5°C scenarios, capacity for solar alone exceeds the 1200 GW target and thus contributes to reductions of power sector emissions. Nuclear electricity also contributes to decarbonisation, reaching 96 GW in NDC-LTS and 270-320 GW in the 1.5°C scenarios in 2030 relative to 43 GW in 2019 (this is included in "Other non-fossil" in Figure 42. Beyond 2040, CCS & DACCS also contribute to emission reductions, with the majority of emissions captured by 2050 coming from industrial processes and, beyond 2050, from BECCS – captured emissions from coal-fired power generation are relatively modest, with coal phase-out being a preferred option in both the NDC-LTS (by 2050) and 1.5°C scenarios (before 2040). As the power sector is increasingly decarbonised, it contributes also via demand electrification. This potential materialises mainly after 2035, until then switching towards cleaner fossil fuels also support decarbonisation.

Figure 42: China. Change in GHG emissions compared to CurPol by technology and year

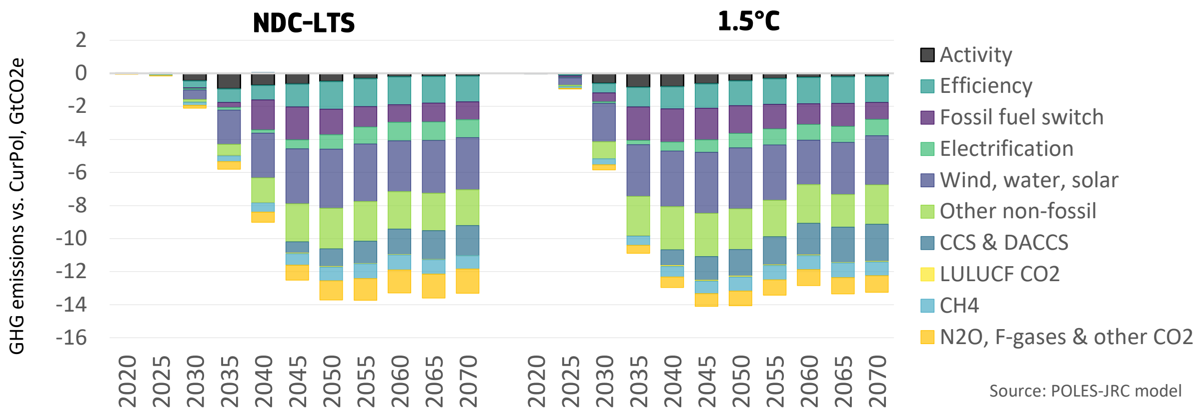
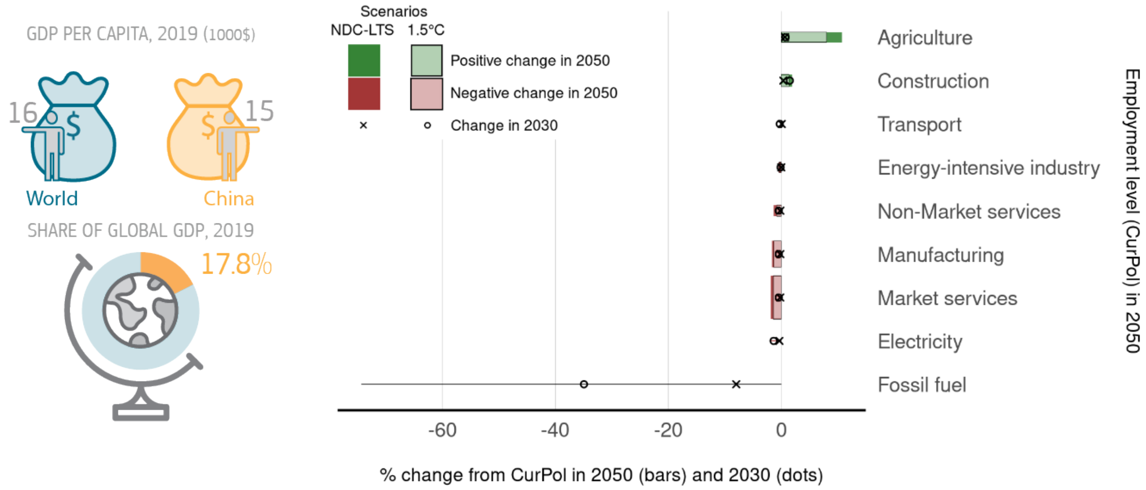


Figure 43: China. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).

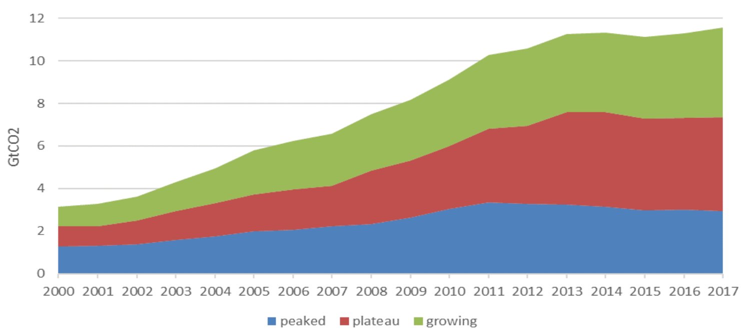


Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. The fossil fuel sector is heavily affected by the phase-out of coal, as compared to the Current Policies scenario, although with a relatively low number of jobs in contrast to other sectors. The 1.5°C scenario accelerates the decline of employment in the coal sector already in 2030. As the economy decarbonises, the main sectors absorbing job losses from the fossil fuel industry become agriculture, construction and transport. Major growth in employment levels occurs in agriculture, partially driven by the expansion of biomass production from dedicated forestry, due to an increasing use of BECCS technologies, whereas the increase in employment levels in the construction sector is mainly driven by the deployment of renewables.

COUNTRY-SPECIFIC ELEMENT. The 14th Five Year Plan (2021-2025) needs to prepare the peaking of emissions, which China announced for "before 2030". Annual GDP growth peaked in 2007 at 14% and has since decreased to 5.9% (2019). The share of industry in GDP peaked in 2008 at 45% and has since decreased to 38% (2019). Cement demand peaked in 2014 and has decreased every year since. Total population is expected to peak at 1.44 billion in 2025. The date of the emissions peak will depend on a number of factors, chief among them is the rate of growth of the economy and the way that coal demand is reined in. Carbon intensity decreased at 4.4%/yr over 2015-2020, at about the same average rate as 2005-2015. The 2021-2025 policy objective points to a relative deceleration to 3.2%/y. However, the NDC target points to an effort more aligned with recent history at 3.7%/yr on average over 2020-2030 while the GECO 1.5°C scenarios see more aggressive action, with 7.0-9.2%/yr for the same period. With GDP growth projected to be 5.0%/yr on average for 2020-2030 (as assumed in GECO 2021), it follows that after the 2021-2025 FYP stronger efforts are needed in order to reach peak emissions before 2030. Within the country, a great number of provinces appear to have reached peak emissions already, or are close to it with a plateau in recent years.

Figure 44: Provincial CO_2 emissions in China, provinces classifies as peaked, plateauing, or growing



Classification of provinces:

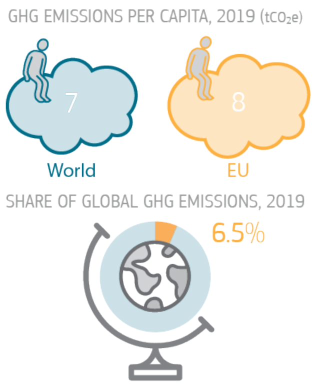
Peaked (13): Beijing, Tianjin, Hebei, Jilin, Heilongjiang, Shanghai, Henan, Hubei, Hainan, Chongqing, Sichuan, Gansu, Qinghai

Plateau (7): Shanxi, Inner Mongolia, Liaoning, Jiangsu, Anhui, Fujian, Guizhou.

Growing (10): Zhejiang, Jiangxi, Shandong, Hunan, Guangdong, Guangxi, Yunnan, Shaanxi, Ningxia, Xinjiang

Sources: Own calculations based on data from (Shan, et al., 2018) and (Shan, Huang, Duan, & Hubacek, 2020) with emissions only from combustion and cement. Because of the different data source, the data differs from the national results of GECO.

4.6. European Union



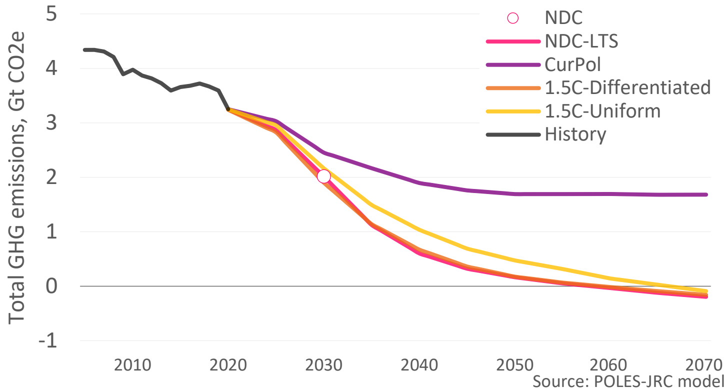


Figure 45: European Union. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)[24]

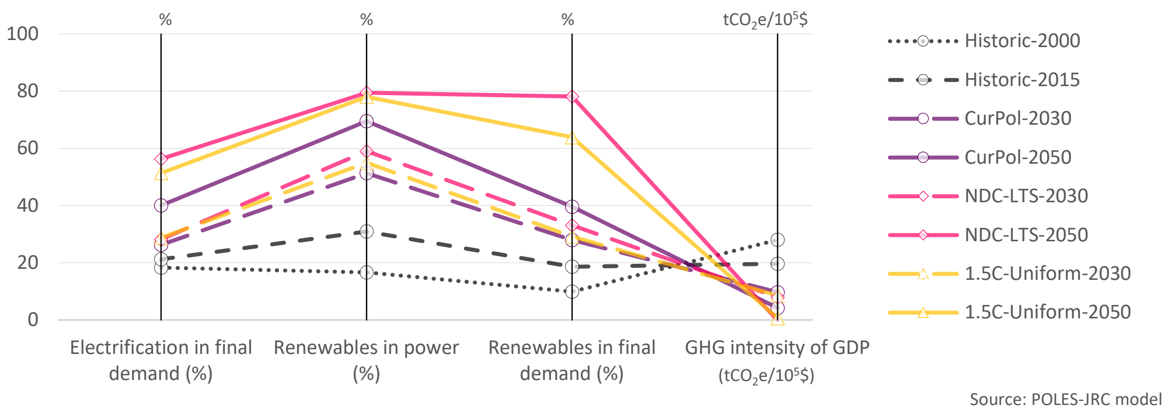
Pledges	Key targets
NDC	GHG emissions -55% below 1990 levels
LTS	Climate neutrality by 2050

POLICY CONTEXT. The European Union was the third largest GHG emitter with 3438 Mt CO_2e in 2019, with emissions in a general downward trajectory since 1979 thanks to substantial energy-related efforts. Primary energy needs are predominantly met by oil and gas, accounting for more than half of the total. Renewables in gross final energy consumption stood at 19.7% in 2019, having slowly increased over the years, and mostly constituted by biomass-related energy (9%) and renewable electricity (8%). EU policies tackle greenhouse gases with an emission trading system in energy intensive industry, electricity generation and aviation. These policies are complemented by measures to increase renewable energy penetration, increase energy efficiency as well as reducing emissions in vehicles.

The EU updated its NDC in December 2020, enhancing the target to a net GHG emissions reduction of 55% below 1990 levels by 2030, up from 40% previously. Proposals for legislation to meet this target were released by the European Commission in the “Fit for 55” package in July 2021. The EU has also committed to achieving climate neutrality by 2050, as confirmed in the European Climate Law adopted in 2021.

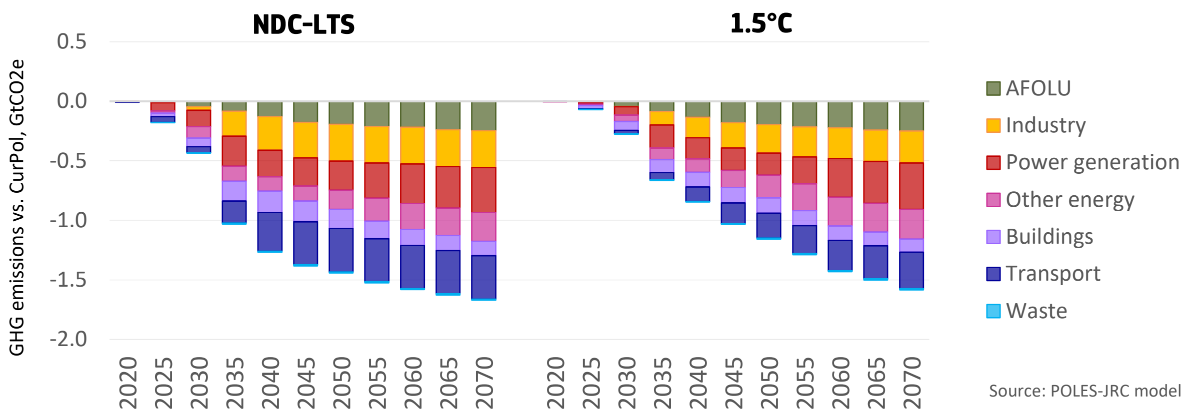
ENERGY TRANSITION DYNAMICS. The -55% emissions reduction goal of the European Green Deal – implemented in the NDC-LTS scenario – requires a significant change, essentially related to the energy and transport sectors. After 2030, the European Union sustains and strengthens its transition efforts to achieve carbon neutrality in 2050. This step will be especially meaningful in a 1.5°C scenario trajectory.

Figure 46: European Union. Key indicators characterising the energy transition across time and scenarios



[24] GHG emissions in EU include intra-EU aviation and maritime

Figure 47: European Union. Change in GHG emissions compared to CurPol by sector and year

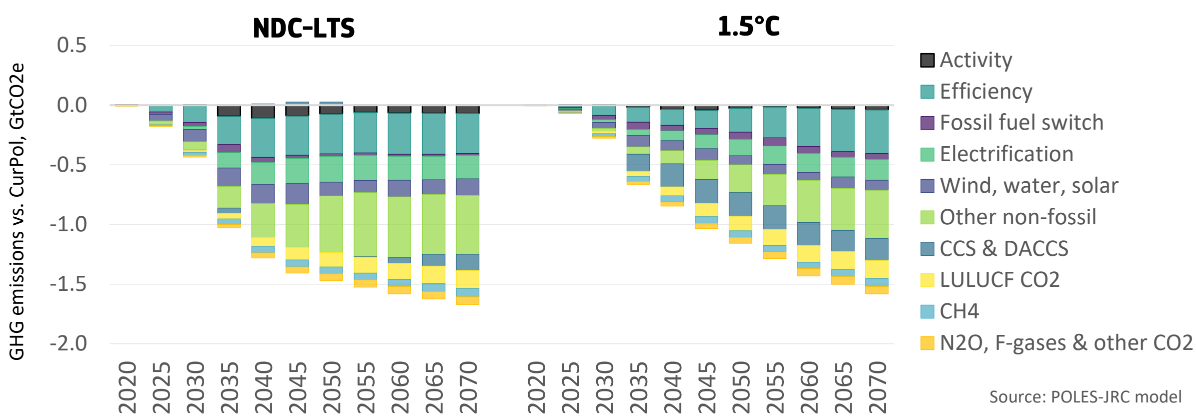


Source: POLES-JRC model

SECTOR CONTRIBUTIONS. NDC-LTS scenario is mainly driven by efforts in the energy and transportation sectors, accounting for 57% of emissions reduction compared to Current Policies in 2050. Switching from fossil to non-fossil fuels is by far the key factor of the European Union transition until then. As the EU historically produced electricity from coal and nuclear plants, the decentralisation of power generation therefore has a preponderant role in the achievement of climate neutrality. Renewables are one of the main components of the transition as they account for 33% of primary energy demand in 2030 – almost consistent with the “fit for 55” package indicators – and 78% in 2050. Electrification of road transportation also plays a key role. Apart from these segments, the European Union effort is diversified over other sectors of industry, residential and services. In the 1.5°C scenario, the pathway is similar in terms of emission level and contributions of the different sectors as a very similar emission reduction is achieved in 2050, except that the transition is faster, especially until 2030.

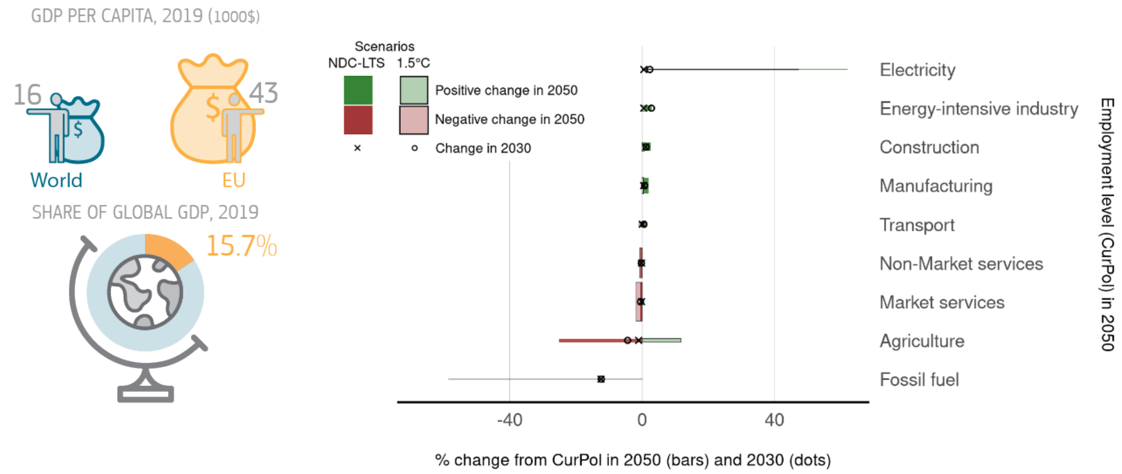
MITIGATION OPTIONS. The development of wind, solar and biomass is expected to lead the expansion of renewables in the European Union power generation sector to reach carbon neutrality. Meanwhile, gas supplants coal in the short term to accelerate the green transition until 2030 before a slight decrease and stabilization afterwards. In road transportation, efficiency improvements and notably hybridisation of internal combustion engines, as well as electrification of light and heavy vehicles contribute substantially to reaching the GHG reduction target in 2050. Further reductions are also provided by zero-emission fuels (biofuels, hydrogen and e-fuels). Electrification and energy efficiency enhancements are also one of the main drivers for industrial processes to contribute to the transition effort towards the net-zero emissions goal. In 2050, most of the emissions of the European Union (offset by sinks and negative emissions technologies) come from agriculture, representing more than 50% of the total.

Figure 48: European Union. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

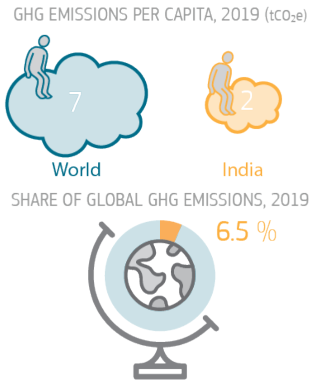
Figure 49: European Union. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. In the EU, the phase-out of coal leads to a decrease of employment levels in the fossil fuel sector, while the movement towards green jobs is driven by strong electrification efforts, as part of its mid-century strategy. Electrification of the transport sector advances rapidly after 2030 and the decarbonisation of the power sector raises employment opportunities in the construction sector. Energy-intensive industries and manufacturing see increases of jobs due to electrification, but also driven by increased competitiveness as EU industry is starting from a relatively lower emission intensity than other countries. Labour demand in agriculture sees a net decrease – i.e. emerging business opportunities in biomass production in the forestry sector do not entirely offset employment losses in crops production, which decrease as imports grow in the long-term.

4.7. India



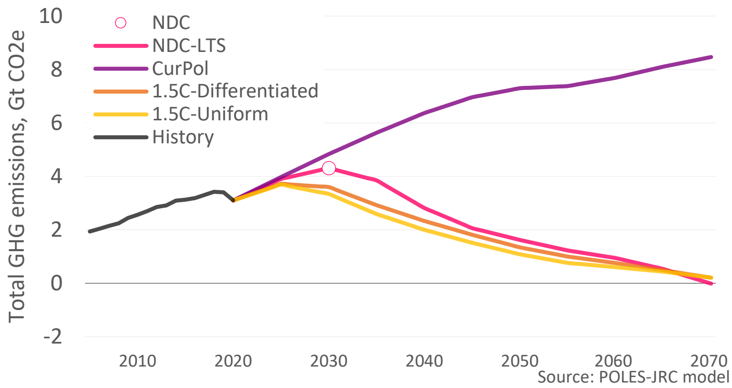


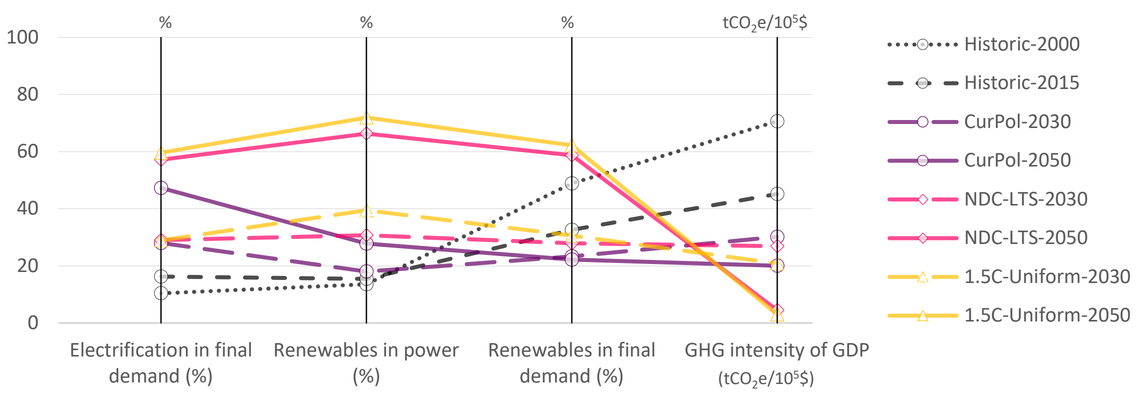
Figure 50: India. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Reduce GHG intensity of GDP by 45% by 2030 from 2005 level; 50% non-fossil electricity generation capacity by 2030; 500 GW renewables in electricity generation capacity by 2030
LTS	Net zero GHG emissions by 2070

POLICY CONTEXT. The population projections underlying the GECO2021 scenarios indicate that by 2030, India will be home to more than 1.5 billion inhabitants, becoming the most populated country in the world. While India's current share in global greenhouse gas emissions is relatively limited, it is set to double over the next three decades, reaching 12.5% of global emissions by mid-century in the Current Policy scenario. In recent years, major advances took place in ensuring broad access to electricity supply. However, the large majority of electricity generation remains coal-based. During the Leader's Summit of COP26 (November 2021), Prime Minister Narendra Modi announced renewed pledges for 2030, as well as a climate neutrality target by 2070 that marks a strong deviation from projected emissions under Current Policies. The analysis shows that installing 500 GW of renewable electricity generation capacity fully closes the implementation gap by 2030, paving the way to deliver on the other renewed 2030 targets. The announced pledges close the ambition gap with 1.5°C pathways by more than one third by 2030, by more than two thirds by 2050, and fully by 2070, the target date for Net Zero greenhouse gas emissions.

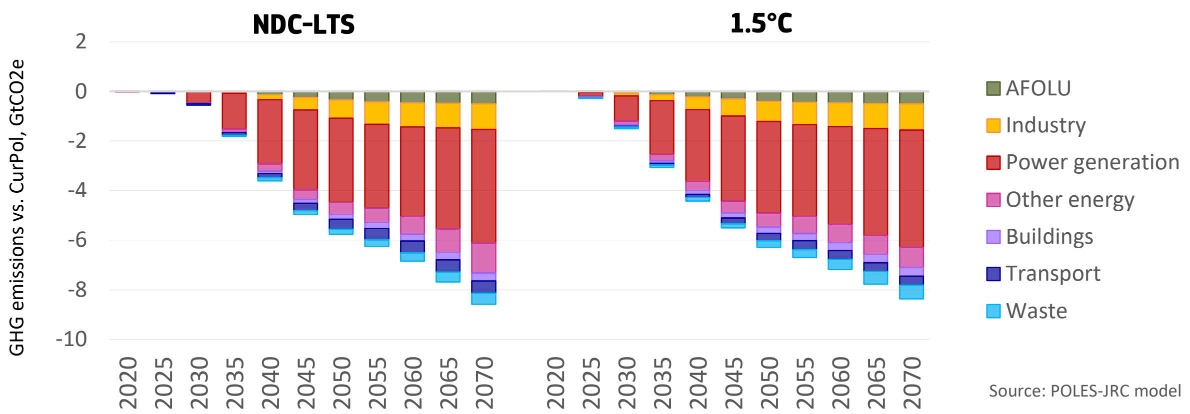
ENERGY TRANSITION DYNAMICS. Recent improvements in electricity access enable further electrification under Current Policies, historically coming from low shares of electricity in final energy demand but reaching (and exceeding) electrification levels in high-income countries in the future. The share of coal-based electricity generation declines from 75% in 2015 to below 60% in 2030 and around 30% in 2050 under CurPol. Improved connection to the electricity grid enables a shift away from traditional biomass, bringing the share of renewables in final demand in 2030 below that of 2015 in all scenarios, while it increases to more than 60% in 2050 in the 1.5°C pathway. Gearing the economy towards services limits GHG intensity.

Figure 51: India. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 52: India. Change in GHG emissions compared to CurPol by sector and year



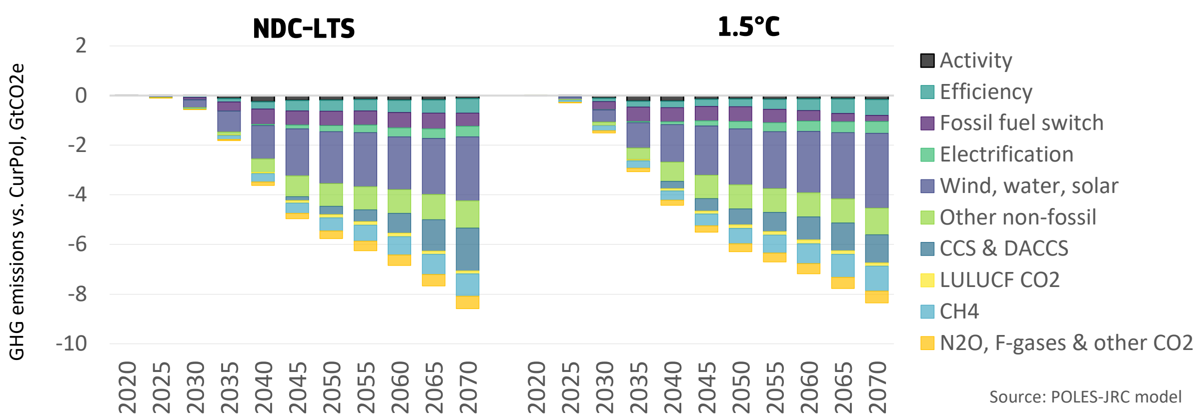
Source: POLES-JRC model

SECTOR CONTRIBUTIONS. The ambitious goal of 500 GW renewable electricity generation capacity by 2030 drives emissions down in the power sector compared to the Current Policies scenario. While the share of coal in electricity falls over time under Current Policies, the volumes of electricity produced from coal and the installed coal capacity continue to rise gradually over time. In contrast, the 1.5°C scenario depict a power system that does not feature any coal-fired electricity generation without CCS from 2040. The same holds for the NDC-LTS scenario, but the pathway to 2040 differs, as coal-powered electricity increases until 2030, after which coal is rapidly phased out. The simulation results indicate more than 160 GW of unused coal capacity in 2040, pointing to a risk for stranded assets.

The trend of increasing CO_2 emissions from transport levels off around 2040 under CurPol, while electrification occurs earlier in the 1.5°C scenario. The NDC target of creating an additional carbon sink of 2.5-3 Gt CO_2 through additional forest and tree cover does not lead to emission reductions compared to CurPol as we assume 2005 as the benchmark year (Mathur, Sharma, & Priyanka, 2020), although uncertainty around this pledge remains.

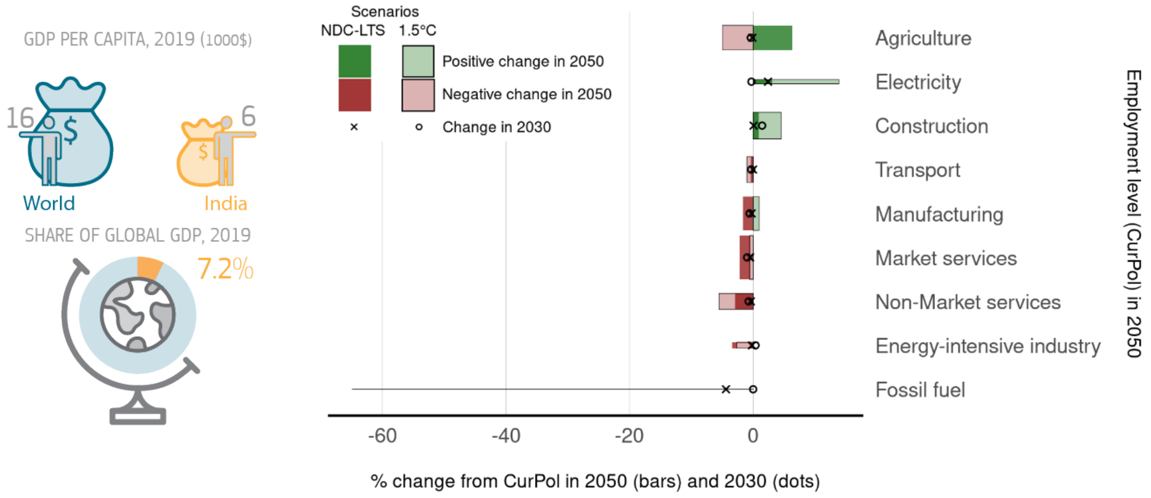
MITIGATION OPTIONS. While the hydro-electric capacity nearly triples over the 2015-2050 period in the 1.5°C scenario, its capacity growth rate is far exceeded by that of wind and solar, which jointly reach more than 550GW in 2030 and around 2800GW in 2050 in the 1.5°C scenarios. Coal-to-gas switching, nuclear and biomass (Other non-fossil) further contribute to emission reductions in the power sector. In the 1.5°C scenario, carbon capture and storage is used mainly in the power sector, but also in non-metallic minerals. Due to cultural habits and religion, there is limited beef consumption and corresponding abatement potential. Methane emissions from rice fields and the waste sector make non-negligible contributions to overall GHG emissions. Methane emission reduction represents an important abatement option in the 1.5°C scenario, although much smaller than wind, water and solar energy. In August 2021, Prime Minister Modi announced the National Hydrogen Mission. While hydrogen and e-fuels play a role in decarbonising transport and industry, they make up only a limited share of emission reductions in the overall category of Other non-fossil.

Figure 53: India. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 54: India. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).

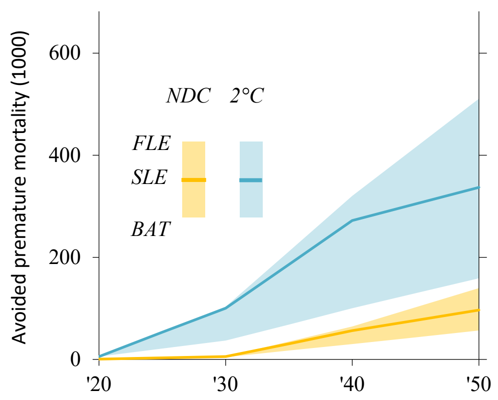


Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Decarbonisation efforts in both the NDC-LTS and the 1.5°C scenarios drive the decrease in jobs in the fossil fuel industry due to the phase-out of coal. While the decline in jobs in fossil fuel sectors may be moderate in the near term, more than half of the fossil jobs under Current Policies in 2050 would not exist in the NDC-LTS or 1.5°C scenarios. As some of the related jobs are concentrated in the east of the country, this result points to the need for complementary policies to ensure a just transition. Increased electrification draws workers from other sectors into the electricity sector, while investments related to the transformation of the power sector indirectly lead to additional jobs in the construction sector.

AIR QUALITY CO-BENEFITS. Impacts of air pollution are particularly pronounced in India, causing 1.67 million premature deaths and leading to economic costs of 1.36% of GDP in 2019 (Pandey, et al., 2021). Earlier work (Vandyck, et al., 2018) (see Figure 55) indicates that air quality co-benefits of climate policy can avoid up to half a million premature deaths in India by 2050 under a 2°C-compatible pathway compared to a current policy reference. Co-benefits may be particularly strong for climate policy in transport and the residential sector (Vandyck, Keramidas, Tchung-Ming, Weitzel, & Van Dingenen, 2020). These localised benefits can provide a strong argument in favour of ambitious climate and clean air policies in India.

Figure 55: Avoided premature deaths due to air quality co-benefits of climate policies in India



Source: (Vandyck, et al., 2018)

4.8. Indonesia

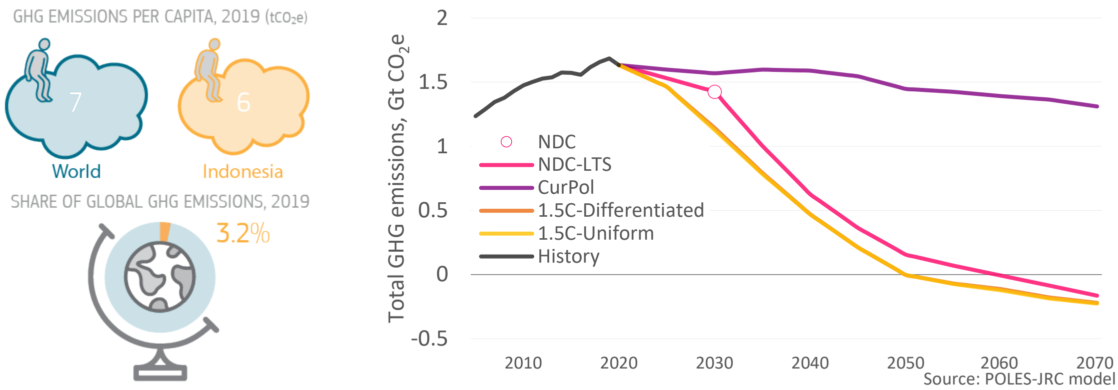


Figure 56: Indonesia. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

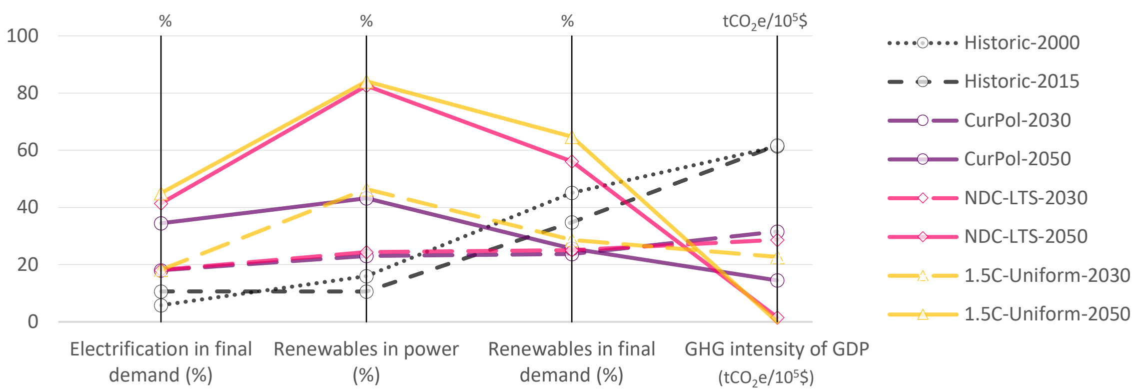
Pledges	Key targets
NDC	Reduce LULUCF emissions to only 22 Mt and limit total GHG emissions to 1683 Mt by 2030.
LTS	Aiming to progress rapidly towards net-zero GHG emissions in 2060 or sooner.

POLICY CONTEXT. Indonesia is an emerging economy projected by 2070 to expand its GDP by a factor of five and increase electricity consumption by a factor of seven compared to current levels. Following business as usual, the envisaged growth would result in a significant increase in emissions. Therefore, it is crucial for Indonesia to apply sustainable policies as pointed out in its NDCs. Almost half of current emissions come from forest and land-use changes (about 700 Mt). Indonesia has specified in its NDC the ambitious aim to avoid these emissions swiftly (22 Mt in 2030). The emission path in the current policy scenario is stable as increasing emission of the emerging economy are balanced by decreasing emission in the forest sector due to already implemented practises.

Indonesia has the potential to become a significant sink for CO_2 like few other countries (1.5°C scenario). The prerequisite for this is a deep decarbonisation of the energy and industrial sector, combined with strict protection of its forests and substantial afforestation.

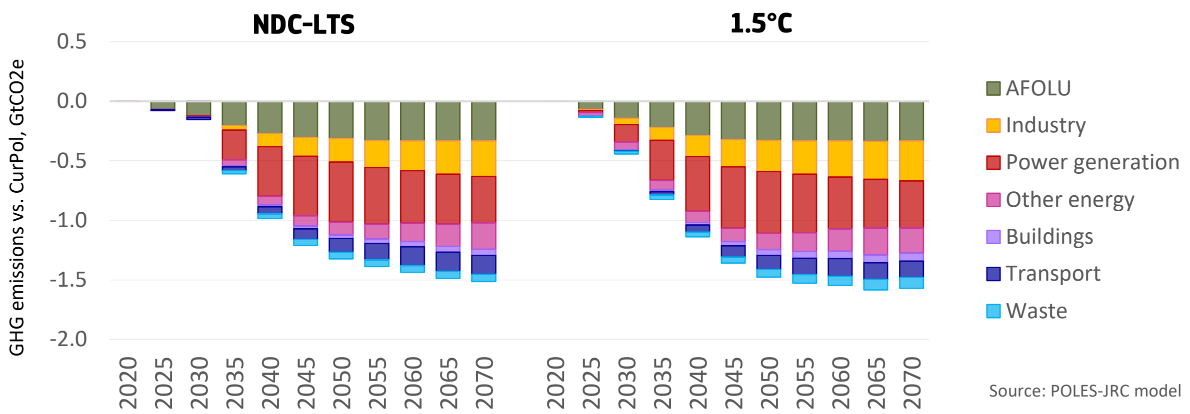
ENERGY TRANSITION DYNAMICS. Decarbonising the growing final energy demand sectors consists essentially in decarbonisation of the power sector in combination with extensive electrification of final demand. Decarbonisation of the power sector is achieved with renewable shares of more than 80% (1.5°C scenario) relying on Indonesia's rich potential of solar, wind, hydro and geothermal resources.
The NDC-LTS and 1.5°C scenarios, until 2030, have in common the phase-out of coal and increased use of gas. From 2030 onwards, the key to further decarbonisation is increasing the share of renewables substantially and phasing out gas eventually.

Figure 57: Indonesia. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 58: Indonesia. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. The AFOLU sector accounts for about half of Indonesia's current emissions. The emissions related to forest and land-use change could be almost completely avoided as soon as 2030 (NDC objective). In the longer-term, Indonesia has the opportunity to convert its forests into a huge sink for CO_2 by increasing afforestation and applying sustainable forest management practises. The second major emission source is the energy sector. Power generation, which is still dominated by coal, is decarbonised in the next decades by gas and from 2050 onwards by large renewable capacities. In the 1.5°C scenario the contribution of industry, buildings and transport increases substantially. In all three sectors, the rising green electrification is a key element. Moreover, bioenergy is increasingly used in transport (biofuels) and industry.

To conclude, the gap between the NDC-LTS and the 1.5°C scenario is huge and reflects that Indonesia needs to implement more ambitious policies to achieve this target.

MITIGATION OPTIONS. The most important mitigation option refers to decreasing emissions related to forest and land-use changes (LULUCF CO_2). From 2050, Indonesian forests absorb about 365 Mt in the NDC-LTS and 1.5°C scenarios. In the power sector, coal plants are phased out in the coming decades and substituted by gas plants (both scenarios) which is visible by the peak in fossil fuel switching in 2050 (1.5°C scenario). From about 2050 onwards, renewable electricity generation contributes more and more to the decarbonisation of the electricity sector. The main pillars of renewable electricity generation are wind and solar; complemented by hydro and geothermal sources. CCS is applied from 2050 onwards to all new combustion power plants (1.5°C scenario). Among these, CCS biomass is the predominant technology, which reflects Indonesia's abundant biomass resources (sink of 143 Mt CO_2 in 2070). Moreover, direct CO_2 capture (DACCS) amounts to about 50 Mt in 2070 (1.5°C scenario). To conclude, Indonesia could capture 225 Mt CO_2 in 2070 (1.5°C scenario) due to its huge sinks (forests, CCS biomass & DACCS) making it one of the countries that absorb the most CO_2.

Figure 59: Indonesia. Change in GHG emissions compared to CurPol by technology and year

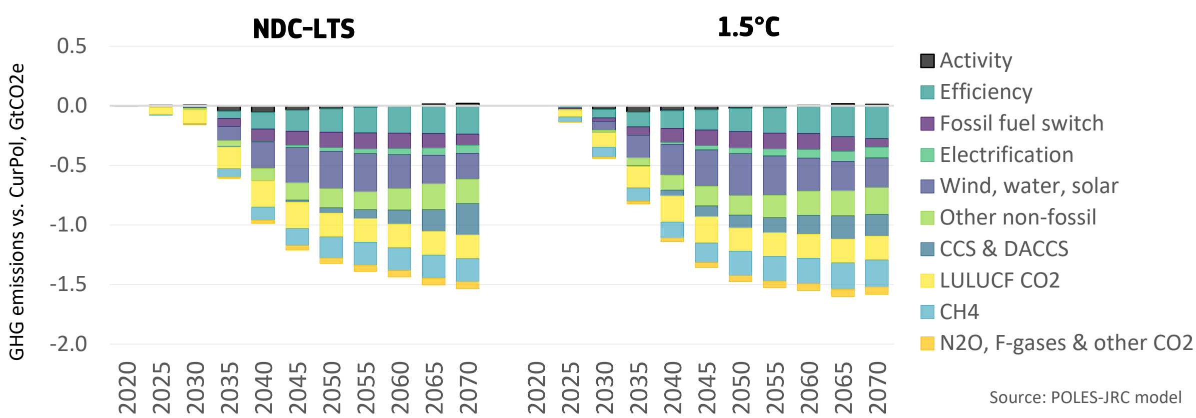
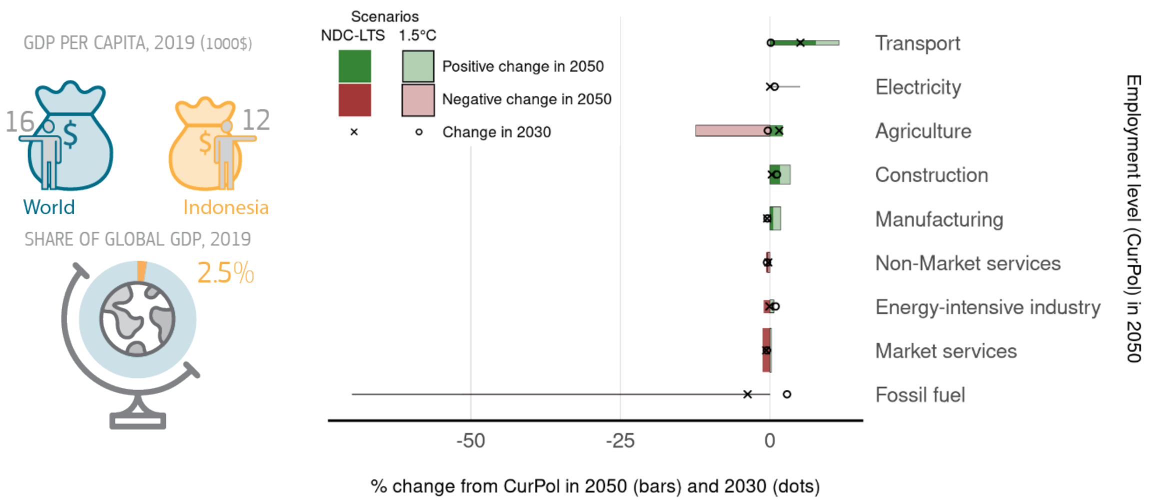


Figure 60: Indonesia. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

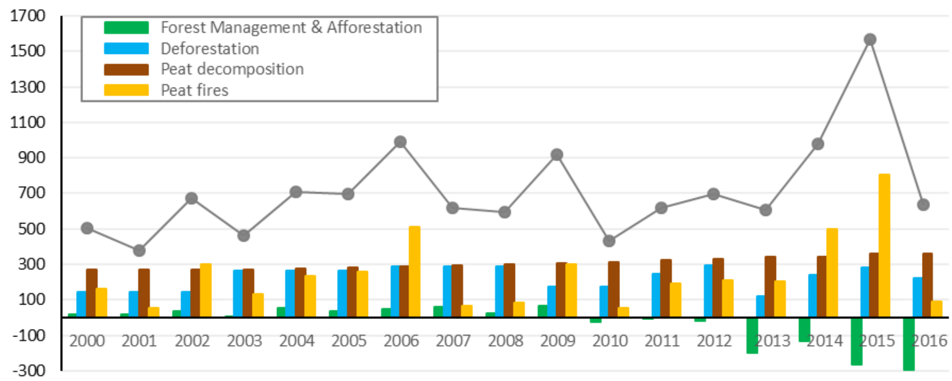
ECONOMICS OF TRANSITION. In all scenarios, the dynamics of the emerging economy increase employment substantially by 2050. In the 1.5°C scenario, the net employment effect is significantly higher compared to the CurPol scenario. Decarbonising the economy leads to job growth in transport, manufacturing and construction, which compensates losses in the other sectors (e.g. fossil fuels).

In agriculture, employment grows under the NDC-LTS scenario led by the crops sector, mainly due to increased production of exported commodities (e.g. palm oil). In the 1.5°C scenario, sustainable land use practises are applied, resulting in changes in the agriculture production (e.g. oil palm plantation). Therefore, under the 1.5°C scenario, the exports of crops decrease from 2030 onwards, leading to a reduction of employment in agriculture, as compared to the CurPol scenario. The huge expansion of renewable capacities create jobs in rural areas compensating job losses to some extent in agriculture (1.5°C scenario).

FOREST AND LAND-USE CHANGES. Huge peat-related emissions are a specific challenge for Indonesia. Deforestation of peatland is common practise in Indonesia. Once deforested, the organic matter of the peat land decomposes resulting in CO_2 emissions, which come on top of the emissions due to the actual deforestation of trees. Furthermore, peat fires are a very strong source of missions. Immense peat fires in 2015 caused emissions of about 800 Mt CO_2. Finally, natural forests growing on non-peatland are deforested at large scale. The sum of these land-use changes are immense and have been oscillating between 400 to 1.6 Mt CO_2 annually (2010-2016).

To avoid these emissions a bundle of sustainable practises need to be implemented aiming at limiting lumbering, sustainable cultivation of oil palms, suppression of peat fires, renaturation of peatland and reducing land-use changes (e.g. settlements, agriculture). Indonesia has set itself the goal of implementing these measures in the coming years, as the objective to reduce its forest and land-use emissions to 22 Mt in 2030 (updated NDC 2021).

Figure 61: LULUCF emissions of Indonesia and its components



Source: (BUR2 Indonesia, 2018).

4.9. Japan

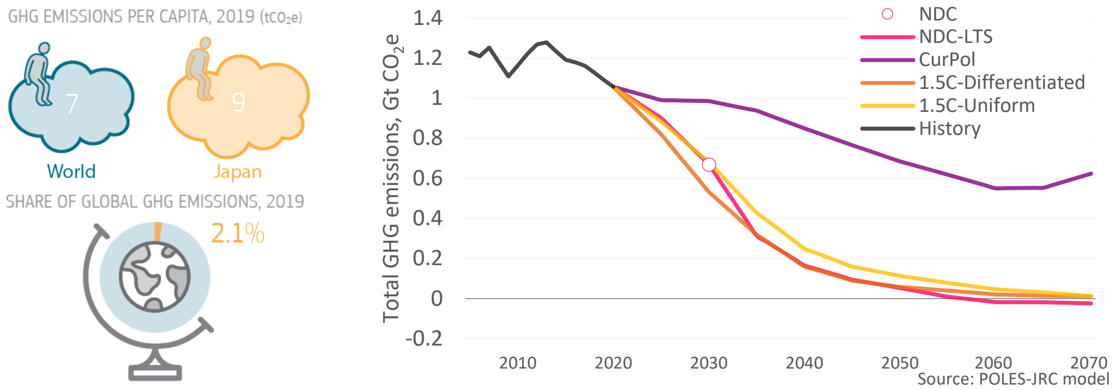


Figure 62: Japan. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

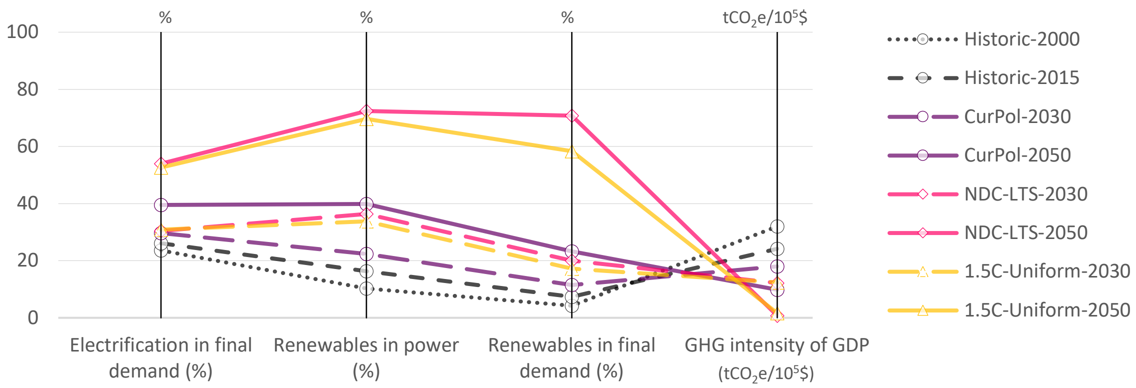
Pledges	Key targets
NDC	46% GHG emissions reduction in 2030 compared to 2013 levels (all sectors including LULUCF)
LTS	Net-zero GHG emissions by 2050

POLICY CONTEXT. Japan was the tenth largest CO_2 emitter with 1091 Mt CO_2 in 2019. Primary energy demand is currently almost entirely satisfied by imported fossil fuels, as they account for more than 90% of the total, with an oil share of almost 40%. Since the 2013 peak, the decrease in Japan greenhouse gases emissions is essentially driven by nuclear plant restarts after the Fukushima catastrophe, as well as the gradual expansion of renewables and the reduction in primary energy demand. The later has a key role to play in achieving climate targets because of the high population density of the country, and Japan has already seen decreasing energy consumption.

Japan updated its NDCs in April 2021, related to the "Green Growth Strategy Through Achieving Carbon Neutrality in 2050". In this framework, the Ministry of Economy, Trade and Industry (METI) identified 14 fields as priorities to reach carbon neutrality. The 6th Strategic Energy Plan (SEP), approved in October 2021, also strengthens the 5th SEP goals to meet the 2050 trajectory.

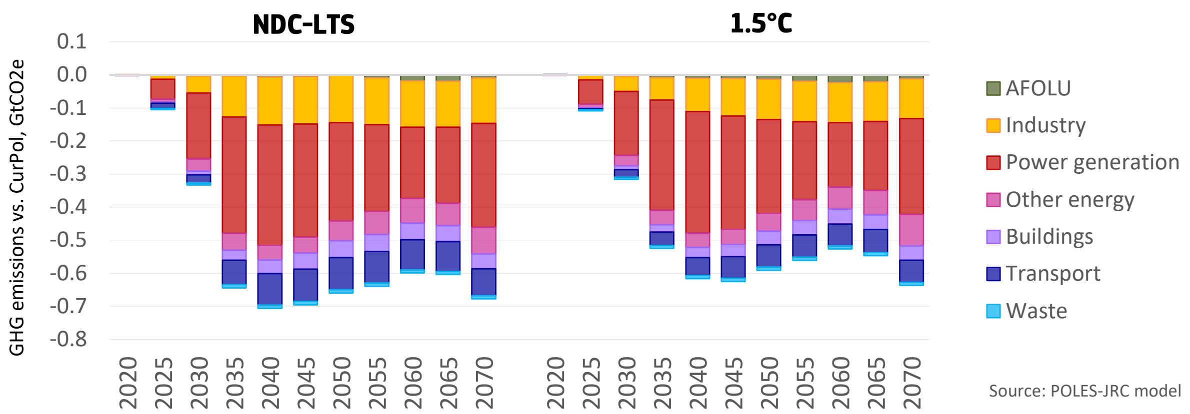
ENERGY TRANSITION DYNAMICS. The greenhouse gases emissions reduction targets have increased from -26% to -46% in 2030 compared to 2013 levels in the last NDC submission. The government also aims to implement new measures to reach -50% in 2030 in order to achieve the 2050 net-zero target. Achieving NDC and LTS targets for Japan leads to a rather linear – while significant – transition to 2050.

Figure 63: Japan. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 64: Japan. Change in GHG emissions compared to CurPol by sector and year



Source: POLES-JRC model

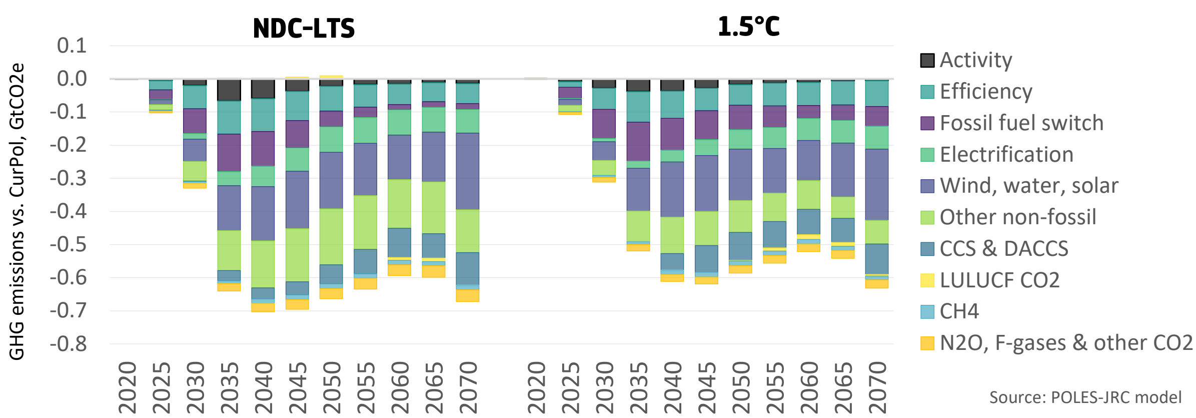
SECTOR CONTRIBUTIONS. About half of the emissions reduction in the 2030-2050 period derive from the energy sector and especially power generation switching to non-fossil fuels. Japan plans to maximise its renewables potential and nuclear power recovery. Hence, the renewable share in power production reaches the NDC target of 36-38% in 2030, representing an improvement of 14% compared to the Current Policies scenario. In 2030, the energy sector accounts for a third of total emissions, in comparison to a half in 2020. Japan produces almost only decarbonised electricity from 2050 in the NDC-LTS scenario.

Steel production in Japan represented more than half of total industrial emissions in 2019, and about 13% of the total country emissions. It has a meaningful role to play in mitigation, reducing by half in 2030 and almost completely in 2050 in the NDC-LTS scenario. Similarly, road transport is also expected to make its contribution on the carbon neutrality pathway. Reported at 16% of Japanese total emissions in 2019, road transport greenhouse gases are cut in the NDC-LTS scenario by 19% in 2030 and 60% in 2050.

MITIGATION OPTIONS. Japan's climate mitigation pathways imply substantial effort, mainly in power generation, shifting from coal and oil to gas, and mostly from fossil fuels to renewables. Nuclear plants account for a constant share of the electricity production and allow non-fossil generation to expand. Solar and wind represent 36% of the total in 2050.

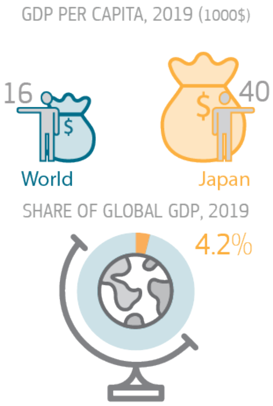
The increase in public transportation and in hybridisation of private vehicles leads to a decrease in transport emissions until 2030. Afterwards, the effort is diversified rather equitably in 2050 with the substantial increase of biofuels – mainly from the 2nd generation – and the electrification of the fleet. The progressive development of e-fuels also complements the mitigation.

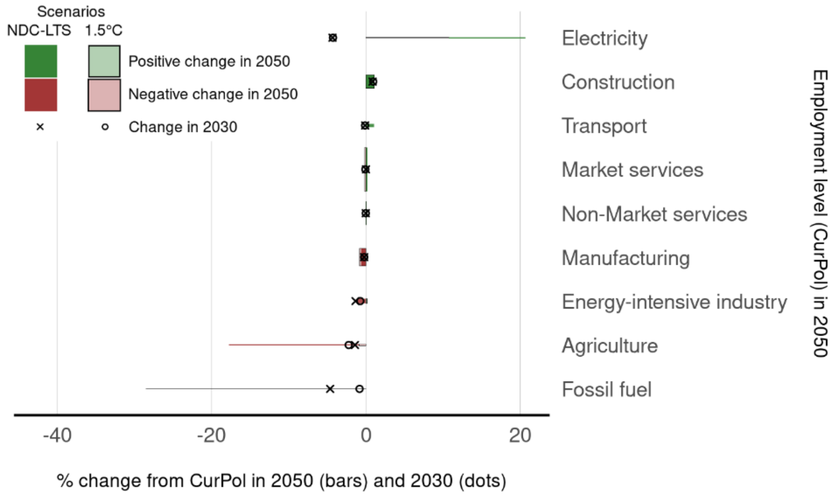
Figure 65: Japan. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 66: Japan. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).





Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Similar to other developed economies, the service sector contributes a large share to the Japanese economy. In addition, the lack of fossil resources means that very little employment is related to fossil industries. Therefore, the sectors in need for transition are relatively small relative to the overall economy.

Strong increases in the share of renewables from 2030 onwards promotes employment in the electricity sector, which absorbs losses from the fossil fuel sectors, agriculture and energy-intensive industry, and is the main driver of growth in the number of jobs in the construction sector. Labour demand in the services sector grow slightly under both scenarios. Changes from the Current Policy scenario are relatively small, with market services facing tiny losses, while non-market services see little gains under the 1.5°C scenario in 2050.

Employment losses in the crops sector are due to replacement of domestic production by imports. In the overall labour market, this sector plays a quite limited role.

4.10. South Korea

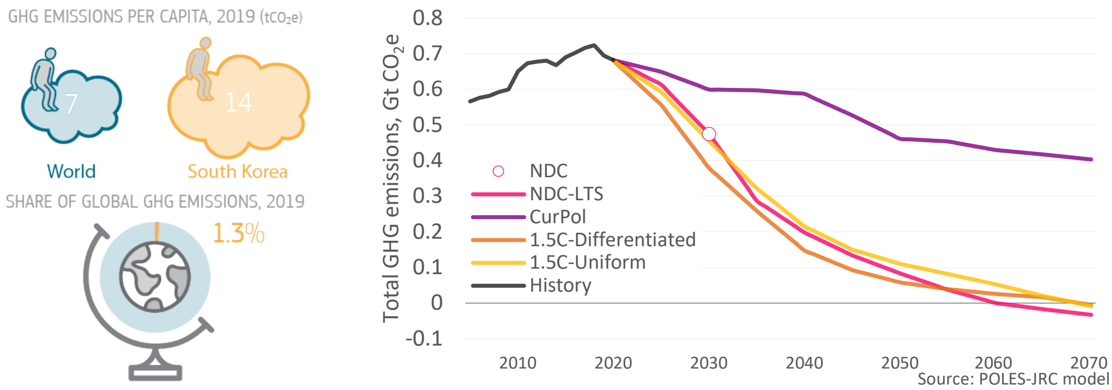


Figure 67: South Korea. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

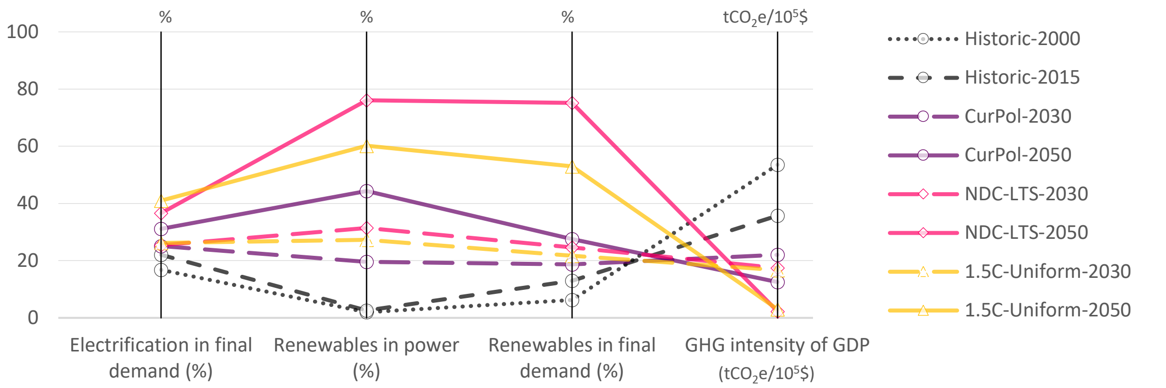
Pledges	Key targets
NDC	40% GHG emissions reduction in 2030 compared to 2018 levels (all sectors, including LULUCF)
LTS	Carbon neutrality by 2050

POLICY CONTEXT. South Korea emitted 695 Mt CO_2 in 2019 , with primary energy needs led by fossil fuels, mainly imported and accounting for more than 86% of the total, and an oil share of about 39%. However, the emissions peak was reached in 2018, and since then the renewables share has increased while primary energy demand has diminished.

Recently, South Korea amended the Third Energy Master Plan, and updated its NDC in December 2020 while also releasing the 9th Basic Plan for Long-term Electricity Supply and Demand to define actions to achieve these strengthened and numerous targets. Most recently, in September 2021, the Korean National Assembly accepted the bill for the legislation of carbon neutrality in 2050. This implied an adjustment of the 2030 milestone by cutting down the emissions objective to at least -40% compared to 2018 levels.

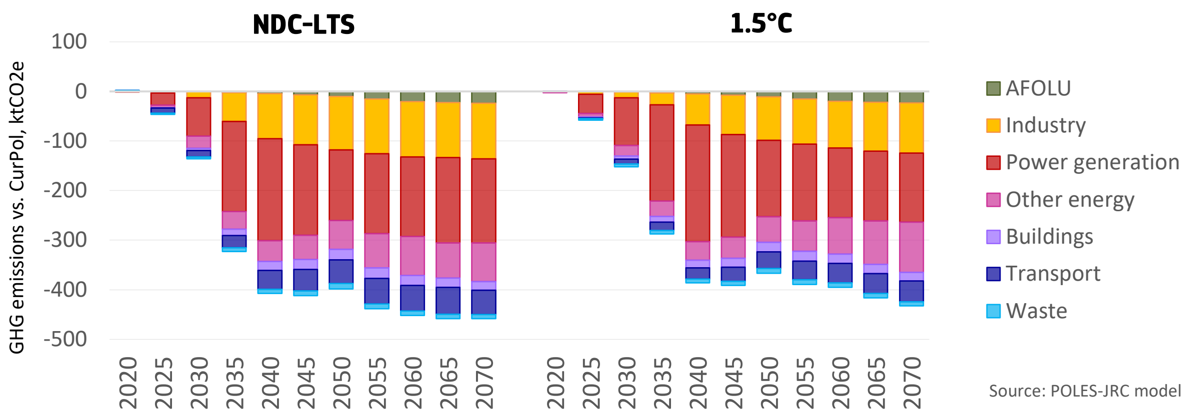
ENERGY TRANSITION DYNAMICS. The adaptation of the 2030 step and even more the recent legislation about carbon neutrality imply major changes in the South Korean consumption. Substantial efforts will be needed to reach the 2030 -40% objective and the net-zero emissions target in 2050. In particular, coal plants are expected to be phased-out and some cities and provinces are already paving the way for this. Indeed, seven subnational entities (including the provinces of Chungnam, Gangwon, and Jeollanam, as well as the cities of Incheon and Daegu), which account for more than 75% of the South Korean coal power plants, aim to make it the first Asian country to be a member of the Powering Past Coal Alliance (PPCA).

Figure 68: South Korea. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 69: South Korea. Change in GHG emissions compared to CurPol by sector and year



Source: POLES-JRC model

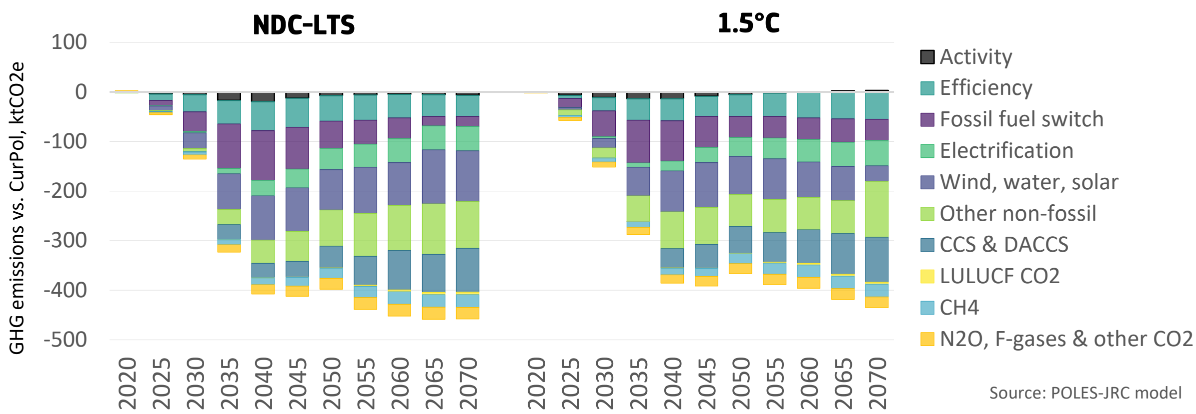
SECTOR CONTRIBUTIONS. The power generation sector accounted for more than half the total emissions of South Korea in 2020 and is expected to account for the same up to 2030. Therefore, this sector offers the main reduction potential and consequently is by far the major contributor to the carbon neutrality pathway. Until 2030, about three-quarters of the greenhouse gas reduction, in comparison to the Current Policies scenario, are come from power generation. Afterwards, it drops to around 50% in 2050, as a result of the growing share of industry and transportation reductions in the green transition. Road and maritime are the main segments affected.

For all these sectors, the switch from fossil to renewable sources, already initiated by South Korea, is the principal input. Despite massive efforts, petrochemical feedstocks still represent a substantial share of oil consumption in 2050 (up to 83% in the NDC-LTS scenario, more than one quarter of the total final energy consumption). The lack of low-emission options for Naphtha replacement and the time needed to develop highly efficient plastics recycling may explain this inertia in the petrochemicals industry.

MITIGATION OPTIONS. The accelerated planned coal phase-out in South Korea involves a sharp increase in a temporary buffer, natural gas, until 2030. Then, renewables supplant it to reach the 2050 net-zero emissions target. Among them, solar and wind inevitably represent the major part, corresponding to almost all the renewables share. The later is expected to account for half the power production in 2050, compared to 21% in 2030.

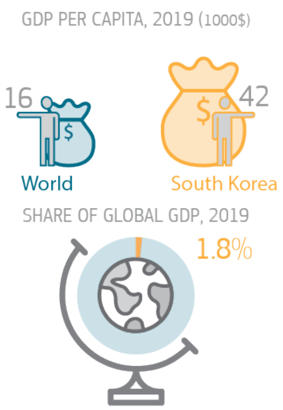
In the short term, the efficiency enhancement of maritime leads almost all the transportation sector emissions reduction. However, after 2030, the road transport electrification and the increase of biofuels are the drivers for the sector's emission reduction contribution. South Korea plans an ambitious program for hydrogen vehicles, which along with e-fuels, increase their share decarbonisation in road transport, mainly in heavy road transportation.

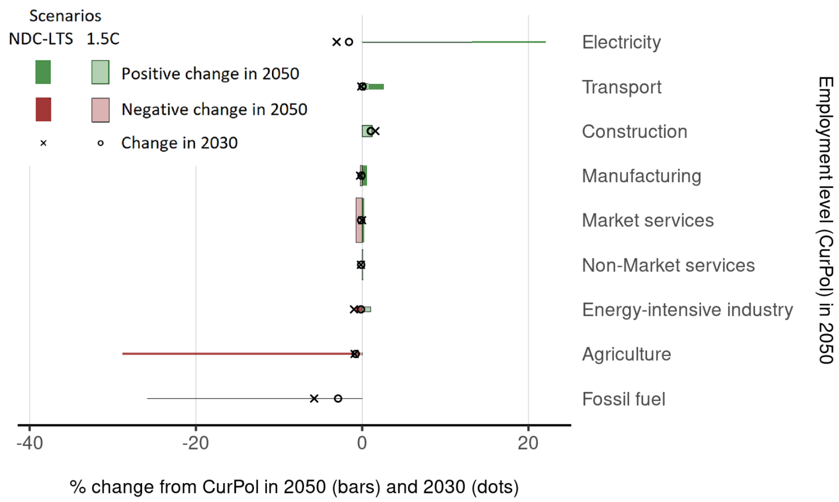
Figure 70: South Korea. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 71: South Korea. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).





Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Similar to Japan, South Korea is an economy with minimal domestic fossil fuel extraction, and a high share of services. This reduces the need for re-adjustments in response to decarbonisation efforts. In percentage terms, reductions in agriculture and fossil fuel sectors and increases in the electricity sector are largest, but these sectors only account for a very small share of the labour force.

Transition towards green infrastructure, including renewable electricity generation, leads to increases in the construction sector, with employment gains also in the transport sector. The energy intensive industry are faced with some job losses under the NDC-LTS scenario as production relocates to other countries without ambitious long-term targets, but could benefit from the already relatively clean production structure under a global push for 1.5°C.

4.11. Mexico

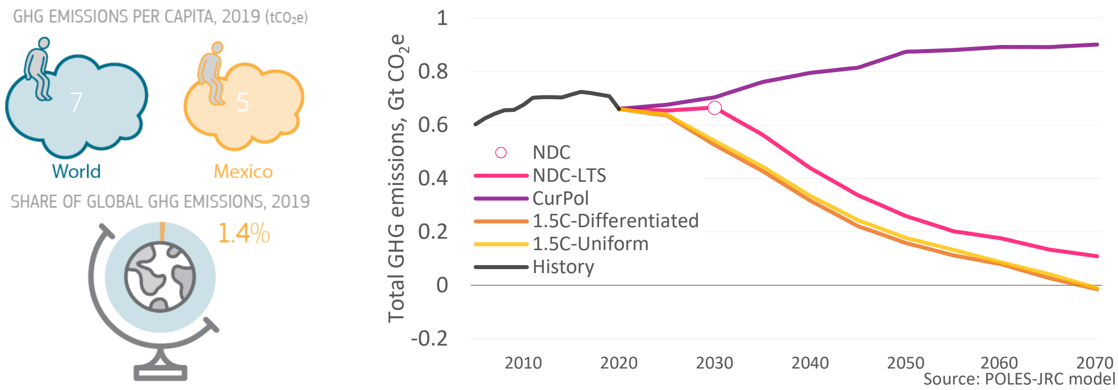


Figure 72: Mexico. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Unconditional reduction of 22% for GHG emissions and 51% for black carbon for 2030 compare to BAU scenario
LTS	GHG emissions reduction to 50% below 2000 levels in 2050

POLICY CONTEXT. Mexico submitted its updated NDC in 2020, which translates into a reduction of approximately 210 MtCO_2e. (BAU scenario to 2030, 991 MtCO_2e). Additionally, as a conditional contribution in its NDCs, Mexico could cut up to 36% of GHG emissions and 70% of black carbon emissions by 2030 compared to the BAU scenario. However, the unconditional emission target represents a +2.3% annual increase in emissions from 2015 to 2030, against a +0.3% emission trend in recent years. Remarkably, the new NDC has revised the BAU projections upwards, resulting in higher emissions by 2030. This is, in part, a result of the cancelation in February2019 of Mexico's highly successful renewable auction program started in 2012.

Mexico does not have a net zero target. In November 2016, Mexico submitted its "Climate Change Mid-Century Strategy". Within this strategy, Mexico pledges to reduce its GHG emissions to 50% below 2000 levels in 2050, leading to emissions levels of between 276 – 321 MtCO_2e excluding LULUCF, by 2050. Mexico has clean power generation targets of 30% by 2021 and 35% by 2024.

ENERGY TRANSITION DYNAMICS. Despite wind and solar generation having tripled over the past five years, Mexico's climate progress has slowed and its emissions have continued to rise. Meeting the NDC 2030 target requires more than doubling the share of renewables compared to 2015. While the electrification rate hardly increases by 2030, for all three scenarios, the 1.5°C target requires higher electrification rates by 2050, reaching up to 60%. Strong climate scenarios also involves significant shares of renewables in final demand and power generation see Figure 73: Mexico. Key indicators characterising the energy transition across time and scenarios.

Figure 73: Mexico. Key indicators characterising the energy transition across time and scenarios

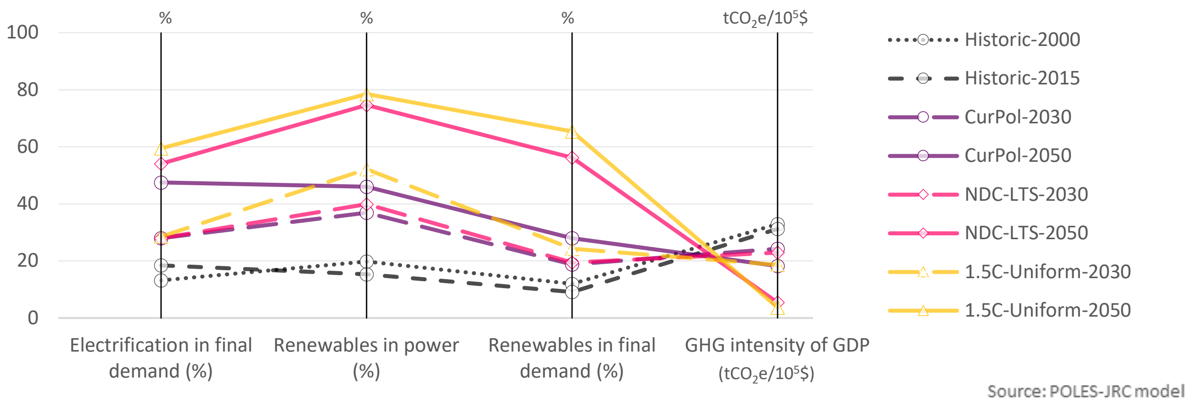
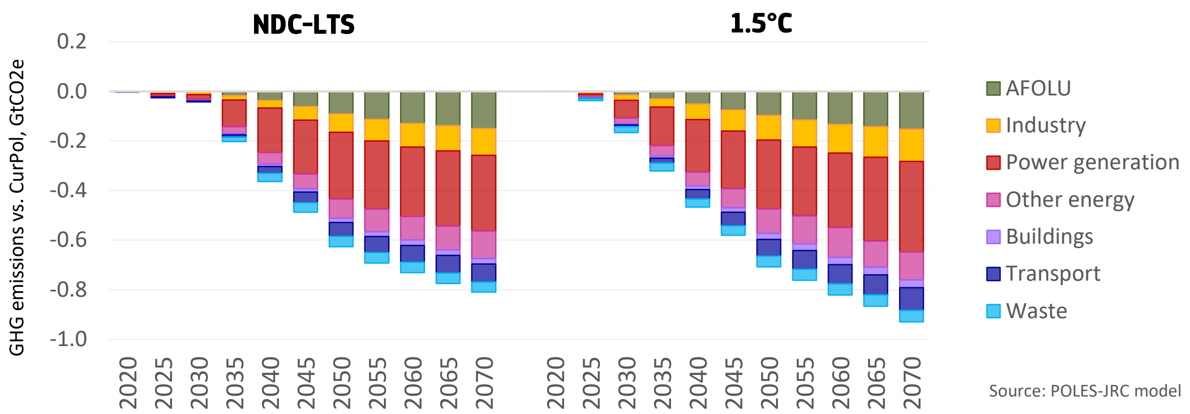


Figure 74: Mexico. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. A deep decarbonisation of the power sector is the main driver of reducing GHG emissions to reach Mexico's climate targets. The power sector, which has been dominated by gas, coal and oil, shifts toward renewable sources and nuclear around 2035 for the most emissions-restricted scenarios. Besides the energy sector, the NDC-LTS scenario also comprises GHG mitigation reductions from the industry and from improved management in forestry and agriculture, as well as deforestation reduction. Additionally, reaching the 1.5°C target requires further emissions reductions from the energy sector, accounting for about 80% of the total contribution. Achieving strong climate protection targets demands further effort in reducing GHG emissions from the AFOLU sector via forest management, afforestation and better agricultural practices, followed by cutting emissions in the industrial and the transport sectors.

MITIGATION OPTIONS. Following the modelling results of GECO 2021, reaching the NDC-LTS pathway includes mitigation mainly by increasing renewable sources for energy production, CCS for biomass, efficiency gains in industry and AFOLU.

For the 1.5°C scenario, the mitigation options in the energy sector are led also by increasing the participation of low-carbon energy sources, as wind, solar, ocean, biomass followed by CCS technologies applied mainly to biomass and industrial processes. Regarding industry, efficiency is the primary driver for emissions reduction. For transport, almost half of the emission reductions arises from light vehicles, with electrification and a switch to lower-emission fuels such as biofuels, e-fuels, and hydrogen are crucial in the long term.

Figure 75: Mexico. Change in GHG emissions compared to CurPol by technology and year

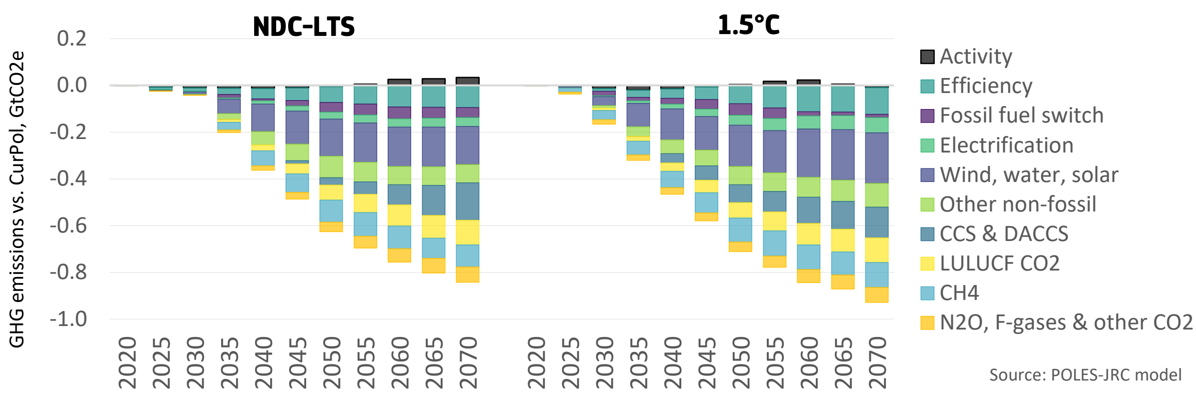
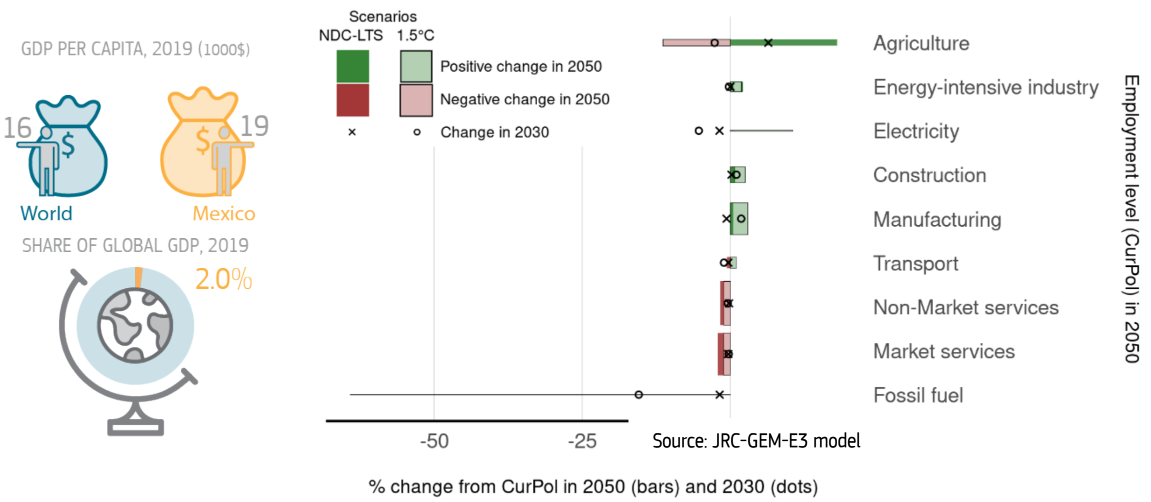


Figure 76: Mexico. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. While the economics of transition may differ across sectors under the NDC-LTS and 1.5°C scenarios, it essentially entails shifting employment away from the crude oil production and absorbing it across other sectors. This makes for a difficult transition for the Mexican economy, as the oil industry accounts for a large share of its government revenues. As a matter of fact, further development of the oil and gas industry, largely based on the upstream sector in the Gulf of Mexico, is expected in the Current Policy scenario. However, labour demand in the fossil fuel sector is relatively low compared to other sectors. More pronounced changes occur under the 1.5°C scenarios by 2050, with employment levels increasing in the construction and energy-intensive sectors, driven by renewables' deployment and electrification, helping to absorb losses from services. Growth in the agriculture sector employment under the NDC-LTS scenario is led by the crops sector, mainly due to increased production of exported-oriented commodities (e.g., fruit, tomatoes).

4.12. Russia

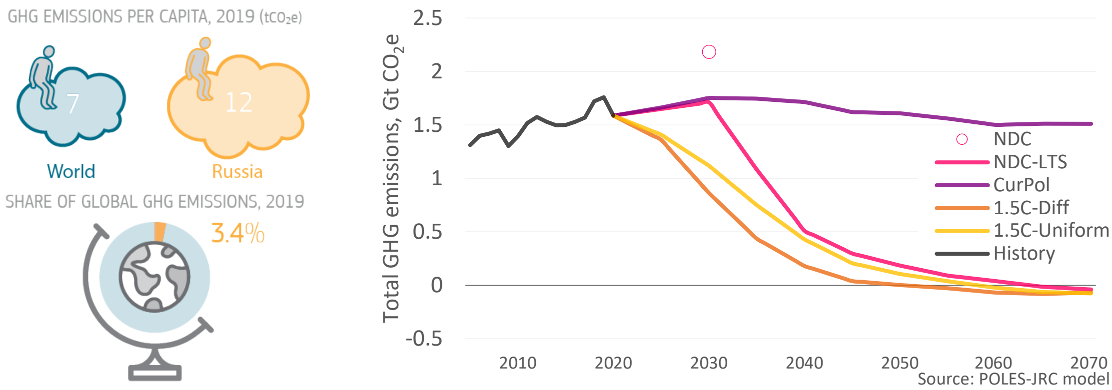


Figure 77: Russia. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

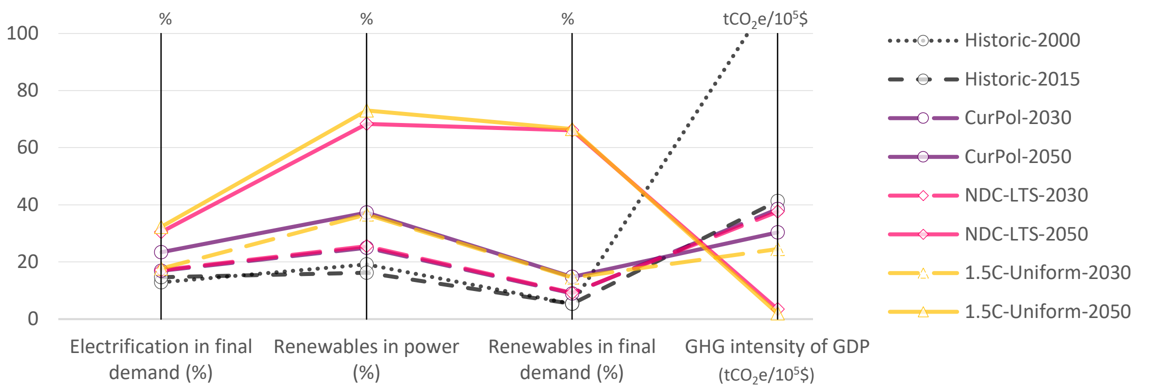
Pledges	Key targets
NDC	Reduction of GHG emissions including LULUCF by up to 30% by 2030 compared to 1990
LTS	Net GHG emission reductions of 80% in 2050 compared to 1990 and climate neutrality in 2060

POLICY CONTEXT. One of the key strategic documents on Russia's energy policies is the Energy Strategy (Ministry of Energy of the Russian Federation, 2019). This policy framework still supports the export-oriented model of energy development in Russia and, while recognising the decreasing role of the carbon intensive economy, the development of fossil resources is strongly emphasised (Alekseev et al, 2019; Mitrova & Yermakov, 2019). A major focus of the Energy Strategy is to benefit from opportunities in the growing global gas market as revenues from gas exports are foreseen to compensate for losses resulting from decreasing global oil demand.

Regarding climate mitigation, the first Nationally Determined Contribution of Russia calls for a reduction in GHG emissions including LULUCF by up to 70 percent by 2030 relative to the 1990 level. This target takes into account the maximum possible absorptive capacity of forests and other ecosystems and a sustainable socio-economic development of the Russian Federation (Government of the Russian Federation, 2020). During the COP26 Russia adopted a strategy to reduce net GHG emissions by 80% in 2050 compared to 1990 enabling climate neutrality not later than 2060.

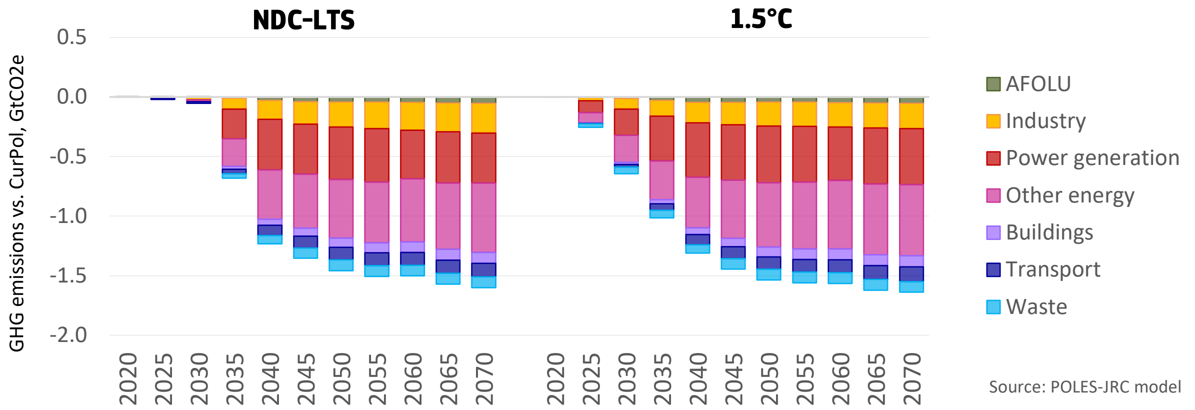
ENERGY TRANSITION DYNAMICS. Setting the focus on the development of fossil resources, the ambition in reducing GHG emissions is rather low, which results in little or even no difference between the current policy and the NDC-LTS scenario (Figure 77 and Figure 78). The low share of renewables in power generation and in final demand are in contrast with Russia's large renewable resource potential and with what is required for a 1.5°C scenario. Hence, the GHG emission reduction per GDP between 2030 and 2050 remains low except in the 1.5°C scenario in 2050.

Figure 78: Russia. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 79: Russia. Change in GHG emissions compared to CurPol by sector and year

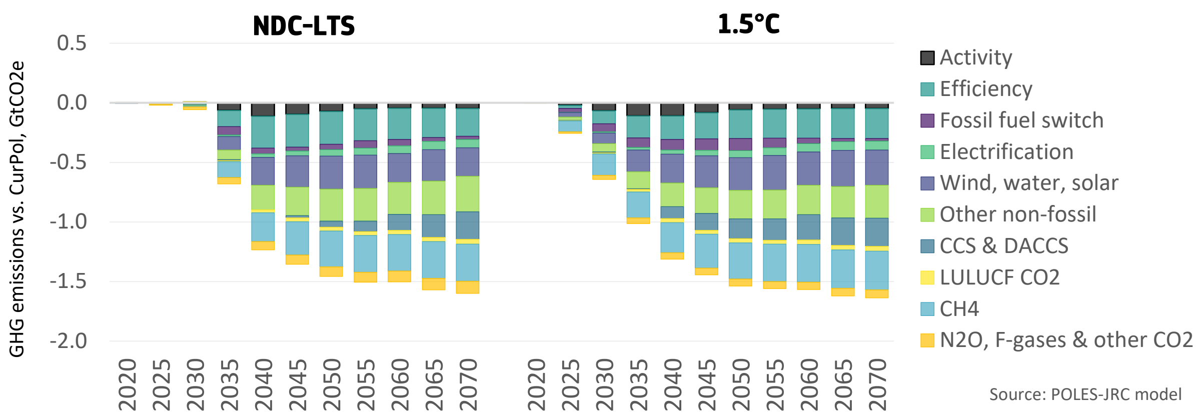


Source: POLES-JRC model

SECTOR CONTRIBUTIONS. Changes in GHG emissions of the NDC-LTS scenario compared to the current policy scenario for the Russian Federation are very modest until 2030. After 2030 GHG emission reductions increase massively as a result of the envisaged long-term target of an 80% reduction by 2050. In the absence of clear and detailed policies to reach the LTS, GHG emission reductions are driven by carbon pricing. Hence, the distribution of GHG emission reductions between sectors in the NDC-LTS scenario are very similar to the 1.5°C scenario. Low levels of renewables until 2030 are in contrast with the high reduction potential which is illustrated if we compare the 1.5°C scenarios with the Current Policy scenario. As Russia is one of the most important energy producers and exporters, important mitigation opportunities appear in the sectors ´other energy´ and `power generation´. Indeed, the highest emission saving potential is identified in the methane leak reductions associated to oil production, gas transport and both surface and underground coal mining (all of which are part of ´other energy´). Another important source of CO_2 emission cuts is related to fossil fuel combustion in the power generation sector.

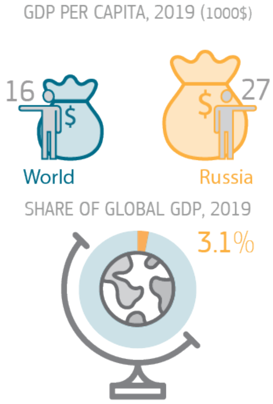
MITIGATION OPTIONS. The most important mitigation options refer to methane emissions in oil production, gas transport and coal mining, and efficiency improvements, both being particularly relevant in the NDC-LTS and 1.5°C scenarios. The role of renewables is much more prominent in the NDC-LTS scenario after 2030 and in the 1.5°C scenarios. The current installed capacity of renewables is rather small although Russia has a huge potential as it has vast available land areas and many regions with good wind and solar exposure. Additionally, GHG emissions reductions due to lower activity levels in the energy sector and through lower use of gas and coal in heating are important. Further mitigation options refer to switches to non-fossil fuels e.g. electricity in steel production and biomass in the chemical industry. Russia has also large implementation possibilities for synthetic fuels using the abundant gas resources as feedstock and coupled with direct air capture. In addition, carbon capture and storage (CCS) technologies provide interesting opportunities in Russia as CO_2 emissions can be captured at the source and stored in depleted oil and gas fields.

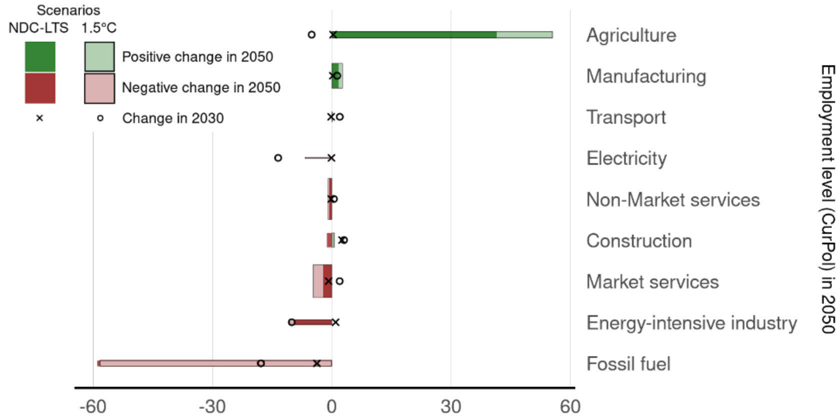
Figure 80: Russia. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 81: Russia. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



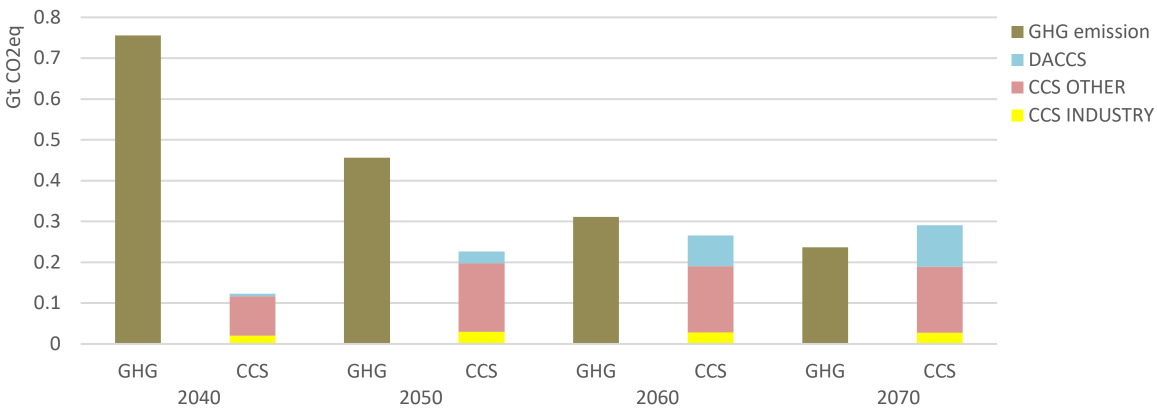


Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Russia has large employment levels in the fossil fuel sector, which face a significant reduction in all scenarios, in a demand driven structural change that involves both the O&G and coal industries, especially under the more stringent 1.5°C scenarios. The job losses also impact energy–intensive industries and other sectors like the construction sector due to a decrease in fossil fuel infrastructure. In the transition to a decarbonised economy, agriculture stands out as the main sector absorbing the job losses. Jobs in agriculture also increase, as compared to the Current Policies scenario in 2050, due to the promotion of biomass production from dedicated forestry. Manufacturing shows a certain increase in labour demand, motivated by increased competitiveness in the production of consumer goods and other equipment goods, under the 1.5°C scenarios.

CAPTURING CARBON. The GECO2021 analysis indicates that a direct air capture and carbon storage (DACCS) and as well other CCS technologies could be an option fitting well to the characteristics of the Russian Federation's industrial structure. Russia has large hydrocarbon reservoirs and depleted oil and gas fields are already used for CO_2 storage (Oeko Institute, 2021). The availability of large areas of relatively unpopulated land could enable Russia to consider this technology. If CO_2 is captured from air in large quantities, large areas are required for DAC plants. In addition, the process of capturing CO2 from ambient air is an energy-intensive process, possibly relying on low carbon carriers for consistency with the decarbonisation targets. Additional benefits of this technology option could be the use of captured CO_2 for the production of synthetic fuels. Overall, Russia follows the USA, China and Canada in emission reductions from DACCS in the 1.5°C scenario between 2050 and 2100. Figure 82 shows that increasing CCS technologies - and among them DACCS – can surpass levels of GHG emissions in 2070 leading to overall negative emissions.

Figure 82: GHG emissions and removals through CCS technologies in Russia in 1.5°C in 2070



Source: JRC-GEM-E3 model

4.13. Saudi Arabia

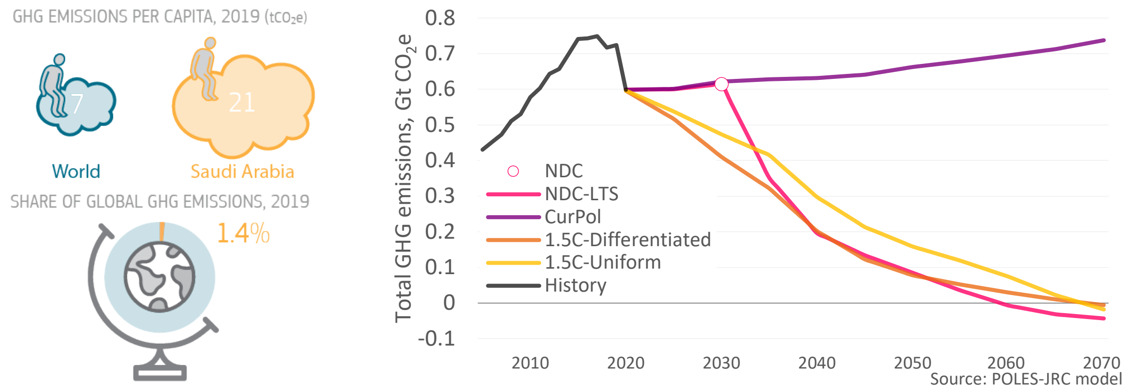


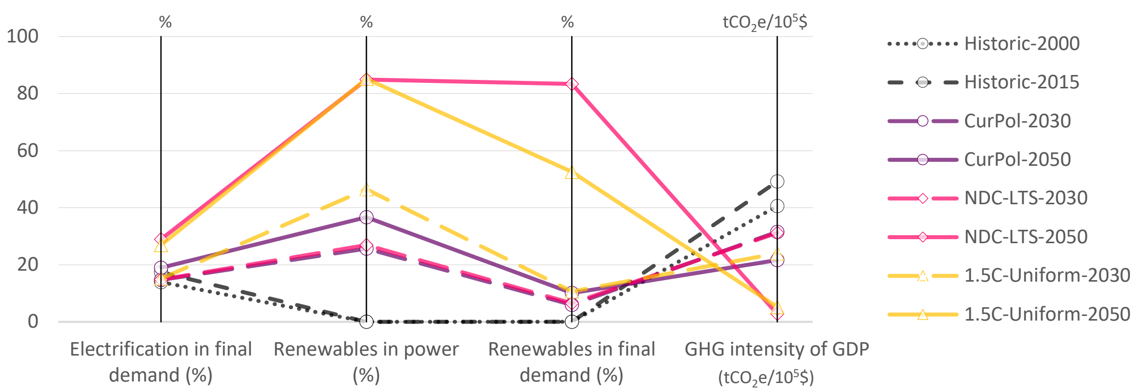
Figure 83: Saudi Arabia. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Abate up to 278 Mt CO_2e by 2030 relative to business as usual.
LTS	Climate neutrality by 2060 (announced in October 2021 included in this report)

POLICY CONTEXT. Saudi Arabia is the largest economy in the Middle East, and the world's largest oil exporter. In 2015 Saudi Arabia ratified the Paris Agreement. In 2019 Saudi Arabia updated its renewables targets – current objectives are 58.7GW of renewables by 2030, of which 40GW are PV. Today, less than 1% of its electricity supply comes from carbon-free resources. The renewable sector has had some setbacks, but the results of recent auction programs might indicate a brighter future. In March 2021 the Saudi Green Initiative and the Middle East Green Initiative were announced aiming at rallying the region and significantly contributing to global climate protection targets. Within this initiative, Saudi Arabia aims to generate 50% of its energy from renewables by 2030 and plant 10 billion trees in coming decades. These announcements, however, have not been considered in the scenarios included in this report. Saudi Arabia has recently also announced its net-zero target for 2060, which foresees an increased contribution from afforestation and other land-use abatement options, in addition to efficiency gains from its circular economy strategy.

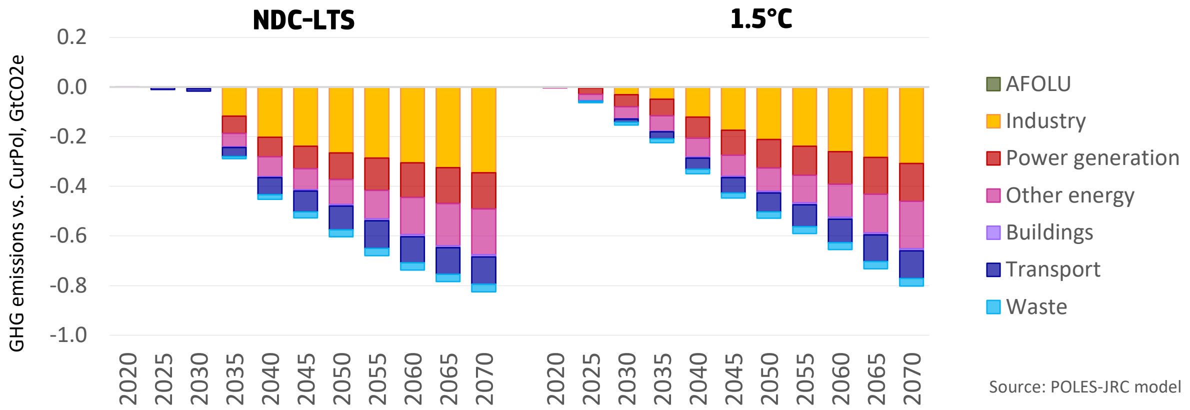
ENERGY TRANSITION DYNAMICS. The emissions intensity in GDP for Saudi Arabia started dropping as recently in 2015. The final demand electrification share hardly grows in all scenarios; even in 2050 values are below 45% for the most climate-restricted scenario. The bulk of emissions reductions come from a massive increase of the renewables share in power and in final energy demand by 2050, see Figure 84. Keeping in mind that renewables made up just 0.02% of final energy demand in 2017, the challenge is huge.

Figure 84: Saudi Arabia. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 85: Saudi Arabia. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. Saudi Arabia can easily meet its NDC target with existing policies by 2030. During COP26 Saudi Arabia announced its LTS targets, net zero GHG by 2060. Therefore, the 1.5°C scenario closely follows the NDC-LTS pathways around 2070. Reaching this new target requires a bigger effort, mainly from the industry, energy and transport sectors. In 2050, more than 40% of the reductions stem from the industrial sector, mainly via energy efficiency, CCS in industrial processes and the increasing participation of renewables. Followed by 30% of the reduction coming from the energy sector due to the substitution of fossil fuels with renewable sources. From 2060 onwards, CCS and DACCS will play a large role in emissions reductions. The remainder comes from waste and transport, which reduces emissions due to efficiency gains and electrification in road transport.

MITIGATION OPTIONS. Methane reductions are the low-hanging mitigation options for the oil & gas industry. Saudi Arabia has joined the global methane pledge which aims to reduce methane emissions by 30%, through the reduction of losses from new and existing oil and gas pipelines. Additionally, GHG emissions decrease due to lower activity levels in the energy sector. Further mitigation options refer to CCS use and DACCS, followed by switching to non-fossil fuels e.g. decarbonisation of the power sector. Additionally, the role in mitigation of other non-fossil is far more prominent in the NDC-LTS scenario. Saudi Arabia also has a high potential to increase solar generation. The country's renewables sector has had a few false starts, but recent activity shows signs of a more solid progress.

Figure 86: Saudi Arabia. Change in GHG emissions compared to CurPol by technology and year

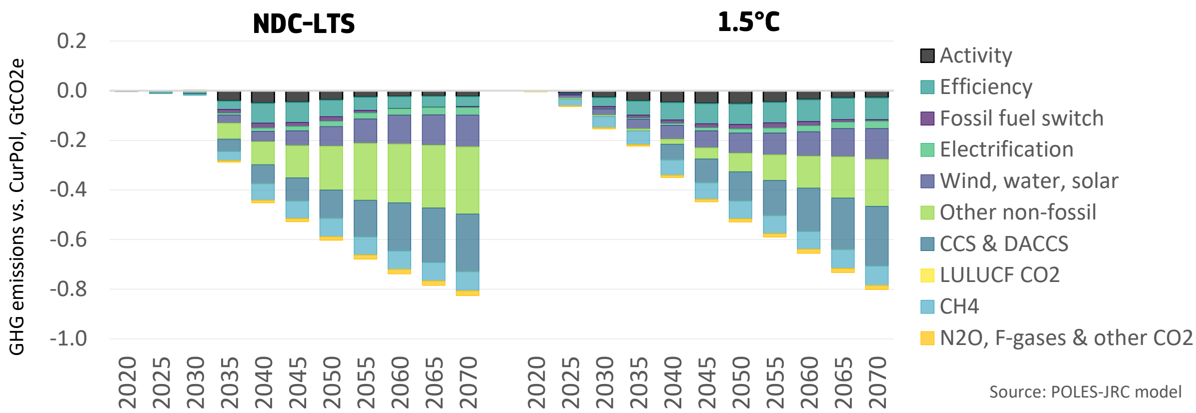
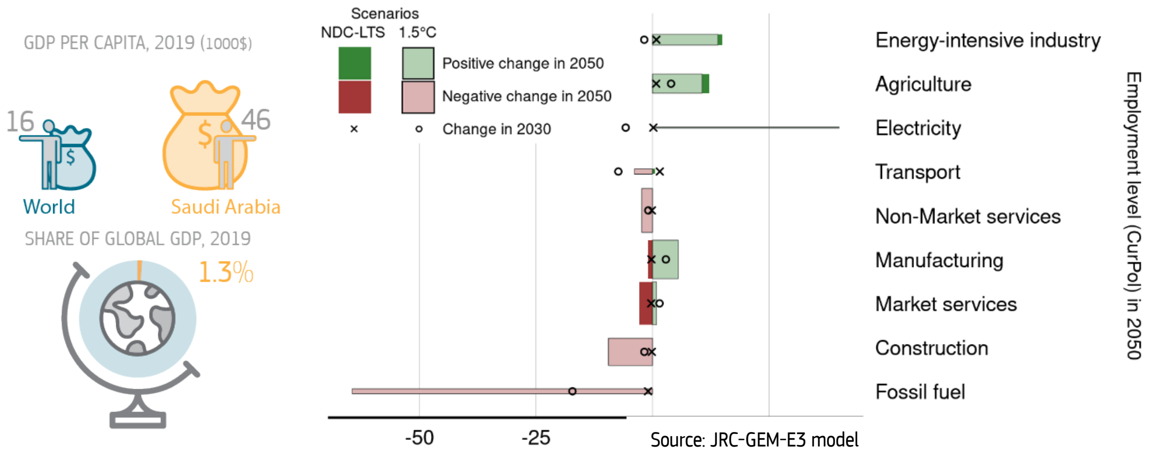


Figure 87: Saudi Arabia. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Investment is the main driver of the transition in Saudi Arabia and promotes growth in the domestic production of energy-intensive goods (e.g. chemical products) and manufacturing sectors (e.g. electric goods and transport equipment), especially in the 1.5°C scenario. The fossil fuel sectors are strongly affected from 2030 onwards by lower international and domestic demand for oil products, reducing job demand in the O&G industry and in the construction sector. Labour demand in energy-intensive sectors grows in both scenarios, propelled by the comparative advantages of the Saudi economy. Employment levels in the agriculture sector increase, particularly driven by growth in the domestic deliveries from the forestry sector, in line with the recently announced LTS. A strong increase in the share of renewables is observed from 2030 onwards, which helps boosting jobs in the electricity sector.

STRANDED ASSETS AND GREEN TRANSFORMATION. Global efforts to reduce fossil fuel use in response to climate change are a major source of concern for the Saudi Arabian economy. Approximately one-third of the global crude oil production is pumped in the region, in addition to significant natural gas production. Net-zero targets can strongly threaten global oil demand and therefore puts fossil fuel reserves at risk of being stranded assets. Limiting new investment in fossil fuels is needed as vast reserve of oil and gas must remain untapped in the ground to ensure climate targets are reached. Re-directing these investments towards a carbon-free technology portfolio could accelerate the clean energy transition, enabling the emergence of competitive energy-intensive industries and reducing financial risks.

Saudi Arabia has a large renewable capacity based on abundant areas with high solar irradiation, and considerable wind potential in its mountains. Solar power can be deployed at low-cost due to large economies of scale and the favourable irradiation conditions. Abundant renewable energy can also promote the development of low-emission fuels production, so that the world's leading oil producer could become a global leader in forging a greener world.

4.14. South Africa

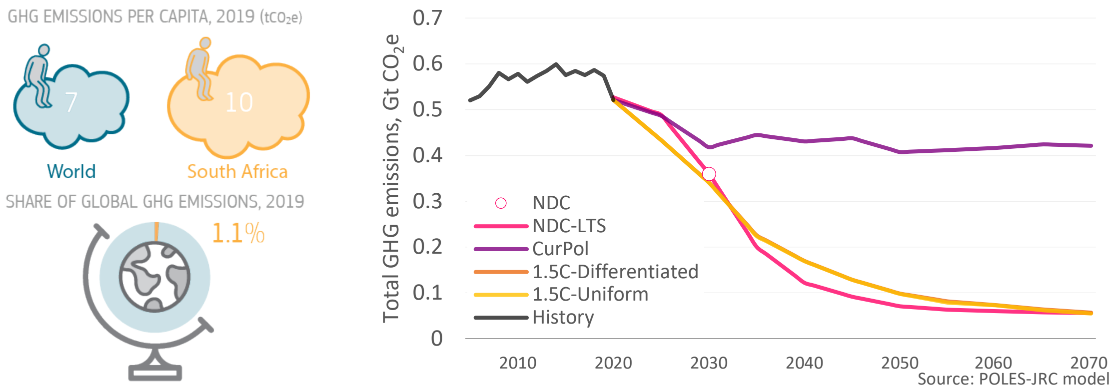


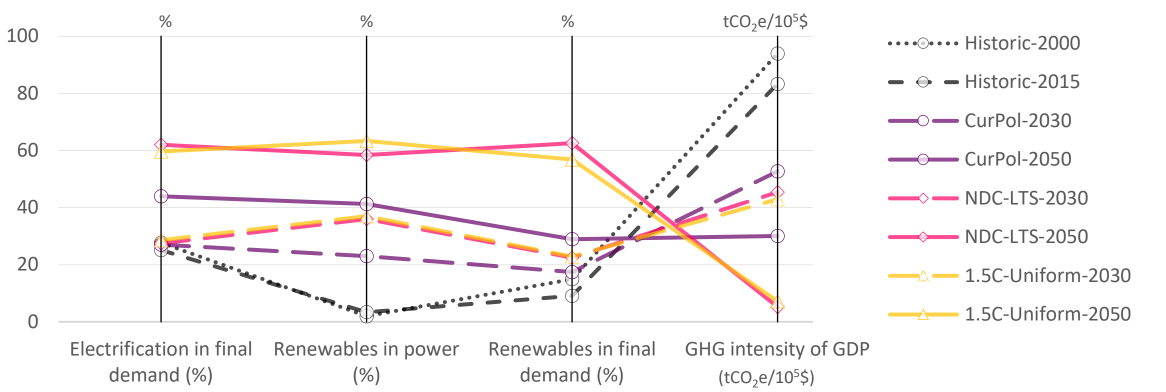
Figure 88: South Africa. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	Decarbonising the power sector by 2050, expansion of electric vehicles and CCS for producing synfuels.
LTS	Reaching a net-zero CO_2 economy by 2050.

POLICY CONTEXT. Coal is an important factor in South Africa. The country is the third largest coal exporter worldwide and coal is the backbone of its power production. Consequently, substituting coal power plants with low-carbon technologies and closing down coal-related activities is key for achieving the 1.5°C objective. Decarbonising the power sector will be mainly driven by a huge expansion of various renewable technologies. In recent years, significant renewable capacities (6.4 GW by 2019) have been built driven by the *"Renewable Energy IPP Procurement Programme"*. The funds of USD 8.5 billion pledged at the COP26 to support South Africa in decarbonising its power sector will accelerate the deployment of renewables (UKCOP26, 2021). But also nuclear power is very likely to play a role in decarbonising the power production as envisaged in the scenarios. Indeed, South Africa currently operates 1.9 GW of nuclear power and has plans to build new capacities. Finding the right balance between expansion of renewables and nuclear will be an important decision South Africa has to take. Beyond 2050, a substantial amount of emissions still persist according to the scenarios. These emissions come mainly from the industrial sector, coal mines (CH_4) and the AFOLU sector.

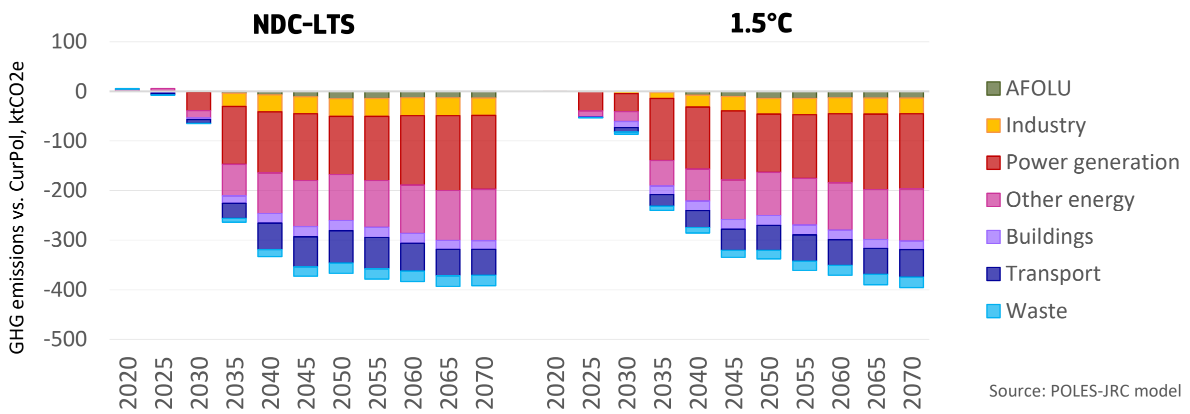
ENERGY TRANSITION DYNAMICS. Renewables are key for the decarbonisation. From 2030 to 2050, the dynamics in electrification and renewable expansion increases substantially. As nuclear power contributes substantially to decarbonise the power sector, the renewable shares remain at lower levels compared to a case without nuclear power.

Figure 89: South Africa. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 90: South Africa. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. Renewables and nuclear provide the main contributions for the decarbonisation of the power sector. Biomass power with CO_2 capture also plays an important role and forms the major part of South Africa's carbon sink. Remarkably, coal power with CO_2 capture only plays a minor role despite huge coal resources (1.5°C scenario),Closing down coal-related activities reduces associated emissions such as CH_4 emissions from coal mines. In the 1.5°C scenario coal associated emissions and CO_2 capture from industrial processes account for the major part of "Other energy" in the Figure 90. In transport, emissions are reduced mainly in the road and maritime sector. With the Green Transport Strategy (2018) crucial developments have been initiated towards low emission transportation.

Producing synfuels from coal gasification was pioneered in the 1980's in South Africa. Building on these competences the country has the potential to become a technology leader in carbon capture from synfuel production. The NDCs already envisage the capture of 22 Mt CO_2 from synfuel production.

MITIGATION OPTIONS. South Africa is blessed by abundant renewable resources. As sun-rich country, solar energy plays a major role, expanding to more than 100 GW in 2070 (1.5°C scenario). Strong winds and sea currents along its extensive coastlines can be exploited. Consequently, large off-shore capacities are installed. Remarkably, there is substantial contribution of ocean energy from 2050 onwards. On-shore wind also plays a crucial role.

The contribution of "Other non-fossil" sources is significant and reflects the increase of nuclear capacities projected to increase from the current 1.9 GW to 18 GW by the mid of the century in the 1.5°C scenario. With the "*Waste Management Flagship Programme*", South Africa has taken up the challenge of reducing emissions from waste substantially (mainly CH_4).

Figure 91: South Africa. Change in GHG emissions compared to CurPol by technology and year

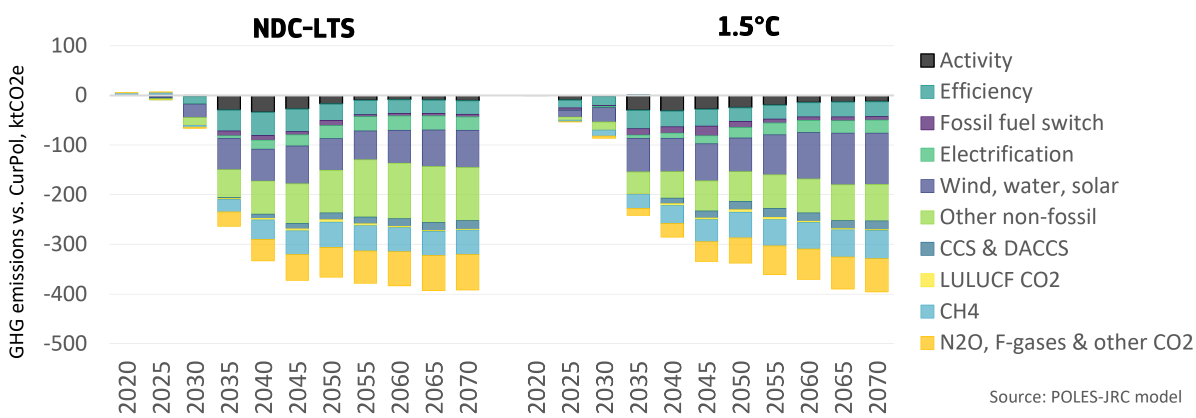
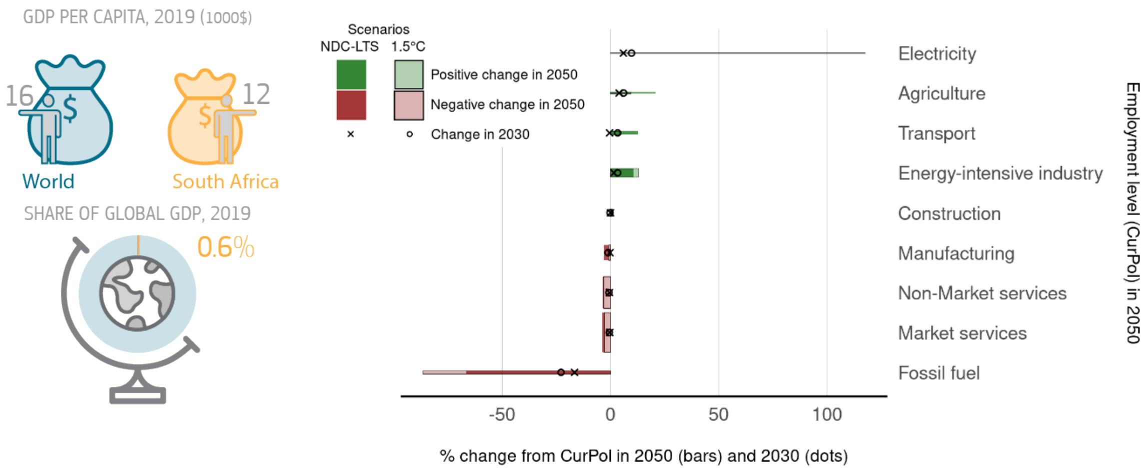


Figure 92: South Africa. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. The transition towards decarbonisation has several positive job boosting effects with a very dynamic increase from 2030 to 2050 reflecting the profound changes in power production (i.e. huge renewable expansion), transport (i.e. low-emission vehicles), energy intensive industry and agriculture.

Remarkable is the employment growth in energy-intensive industry driven by the non-ferrous metals sector. In particular, copper and aluminium production benefit from increased competiveness in scenarios with stringent climate targets. Also in the agriculture sector, employment increases sharply, particularly driven by growth in the domestic deliveries from the crops sector. Given the importance of the non-ferrous sector and agriculture for South Africa, this is an encouraging result.

These positive employment effects absorb the obvious job losses in the fossil fuel industry from closing down coal-related activities.

NUCLEAR POWER IS AN OPTION. Nuclear power could play a major role in decarbonising the power sector in combination with a substantial expansion of renewables. Nuclear power generation is an established technology in South Africa. Therefore, increasing its nuclear power production is a realistic option.

In the last 15 years there have been repeated plans published to extend the nuclear capacity in the range of 10 to 20 GW. However, these targets have been revised downwards in the last years. As of 2020, it seems that the government envisages a roadmap for building 2.5 GW of nuclear capacity. From today's point of view, it remains unclear if, or to which extent, South Africa aims to expand its nuclear capacities.

From an international point of view, the opportunity of expanding the nuclear capacities of South Africa is an interesting case. The construction of nuclear plants and supply of nuclear can only be provided by foreign companies from few countries with nuclear capabilities. Moreover, financing new nuclear plants could require substantial foreign assistance. In turn, these circumstances might raise questions for South Africa regarding international relations and security of supply. Therefore, emerging countries thinking of nuclear expansion are likely to carefully watch the strategic decisions taken in South Africa in this regard.

4.15. Turkey

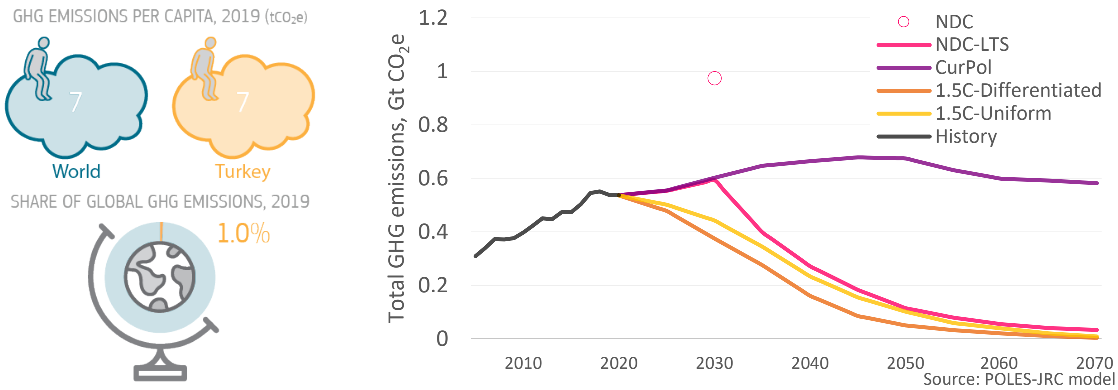


Figure 93: Turkey. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	21% reduction in GHG emissions from BAU in 2030; Interpreted as 116% increase from 2012 GHG emission levels
LTS	Net zero GHG emissions by 2053

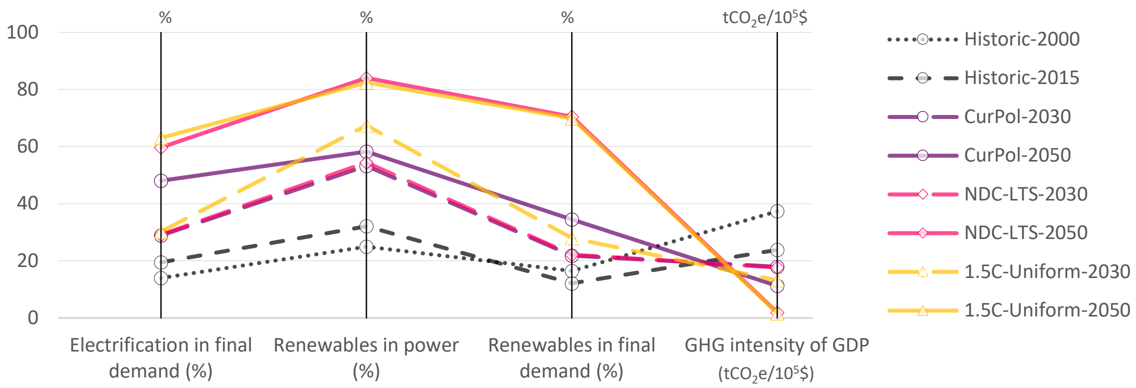
POLICY CONTEXT. Following strong growth since 2000, Turkey's emissions have stabilised in the last few years, in tandem with the country's economic stagnation due to currency and debt crises.

Turkey's energy and climate policies have been motivated primarily by the issue of energy security. The key policy targets are: (a) the National Energy Efficiency Action Plan (14% below BAU in 2023); (b) the renewable energy objectives (38.8% and 20.5% in power and gross final energy, respectively, by 2023); and (c) the development of a nuclear industry (first plant due in 2023). The country's NDC, defined as 21% below BAU, appears to be far from binding, as illustrated in the chart above.

Despite a strong growth of renewable power over the past decade, Turkey continues to rely on coal power significantly (>30% of power production), fuelled by low-quality domestic lignite and coal imports. Although no new coal plant licenses have been issued since 2019, this is likely more due to the overabundance of already-issued licenses resulting from the decelerated economic growth than to climate concerns. In these circumstances, some coal plants were suspended in 2020 due to air pollution limit violations.

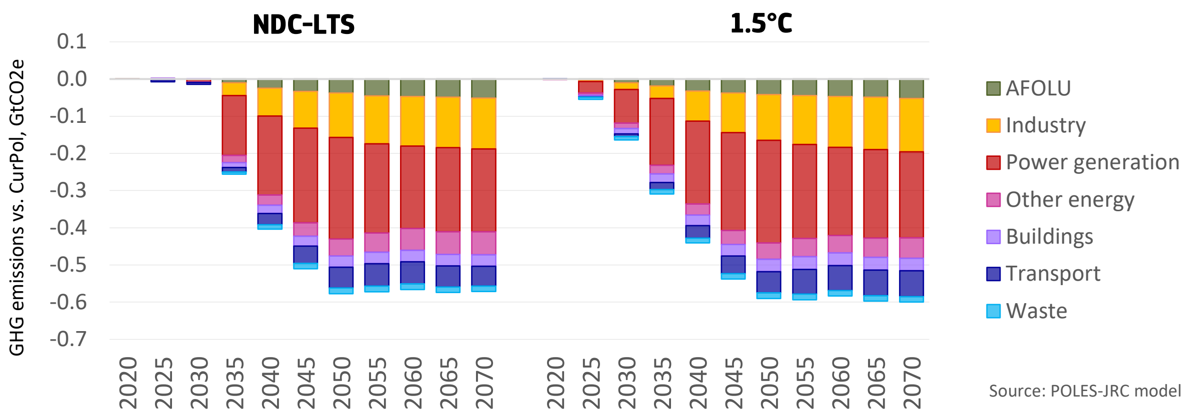
ENERGY TRANSITION DYNAMICS. The electrification share in final energy demand and the renewable share in the power mix are expected to increase significantly even without strong climate policies (Current Policies scenario), reaching 35% and 58% in 2050, respectively. In the 1.5°C scenario, electrification accelerates only after 2030, reaching 67% in 2050, while renewables in power accelerate immediately from the start of the projection, reaching 82% in 2050.

Figure 94: Turkey. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 95: Turkey. Change in GHG emissions compared to CurPol by sector and year



SECTOR CONTRIBUTIONS. The GECO2021 projections of current policies lead to an overachievement of Turkey's NDC objectives. The LTS objective of net-zero emissions just over two decades later sees a sharp change in energy supply and demand patterns.

Power generation is the prime lever of action for achieving net-zero, followed by industry; for both these sectors most of the mitigation is achieved by 2040. Buildings, transport (mainly road) and AFOLU (mainly agriculture) contribute to fill most of the remaining mitigation gap. Turkey becomes carbon-neutral in 2060 in the 1.5°C scenario.

MITIGATION OPTIONS. The power sector sees a near phase-out of coal capacities by 2040 and a stabilisation and CCS-retrofit of gas capacities in the 1.5°C scenario (by 2050 in the NDC-LTS scenario). Although wind and solar are projected to experience a more than tenfold increase compared to today by 2050 in the Current Policies scenario, their expansion accelerates further in the 1.5°C scenario, reaching 55% of power production in 2050. Nuclear plays an important role in decarbonisation, with some 20 GW installed by 2050 (1.5°C scenario).

Biomass plays a minor role in power (<5% of power generation, all scenarios throughout 2050), but it becomes significant in the production of biofuels, where a third is coupled with CCS in the NDC-LTS and 1.5°C scenarios; from a negligible market today, biofuels represent 30-39% of liquids in road transport in 2050 in the NDC-LTS and 1.5°C scenarios (only 12% in CurPol).

Figure 96: Turkey. Change in GHG emissions compared to CurPol by technology and year

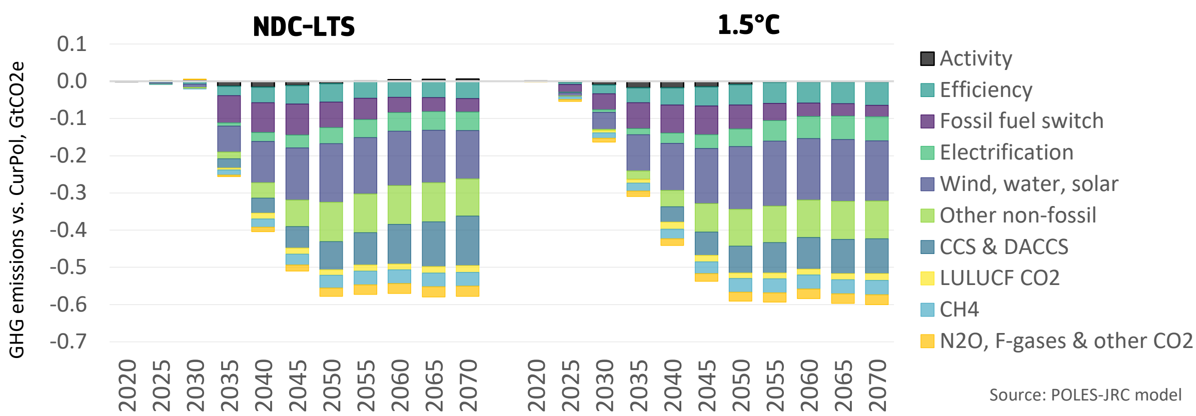
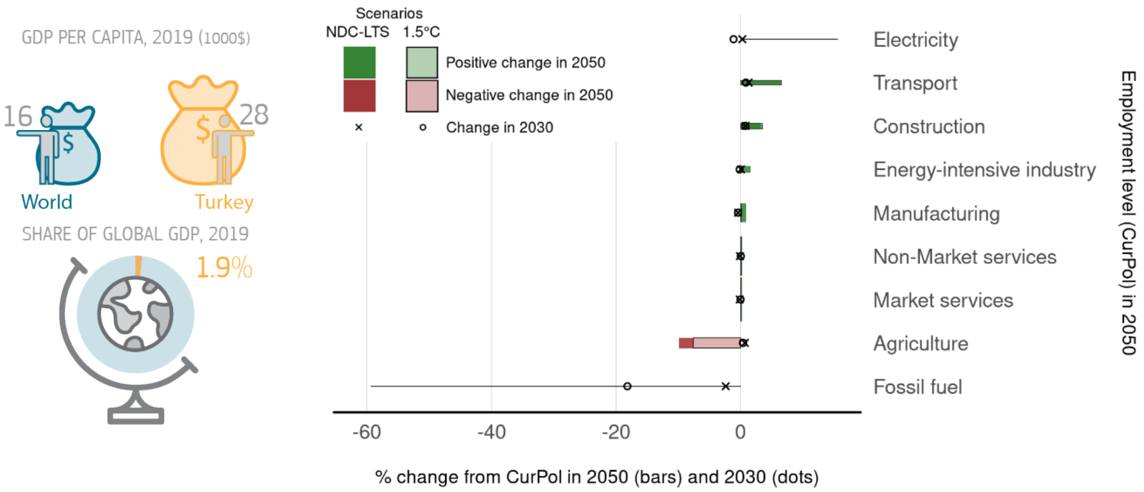


Figure 97: Turkey. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).

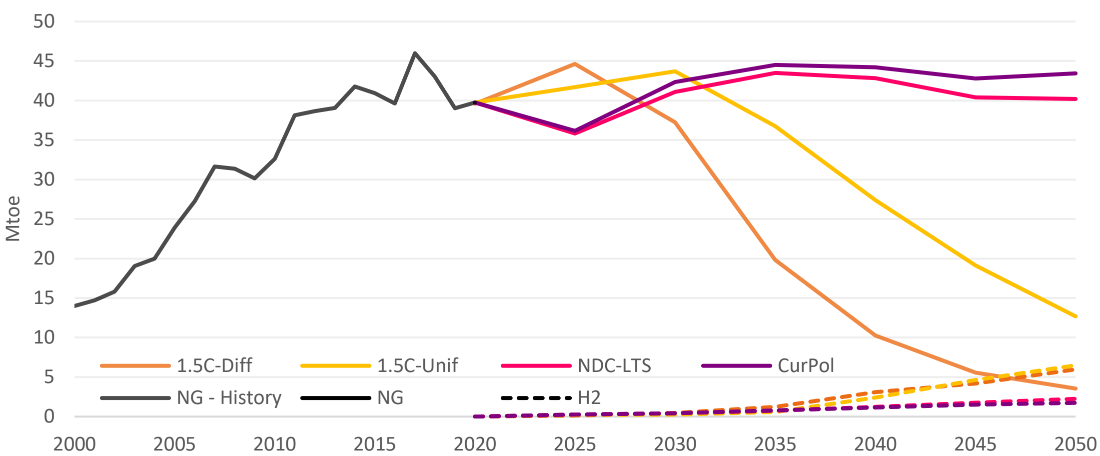


Source: JRC-GEM-E3 model

THE ROLE OF NATURAL GAS. Turkey's infrastructure development over the past two decades has focused on developing its gas import facilities and transport and distribution network; nearly all gas is currently imported. Most recently, two new pipelines were commissioned in 2019 and a floating LNG import facility close to Izmir in 2021; the 2023 target would be to increase 2019 import capacities by nearly 50%. However, gas demand has stabilised since reaching a peak in 2017 and it is projected to have entered a plateau throughout 2070 under current policies. This would render the additional gas infrastructure superfluous. Indeed, energy efficiency and electrification limit the need for gas in buildings space heating and in industry; in power generation, gas remains exclusively in peaking plants.

In the 1.5°C scenarios, natural gas demand increases in the coming decade compared to CurPol due to fuel switching in power generation; however, demand decreases after the current decade. This decrease occurs in the NDC-LTS scenario as well. The emergence of hydrogen as a gaseous energy vector would only very partially counter-balance the decrease in natural gas demand.

Figure 98: Turkey. Natural gas primary demand and hydrogen-for-energy demand in Turkey



Source: POLES-JRC model

4.16. United Kingdom

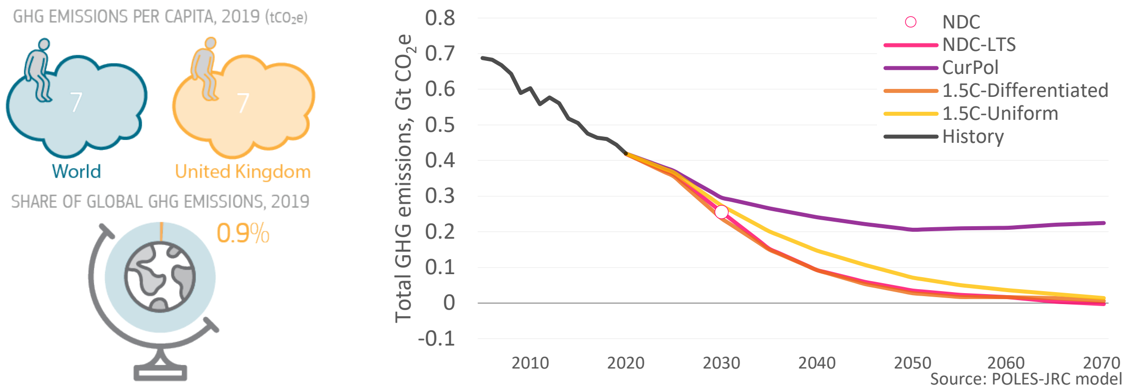


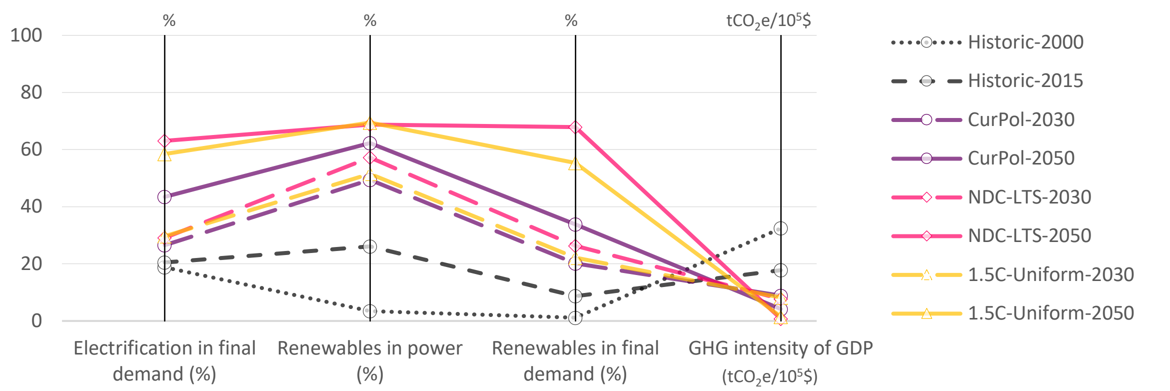
Figure 99: United Kingdom. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	At least -68% GHG emissions reduction by 2030 compared to 1990
LTS	Net-zero GHG emissions in 2050

POLICY CONTEXT. The UK's emissions have been decreasing steadily since before 2000. Since 2008, the UK sets itself five-year carbon budgets that have become more stringent over time. In parallel, until recent times the UK's climate objectives for 2030 were established from within the EU. Since exiting the EU, the UK adopted a net-zero emissions target for 2050 in 2019 and submitted its first NDC independently in 2020, which sets the target of a 68% emissions reduction by 2030 compared to 1990. The UK is still part of the EU's ETS, which has an overall reduction target of 43% compared to 1990 (under revision to as much as 65%); in addition, the UK also applies a carbon price floor to the ETS price. Renewables in final demand reached 12% in 2019; they expanded to 38% in power generation, rapidly increasing over the past decade, in particular wind. Coal in the power sector has been nearly totally phased out (to be fully completed by 2024). The UK plans a future expansion of its nuclear fleet, despite multiple delays and cancellations of projects in recent years. The sale of fossil fuelled light vehicles is set to be banned in 2030 (2035 for hybrids).

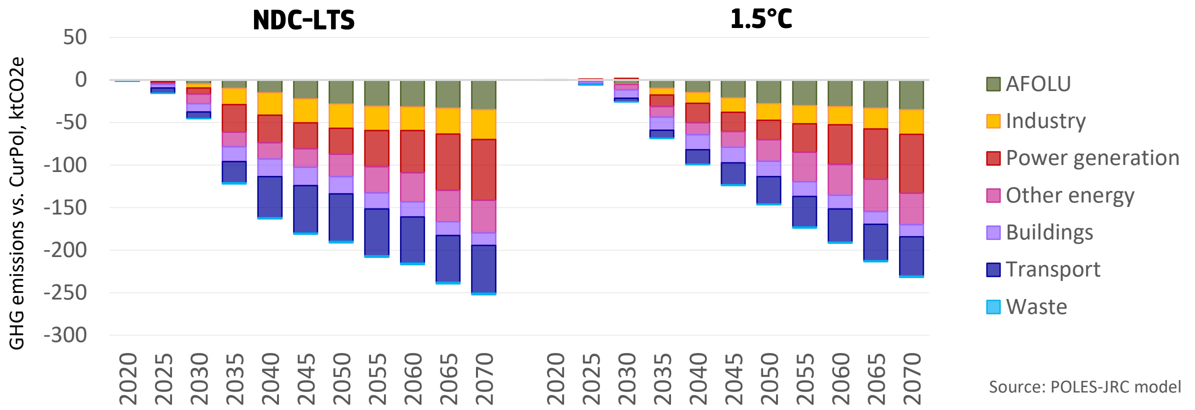
ENERGY TRANSITION DYNAMICS. In the transition to a net-zero emissions economy, the UK is set to make use of the two main levers: demand electrification, and increasing the renewables share. By mid-century, electricity covers much more than half of final energy demand in the NDC-LTS scenario (62%, compared to 20% in 2019). This comes at the expense of the dominant current fuel sources, oil and gas. Climate policies accelerate the uptake of renewables compared to the Current Policies scenario: 20% in CurPol to 25% in NDC-LTS in 2030 (34% and 66% in 2050, respectively). The rate of emissions intensity reductions remains close to the levels of the recent past (circa 5%/year) until 2030 in the NDC-LTS scenario and accelerates significantly in the period 2030-2050 (to 10%/year).

Figure 100: United Kingdom. Key indicators characterising the energy transition across time and scenarios



Source: POLES-JRC model

Figure 101: United Kingdom. Change in GHG emissions compared to CurPol by sector and year



Source: POLES-JRC model

SECTOR CONTRIBUTIONS. The country's NDC brings the emission trajectory somewhere in-between the two 1.5°C scenario trajectories. The energy sector contributes the bulk of emissions reductions. The power sector becomes carbon-neutral around 2050. It is followed by transport (mainly road transport) and, in similar commensurate contributions, AFOLU, industry and buildings. This balanced representation of all sectors in the overall mitigation reflects a broad policy effort where all sectors of a diversified economy do their share.

In the NDC-LTS scenario, 70% of private cars are electric by 2040 (plug-in hybrid and full-electric) and extensive renovation results in building shells that are twice as efficient in 2050 as they are today.

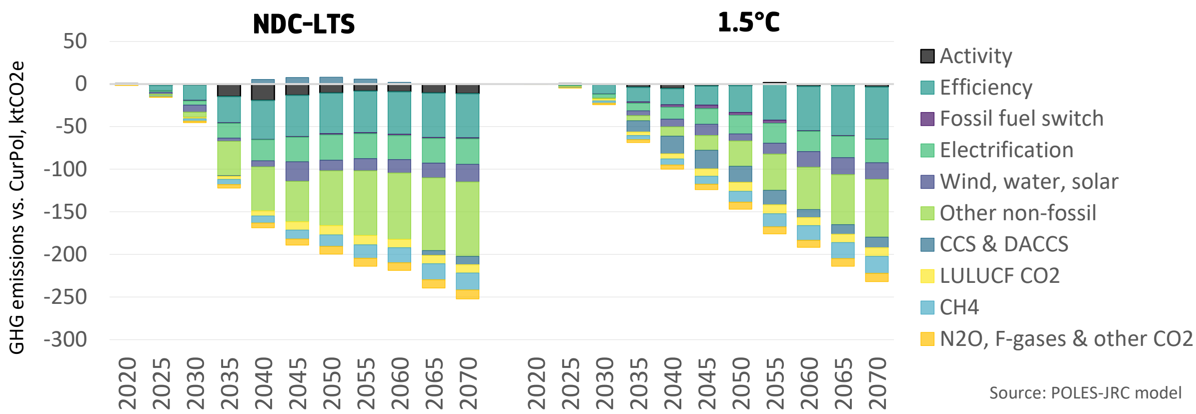
The situation for natural gas is reversed compared to the "dash for gas" period of the 1980s-1990s, as it is displaced by energy efficiency and other fuels. In NDC-LTS, total gas demand falls below the 1990 level in 2030.

MITIGATION OPTIONS. In the power sector, renewables experience a strong growth in all scenarios, mainly wind, followed by solar and ocean. Nuclear also contributes, with a tripling of its current capacity by 2050 in the NDC-LTS scenario. By 2040, gas power plants are reduced to a fifth of their present capacity. CCS, with biomass or from direct air capture, become significant only beyond 2040.

Biomass gains in importance, in the power sector and in liquid biofuels production, both equipped with CCS after 2040. By 2050, electrified vehicles (battery electric and plug-in hybrids) make up 75% of the light vehicles fleet in the NDC-LTS scenario. In buildings, a combination of shell efficiency and strong deployment of electric heat pumps result in a strong decrease of natural gas demand for heating.

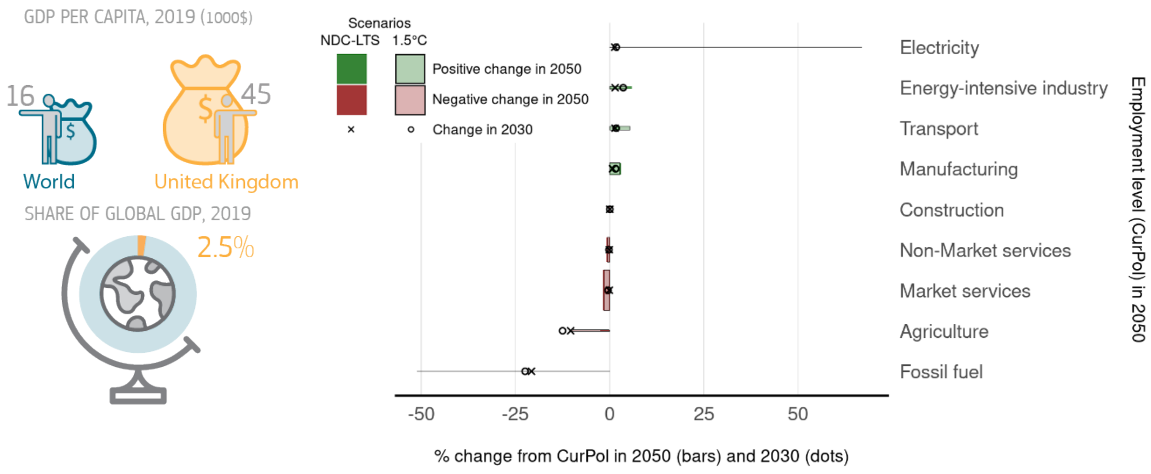
Efforts in the land sector such as forest management and limiting methane emissions gradually contribute to a sizable share of reductions by 2050.

Figure 102: United Kingdom. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 103: United Kingdom. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).



Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. Employment decreases in the fossil fuel industry are led by the natural gas sector, while the movement towards green jobs is driven by strong electrification, as part of the UK's mid-century strategy. In particular, electrification of the transport sector advances rapidly after 2030, and offers new opportunities for green jobs. Labour demand also increases in energy-intensive industries and manufacturing as a consequence of growing electrification and enhanced competitiveness. In the agriculture sector, employment levels see a net decrease – although the production of biomass raises opportunities in the forestry sector, the levels do not entirely cover employment losses in the crops sector, which decrease as domestic production faces increased competition from imports in the long-run. Employment in service-oriented sectors grows over the 2020-2050 period, albeit at a slower rate than projected in the Current Policies scenario.

HYDROGEN. The production of hydrogen for its use in industry (mainly in fertilizer production and in oil refineries) is currently responsible for approximately 7 MtCO_2 of emissions due to the use of natural gas steam reforming as the principal means of production. With new uses in energy, hydrogen use is projected to increase significantly in the coming decades, by a factor of four in the NDC-LTS scenario by 2050.

This is accompanied by a replacement of steam reformers with electrolysers (using wind, PV, nuclear or grid electricity) as the main producing technology during the ramp-up decades of 2020-2040. By 2050, as a result of this decarbonisation push, the UK sees installations of over 30 GW of electrolysers consuming some 70 TWh annually (NDC-LTS scenario) – the equivalent of a quarter of the UK's current electricity consumption.

In the energy sector, hydrogen is used principally in the production of e-fuels for road and air transport and in fuel cells in road transport. Use of hydrogen in space heating is limited by blending constraints in the natural gas distribution grid and the faster uptake of heat pumps as a decarbonisation solution for buildings.

4.17. United States

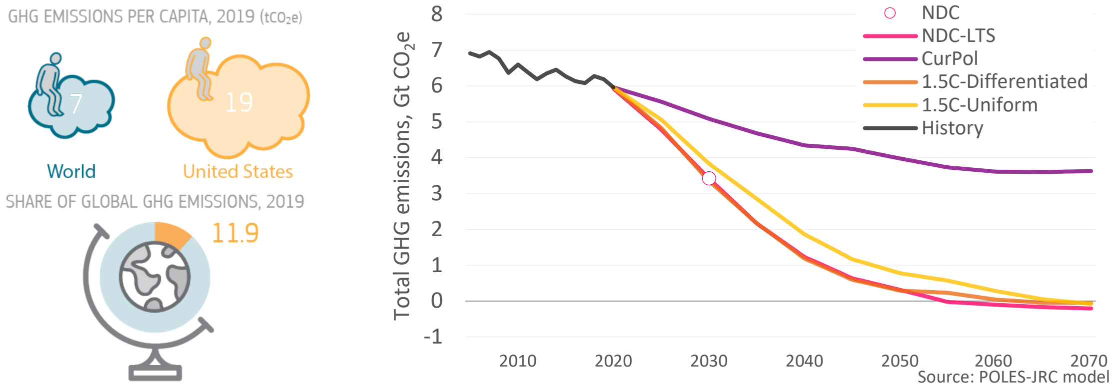


Figure 104: United States. GHG per capita and share of global GHG in 2019 (left). Total GHG emissions (right)

Pledges	Key targets
NDC	50-52% GHG reduction in 2030 relative to 2005
LTS	Net zero GHG emissions in 2050

POLICY CONTEXT. The United States features high per capita emissions and absolute emission levels peaked around 2005. Since then, emissions have declined mainly due to reductions in the power sector, aided by a market driven switch from coal to gas (fuelled by increased domestic gas production) as well as increases in renewable generation capacity. Federal climate policy has been limited to tax credits for technologies like wind and solar, regulations for certain sectors (e.g. vehicles, renewable fuels standards), and measures e.g. on air pollutants that also lower GHG emissions. However, many sub-national policies and targets exists, such as renewable portfolio standards to increase the share of renewable electricity and regional emission trading systems. Under current policies, US emissions are expected to continue to decline, see also (Hultman, et al., 2020).

Under President Trump, the US left the Paris Agreement, but the Biden administration re-joined in 2021 and submitted an updated NDC, which also states the intention of reaching net zero emissions in 2050. Although no update of the long-term strategy has been sent to the UNFCCC, this is included in the NDC-LTS scenario.

ENERGY TRANSITION DYNAMICS. All scenarios project an increase in share of renewables, however, this is particularly large in the scenarios approaching net zero emissions by the middle of the century. While this is helped by high renewables shares in the power sector and a power sector that boasts negative emissions in 2050 under the NDC-LTS and 1.5°C scenarios, the electrification share remains lower than other comparable countries.

Figure 105: United States. Key indicators characterising the energy transition across time and scenarios

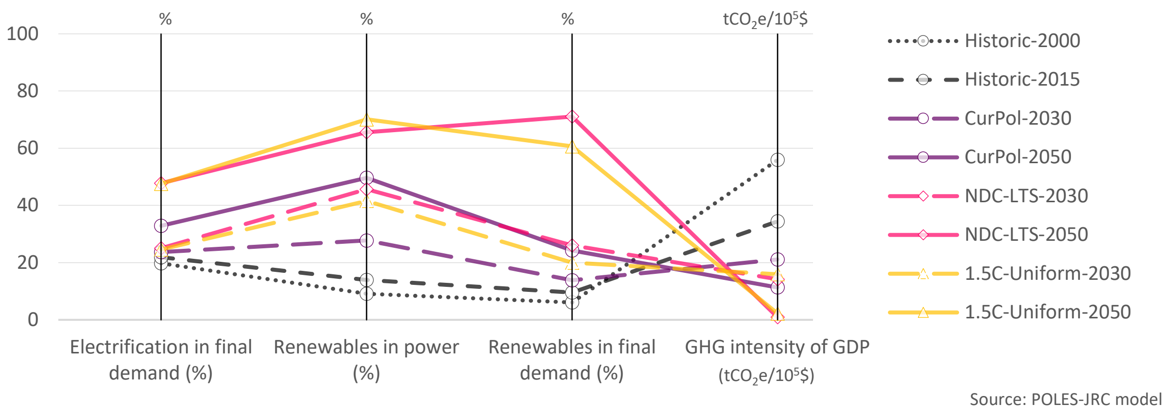
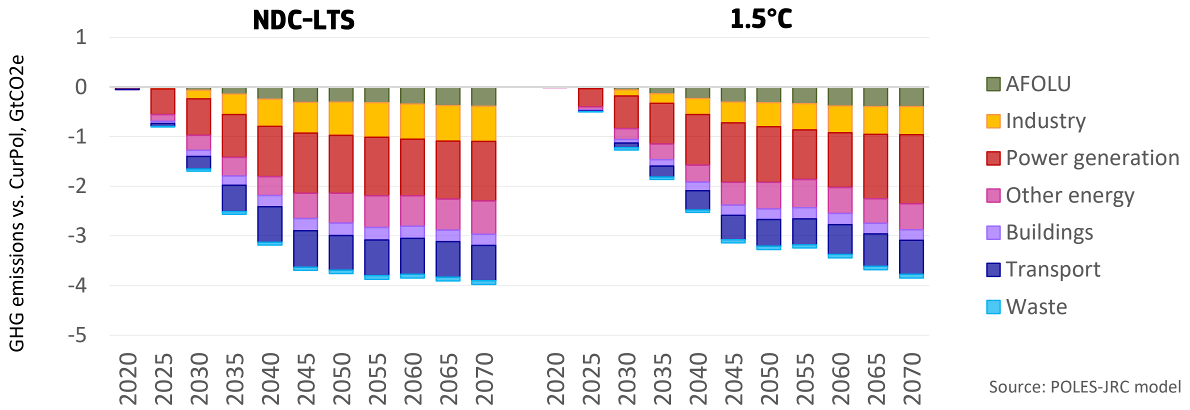


Figure 106: United States. Change in GHG emissions compared to CurPol by sector and year



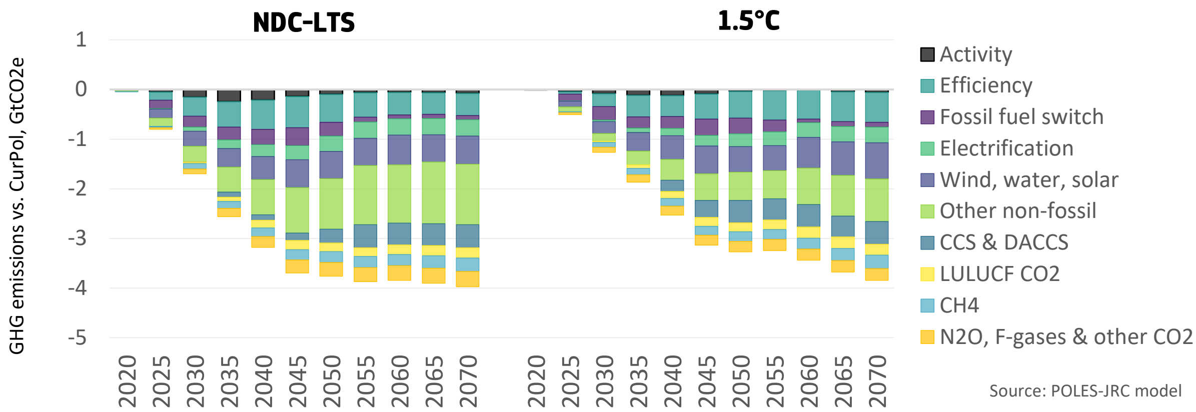
Source: POLES-JRC model

SECTOR CONTRIBUTIONS. The mitigation options rely on all sectors, but the biggest contribution especially in the short term comes from continued emission reductions in the power sector. This reductions are accelerated in the NDC-LTS and 1.5°C scenarios, as electricity generation from coal is almost phased out over the coming decade. A closer look at the power sector is also provided on the next page. While absolute emission reductions from industry are smaller than those of power, the NDC-LTS scenario actually implies a full decarbonisation of this sector in 2050, mainly through efficiency improvements, increased biomass use as energy inputs e.g. in the chemical and minerals industries and electrification e.g. in the metals industry. Emissions in transport have been on a declining trend since around 2005. This continues under current policies due to stricter fuel standards. In the policy scenarios, more efficient vehicles and the use of biofuels lead to a much faster decline of oil use in the transport sector, electrification and the use of hydrogen and e-fuels can contribute especially after 2030.

MITIGATION OPTIONS. While electricity generation from gas may increase over the next decade to push coal out of the generation mix, gas generation itself substantially declines towards 2050. The gap is filled with renewable electricity, of which wind provides the biggest increase followed by solar. Switching to biomass (represented under "other non-fossil" below) leads to emission reductions mainly in industry and transport. Under the NDC-LTS scenario, about 0.2 Gt CO_2 emissions are captured with CCS in 2050 (0.5-0.7 under 1.5°C scenarios), most of it from biomass to offset emissions in other sectors.

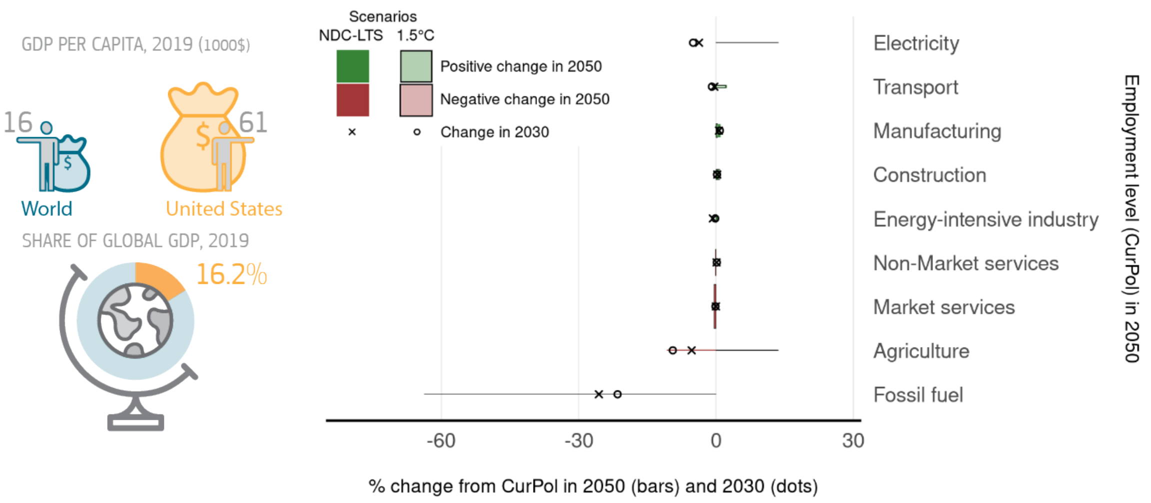
Abatement of non-energy emissions includes substantial reductions of methane. Emissions in 2050 in the NDC-LTS scenarios amount to about 0.2 Gt CO_2e, a reduction of about 50% below the value in the current policy scenario and less than a third of current emissions. The strongest decline occurs in the energy sector where emissions are reduced by more than 90%. These emissions relate mainly to the extraction of oil and gas and decline due to less extraction as well as implementation of abatement measures.

Figure 107: United States. Change in GHG emissions compared to CurPol by technology and year



Source: POLES-JRC model

Figure 108: United States. GDP per capita and share of global GDP in 2019 (left). Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenarios (right).

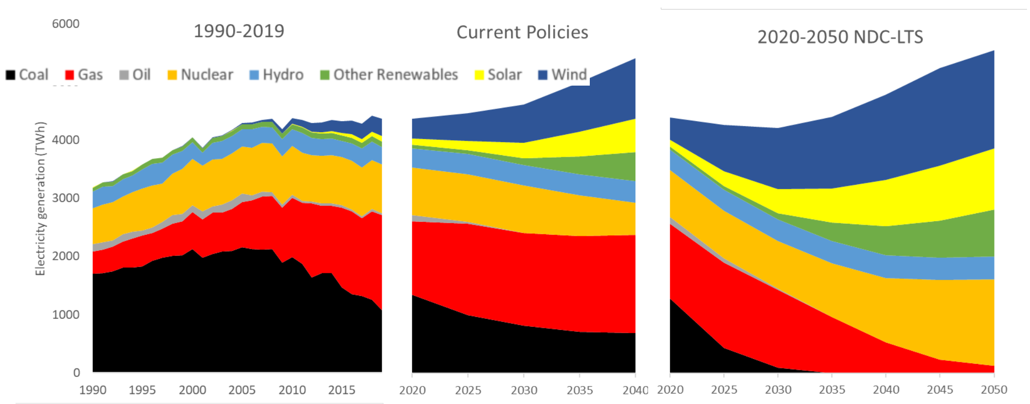


Source: JRC-GEM-E3 model

ECONOMICS OF TRANSITION. As a service-based economy with a high share of employment in service sectors, the US economy is shielded relatively well against changes in energy and industry sectors – these changes are relatively minor in percent of population affected relative to other countries. The economics of transition substantially affect the employment levels in the fossil fuel sector, which however contributes only a small share to the US labour market. The decline of jobs in coal extraction observed in the past is projected to continue, and job losses in oil and gas industries below levels of the Current Policy become apparent already in this decade. Jobs are moving towards construction and manufacturing. Towards the middle of the century, electrification increases, which helps to promote growth in the employment levels of the transport sector. Also, the expansion of renewables fosters increased opportunities in the construction sector. Under the 1.5°C scenarios, investment in the deployment of BECCS promotes growth in the employment levels of the agriculture, led by dedicated biomass production.

COUNTRY-SPECIFIC ELEMENT. The power sector has played a strong role in the US emission increases until about 2005, but was also key in reducing emissions over the past decade and plays a key role in achieving the NDC target in 2030 (Figure 109). The decline of coal generation since 2005 was driven mainly by the availability of cheap gas. This pushed uneconomic coal plants out of the market. Since about 2010, noticeable amounts of wind and solar entered the market, but the decline of coal was mostly compensated by additional gas generation. Current policies project these trends to continue, with further declines of coal and increases of renewables due to state-level renewable portfolio standards (Hultman, et al., 2020). The NDC targets accelerate the decarbonisation of the power sector, with very little coal remaining in the system in 2030 and gas increasingly making room for zero-carbon electricity. Additional policy measures to push the power sector transformation in this direction are currently proposed by the Biden administration.

Figure 109: Electricity generation by source



Source: POLES-JRC model

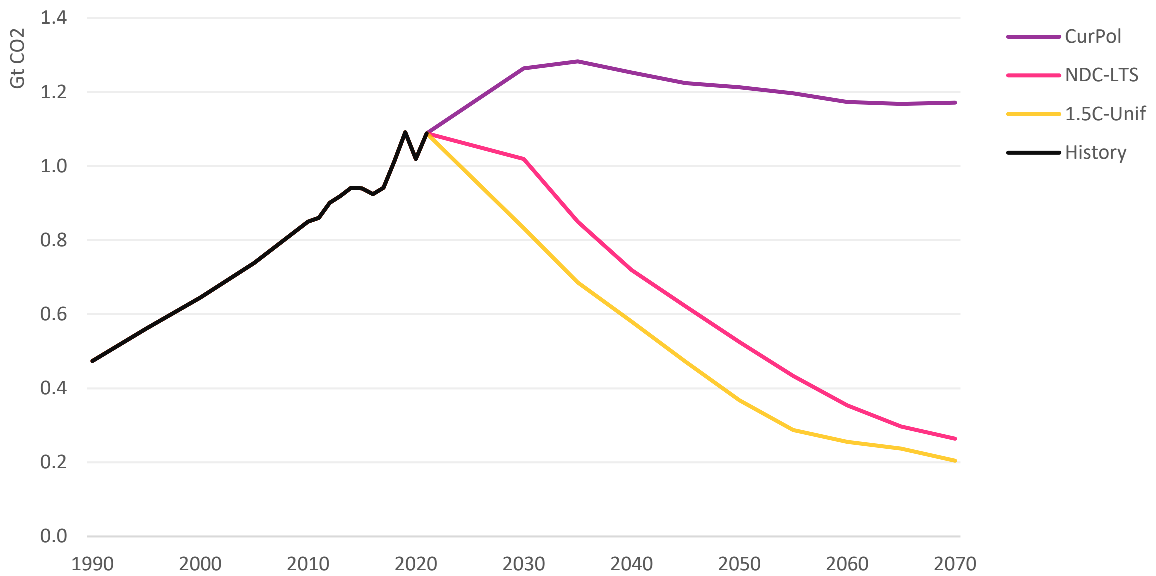
4.18. International Transport

International bunkers generated around 4.3% of global CO_2 emissions in 2019 and rank as fifth most important emitter after China, US, EU and India. International shipping reached more than 1.1 $GtCO_2$ emissions in 2019 (2.8% of world CO_2 emissions), while international aviation climbed to 0.6 $GtCO_2$ emissions in 2019 (1.5% of world CO_2 emissions). Both sectors recently experienced very rapid emissions growth at the same annual rate of 3.8% between 2015 to 2019. The pandemic led to steep reductions of more than 40% of CO_2 emissions for international aviation in 2020 compared to the previous year, while the reduction for international shipping was only about 3%.

According to IPCC guidelines emissions from international aviation and maritime transport should be calculated as part of the national GHG inventories of Parties, but should be excluded from national totals and reported separately. Limitations and reductions for emissions of international bunker fuels should be pursued working through the International Maritime Organisation (IMO) and the International Civil Aviation Organization (ICAO).

The Energy Efficiency Design Index (EEDI) was adopted aiming at 30% greater efficiency for new vessels by 2025 (MEPC, 2011). In a broader context IMO has addressed climate change with the initial IMO GHG strategy in 2018 (IMO, 2018), for which a revision is planned in 2023. The initial IMO GHG strategy envisages, in particular, a reduction in carbon intensity of international shipping (to reduce CO_2 emissions per transport work, as an average across international shipping), by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and that total annual GHG emissions from international shipping should be reduced by at least 50% by 2050 compared to 2008.

Figure 110: CO_2 emissions of international maritime

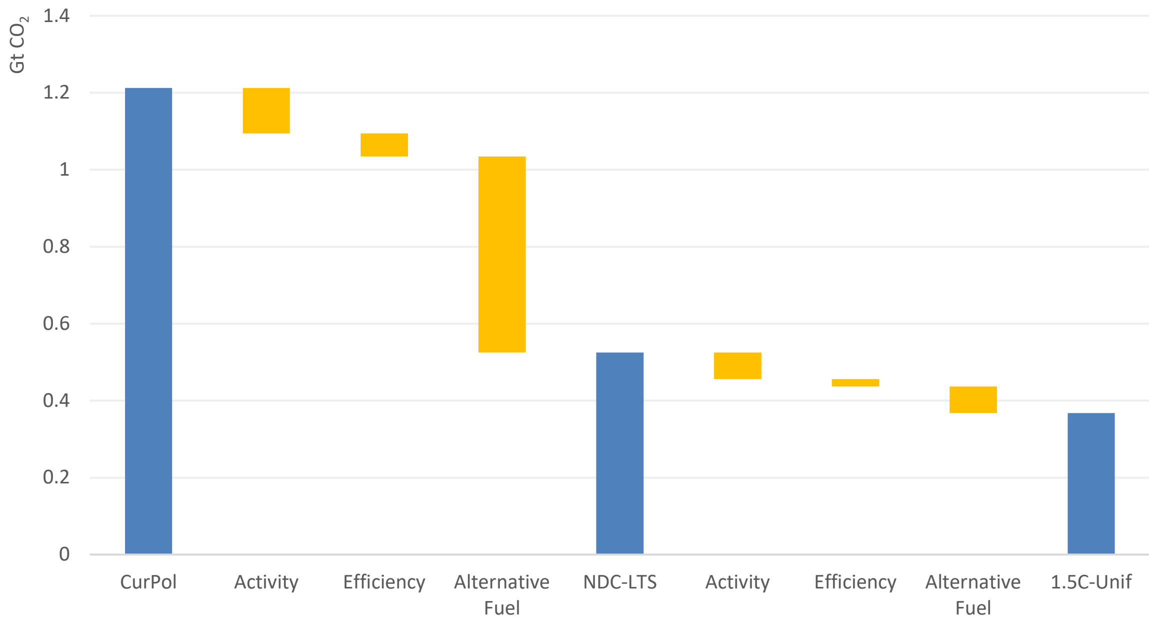


Source: POLES-JRC model

Figure 110 illustrates CO_2 emissions of international shipping following the vessel-based approach. The IMO GHG strategy is implemented in the NDC-LTS scenario as it is considered a long-term strategy of this sector, while the emission reductions of the 1.5°C scenario are driven by carbon pricing. The NDC-LTS and the 1.5°C scenarios lead to significantly lower levels of CO_2 emissions compared to the Current Policy scenario.

Several drivers lead to reductions of CO_2 emissions over time, see Figure 111. The main driver for the reduction in 2050 in the NDC-LTS scenario compared to Current Policies is the use of alternative fuels, which include biofuels, e-fuels and hydrogen. Only minor changes regarding activity and additional efficiency improvements lead to further emission reductions. In the 1.5°C scenario carbon prices lead to further replacement of oil products by alternative fuels.

Figure 111: Drivers of CO_2 emission reduction of international maritime sector in 2050

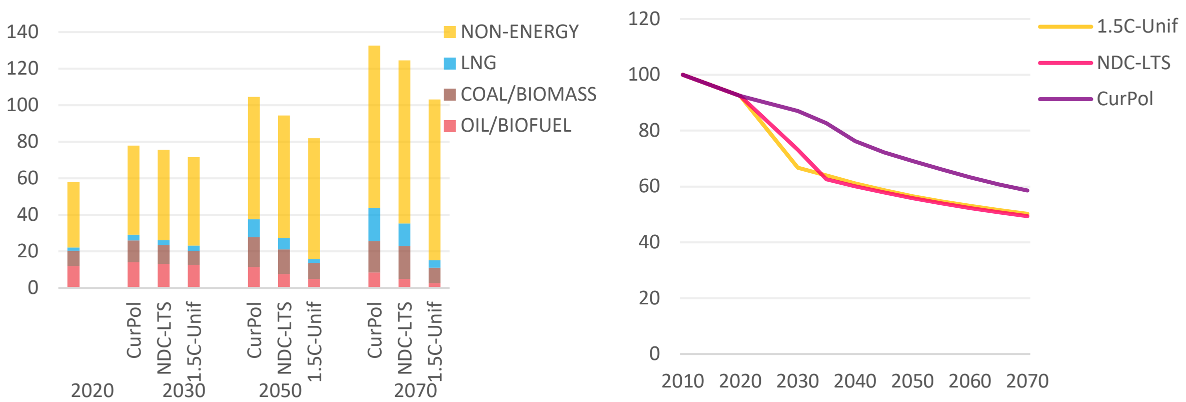


Source: POLES-JRC model

Overall fossil fuel production and consumption is reduced over time in the NDC-LTS and the 1.5°C scenarios. This leads to a decrease of international trade in fossil fuels, which is partially compensated through an increase of biofuels and biomass trade. This results in a reduction of transported energy commodities (in ton-miles) in international shipping of two thirds in 2070 in the 1.5°C scenario compared to the Current Policy scenario. The levels of transported oil and biofuels generally decrease over time. Coal and biomass transport increases compared to the year 2020 under Current Policies, but decreased coal trade is offset by increased biomass trade in the 1.5°C scenario. Gas transport increases by factor of 10 between 2020 and 2070 in the Current Policy scenario, while it only doubles in the 1.5°C scenario within the same time period. Trade in non-energy commodities increases over time, but remains more or less unchanged between scenarios.

Energy efficiency improvements of the fleet take place over time due to policies encouraging technology progress or carbon pricing. Hence, the trends of the NDC-LTS, which includes efficiency policies, and the 1.5°C scenario lead to similar improvements compared to the current policy scenario, see Figure 112.

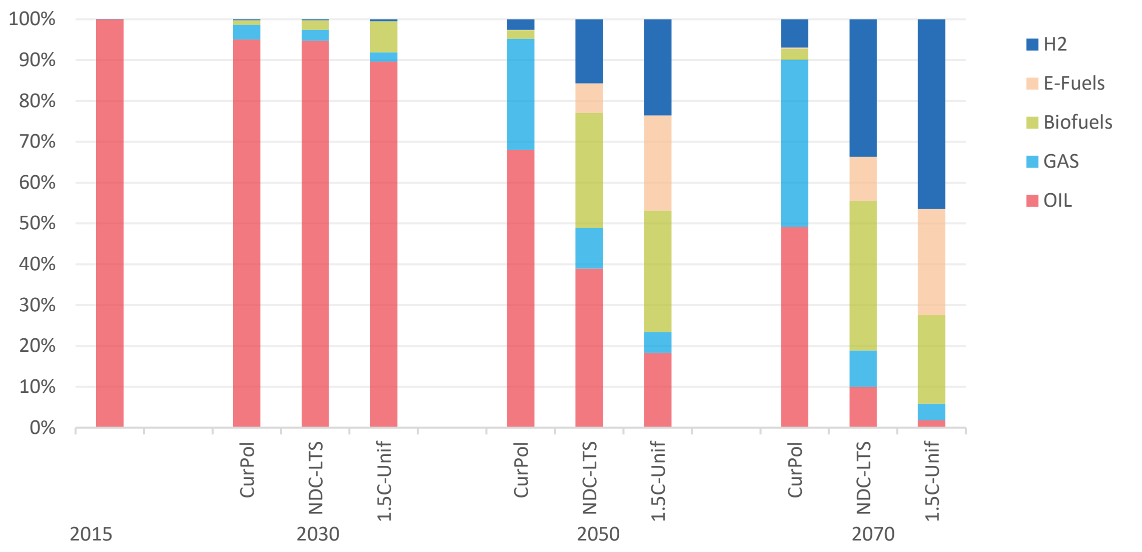
Figure 112: Freight transport of international shipping in ton-miles (left) and energy intensity of the global maritime sector (2010 = 100) (right)



Source: POLES-JRC model

The fuel decomposition in the maritime sector shows in Figure 113, that in the absence of a strong carbon price, natural gas increases its share progressively until 2070. Natural gas mainly replaces oil in the fuel mix while biofuels and hydrogen play only a minor role in this scenario. The NDC-LTS pushes more alternatives in the market leading to higher levels of biofuels and also hydrogen in the longer run. High carbon pricing favours hydrogen and e-fuels in the longer run.

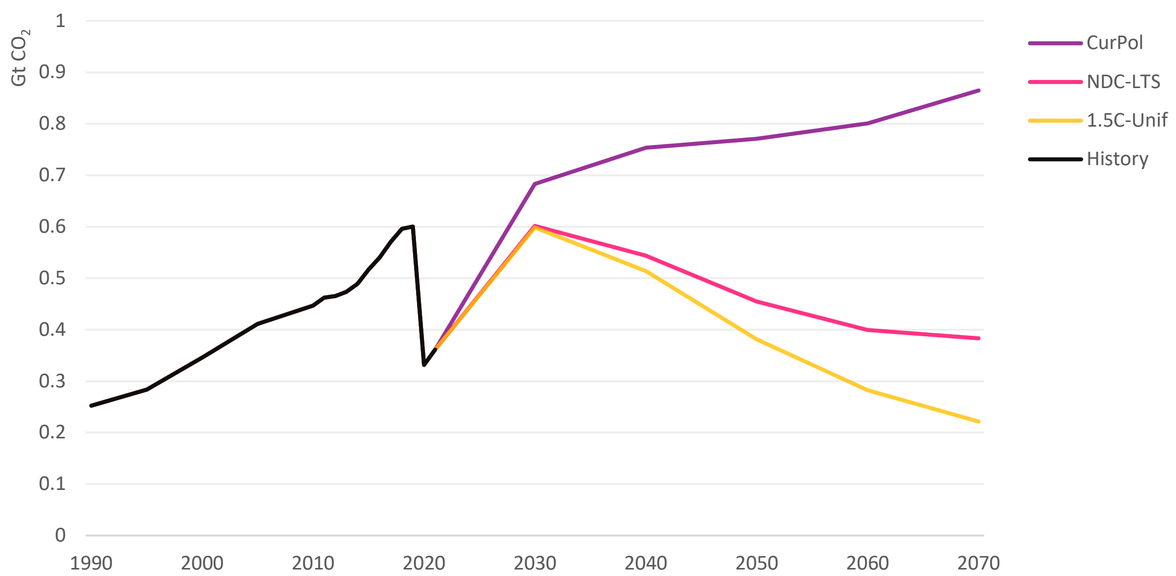
Figure 113: Fuel decomposition of international maritime transport



Source: POLES-JRC model

In Figure 114 international aviation, ICAO adopted two global aspirational goals for the international aviation sector of 2% annual fuel efficiency improvement through 2050 and carbon neutral growth from 2020 onwards (ICAO, 2021). To achieve the global aspirational goals and to promote sustainable growth of international aviation, ICAO is pursuing a basket of measures including aircraft technology improvements, operational improvements, sustainable aviation fuels, and market-based measures (CORSIA) (ICAO, 2016).

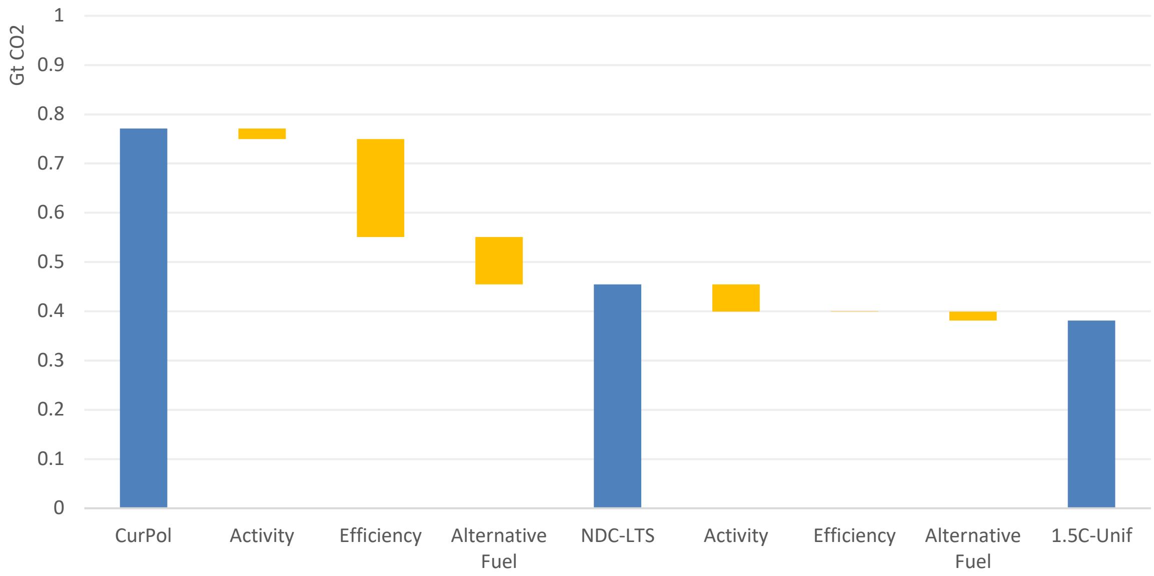
Figure 114: CO_2 emissions of international aviation



Source: POLES-JRC model

Figure 115 shows the main driver for the reduction of emissions from international aviation in 2050 in the NDC-LTS scenario compared to Current Policies are efficiency improvements followed by alternative fuels, which include biofuels, e-fuels and electricity. Only minor changes regarding activity lead to further emission reductions. As in the case of international maritime, in the 1.5°C scenario, carbon pricing leads to further replacement of oil products by alternative fuels.

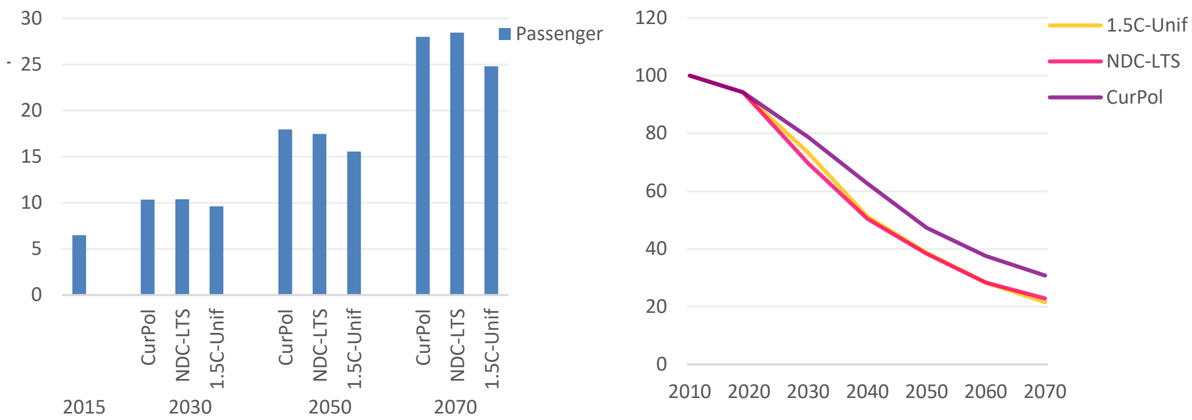
Figure 115: Drivers of CO_2 emission reduction of international aviation in 2050



Source: POLES-JRC model

Energy efficiency is expected to improve significantly in the coming decades. This improvement is more pronounced in the NDC-LTS (due to efficiency policies) and in the 1.5°C scenario (due to carbon pricing). The improvements are achieved both through fuel use efficiency (more efficient engines, re-engining) and non-engine-related measures (better air traffic management, flight patterns) see Figure 116.

Figure 116: Passenger transport of international aviation in passenger kilometre (left) and efficiency of aviation per passenger kilometre (2010 = 100) (right)



Source: POLES-JRC model

The deployment of electric aircraft is very limited in international aviation, see Figure 117. Despite technological learning, the weight of batteries limits the competitiveness of electric aircraft to short distances up to 1500 km. Until 2030, alternative fuel do not replace oil products at large scale. Biofuels gain higher market shares after 2030 and extend their role even after 2050. E-fuels refer to liquid fuels from produced from hydrogen; while more costly to produce than hydrogen, such fuels can directly substitute oil products without significant cost to adapt aircraft engines. Hydrogen-powered aircraft are not explicitly modelled; however, they present additional costs to adapt engines and for pressurized or liquid storage costs. Due to this trade-off, the market share does not to change significantly when hydrogen aircraft are included with e-fuels.

Figure 117: Fuel decomposition of international aviation

Source: POLES-JRC model

The analysis shows that the long-term targets of international transport implemented in the scenarios lead to significant CO_2 emission reductions. It is worth mentioning that policies are either subject to a later revision (international maritime) or are formulated as "aspirational goals" (international aviation). Furthermore, in international aviation the base year has been modified due to the pandemic for the pilot phase of CORSIA and it might be modified as well for later phases. CO_2 emission reductions for international transport mainly take place due to efficiency improvements and substitution of fossil fuels with alternative fuels. Usage of biofuels and synthetic fuels compete with other sectors like road freight transport.

The 1.5°C scenario leads to further emission reductions. In 2070 both sectors still emit around 0.2 $GtCO_2$ each, which means that to reach global net zero targets substantial amounts of GHG emissions still have to be compensated in other sectors.

5. Conclusions

The 2021 edition of the Global Energy and Climate Outlook assesses country pledges for the short term (2030) and long term (mid-century and beyond) announced ahead of and during the COP 26 in Glasgow. The analysis shows that if countries deliver on the newly announced domestic targets, global GHG emissions peak by the middle of this decade and decline thereafter, resulting in a clear departure from historic trends and current policies. Under this emission trajectory, the global temperature increase is limited to about 1.8°C by 2100 (50% probability). This is significantly lower than assessed in previous editions of the GECO. For instance, GECO 2019 projected a temperature change in excess of 3°C under current policies and of 2.7°C under an NDC scenario. Since then, there have been important developments that influence projected emissions: new net-zero pledges from several large emitters, more ambitious NDC targets, as well as technology development and long-term effects due to the COVID-19 pandemic. The projected temperature increase is comparable to similar recent studies when comparing scenarios that include both new NDC targets and recent net zero pledges (Birol, 2021; Climate Action Tracker, 2021; Meinshausen, Lewis, Nicholls, & Burton, 2021), as well as in the UNEP (United Nations Environment Programme, 2021a), updated in the addendum (United Nations Environment Programme, 2021b).

While these new targets have brought the 2°C mark within reach, the report also highlights that further collective policy action is required to achieve global climate targets. Current policies lead to warming in excess of 3°C. This indicates that strong action is needed by countries to deliver on their domestic targets and that reaching the Paris Agreement target of 1.5°C will require a substantial increase in ambition both in the short term to 2030, and in the long term via a rapid transition to climate neutrality.

GECO 2021 analyses the abatement options that can shift the emissions trajectory from current policies to a pathway that achieves the NDCs and net zero targets, and reveals further actions that can bring emissions onto a 1.5°C compatible pathway. Accelerated departure from coal in electricity generation reduces emissions in the short term. Furthermore, by 2030, a robust transition to a low-carbon economy relies primarily on the energy supply and transformation sector, including a significant shift to renewables for power generation, followed by increased energy efficiency. Beyond 2030 and moving towards the 1.5°C target, all sectors and regions need to contribute to bring the planet on track to reach net zero GHG emissions early in the second half of the century. Emission reductions need to be mobilised in the land sector and in the final demand sectors as well, including increased demand-side efficiency and electrification.

While a reduction of coal use is the most important change of primary energy use when moving from the current policies to the NDC-LTS scenario, reaching the 1.5°C target implies a strong reduction of all fossil fuels. In 2019, more than three quarters (83%) of global energy demand was still met by fossil fuels, despite the significant growth of renewable energy over the previous decade. However, fossil fuels represent only 29% of energy supply in the 1.5°C-Uniform scenario in 2050.

As the policy targets are brought forward in a bottom-up fashion, we model those targets at the country level, taking into account the particular situation of G20 countries. On the one hand, some countries appear on track for emission reductions implied by a cost-efficient 1.5°C pathway, especially those with net zero emission targets by mid-century. On the other end of the scale are countries with non-binding NDC targets in the short term and no announced plan for deep emission reductions in the long term. This indicates that there is strong heterogeneity between countries both in ambition and in the mitigation options for decarbonisation, with the main mitigation options for developed countries being renewables for power generation and demand-side efficiency, while for developing countries reduction of emissions from AFOLU plays an important role.

Putting in place the transition towards a net zero emissions economy requires an increase in investment levels to transition the capital stock to carbon-free production. Therefore, investment in the overall economy grows relative to current policies, with the investment in clean power technologies as the main driver, while entailing the shift of employment from fossil fuel sectors to other sectors in the economy. GECO 2021 further analyses the resulting employment consequences under announced policy targets and under a 1.5°C pathway. Sectors with the strongest decrease in employment levels, such as the fossil fuel industry, provide only a small numbers of overall jobs. As the decarbonisation advances, bioenergy and electrification lead to increased employment opportunities, boosting the employment levels in the construction sector. These socio-economic transitions will benefit from timely and well-anticipated climate action, while enabling complementary policies can ensure a fair transition towards climate neutrality.

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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

CGE: Computable General Equilibrium model

CH_4: Methane

CO_2: Carbon dioxide

COM: Communication from the European Commission

COP: Conference of the Parties

DACCS: Direct Air CO_2 Capture and Sequestration

EC: European Commission

ETS: Emission Trading Scheme

EU: European Union as of November 2019 (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

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 Statistical 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

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

SF6: Sulphur hexafluoride

TC: Transport changes

UN: United Nations

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: Policies considered

The scenario presented in this report builds on past work: GECO 2019 (Keramidas, et al., 2020) and GECO 2020 (Keramidas, et al., 2021). The Current Policies scenario builds from the GECO 2020 Base_C19+TC scenario, derived which included adopted energy and climate policies in world countries until June 2019. A full list of the policies considered in the GECO 2019 Reference scenario can be found in the GECO 2019 report. The GECO 2021 scenarios includes additional modelling to include the effects of the Covid-19 pandemic and its aftermath, described in Annex 6.

The NDC-LTS scenario includes the policies of the Current Policies scenario as well as additional policies presented in the tables below. The country-level policies of the New Normal inherited from GECO 2019 Reference were removed from the 1.5°C scenarios, 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 carbon price scenarios.

For land sectors (agriculture and emissions related to land use, land use change and forestry): the carbon price is capped (where necessary) to the maximum carbon price point provided by the soft-linking with a specialized sectoral model[25].

The 1.5°C-Unif scenario has the same carbon price for all countries. For the 1.5°C-Diff scenario, the carbon price is differentiated by country according to per capita income until the end of the projection period. The corresponding carbon price followed the differentiation presented in Table 2 with 100% representing a "leading" carbon price that increases over time.

Table 2: Average carbon price differentiation in the 1.5°C-Diff scenario

Income in 2030 (USD(2015)/cap)	Countries	2030	2050	2075	2100
> 30,000	EU, Australia, Canada, Chile, Iceland, Japan, Korea (Republic), Malaysia, New Zealand, Norway, Russian Federation, Saudi Arabia, Switzerland, Turkey, United Kingdom, United States	100%	100%	100%	100%
20,000-30,000	Argentina, China, Rest of Balkans, Thailand	48%	100%	100%	100%
10,000-20,000	Algeria and Libya, Brazil, Egypt, India, Indonesia, Iran, Mediterranean Middle-East, Mexico, Rest of CIS, Rest of Central America and Caribbean, Rest of Persian Gulf, Rest of South-East Asia, South Africa, Tunisia, Morocco and Western Sahara, Ukraine, Vietnam	22%	41%	100%	100%
<10,000	Rest of Pacific, Rest of South America, Rest of South Asia, Rest of Sub-Saharan Africa	9%	17%	46%	100%

Source: Own assumptions

The following tables summarize all the policies considered to build the emissions pathways in the Current Policies 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:

[25] The projections for agriculture and land use metrics in this report were done by soft-linking the specialized model GLOBIOM-G4M (IIASA, 2017) with the energy system model POLES-JRC.

They may be announced but not be ratified: e.g. Argentina and South Africa carbon neutrality objectives.

- The policy might lack sufficient information to be represented: e.g. certain mitigation measures in NDCs where emissions without measures are not informed or where the effect is not quantified.
- The POLES-JRC model is not able to take them into account for different reasons: e.g. specific land-related or agriculture-related measures.

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

Table 3: Current Policies – Energy-related policies

Region	Sector	Gas	Subsector	Target	Base year	Target year	Objective	Source
Western Europe								
EU	Transport		New passenger vehicles	Emissions reduction	2015	2021	-27%	European Commission, DG Energy
EU	Transport		New passenger vehicles	Emissions reduction	2021	2025	-15%	European Commission, DG Energy
EU	Transport		New passenger vehicles	Emissions reduction	2021	2030	-38%	European Commission, DG Energy
EU	Transport		New heavy vehicles	Emissions reduction	2019-2020	2025	-15%	European Commission, DG Energy
EU	Transport		New heavy vehicles	Emissions reduction	2019-2020	2030	-30%	European Commission, DG Energy
EU	Energy		Gross final demand	Share of renewables		2030	32%	European Commission, DG Energy
EU	Transport		Transport demand	Share of renewable fuels		2030	14%	European Commission, DG Energy
EU	Energy		Primary energy demand	% reduction in 2030 vs BAU (2007)	BAU 2030	2030	-39%	European Commission, DG Energy
EU	Energy		Final energy demand	% reduction in 2030 vs BAU (2007)	BAU 2030	2030	-36%	European Commission, DG Energy
North America								
Canada	Transport		New passenger vehicles	Emissions reduction	2017	2025	-34%	Adapted from Canadian Environmental Protection Act (2008)
Canada	Transport		New passenger vehicles	Zero emissions vehicles share		2025	10%	Zero emissions vehicle infrastructure program (2019)
Canada	Transport		New passenger vehicles	Zero emissions vehicles share		2030	30%	Zero emissions vehicle infrastructure program (2019)
Canada	Transport		New passenger vehicles	Zero emissions vehicles share		2040	100%	Zero emissions vehicle infrastructure program (2019)

Canada	Transport	Transport demand	Share of renewable fuels	2012	2030	7%	Canadian Environmental Protection Act (2008)
Mexico	Power	Power production	Share of renewables (including large hydro and nuclear)		2021	30%	Energy Transition Law (2015)
Mexico	Power	Power production	Share of renewables (including large hydro and nuclear)		2024	35%	Energy Transition Law (2015)
USA	Power	Power production	Share of renewables		2030	26%	Fusing subnational with national (Hultman, et al., 2020)
USA	Power	Power production	Share of nuclear		2030	17%	Fusing subnational with national (Hultman, et al., 2020)
USA	Power	Power production	Share of coal		2030	16%	Fusing subnational with national (Hultman, et al., 2020)
USA	Transport	Transport demand	Electric vehicles and PHEV sales		2020-2030	13500000	Fusing subnational with national (Hultman, et al., 2020)
USA	Transport	New passenger vehicles	Emissions reduction	2017	2025	-21.9%	Adapted from EPA GHG standard (2012)
South America							
Argentina	Power	Power production	Share of renewables (including large hydro)		2025	20%	RenovAr (2016)
Argentina	Power	Power production	Share of renewables (including large hydro)		2023	18%	RenovAr (2016)
Brazil	Energy	Primary energy demand	Share of renewables (including biofuels)		2024	45%	Decennial Energy Expansion Plan (2014)
Brazil	Power	Power production	Share of renewables (including biofuels)		2024	86%	Decennial Energy Expansion Plan (2014)
Brazil	Power	Power capacity	Hydro (GW)		2024	117	Decennial Energy Expansion Plan (2014)
Brazil	Power	Power capacity	Small hydro (GW		2024	8	Decennial Energy Expansion Plan (2014)
Brazil	Power	Power capacity	Nuclear (GW)		2024	3	Decennial Energy Expansion Plan (2014)

Brazil	Power	Power capacity	Wind (GW)		2024	24	Decennial Energy Expansion Plan (2014)
Brazil	Power	Power capacity	Solar (GW)		2024	7	Decennial Energy Expansion Plan (2014)
Brazil	Transport	Transport demand	Share of biodiesel		2023	15%	Res. MAPA 75/2015
Brazil	Transport	Transport demand	Share of bioethanol		2030	27%	Ethanol Blending Mandate (1993)
Chile	Power	Power production	Share of renewables (including large hydro)		2030	60%	Energy Plan 2050 (2016)
Chile	Power	Power production	Share of renewables (including large hydro)		2050	70%	Energy Plan 2050 (2016)
Chile	Transport	Passenger vehicles	Share of electric vehicles		2050	40%	Electromobility Strategy (2017)
Asia-Pacific							
Australia	Power	Power production	Share of renewables		2030	50%	Australian Government, Department of Environment (2010)
Australia	Economy	Energy productivity of the economy	Productivity increase	2015	2030	40%	National Energy Productivity Plan 2015-2030 (2015)
New Zealand	Power	Power production	Share of renewables		2025	90%	New Zealand Energy Efficiency and Conservation Strategy 2011-2016
South.Korea	Power	Power production	Share of renewables		2024	10%	7th Basic Plan for Long-term Electricity Supply and Demand (2014)
South.Korea	Power	Power production	Share of renewables		2030	20%	Renewable Energy 3020 of Korea (2017)
South.Korea	Energy	Electricity demand	Reduction vs BAU	BAU 2029	2029	-14%	7th Basic Plan for Long-term Electricity Supply and Demand (2014)
Indonesia	Energy	Primary energy demand	Share of renewables		2025	23%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of renewables		2050	31%	Government Regulation No. 79/2014 on Indonesia

						National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of oil	2025	25%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of oil	2050	20%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of coal	2025	30%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of coal	2050	25%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of gas	2025	22%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Energy	Primary energy demand	Share of gas	2050	24%	Government Regulation No. 79/2014 on Indonesia National Energy Policy (2014)
Indonesia	Transport	Transport demand	Share of renewables	2025	15%	Biofuel targets (2013)
Indonesia	Energy	Primary energy demand	Share of renewables	2025	23%	Renewable energy targets (2014)
Indonesia	Power	Power generation	Share of low-carbon	2025	23%	National Electricity Plan (2018)
Asia						
China	Power	Power capacity	Nuclear (GW)	2025	70	Energy Development Strategy Action Plan (2014-2020) (2014)

China	Power	Primary energy demand	Share of non-fossil		2030	20%	Energy Development Strategy Action Plan (2014-2020) (2014)
China	Power	Primary energy demand	Energy intensity reduction	2020	2025	-14%	Energy Development Strategy Action Plan (2014-2020) (2014)
China	Transport	New passenger vehicles	Share of BEV, PHEV and Fuel Cells Vehicles in sales		2025	20%	New Energy Vehicle development plan (2020)
China	Transport	New passenger vehicles	Fuel consumption reduction	2020	2025	-20%	Phase V standards (2019)
Thailand	Energy	Primary energy demand	Share of renewables		2021	25%	Alternative Energy Development Plan (2015)
Thailand	Energy	Primary energy demand	Share of renewables		2036	30%	Alternative Energy Development Plan (2015)
Thailand	Power	Power production	Share of renewables		2036	20%	Power Development Plan (2015)
Thailand	Transport	Transport demand	Share of renewables		2036	25%	Alternative Energy Development Plan (2015)
Thailand	Energy	Primary energy demand	Reduction of energy intensity	2010	2036	-30%	Energy Efficiency Plan (2015)
Eastern Europe							
Russia	Buildings	Residential heat consumption	Consumption reduction	2014	2030	-20%	Strategy for building materials (2016)
Russia	Power	Power production	Share of renewables (including hydro)		2024	20%	Resolution of the Government No. 1-r of 8 January 2009
Russia	Power	Power production	Share of renewables (excluding hydro)		2024	4.5%	Resolution of the Government No. 1-r of 8 January 2009
Russia	Power	Power capacity	Renewables (excluding hydro) (GW)		2025	5.4	Capacity Supply Agreement for Renewable Energy Sources (CSA-RES) 1.0
Russia	Power	New power capacity	Solar (GW)	2025	2035	2.2	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)

Russia	Power	New power capacity	Wind (GW)	2025	2035	3	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)
Russia	Power	New power capacity	Small Hydro (GW)	2025	2035	0.17	Adapted from the new program of contracts for the supply of capacity (DPM) (2019)
Ukraine	Power	Power production	Share of renewables (including hydro)		2035	25%	Energy Strategy (2017)
Ukraine	Power	Power production	Share of nuclear		2035	50%	Energy Strategy (2017)
Middle East							
Turkey	Energy	% reduction of primary energy consumption	Energy demand	2017	2023	-14%	Energy Efficiency Action Plan (2018)
Turkey	Power	Gross final energy consumption	Share of renewables		2023	21%	National Renewable Energy Action Plan (2014)
Turkey	Power	Power capacity	Hydro (GW)		2023	34	National Renewable Energy Action Plan (2014)
Turkey	Power	Power capacity	Solar (GW)		2023	5	National Renewable Energy Action Plan (2014)
Turkey	Power	Power capacity	Wind (GW)		2023	20	National Renewable Energy Action Plan (2014)
Turkey	Power	Power capacity	Biomass (GW)		2023	1	National Renewable Energy Action Plan (2014)
Turkey	Power	Power capacity	Geothermal (GW)		2023	1	National Renewable Energy Action Plan (2014)
Turkey	Power	Power production	Share of renewables		2023	39%	Energy Strategy Plan 2010-2014 (2011)
Saudi Arabia	Power	Capacity targets	Renewables (GW)		2023	27.3	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	Renewables (GW)		2030	58.7	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	Wind (GW)		2030	16	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	PV (GW)		2030	40	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	CSP (GW)		2030	2.7	Vision 2030 (2016)
Saudi Arabia	Energy	Primary energy demand	Share of renewables		2030	10%	Energy markets mechanism (2012)

Saudi Arabia	Energy	Electricity	Electricity intensity reduction	2005	2030	-30%	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	Nuclear (GW)		2030	2.8	Vision 2030 (2016)
Saudi Arabia	Power	Capacity targets	Nuclear (GW)		2040	17.6	Vision 2030 (2016)
Saudi Arabia	Energy	Electricity	Energy efficiency increase	2005	2030	30%	National Energy Efficiency program (2013)
Africa							
South Africa	Power	Capacity targets	Solar (GW)		2030	9.4	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	Capacity targets	Wind (GW)		2030	8.5	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	Decommissioning coal capacity	Coal remaining (GW)		2022	32.37	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	Decommissioning coal capacity	Coal remaining (GW)		2030	27.27	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	Decommissioning coal capacity	Coal remaining (GW)		2050	2.77	Integrated Resource Plan (2010, updated 2013)
South Africa	Power	New Capacities	Renewables (GW)	2012	2020	5.243	Renewable Energy Independent Power Producer Procurement Programme (REI4P)
South Africa	Buildings	Final energy demand	Consumption reduction	2015	2030	-33%	Post-2015 National Energy Efficiency Strategy

Table 4: Current Policies – GHG-related policies

Region	Sector	Gas	Subsector	Target	Base year	Target year	Objective	Source
Western Europe								
EU	Transport	All GHG	Transport	% reduction in 2050 vs 1990	1990	2050	-60%	European Strategy for low-emission mobility
EU	Transport	CO_2	Road transport	% reduction in 2030 vs 2005	2005	2030	-23%	European Commission, DG Energy
North America								
USA	Power	All GHG	Power production	% reduction in 2030 vs 2005	2005	2030	-32%	Clean Power Plan (2014) (scrapped 2016) (not implemented but reached)
USA	Oil & Gas	CH_4	Oil & gas production	% reduction in 2025 vs 2012	2012	2025	-45%	Environmental Protection Agency (EPA) (2016)
USA	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-25%	Fusing subnational with national (Hultman, et al., 2020)
Asia								
China	Industry	CO_2	CO_2 emissions per unit of industrial added value	Carbon intensity reduction	2015	2025	-40%	Made in China 2025 (2013)
Eastern Europe								
Ukraine	Energy	CO_2	Fuel use	Carbon intensity reduction	2010	2025	-10%	National Renewable Energy Action Plan 2020 (2014)
Ukraine	Energy	CO_2	Fuel use	Carbon intensity reduction	2010	2030	-15%	National Renewable Energy Action Plan 2020 (2014)
Ukraine	Energy	CO_2	Fuel use	Carbon intensity reduction	2010	2035	-20%	National Renewable Energy Action Plan 2020 (2014)

Table 5: NDC – Energy-related policies

Region	Sector	Gas	Subsector	Target	Base year	Target year	Objective	Source
Western Europe								
EU	Energy		Primary energy demand	% reduction in 2030 vs BAU	BAU 2030	2030	-39%	European Commission, DG Energy
EU	Energy		Final energy demand	% reduction in 2030 vs BAU	BAU 2030	2030	-36%	European Commission, DG Energy
EU	Power		Coal power generation	Phase-out of coal and lignite (does not apply to integrated gasification and CCS plants)				AUT: 2025; BEL: 2015; DNK: 2030; FIN: 2030; FRA: 2022; DEU: 2038; IRL: 2025; ITA: 2025; NLD: 2029; PRT: 2030; SWE: 2022
EU	Power		Nuclear power generation	No more construction				AUT, CYP, DNK, EST, GRC, HRV, IRL, ITA, LUX, LVA, MLT, PRT
EU	Energy		Final energy demand	Share of renewables		2030	32%	European Commission, DG Energy
United Kingdom	Power		Coal power generation	Phase-out of coal and lignite (does not apply to integrated gasification and CCS plants)				2025
North America								
Canada	Power		Power production	Share of renewables		2030	85%	Pan-Canadian framework on Clean Growth and Climate Change (2016)
Canada	Power		Power production	From traditional coal-fired plants		2030	0	Pan-Canadian framework on Clean Growth and Climate Change (2016)
Canada	Carbon price		Carbon price	20 C$/t$CO_2$		2019	20	GHG Pollution Pricing Act (2018)
Canada	Carbon price		Carbon price	50 C$/t$CO_2$		2022	50	GHG Pollution Pricing Act (2018)

Canada	CO_2	CO_2	New passenger light vehicles	Emissions intensity reduction in 2025 vs 2017	2017	2025	-34%	Emissions standards (2018)
Canada	CO_2	CO_2	Power generation from coal	Emissions intensity (gCO_2/kWh)		2030	420	Electricity Regulations (2018)
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	Power		Power production	Share of renewables (excluding large hydro)		2030	23%	NDC (2016)
Brazil	Energy		Primary energy demand	Share of biomass		2030	18%	NDC (2016)
Asia-Pacific								
Australia	Power		Power production	From renewables from 2020 onwards (GWh)		2020-2030	33000	Large-scale Renewable Energy Target (2019)
Indonesia	Power		Renewables	Share in power production (refers to 7.4 GW capacity)		2030	20%	NDC (2016)
Indonesia	Power		Renewables	Electricity generation (GWh)		2030	132740	NDC (2016)
Japan	Power		Power production	Share of renewables		2030	24%	NDC (2015)
Japan	Transport		Private vehicles consumption	Fleet average [km/L)	2016	2030	-32%	Adapted from fuel economy standards (2019)
Japan	Power		Coal power generation	Phase-out old technologies (excludes USC, IGCC)		2050	0	Ministry of Economy, Trade and Industry (2021)
South Korea	Power		Power production	Share of renewables		2040	35%	Third Energy Master Plan (2019)
South Korea	Power		Power production	Share of renewables		2034	42%	Ninth Basic Plan for Electricity Supply and Demand for the years 2020-2034
South Korea	Power		Power production	Share of distributed renewables		2030	18%	Third Energy Master Plan (2019)
South Korea	Power		Power production	Share of distributed renewables		2040	30%	Third Energy Master Plan (2019)

South Korea	Power	Power capacity	Renewables (MW)		2034	77800	Ninth Basic Plan for Electricity Supply and Demand for the years 2020-2034
South Korea	Power	Power capacity	Distributed renewables (MW)		2025	42700	Ninth Basic Plan for Electricity Supply and Demand for the years 2020-2034
South Korea	Power	Power capacity	Nuclear (MW)		2034	19271	Ninth Basic Plan for Electricity Supply and Demand for the years 2020-2034
South Korea	Energy	Final energy demand	% reduction in 2040 vs BAU	BAU 2040	2040	-19%	Third Energy Master Plan (2019)
South Korea	Industry	Energy intensity	% reduction in 2040 vs 2017	2017	2040	-21%	Third Energy Master Plan (2019)
South Korea	Buildings	Energy intensity	% reduction in 2040 vs 2017	2017	2040	-38%	Third Energy Master Plan (2019)
South Korea	Transport	Electric vehicles	Share in cars fleet		2040	8%	Third Energy Master Plan (2019)
South Korea	Transport	Hydrogen vehicles	Share in cars fleet		2040	3%	Third Energy Master Plan (2019)
South Korea	Power	Power production	Nuclear: no further extensions, no new reactors		2050	0	Third Energy Master Plan (2019)
South Korea	Power	Power production	Coal: drastically reduced		2050		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	1200	NDC (2021)
India	Transport	Electric vehicles	Share in cars fleet		2030	30%	Electric vehicle target (2018)
India	Power	Power capacity	Share of non-fossil		2030	40%	NDC (2016)
India	Power	Power capacity	Biomass (GW)		2022	10	India's Union Budget 2015-2016
India	Power	Power capacity	Solar (GW)		2022	100	India's Union Budget 2015-2016

India	Power		Power capacity	Wind (GW)		2022	60	India's Union Budget 2015-2016
India	Power		Power capacity	Small hydro (GW)		2022	5	India's Union Budget 2015-2016
India	Power		Power capacity	Solar (GW)		2030	300	NDC (2019)
India	Power		Power capacity	Wind (GW)		2030	140	NDC (2019)
India	Power		Power capacity	Renewables (GW)		2030	450	NDC (2019)
Middle East								
Turkey	Power		Power capacity	Solar (GW)		2030	10	NDC (2021)
Turkey	Power		Power capacity	Wind (GW)		2030	16	
Turkey	Power		Power capacity	Nuclear (GW)		2030	1.2	
Turkey	Power		Power production	Transmission losses in 2030		2030	15%	
Africa								
South Africa	Transport		Hybrid vehicles	Share in cars fleet		2030	20%	NDC (2016)
South Africa	Transport		Electric vehicles	Number in cars fleet		2050	14657	NDC (2016)
South Africa	Power		Power capacity	Renewables in 2025 from 2012 (MW)	2012	2025	11543	NDC (2016)
South Africa	Power	CO_2	Power production	Carbon-free by 2050		2050	0	
South Africa	All incl LULUCF	CO_2	Carbon price	120 Rand/tCO_2 from 2019		2019	120	Carbon Tax Bill (2019)
South Africa	All incl LULUCF	CO_2	Carbon price	600 Rand/tCO_2 from 2023		2023	600	Carbon Tax Bill (2019)
Bunkers								
Aviation	Aviation		Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2030	-40%	ICAO (2010)
Aviation	Aviation		Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2040	-51%	
Aviation	Aviation		Fuel efficiency	Improvement of at least 2% per year from 2005	2005	2050	-60%	

Table 6: NDC – GHG-related policies

Region	Sector	Gas	Subsector	Target	Base year	Target year	Objective	Source
Western Europe								
EU	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	NDC (2021)
EU	ETS sectors	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	NDC (2021)
Norway	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-55%	NDC (2020)
Switzerland	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2025 vs 1990	1990	2025	-35%	NDC (2020)
Switzerland	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-50%	NDC (2020)
United Kingdom	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-68%	NDC (2020)
Rest of Central Europe[26]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	31%	NDC (2016-2021)
Rest of CIS[27]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	12%	NDC (2016-2021)
North America								
Canada	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-43%	NDC (2021)
Canada	CH_4	CH_4	Emissions reduction	% reduction in 2025 vs 2005	2012	2025	-45%	Government (2016)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions reduction vs BAU	% reduction in 2030 vs BAU	BAU 2030	2030	-36%	NDC (2020)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions peak year	Peak before		2026		NDC (2020)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions intensity per GDP	% reduction in 2030 vs 2013	2013	2030	-40%	NDC (2020)
USA	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-52%	NDC (2021)
South America								
Argentina	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-2%	NDC (2020)
Argentina	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2007	2007	2030	-19%	NDC (2020)
Brazil	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2025 vs 2005	2005	2025	-37%	NDC (2020)
Brazil	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2005	2005	2030	-50%	NDC (2021)

[26] Includes targets of Albania (2016), Bosnia-Herzegovina (2021) and Serbia (2017)
[27] Includes targets of Armenia (2021), Azerbaijan (2017), Belarus (2021), Georgia (2021), Kazakhstan (2016), Kyrgyzstan (2020), Tajikistan (2017) and Uzbekistan (2018)

Chile	All excl LULUCF	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	95	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions budget	Over 2020-2030 ($MtCO_2e$)	2020	2030	1100	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions peak year	Peak before		2025		NDC (2020)
Chile	AFOLU	All GHG	Emissions reduction	% reduction in 2030 vs average 2001-2013	2001-2013	2030	-25%	NDC (2020)
Chile	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2016	2016	2030	-45%	NDC (2020)
Rest of Central America[28]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	9%	NDC (2017-2021)
Rest of South America[29]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	8%	NDC (2017-2021)
Asia-Pacific								
Australia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2015	2005	2030	-28%	NDC (2021)
Indonesia	All incl LULUCF	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	1683	NDC (2021)
Indonesia	Energy	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	1223	NDC (2021)
Indonesia	Industry	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	66	NDC (2021)
Indonesia	Waste	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	256	NDC (2021)
Indonesia	Agriculture	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	116	NDC (2021)
Japan	All incl LULUCF	All GHG	Emissions reduction		2013	2030	-46%	NDC (2021)
Japan	Energy originated	CO_2	Emissions reduction	% reduction in 2030 vs 2013 (corresponding to 1235 $MtCO_2$)	2013	2030	-45%	NDC (2021)
Japan	Non-energy originated	CO_2	Emissions reduction	% reduction in 2030 vs 2013 (corresponding to 75.9 $MtCO_2$)	2013	2030	-15%	NDC (2021)
Japan	All incl LULUCF	CH_4	Emissions reduction	% reduction in 2030 vs 2013 (corresponding to 36 $MtCO_2e$)	2013	2030	-11%	NDC (2021)
Japan	All incl LULUCF	N_2O	Emissions reduction	% reduction in 2030 vs 2013 (corresponding to 22.5 $MtCO_2e$)	2013	2030	-17%	NDC (2021)
Japan	All incl LULUCF	F-gases	Emissions reduction	% reduction in 2030 vs 2013 (corresponding to 37.2 $MtCO_2e$)	2013	2030	-44%	NDC (2021)
Malaysia	All incl LULUCF	All GHG	Emissions intensity reduction	% reduction in 2030 vs 2010	2010	2030	45%	NDC (2021)
New-Zealand	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 (all GHGs) vs 2005 (all GHGs excl sinks)	2005	2030	-30%	NDC (2021)

[28] Includes targets of Dominican Republic (2020), Guatemala (2017), Honduras (2021) and Trinidad and Tobago (2021)
[29] Includes targets of Colombia (2020), Ecuador (2019), Paraguay (2021), Peru (2020), Uruguay (2017) and Venezuela (2018)

South Korea	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2018	2018	2030	-40%	NDC (2021)
Rest of Pacific[30]	All incl LULUCF	All GHG	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)
India	All incl LULUCF	All GHG	Emissions per unit of GDP reduction	% reduction in 2030 vs 2005	2005	2030	-35%	NDC (2016)
India	Absorption	All GHG	Emissions budget	Over 2020-2030 ($GtCO_2e$)		2020-2030	2.5-3	NDC (2016)
Iran	Energy sectors	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	128%	NDC (2015)
Thailand	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	66%	NDC (2020)
Vietnam	LULUCF	CO_2, CH_4, N_2O, HFCs	Emissions reduction	% reduction in 2030 vs BAU	BAU 2030	2030	-1%	NDC (2020)
Vietnam	All excl LULUCF	CO_2, CH_4, N_2O, HFCs	Emissions reduction	% reduction in 2030 vs BAU	BAU 2030	2030	-27%	NDC (2020)
Rest of South Asia[31]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	97%	NDC (2016-2021)
Rest of South-East Asia[32]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-11%	NDC (2015-2021)
Eastern Europe								
Russia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-30%	NDC (2020)
Ukraine	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 1990	1990	2030	-65%	NDC (2021)
Middle East								
Saudi Arabia	All excl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU ($MtCO_2e$)	BAU 2030	2030	-278	NDC (2021)
Turkey	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs BAU	BAU 2030	2030	-21%	NDC (2021)

[30] Includes target of Papua New Guinea (2020)
[31] Includes targets of Afghanistan (2016), Bangladesh (2021) and Pakistan (2021)
[32] Includes targets of Brunei (2020), Cambodia (2020), Lao PDR (2021), Mongolia (2020), Myanmar (2021), North Korea (2019), Philippines (2021), Singapore (2021), Taiwan (2015)

Mediterranean Middle East[33]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	0%	NDC (2016-2021)
Rest of Persian Gulf[34]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	44%	NDC (2015-2021)
Africa								
South Africa	All incl LULUCF	All GHG	Emissions budget	In 2030 ($MtCO_2e$)		2030	398	NDC (2021)
Algeria and Libya[35]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-19%	NDC (2016)
Morocco and Tunisia	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	-3%	NDC (2021)
Rest of Sub-Saharan Africa[36]	All incl LULUCF	All GHG	Emissions reduction	% reduction in 2030 vs 2010	2010	2030	4%	NDC (2021)
Bunkers								
Maritime	Maritime		Carbon intensity reduction	% reduction of tCO_2 per tkm	2000-2010	2025	-30%	IMO (2018)
Maritime	Maritime		Carbon intensity reduction	% reduction of tCO_2 per tkm	2008	2030	-40%	IMO (2018)
Maritime	Maritime		Carbon intensity reduction	% reduction of tCO_2 per tkm	2008	2050	-70%	IMO (2018)

Table 7: LTS GHG policies

Region	Sector	Gas	Subsector	Target	Source
Western Europe					
EU27	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2020)
EU28	Transport	All GHG	Emissions reduction	90% reduction in 2050 vs 1990	European Green Deal (2019)
Norway	All incl LULUCF	All GHG	Emissions reduction	95% reduction in 2050 vs 1990	LTS (2019)
Switzerland	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2021)
United Kingdom	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2021)

[33] Includes targets of Israel (2021), Jordan (2016) and Lebanon (2021)
[34] Includes targets of Iraq (2015), Kuwait (2021), Qatar (2021) and United Arab Emirates (2020)
[35] Includes target of Algeria (2016) only
[36] Includes targets of Angola (2021), Botswana (2016), Burkina Faso (2016), Cameroon (2021), Central African Republic (2016), Chad (2017), Congo DR (2017), Ivory Coast (2016), Ethiopia (2021), Ghana (2021), Guinea (2016), Kenya (2021), Madagascar (2020), Niger (2016), Nigeria (2021), Tanzania (2021), Uganda (2021) and Zambia (2021)

North America					
Canada	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	NDC (2021)
Mexico	All incl LULUCF excl absorption	All GHG	Emissions reduction	50% reduction in 2050 vs 2000	NDC (2015)
USA	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2021)
South America					
Argentina	All incl LULUCF	CO_2	Net-zero emissions	Emissions 2050	NDC (2021)
Brazil	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	Brazilian Administration (2021)
Chile	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2021)
Asia-Pacific					
Australia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2021)
Indonesia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060	LTS (2021)
Japan	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2019)
New-Zealand	All incl LULUCF	All GHG, excl CH_4 from agriculture	Net-zero emissions	Emissions 2050	LTS (2021)
New-Zealand	All incl LULUCF	CH_4	Emissions reduction	47% reduction in 2050 vs 2017	LTS (2021)
South Korea	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2050	LTS (2020)
Asia					
China	All incl LULUCF	CO_2	Net-zero emissions	Emissions 2060	LTS (2021)
India	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2070	NDC (2021)
Thailand	All incl LULUCF	CO_2	Net-zero emissions	Emissions 2065	LTS (2021)
Vietnam	All incl LULUCF	CO_2	Net-zero emissions	Emissions 2060	LTS (2021)
Eastern Europe					
Russia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060	NDC (2021)
Ukraine	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060	NDC (2021)
Middle East					
Saudi Arabia	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2060	NDC (2021)
Turkey	All incl LULUCF	All GHG	Net-zero emissions	Emissions 2053	NDC (2021)
Africa					
South Africa	All incl LULUCF	CO_2	Net-zero emissions	Emissions 2050	NDC (2021)

Bunkers					
Aviation	Aviation	CO_2	Net-zero emissions	Emissions 2050	ICAO (2021)
Maritime	Maritime	All GHG	Emissions reduction	50% reduction in 2050 vs 2008	IMO (2018)

Annex 2: Description of POLES-JRC

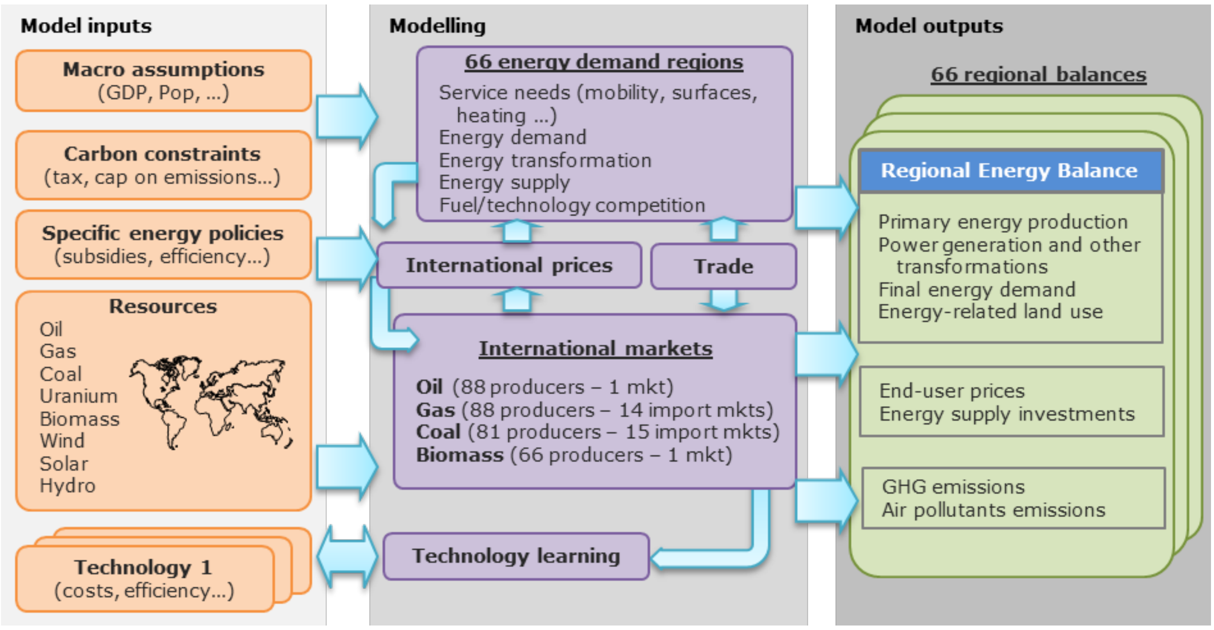
For a more comprehensive description of the model, see (Després, Keramidas, Schmitz, Kitous, & Schade, 2018).

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 118).

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

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

Figure 118. POLES-JRC model general scheme



Source: POLES-JRC model.

Final demand

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

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

Power system

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

The electricity demand curve is built from the sectoral distribution.

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

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

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

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

Other transformation

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

Oil supply

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

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

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

Gas supply

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

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

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

Coal supply

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

Biomass supply

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

Wind, solar and other renewables

They are associated with potentials and supply curves per country.

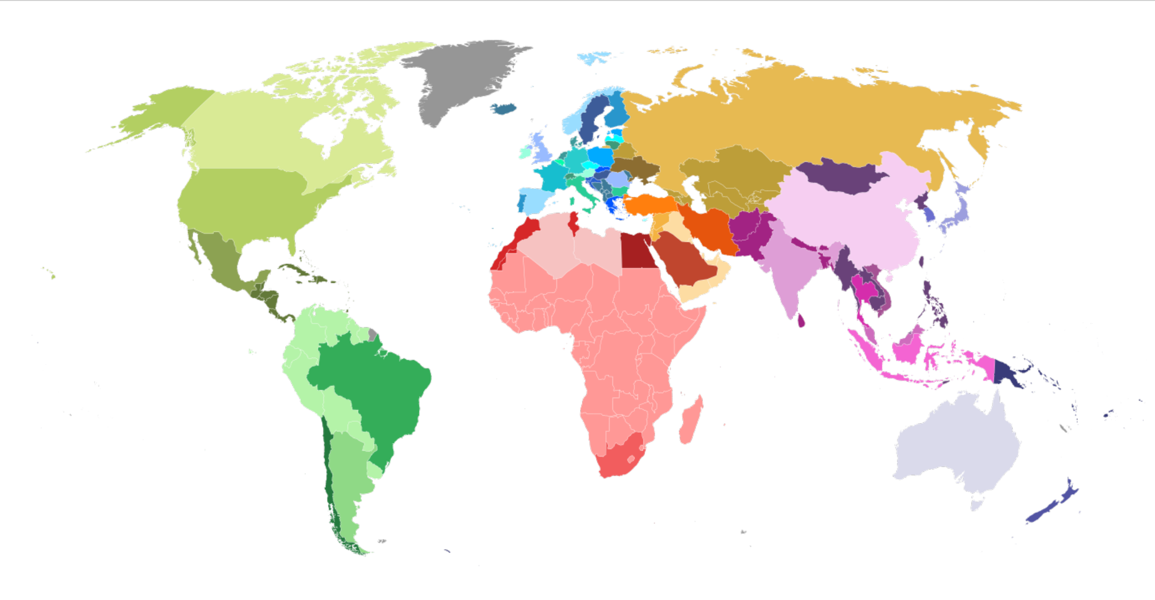
GHG emissions

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

Countries and regions

The model decomposes the world energy system into 66 regional entities: 54 individual countries and 12 residual regions see Figure 119, to which international bunkers (air and maritime) are added.

Figure 119. POLES-JRC model regional detail map (for energy balances)



Source: POLES-JRC model

Table 8. List of 54 individual countries represented in POLES-JRC (for energy balances)

Non-EU individual countries	EU Member States
Argentina	Austria
Australia	Belgium
Brazil	Bulgaria
Canada	Croatia
Chile	Cyprus
China	Czech Republic
Egypt	Denmark
Iceland	Estonia
India	Finland
Indonesia	France
Iran	Germany
Japan	Greece
Malaysia	Hungary
Mexico	Ireland

New Zealand	Italy
Norway	Latvia
Russia	Lithuania
Saudi Arabia	Luxembourg
South Africa	Malta
South Korea	Netherlands
Switzerland	Poland
Thailand	Portugal
Turkey	Romania
Ukraine	Slovak Republic
United Kingdom	Slovenia
United States	Spain
Vietnam	Sweden

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

Table 9. 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 CIS**	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 10. POLES-JRC model historical data and projections

Series		Historical data	GECO Projections
Population		(European Commission, 2021), (Eurostat, 2021)	
GDP, growth		(World Bank, 2019); (IMF, 2021) (IMF, 2020)	(OECD, 2014) and (OECD, 2018)
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 model	
	Hydro	Enerdata	
	Wind, solar	NREL, DLR	
Energy balances	Reserves, production	BP, Enerdata	
	Demand by sector and fuel, transformation (including. power), losses	Enerdata, IEA	
	Power plants	Platts	
Energy prices	International prices, prices to consumer	Enerdata, IEA	POLES-JRC model
GHG emissions	Energy CO_2	Derived from POLES-JRC energy balances	POLES-JRC model
	Other GHG Annex 1	UNFCCC	POLES-JRC model, GLOBIOM-G4M model
	Other GHG Non-Annex 1 (excl. LULUCF)	EDGAR	POLES-JRC model, GLOBIOM-G4M model
	LULUCF Non-Annex 1	National inventories, FAO	POLES-JRC model, GLOBIOM-G4M model
Air pollutants emissions		GAINS model, EDGAR, IPCC, national sources	GAINS model, national sources
Technology costs		POLES-JRC learning curves based on literature, including but not limited to: EC JRC, WEC, IEA, TECHPOL database	

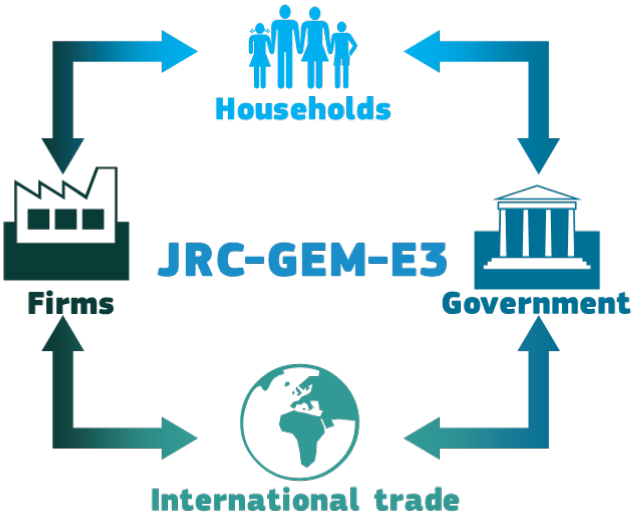
Source: Own elaboration

Annex 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).[37] The agents in the model are households, firms and governments (Figure 120). Households that are endowed with factor 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 120. Schematic overview of the JRC-GEM-E3 model



Source: Own elaboration

The model version used in GECO 2021 is aggregated into 31 sectors (see Table 11), including crude oil, refined oil, gas, coal and electricity generation, the latter further disaggregated into 8 generation technologies. The generation technologies are modelled using a Leontief production function, 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 12. Bilateral international trade flows between these regions are modelled following the Armington formulation and linkages between sectors are included based on the GTAP10a data, described in (Aguiar, Chepeliev, Corong, MacDougall, & Van der Mensbrugghe, 2019).

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

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

Table 11. Sectors in the JRC-GEM-E3 model

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

Source: Own elaboration

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

A baseline is constructed by generating input-output tables based on the initial base year provided by GTAP and projections for economic activities, energy use and emissions. In this way, the economic starting point for the analysis is closely resembling that of energy models POLES-JRC (and PRIMES), as described in more detail in the next section. In addition, we also use several inputs from the energy models in the construction of the scenarios (see following section).

Table 12. Regional aggregation of the JRC-GEM-E3 model

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

Source Own elaboration

Baseline Construction

The macroeconomic balances for a scenario with COVID-19 are constructed on the basis of a variety of data sources. In particular, we obtain an integration of macroeconomic forecasts with energy balances from PRIMES for the EU27 and POLES-JRC for non-EU regions. More details can be found in (Rey Los Santos, et al., 2018) and (Wojtowicz, et al., 2019), while (Faehn, et al., 2020) provides an overview of other approaches used in the literature. The main data sources for the version used in GECO 2021 include:

- The input-output tables and the data on bilateral trade flows are derived from the Global Trade Analysis Project (GTAP) 10 database (Aguiar, Chepeliev, Corong, MacDougall, & Van der Mensbrugghe, 2019). We aggregate the GTAP data to 31 commodities and the regions listed in Table 12.
- GDP growth rates are assumed to be the same as in the PRIMES and POLES-JRC models for the EU and non-EU regions, respectively. The GDP assumptions are described in Annex 6. Projections include the effects of Covid-19.
- The International Labour Organisation (ILO) database was used to project population and labour statistics such as labour force, unemployment rate and the share of skilled and unskilled workers. Short term unemployment projections were taken from IMF as the ILO projections do not include the

effects of Covid-19, implying the implicit assumption that Covid-19 will not have an effect on long-term unemployment. For the EU27, data from the 2021 Ageing report (European Commission, 2021) was used.

- Energy and emission data using energy balances from PRIMES (for EU27 and GBR) and POLES-JRC (for non-EU regions). The alignment with energy balances and emission factors implies that the emission levels of greenhouse gases (totals and by sector) and the shares of electricity generation technologies are harmonised with the reference in the POLES-JRC and PRIMES models.

Note that in particular the data from the PRIMES model is consistent with the EU Reference 2020 scenario (European Commission, 2021). The baseline thus is a time series fully compatible with the economic, energy and emission trends of the reference scenario that was used to assess e.g. the “Fit for 55” policy package.

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.[38] 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).

Before applying the balancing MRGRAS framework, the data has to be pre-processed. This includes the translation of the GTAP data into a multi-regional input-output (MRIO) table, taking into account the intra-region trade for aggregate regions (e.g. trade within the Other Asia region, which consists of an aggregation of GTAP regions). In a first step, all MRIO components are projected into the future, excluding the value added by sector. For this, GDP is first decomposed into its components (private consumption, government consumption and investment) which are then translated into final demand for the 31 commodities (Rey Los Santos, et al., 2018). Certain demand categories can be directly specified, such as demand for energy goods as these are harmonized with data from the energy models. Likewise, certain elements of the input-output tables (e.g. energy demand for key sectors) is taken from the energy models and is not adjusted in the re-balancing procedure, using quantity and price information to calculate monetary flows needed for the input output table. Value added over all sectors sums to GDP per definition, and we align sectoral value added projections for key sectors to be consistent with the overall macroeconomic projections and in particular the energy use projections by sector. In the next step, the tables are re-balanced using the MRGRAS routine and then the value added block is decomposed into its components (capital, labour, taxes and subsidies). Tax and subsidy rates are constant in the forward projection except for carbon taxes which are taken from the energy models.

When creating the baseline, external data is used to project the number of people employed in the coal and oil extraction sectors. The employment factor (jobs/energy unit produced) reported by Pai et al. (Pai, Emmerling, Drouet, Zerriffi, & Jewell, 2021) is multiplied by the total coal and oil production to calculate the number of jobs in those sectors. Then, labour payments reported in the input-output tables are adjusted accordingly. The employment factors are different across countries/regions and evolve over time to reflect the productivity gains.

[38] The balances will be published at https://ec.europa.eu/jrc/en/macroeconomic.baselines.for.policy.assessments

Scenario implementation

In the policy scenarios, we are interested in how achieving an emission pathway in line with climate policy targets influences economic outcomes as compared to a Current Policy trajectory. By implementing a constraint on emissions, differences between scenario and baseline emerge which can provide a picture of the changes that the transition to a low carbon pathway may bring.

The emission constraint is implemented to represent the emissions from POLES-JRC and PRIMES[39] for a given policy ambition in each model region. The constraint is then achieved by implementing a carbon tax (which in modelling terms is equivalent to an emission trading system with full auctioning). In harmonizing the emissions between models, carbon prices e.g. in the CurPol byC scenario may differ between regions, although in POLES-JRC they are designed to be equal. The reaction in the model is adjusting endogenously the inputs to the production function, switching between different fuels of varying emission intensity, decreasing the input of energy at the expense of additional capital and labour inputs, reducing the use of emission intensive products and applying end of pipe abatement (CCS and non-CO_2 emissions).

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

For electricity generation, we replace the JRC-GEM-E3 production function that aggregates electricity from the different generation technologies into a single supply sector through a Leontief function and adjust the share parameters based on electricity generation as projected by POLES-JRC and PRIMES. The energy system models may better reflect intermittency of renewables, storage and grid constraints, joint heat and power generation etc. than a CGE model. In order to account for the additional capital needs required for renewable electricity production the (myopic) investment expectations are adjusted based on the generation mix in the next time step in the model. At the same time, the capital mobility of declining generation technologies, such as coal fired generation is reduced, capital that is released from these generation technologies is eliminated. This ensures that investment activity needed for the transition of the power sector has to come from additional investment rather than capital mobility between sectors.

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.

[39] For the EU, PRIMES is used as to replicate the EU Reference Scenario 2020 (European Commission, 2021) in the baseline. For consistency, PRIMES input is also used in the policy scenarios.

Annex 4: POLES Sector categories

Table 13: Poles Sector categories

Sector	Subsector	Description
AFOLU	Forestry	CO_2: (1) Deforestation: converting forest to other land (e.g. to grassland or to cropland); (2) Afforestation: converting other land (e.g. grassland, cropland) into forest; (3) Forest management: within existing forests planting or cutting trees.
	Agriculture	CH_4 & N_2O: (1) Manure management (all kind of livestock): (2) Enteric fermentation (mainly CH_4, mainly from cattle): (3) Rice cultivation (CH_4 only): (4) from fertilizer use (N_2O only).
	Other land-use changes	CO_2: All non-forest related land-use changes .
Industry	Steel	CO_2: Emissions mainly from primary steelmaking route (i.e. blast furnace) using coal & coke.
	Aluminium	PFCs: Primary aluminium production (mainly CF4, C2F6).
	Chemicals	N_2O: Mainly fertilizer production. CO_2: process emissions & combustion emissions.
	Non-metallic minerals (cement, glass, ceramics)	CO_2: Process emissions from decomposition of carbonates and combustion emissions.
	Other industries	CO_2: Energy related emissions mainly other industries (e.g. manufacturing).
	Other non-energy	HFCs: Production and use (i.e. leakage, end of life) of HFCs mainly for refrigeration and air-conditioning (residential, industrial, automotive); SF6 & PFCs: (1) semiconductor industry; (2) magnesium foundries (only SF6).
Power generation	Power generation	CO_2: Emissions from fuel combustion (coal, gas, oil).

	Transmission	SF6: Gas insulated high-voltage switches (electricity transmission).
Other energy	Coal mining	CH_4: From underground and open pit coal mining.
	Gas production	CH_4: Mainly *natural gas* exploration, production (i.e wells) and processing (e.g. leakage).
	Gas transport	CH_4: Gas transmission and distribution (mainly due to leakage).
	Oil production	CH_4: Mainly oil exploration & production (i.e. wells).
	Fugitive emissions	CO_2: (1) Combustion in oil & gas production (e.g. flaring); (2) Coal mines: CO_2 emissions and from flaring of CH_4 (mitigation measure).
Buildings	Residential	CO_2: Emisisons from residential buildings: heating, cooling, cooking, appliances, lighting.
	Services	CO_2: Emisisons from service sector (e.g. offices): mainly heating, cooling, and lighting.
Transport	Road - Light vehicles	CO_2: Fuel combustion (gasoline, diesel)
	Road - Heavy vehicles	CO_2: Fuel combustion (mainly diesel/light fuel oil)
	Rail - passengers & freight	CO_2: Fuel combustion (diesel/light fuel oil)
	Domestic Aviation - passengers & freight	CO_2: Fuel combustion (kerosene)
	Maritime	CO_2: Fuel combustion (heavy fuel oil)
	All transport sectors	N_2O & CH_4: Combustion and fuel related emissions of entire transport sector.
Waste	Waste	CH_4 : (1) waste water treatment (sewage plants); (2) Solid waste (landfills). N_2O: (1) waste water treatment (sewage plants); (2) solid waste (landfills). CO_2: Combustion of solid waste and CH_4.

Source: Own elaboration

Annex 5: POLES Mitigation option categories

Table 14: Mitigation option categories

Mitigation option	Subcategories	Explanatory note
Activity		Emission reduction due to changes in activities (modelled by elasticities, trends). For instance, substituting travelling by car by public transport.
Efficiency		Emission reduction by improved efficiencies. For instance, more efficient heating systems, improved insulation or more efficient electricity production (e.g. combined cycle instead of gas turbine)
Fossil fuel switch		Changing to a fossil fuel releasing less CO_2. For instance, generating electricity from gas instead of coal.
Electrification		Substituting a technology using fossil fuel with a technology using electricity. For instance, substituting a gas-heating boiler with a heat pump.
Wind water solar	Wind	Electricity production by wind: (1) on-shore wind; (2) off-shore wind
	Hydro	Electricity production by hydropower: plant types: (1) Small hydro (<10 MW); (2) Run-of-river and (3) Lake/dam
	Ocean	Electricity production by wave or tidal plants
	Solar	Electricity production by solar: (1) Distributed PV (e.g. residential, <=1 MW); (2) Centralised PV (large plants 1 > MW); (3) Concentrated solar power plants.
Other non-fossil	E-fuels	E-fuels refer to synthetic fuels (gaseous or liquid). These synthetic fuels are made from hydrogen and a carbon component (e.g. captured CO_2). Ideally, e-fuels can be produced carbon-neutral. For instance, this is the case when hydrogen is produced by renewable electricity or nuclear and the carbon component comes from captured CO_2. Alternatively, carbon neutral e-fuels could be produced from natural gas or coal when the CO_2 is captured.
	Heat	Substitution of fossil fuels with heat (e.g. waste heat in industries).
	Hydrogen	Substitution of fossil fuels by hydrogen. Ideally, the used hydrogen is carbon neutral.
	Biomass	Substitution of fossil fuel by biomass (carbon neutral).
	Geothermal	Electricity produced from geothermal heat sources (depth > 1 km).
	Nuclear	Electricity from nuclear plants (fission): (1) most existing plants are Gen II; (2) plants build from 2000 onwards are Gen III/Gen III+ (improved security); (3) from 2050 installed plant are GEN IV (P).
CCS & DACCS	CCS - Coal	Electricity production from coal (advanced coal technology or retrofitted coal plants)

	CCS - Gas	Electricity production from natural gas combined cycle with CCS
	CCS - Process	CCS from CO_2 process emissions. This refers mainly to non-metallic mineral industry (cement, glass, lime).
	CCS - Bio	Negative emissions (CO_2 sink) by producing electricity from combustion of biomass (biomass gasification or conventional thermal) and subsequent CO_2 capture.
	Direct Air Capture	Negative emissions (CO_2 sink) by capturing CO_2 from the air.
LULUCF CO_2		(1) Reducing CO_2 emissions due to avoided deforestation; (2) CO_2 sink of forests due to improved forest management and increased afforestation.
CH_4		Mitigating CH_4 emissions in (1) Coal mining; (2) Oil & gas production and transport; (3) Agriculture; (4) Waste sector.
N_2O, F-gases and other CO_2	N_2O	Mitigating N_2O emissions in (1) Industry; (2) Agriculture; (3) Waste sector.
	F-gases	Mitigating F-gas emissions: (1) HFCs in refrigeration & air-conditioning; (2) PFCs & SF6 in metal industry (aluminium, magnesium); (3) PFCs & SF6 in semiconductor industry; (4) SF6 for use in transmission lines.
	Other CO_2	Mitigating CO_2 emissions: (1) Process emissions - mainly in non-metallic mineral industry (cement, glass, lime), to a lesser extent in chemical industry; (2) Waste sector (e.g. avoiding waste & recycling).

Source: Own elaboration

Annex 6: Socio-economic assumptions and fossil fuel prices

The population assumptions follow Europop (Eurostat, 2021) for EU and JRC-IIASA projections (Lutz, Goujon, Kc, Stonawski, & Stilianakis, 2018) for the rest of the world.

The GDP projections follow numbers of the 2021 Ageing Report for the EU (European Commission, 2021); for the rest of the world, the sources are IMF (World Economic Outlook) and the OECD (CIRCLE project). The projections for the EU are based on the 2020 spring forecast (European Commission, 2020) which assumed a relatively fast recovery. See references at Table 15.

Table 15: GDP assumptions

Group	Historical (to 2019)	2019-2024	2025-2030	2031-2050	2051-2060	2061-2070	2071-2100
EU27	WB Oct-2019	2021 Ageing Report			intrapolation	GDP/cap as SSP x Europop	
Large non-EU	WB Oct-2019	IMF Apr-2021	intrapolation	GDP OECD Jul-2018 (2) / Pop IIASA-JRC		intrapolation	GDP/cap as SSP x Pop IIASA-JRC
Rest of World	WB Oct-2019	IMF Apr-2021	intrapolation	GDP/cap as SSP x Pop IIASA-JRC			

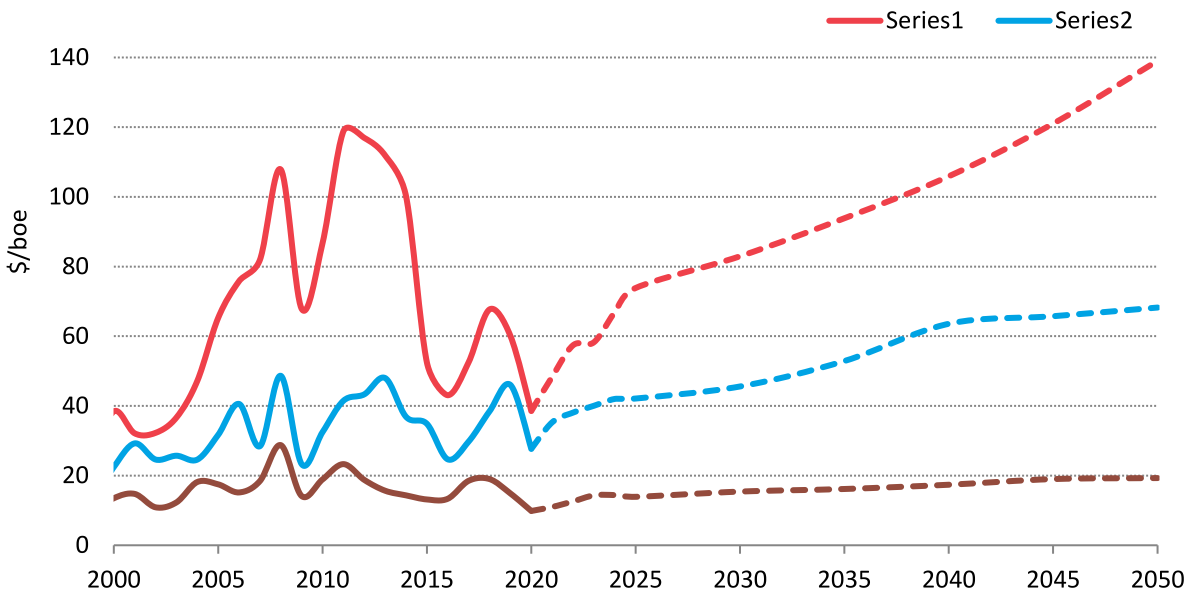
Sources: (Eurostat, 2021), (World Bank, 2019), (European Commission, 2021) (IMF, 2020) (OECD, Long-term baseline projections, No. 103, 2018), (OECD, Long-term baseline projections, No. 95 (Edition 2014), 2014), (IMF, 2021)

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).

Covid-19 has had a significant impact on mobility changes and transportation. GECO 2020 (Keramidas, et al., 2021) describes the short-term assumptions related to the pandemic considered in the scenario modelling. GECO 2021 uses the same data sources as GECO 2020, updated to 2021, and delays the past year report hypotheses of a year. More details are available in annexes 1 and 2 of GECO 2020.

The international fossil fuel prices in the Current Policies scenario are shown in Figure 121. They were endogenously calculated by the POLES-JRC model.

Figure 121: International fossil fuel prices in the Current Policies scenario



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

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