Energy-economy implications of the Glasgow pledges: a global stocktake of COP26

Rafael Garaffa[a], Matthias Weitzel[a], Toon Vandyck[a], Kimon Keramidas[a,b], Paul Dowling[a], Stéphane Tchung-Ming[a], Florian Fosse[a], Ana Díaz Vázquez[a], Jacques Després[a], Peter Russ[a], Burkhard Schade[a], Andreas Schmitz[a], Antonio Soria Ramirez[a], Andrea Diaz Rincon[a], Luis Rey Los Santos[a], Krzysztof Wojtowicz[a]

[a] Joint Research Centre, European Commission, Seville, Spain

[b] Université Grenoble-Alpes, Grenoble, France

ABSTRACT

The 2015 Paris Agreement establishes a framework in which countries submit their policy targets to the United Nations Framework Convention on Climate Change (UNFCCC) and further invites parties to submit long-term low greenhouse gas (GHG) emission development strategies. In this paper, we take stock of recent updates in the nationally determined contributions (NDCs) and long-term low greenhouse gas (GHG) emission development strategies (LTS) announced leading up to and during the Conference of the Parties (COP 26) in Glasgow, in November 2021. We focus on the transition of G20 countries, which accounted for nearly 75% of global GHG emissions since 1990, assessing three different scenarios: (i) current policies; (ii) announced policy targets (NDC-LTS); and (iii) a 1.5°C-compatible pathway. We further analyse decarbonisation drivers and energy system transformation metrics within each scenario, highlighting both the policy options to bring emissions in line with ambitious climate targets, and the associated labour market transition. The regional focus reveals heterogeneous decarbonisation pathways, mitigation options and emission gaps, informing the ongoing first "global stocktake" under the Paris Agreement. Delivering on both NDC and LTS targets could limit the temperature increase of global mean temperature to about 1.8°C above pre-industrial levels by the end of the century, reducing the ambition gap in the long run. The results furthermore suggest that the scale and concentration of cross-sectoral employment transition could warrant careful attention when designing policies to close the remaining implementation gap between current policies and climate targets.

1. Introduction

The 2015 Paris Agreement establishes a policy framework in which countries submit their nationally determined contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) and further invites parties to submit long-term low greenhouse gas (GHG) emission development strategies (LTSs). A first round of NDCs (submitted mainly in 2015 and 2016) coincides with the Paris Agreement negotiations, but the contributions are insufficient to limit the increase in the global average temperature to 1.5 °C above pre-industrial levels by the end of the century (Vandyck et al., 2016; Roelfsma et al., 2020; Höhne et al., 2021). Increasing the ambition regularly and progressively (the "ratcheting" mechanism) is part of the Paris Agreement framework and the first update of NDCs was scheduled ahead of the Conference of the Parties in Glasgow (COP26), in November 2021. By the end of 2021, out of the 196 parties that have adopted the Paris Agreement, 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. Furthermore, 50 parties have communicated their LTSs to the UNFCCC secretariat, several announcing net-zero emission targets for mid-century and beyond (UNFCCC, 2022).

Renewed country-level climate policy commitments call for updated GHG emission pathways to assess to what extent the Paris Agreement targets are within reach. Recent studies have compared scenarios that include the updated NDC targets and net zero pledges (Meinshausen et al., 2022; Birol, 2021; Climate Action Tracker, 2021; United Nations Environment Programme, 2021a; United Nations Environment Programme, 2021b). While these new targets have brought the 2°C mark within reach, these studies commonly acknowledged the fact that further collective climate action is required to achieve global targets (Hausfather and Moore, 2022). For instance, the UNEP Emission Gap Report (United Nations Environment Programme, 2021a; United Nations Environment Programme, 2021b) reports a 66% chance of remaining below 2.7°C for the unconditional NDC pledges and 2.6°C for conditional NDC pledges, without taking into account the announce net zero pledges. Birol (2021) projects that the new targets are likely to hold the rise in global temperatures to 1.8 °C, while Meinshausen et al. (2022) project a rise of 1.9 °C-2.0 °C by the end of the century.

Reaching the Paris Agreement target of 1.5°C will require a substantial increase in individual countries' ambition both in the short term to 2030 and in the long-term (Roelfsma et al., 2020; van Soest et al., 2021; Baptista et al., 2021), through a rapid transition to climate neutrality, and significant CO_2 emission reductions from the international aviation and shipping sectors (Creutzig et al., 2015; Sharmina, et al., 2020). On the one hand, most of these studies focus on the energy-related implications of climate policy pledges, providing highly detailed outcomes from bottom-up technology modelling, but not addressing the socio-economic implications of decarbonisation pathways. On the other hand, several studies that discuss the socio-economic aspects of the low-carbon transition at global level, solely focus on the implications to the energy system, typically overlooking the effects to other sectors of the economy (Pai et al., 2020).

Our contribution to the literature is a comprehensive assessment of the energy system and the socio-economic implications, in which we assess the macroeconomic impacts of decarbonisation pathways, including a shift towards additional investment and a cross-sectoral transition of the labour market (out of fossil fuels and towards sectors that can deliver clean energy). We take stock of recent all (important) updates in the NDCs and LTSs announced ahead of COP 26, highlighting (in our reporting) the transition of the Group of Twenty (G20) countries, which accounted for nearly 75% of global GHG emissions since 1990. We further analyse decarbonisation drivers and transformation metrics under three different scenarios: (i) current policies; (ii) announced policy targets; and (iii) a 1.5°C-compatible pathway; highlighting both the policy options to bring emissions in line with ambitious climate targets, and the energy and socio-economic consequences of this low-carbon transition.

This study also extends earlier work from Vandyck et al. (2016), bringing methodological improvements and detailed employment results by country, sector and scenario, furthermore updating implemented policies, jobs data, near- and long-term climate policy pledges, and the underlying technology cost projections. In addition to the regional focus, which reveals heterogeneous decarbonisation pathways, the results are also relevant for the first "global stocktake" under the Paris Agreement, scheduled for 2023. The remaining of the paper is organised as follows: Section 2 presents the methodology, describing the scenarios assessed; we present results and discuss global and country-specific energy and socio-economic effects of the decarbonisation pathways in Section 3. Section 4 concludes.

2. Methods

We rely on a consistent modelling toolbox to build and assess decarbonisation pathways in the long-term (Fig. 1). We start from the POLES-JRC model (Després et al., 2018), which is a world energy-economy partial equilibrium simulation model, covering all GHG emissions (including non-energy GHG land-use related emissions) and with complete modelling from upstream energy production through to final user demand. Next, the PIRAMID framework (Wojtowicz, et al., 2019) translates the current policy scenario from POLES-JRC into a baseline for economic modelling. In particular, PIRAMID projects input-output tables forward in time that reproduce macroeconomic drivers and energy and emission outcomes from the POLES-JRC model. Finally, we use the computable general equilibrium (CGE) model JRC-GEM-E3 (Capros, et al., 2013) to assess the employment transition implied by NDC and LTS targets and a 1.5°C scenario in contrast to the projected baselines. The JRC-GEM-E3 model is a global, multi-region, multi-sector, dynamic-recursive CGE model designed to analyse energy, climate and environmental policies.

Figure S.1 in the Supplementary Material provides a schematic overview of the modelling toolbox. Keramidas et al. (2021) provide a more detailed description of the models' functionalities, while Table S.1 (in the Supplementary Material) brings a comprehensive list of the several different data sources used in the simulations. This study extends and improves the work of Vandyck et al. (2016) by projecting the number of workers in the energy sectors based on employment factors. The number of jobs per unit of energy produced (taken from the database provided in Pai et al., 2021) is multiplied by the total output of the energy sectors to calculate and project the total number of jobs in those sectors over 2050. Employment factors are different across countries/regions and evolve over time to reflect the productivity gains, while the labour payments reported in the Multi-Regional Input-Output tables for the baseline scenario (Vandyck et al., 2021) used in the study are adjusted accordingly.

2.1. Scenarios

We assess three different scenarios: (i) current policies (CurPol); (ii) announced policy targets (NDC-LTS); and (iii) a 1.5°C-compatible pathway. In all scenarios, we account for the effects of the Covid-19 pandemic on the energy system, by using updated macroeconomic figures (annual Gross Domestic Product-GDP growth revised for 2020-2027) and revised parameters for transport modes (e.g., activity levels for 2020-2023, structural changes in passenger mobility induced by the pandemic compared to earlier behaviour, decreased rate of stock of vehicles turnover for 2020-2022) (Keramidas et al., 2021).

The **Current Policies (CurPol)** scenario is built on existing climate and energy policies, and we do not include additional policies compared to what had been legislated as of 2019 (i.e., policies that have not been translated into a legal framework, such as laws, decrees, resolutions or concrete action plans). Exogenous macroeconomic projections for GDP and population growth (REF), and endogenously calculated energy prices and technological development specific to the JRC-POLES model, combined with the effect of enacted policies, are used to calculate projections of the energy system and CO_2 emissions. Consequently, this scenario may differ from energy and emissions projections from official national sources and international organisations. A comprehensive list of policies considered in this scenario is available in Keramidas et al. (2021).

The **NDC-LTS scenario (NDC-LTS)** considers the policies of NDCs in the medium term and the LTSs in the longer term, assuming 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 are frozen to their 2030 level. The NDC-LTS scenario also considers decarbonisation proposals related to international aviation and maritime transport fuels (international bunker fuels). Submissions up to 05 November 2021 and pledges made in COP26 are included in this paper (Table

1). We also modelled an NDC-Only case, 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.

Table 1. NDCs and LTS pledges of G20 countries and international bunkers, ranked by share of 2019 global GHG emissions

G20 countries + International bunkers	% of 2019 global GHG emissions (incl. LULUCF)	Updated NDC (date of submission, target of previous NDC)	LTS	Net-zero target (all GHG, unless noted)
China	27.5%	Strengthened targets	LTS submitted	2060 (CO2 only)
USA	11.9%	New target for 2030	2016, new 2050 target announced April 2021	2050
India	6.5%	November 2021 Strengthened targets	Announced COP 26	2070
EU	6.5%	December 2020 Strengthened targets	Submitted March 2020	2050
International bunkers	4.3%	n/a	2018 IMO initial strategy 2016 ICAO CORSIA)	n/a
Russia	3.4%	November 2020 Similar targets	Announced COP 26	2060
Indonesia	3.2%	July 2021 Strengthened LULUCF	Announced October 2021	2060
Brazil	3.0%	November 2021 Strengthened targets	Climate neutrality announced	2050
Japan	2.1%	October 2021 Strengthened targets	2016; net zero target announced Oct. 2020	2050
Canada	1.4%	July 2021 Strengthened targets	2016, new 2050 target announced 2021	2050
Saudi Arabia	1.4%	November 2021 Strengthened targets	Announced October 2021	2060
Mexico	1.4%	December 2020 Similar targets	2016	50% reduction by 2050 from 2000 levels
South Korea	1.3%	October 2021 Strengthened targets	Ratified - September 2021	2050
South Africa	1.1%	2016 submission only	September 2020	2050 (CO2 only)
Australia	1.1%	December 2020 Similar targets	Climate neutrality announced	2050
Turkey	1.0%	2016 submission only	October 2021	2053
United Kingdom	0.9%	December 2020 Strengthened targets	April 2018	2050
Argentina	0.8%	December 2020 Strengthened targets	Announced December 2020	2050 (CO2 only)

Source: own elaboration based on UNFCCC (2021) and on European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.3.1 http://edgar.jrc.ec.europa.eu/overview.php?v=431, (2016)

The **1.5°C scenario (1.5C)** assumes a global GHG trajectory consistent with a likely chance of meeting the Paris Agreement long-term goal of a temperature rise over pre-industrial levels of well below 2°C at the end of the century. This scenario was designed with a global carbon budget of approximately 500 GtCO2 cumulated net emissions over 2018-2100 and a 50% probability of not exceeding 1.5°C of warming. 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 Supplementary Material. 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. This scenario does not consider financial transfer between countries to implement mitigation measures. The mobilisation of biomass as an energy resource (<170 EJ/year for all years to reflect the use of only sustainably grown biomass) and the use of negative emissions technologies (<14 GtCO2/year in 2100) is relatively limited; combustion CO_2 capture and CO_2 direct air capture technologies are made available progressively beyond 2030 (<7 GtCO2/year in 2050). Within the above economic and technological constraints, the overshoot of the temperature target was kept at slightly above 1.7°C in 2050.

3. Results

In this section, we present the results of the simulations performed in the POLES-JRC and JRC-GEM-E3 models. We start by looking at the implications of climate policies on the evolution of the GHG emissions and global mean temperature, paying particular attention to national targets for the short term (2030) and the mid-century strategies. Next, we focus in climate change mitigation and in the role of the electrification in the decarbonisation of the energy system. We also look at the economic implications of the announced pledges and their effects on main macroeconomic components and on employment, at regional and sectoral levels.

3.1. Closing the Gap. How far are we?

Our scenarios show a clear departure from historic trends and from the projected current policies in terms of GHG emissions (Fig. 1a). Current policies and technology improvements are only sufficient to stabilize global emissions by 2035-2040, close to a 60GtCO_2e annual level, implying a temperature that exceeds 3°C by the end of the century compared to pre-industrial levels (Fig. 1b). Announced targets for the short term however bend the GHG emissions trajectory, both in the NDC-Only and NDC-LTS scenarios, with global GHG emissions reaching 47GtCO_2e by 2030. We observe a sizeable reduction of 28GtCO_2e in global annual GHG emissions by mid-century, particularly from G20 countries, promoting stabilization after 2060 in terms of the implied temperature change, amounting to about 1.8°C by 2100. Our results are in line with the range shown for similar scenarios in the IPCC AR6 database (Byers et al., 2022).

Our NDC-only scenario is in line with other studies in the literature, in which the conditional NDC pledges lead to temperature increase of about 2.6°C by the end of the century, despite using a different extrapolation method beyond 2030 (United Nations Environment Programme, 2021a; United Nations Environment Programme, 2021b; Birol, 2021). This result however substantially contrasts to the estimate of the NDC-LTS scenario (+1.8°C by 2100), and the 24.3GtCO_2e difference in the GHG emissions between these scenarios (in 2050) reveals that we are crucially dependent on delivering on the LTS to promote early structural changes and keep global warming below 2°C.

The difference in the GHG emissions trajectory of the CurPol and the NDC-LTS scenarios provides the *implementation gap* (dark blue bar in Fig. 1a), which reflects the additional policy measures that the announced targets require to be reached. Further, to limit global warming to 1.5°C levels by 2100, more ambitious targets would be needed, both in the short term for achieving a stronger decline of emissions towards 2030, as well as in the long term. Therefore, by taking the difference in the GHG emissions trajectory of the NDC-LTS and the 1.5C scenarios, we obtain the *ambition gap* (sky blue bar in Fig. 1a, whereas the light blue bar shows the *remaining emissions* under the 1.5C scenario).

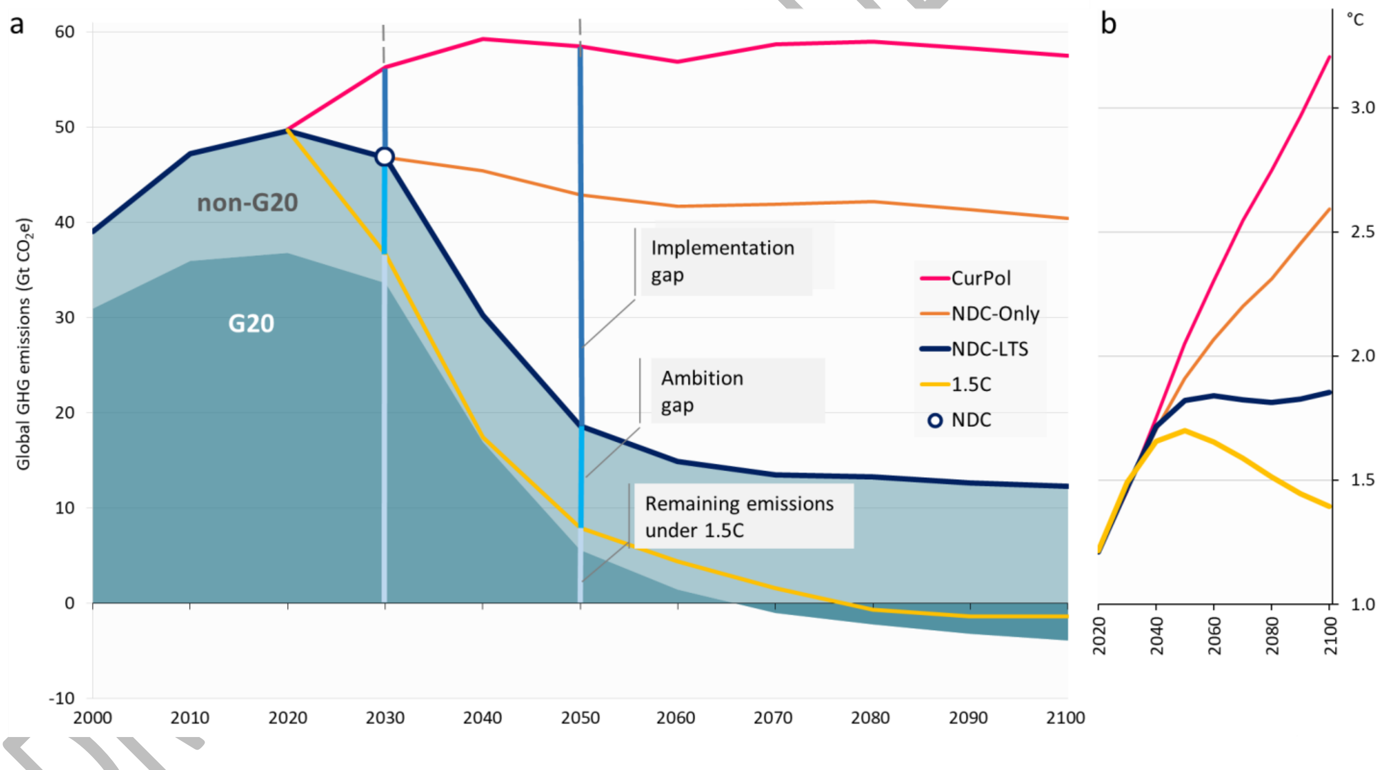

Fig. 1. Global GHG emissions (GtCO_2e) projections by scenario and as share of the G20 countries for the NDC-LTS scenario (a). Projection of the global mean temperature change above pre-industrial levels (b) based on liveMAGICC (Meinshausen et al., 2011).

When looking at the contribution at regional level, the implementation of G20 countries LTS promotes a steep reduction in global GHG emissions over 2030-2050, making non-G20 countries (with full conditional implementation of NDCs) the main global GHG emitters by 2050 (Fig. 1). On a country basis, a comparison to historic GHG emissions (yellow dashed line in Fig. 2) suggests different levels of commitment by mid-century, with important countries still close to (or even above) 2019 levels. An increasing implementation gap over 2030-2050 reinforces the need for immediate adoption of LTS, rewarding early action by avoiding future (and notably higher) costs of climate policy. Conversely, the decrease in the ambition gap over 2030-2050 highlights the role of announced net-zero targets in getting us closer to a 1.5C pathway, but with a sizeable implementation gap still to be closed. Notably, for countries in which CurPol emissions are projected to grow over time (e.g., India, Mexico, and Turkey) this outcome might be reinforced, as the gap further increases.

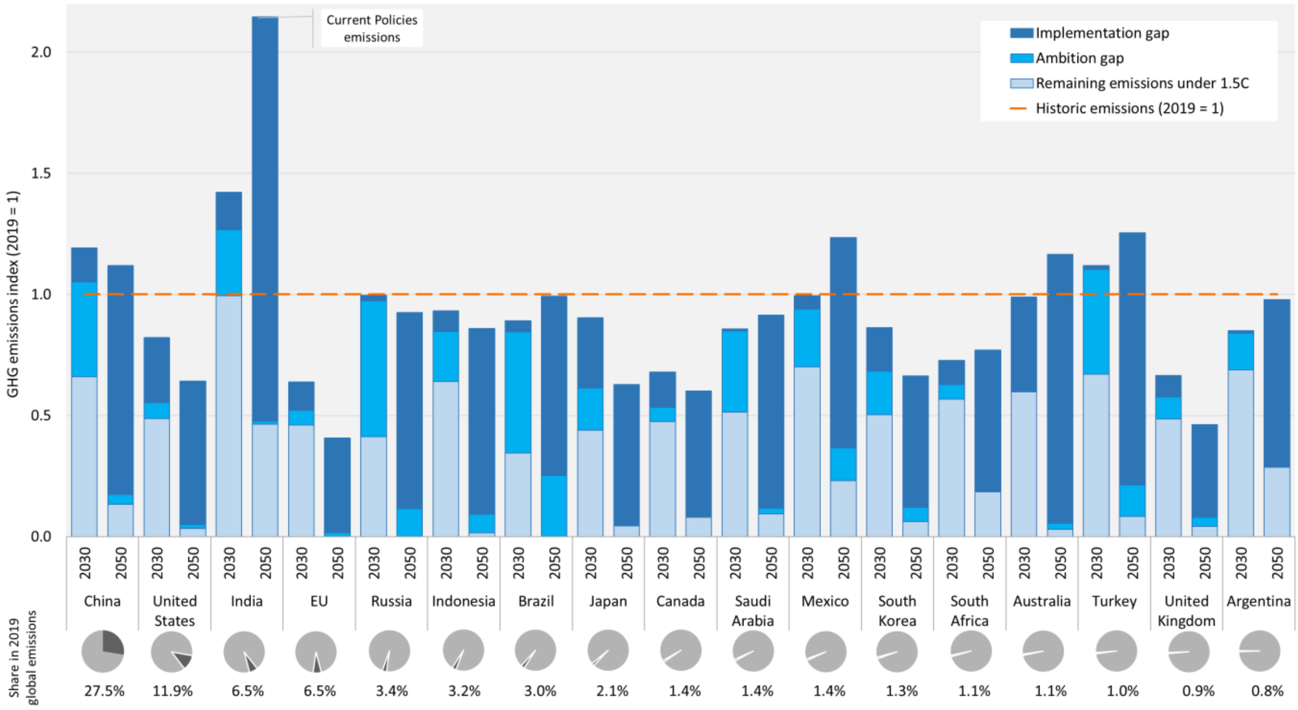

Fig. 2. Closing the gap – Implementation and ambition gaps, and remaining emissions under the 1.5C scenario. GHG emissions index by region (2019 = 1) and share in 2019 global emissions based on EDGAR.

3.2. How to get there? Mitigation options

When looking at the mitigation options needed to close the gap, our findings indicate that a robust transition towards a low-carbon economy would rely primarily on the transformation of the energy system, with emission reductions in the power sector contributing the most towards realizing the emission targets. We observe that the main change of primary energy demand when moving from the CurPol to the NDC-LTS scenario is driven by the phase out of coal, while the largest difference in primary energy demand comes from natural gas when moving from the NDC-LTS to the 1.5C scenario in 2050 (Fig. 3a). Biomass plays an important role as a primary energy source under both scenarios by mid-century, providing solids and liquids to the final energy mix. Most importantly, we note that a strong decarbonisation of power generation, with a shift towards low-carbon sources – mainly wind, solar and nuclear --, would accelerate the phase out of coal in the power sector and could close the ambition gap for 2030 (Fig. 3b).

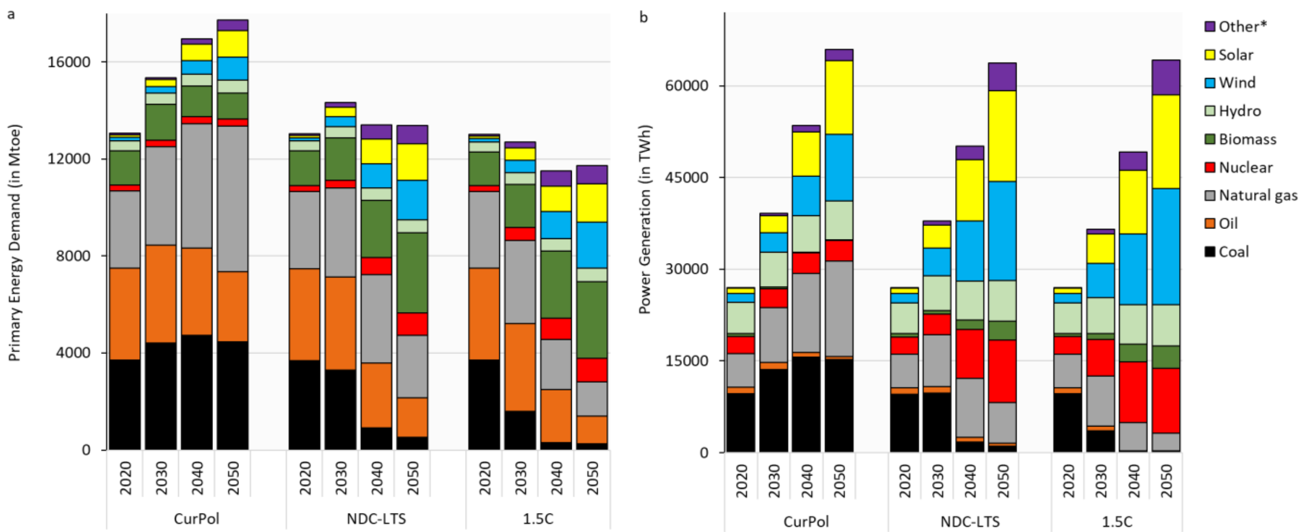

Fig. 3. Primary energy demand in Mtoe (a) and power generation in TWh (b) by scenario over 2020-2050. (*) Geothermal and ocean

Nonetheless, the decarbonisation of the energy system alone is not compatible with the 1.5°C target. Mitigation is also needed in the Agriculture, Forestry and Land-Use (AFOLU) and in the final demand sectors, particularly through improved practices in AFOLU, increased demand side efficiency and electrification. In this regard, suitable abatement options vary by region and over time, and we observe that the AFOLU sector plays a key role in GHG emissions mitigation in Africa and Latin America, while the power sector stands as the prime driver in main emitter regions, like China, India and North America (Fig. 4). Abatement options in the remaining sectors, such as transport and buildings, are largely related to the electrification of final uses (e.g. electric vehicles and heat pumps).

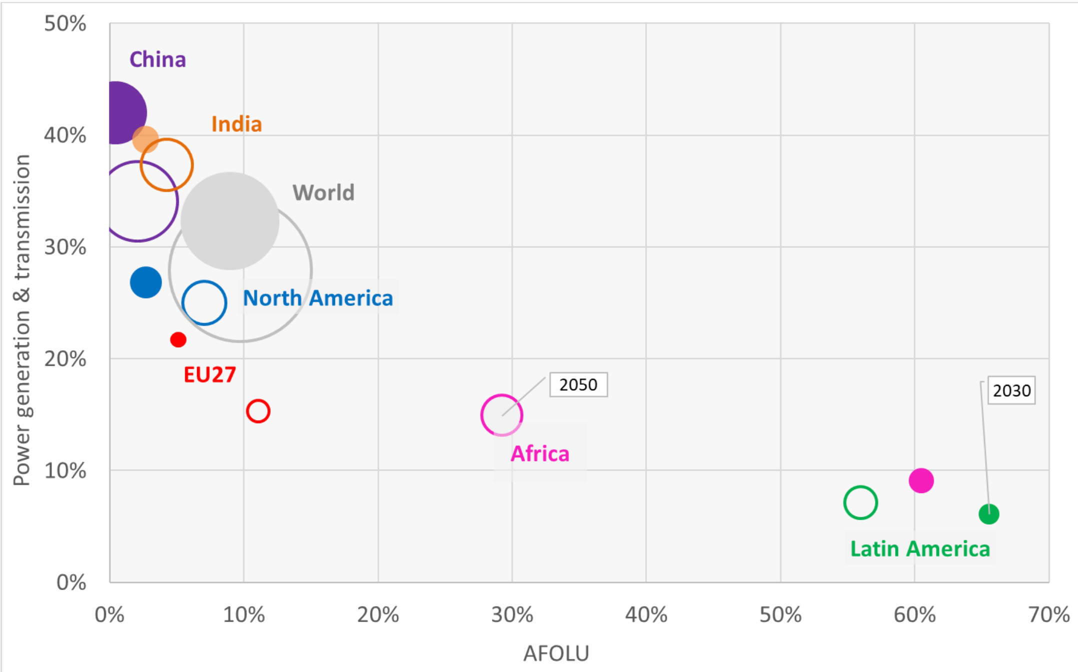

Fig. 4. Share of Agriculture, Forestry and Land-Use (AFOLU) and Power generation and transmission in total GHG emissions mitigation under the 1.5C scenario. Remaining values to 100% are abatement options in other sectors (e.g. transport, buildings). Selected countries/regions in 2030 (solid fill) and 2050 (no fill). The size of the bubbles represents total mitigation under the 1.5C scenario as compared to CurPol.

As indicated by the size of the grey bubble (Fig. 4), the decarbonisation of the power generation is an important source of global mitigation, also enabling the decarbonisation of other sectors through electrification. Due to declining technological costs, change in end-use equipment and favourable policies, we project increased electrification of final demand and lower emissions intensity in the power sector are foreseen in all scenarios. In Fig. 5, countries move to the bottom right of the figure, where both electrification in final demand and lower emissions intensity are relevant. In the short term, electrification of final demand does not change substantially between scenarios, but we observe that emissions intensity (in the y-axis of Fig. 5) do. Nonetheless, in the long term most countries (and the world) reach levels of around 50% of electrification in final demand, with the emissions intensity in power generation sharply declining to about 100gCO2e/kWh under the NDC-LTS and 1.5C scenarios.

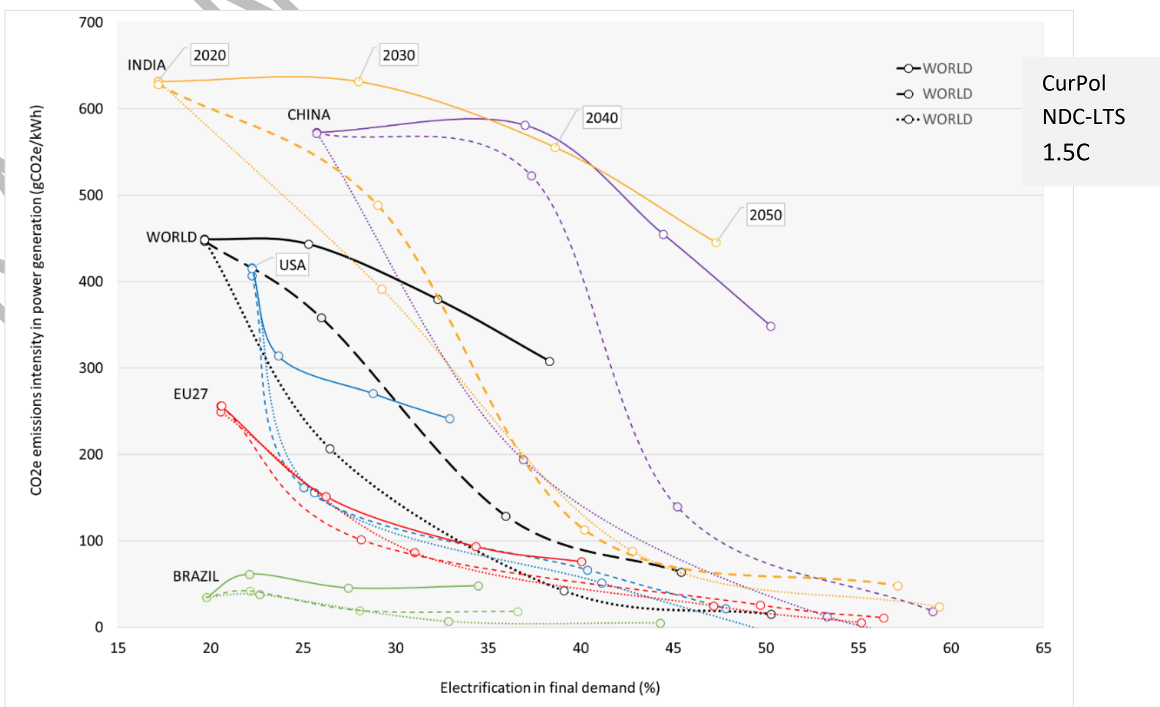

Fig. 5. Share of electrification in final demand (%) and CO2 emissions intensity (gCO2e/kWh) by selected countries/regions under CurPol (solid lines), NDC-LTS (dashed lines) and 15.C-Diff (dotted lines) scenarios.

Such movement is not homogeneous across countries and we observe different patterns in Fig. 5. For instance, over 2020-2030 the United States of America (USA) shows a stronger move downwards, while China and India still present high emissions intensity in power generation and, consequently, move to the right (except in the 1.5C). We also observe similar horizontal trajectories across scenarios in the EU27 and Brazil, which suggests that current policies in the power generation are not detached from more ambitious targets (e.g., Green Deal, in the case of EU27) or the sector is already decarbonised, which is clearly the case of Brazil.

3.3. What are the costs? Macroeconomic impacts of the transition

Our results reveal that the costs of the transition to a decarbonised economy under both the NDC-LTS and 1.5C scenarios are less than half percent of the global GDP by mid-century (Table 2). In other words, we project a 2.70% growth per annum in the GDP under both scenarios, while under the Current Policies scenario GDP is projected to grow 2.72% per annum, over 2020-2040. The output of fossil fuel sectors strongly decrease led by the phase out of coal as opposed to agriculture (including forestry), electricity generation and construction. The expansion of renewables in the power generation and the need for transmission promote growth in the construction sector, while biomass production expands as another source of mitigation in various regions. We also observe some reindustrialisation of certain sectors related to final uses (electric, transport and other equipment goods), in contrast to more traditional energy-intensive industries.

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.

The structural change of the energy system described earlier implies substantial additional investment, expanding the capital stock in clean energy sectors and leading to an increase of about 1% under the NDC-LTS and 0.8% under the 1.5C scenario, in 2040. The investment in power technologies stands out as the prime driver of the transition, and we note a strong correlation between investment expansion and output growth in agriculture and construction sectors – which is not the case in heavy industry and transport, typically due to the maturation of investment.

In addition to sector-specific results for output and investment, Table 2 shows results for employment in 2040 by scenario. We simulate two different tax recycling schemes and two different labour market closures in the JRC-GEM-E3 model. The recycling schemes cover carbon pricing revenues being directly recycled by governments to households through lump-sum transfers (LS), or through a tax rebate (TR), in which the revenue is used to lower labour taxes, potentially affecting the labour market. Regarding the labour market closure, in the fixed setup, we assume that the determinants of unemployment in the long-run are not affected by the climate policy and the net effect on overall employment is zero, i.e. a perfect labour market with adjustments of wages, in which the aggregate employment is stable in the long run. Alternatively, the endogenous setup lays on the efficiency wage approach to represent regional involuntary unemployment according to a wage curve mechanism (Blanchflower,D.G. and Oswald,A.J., 1995).

Table 2. Sector-specific output, investment and employment levels results in 2040, by scenario, under different tax recycling schemes and labour market assumptions. Energy sectors shaded in grey.

% change from CurPol	Output level		Investment		Employment							
Scenario:	NDC-LTS	1.5C	NDC-LTS	1.5C	NDC-LTS				1.5C			
Carbon revenue recycling[1]:	LS	LS	LS	LS	LS	LS	TR	TR	LS	LS	TR	TR
Labour market[2]:	fixed	fixed	fixed	fixed	fixed	endogenous	fixed	endogenous	fixed	endogenous	fixed	endogenous
Global[3]	-0.4	-0.5	1.0	0.8	-	-0.01	-	-0.01	-	-0.02	-	-0.01
Agriculture	5.2	4.4	5.1	4.6	3.9	3.8	4.1	4.1	3.5	3.2	3.7	3.5
Livestock	-1.9	-2.7	-0.4	-1.2	0.8	0.5	0.8	0.7	-1.5	-2.2	-1.6	-2.1
Coal	-73.5	-87.8	-76.9	-87.3	-66.8	-66.9	-66.8	-66.9	-86.8	-86.2	-86.1	-86.1
Crude Oil	-22.0	-25.7	-19.0	-24.8	-12.9	-13.6	-15.1	-15.2	-25.4	-24.9	-26.6	-26.5
Oil Products	-22.2	-26.1	-16.1	-21.4	-10.9	-11.8	-11.0	-11.5	-20.3	-22.3	-20.3	-21.9
Gas	-25.4	-46.0	-20.1	-41.5	-15.6	-15.7	-16.0	-15.9	-43.3	-43.2	-43.6	-43.4
Electricity supply	3.9	5.2	84.1	62.1	15.2	14.8	15.2	14.9	25.7	23.3	25.0	23.6
Ferrous metals	-0.4	-0.1	4.6	10.4	1.4	0.8	1.4	1.0	2.0	-0.1	2.4	0.8
Non-ferrous metals	0.1	-0.5	1.9	3.7	1.3	1.0	1.1	0.9	2.4	1.0	2.7	1.5
Chemical Products	-0.8	-0.9	1.0	0.8	0.1	-0.3	0.1	-0.3	0.7	-0.7	1.1	-0.3
Paper Products	-0.5	-0.4	0.9	1.7	-0.2	-0.9	-0.3	-0.7	0.1	-1.9	0.1	-1.5
Non-metallic minerals	-0.1	-1.1	1.5	1.5	-0.2	-0.6	-0.1	-0.4	-0.1	-1.2	0.0	-0.8
Electric Goods	0.6	1.7	0.8	2.8	0.1	-0.3	0.1	-0.2	3.4	1.5	4.1	2.4
Transport equipment	0.4	0.4	2.4	2.8	-0.7	-1.5	-0.8	-1.3	0.3	-1.7	0.4	-1.2
Other Equipment Goods	0.0	0.3	0.8	2.0	-0.8	-1.4	-0.7	-1.1	0.2	-1.9	0.8	-1.1
Consumer Goods Industries	-0.7	-0.7	0.6	1.3	-0.4	-1.0	-0.4	-0.8	-1.0	-2.7	-1.0	-2.4
Construction	1.0	1.1	2.0	2.9	0.4	-0.1	0.5	0.2	0.8	-0.6	0.9	-0.1
Transport	-1.5	-1.7	2.3	2.3	0.3	-0.7	0.2	-0.5	0.0	-3.0	-0.5	-3.0
Market Services	-0.3	-0.1	0.1	0.5	-0.9	-1.7	-0.9	-1.4	-0.6	-2.7	-0.7	-2.4
Non Market Services	-0.3	-0.2	0.1	0.4	-0.7	-1.2	-0.7	-1.0	-0.8	-1.9	-1.0	-1.8

Notes: [1] LS – lump-sum transfers to households; TR – tax rebates on labour taxes.

[2] *Fixed* unemployment rates per region or *endogenous* regional unemployment rates (efficiency wage assumption)

[3] Output shows global GDP change from CurPol scenario.

The investment expansion positively affects the employment levels in several sectors. Fig. 6 reports the projected changes in global labour demand in 2030 and 2050 by scenario. The horizontal axis in Fig. 6 presents the change in sectoral employment relative to the CurPol scenario and the width of the bar represents that sector's level of employment under the CurPol scenario in year 2050. The area of a bar thus corresponds to volume of jobs subject to transition to/from a sector, whereas the dots (circle/triangle) only show the relative change in 2030.

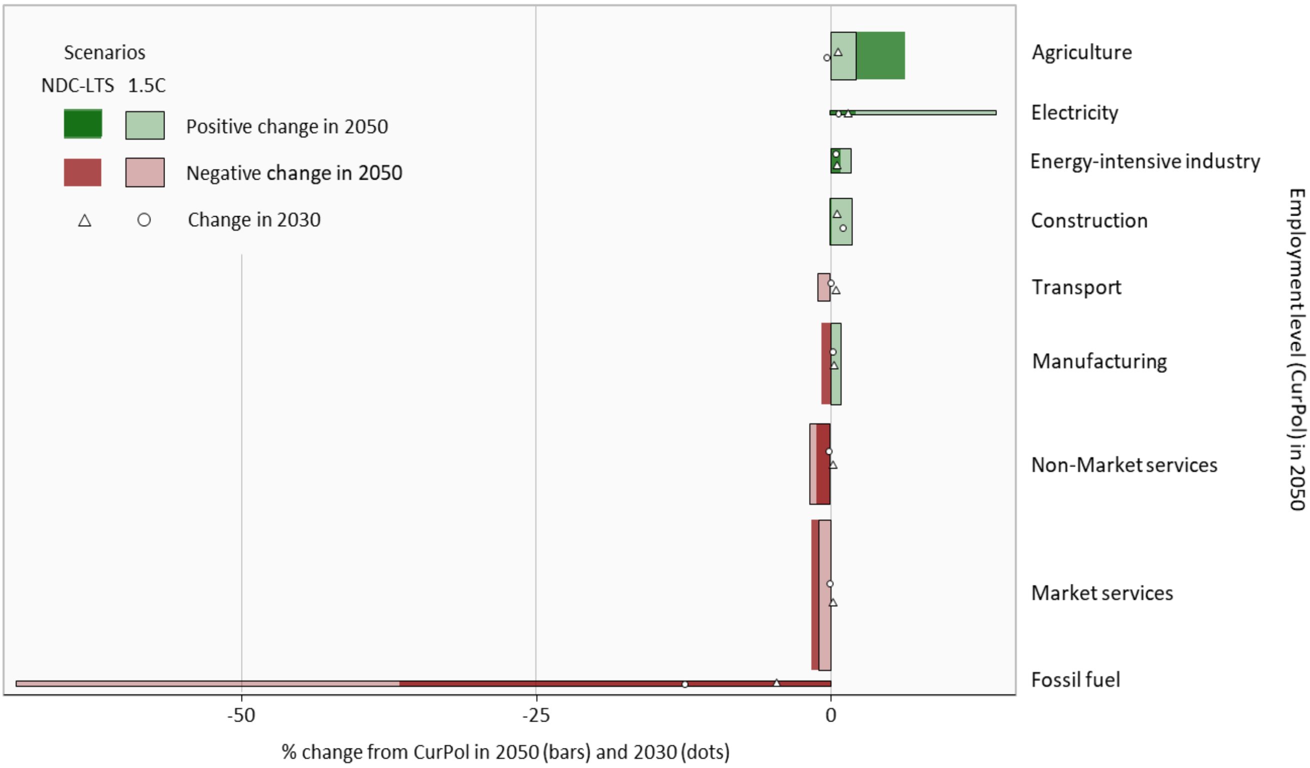

Fig. 6. Transition of jobs by sector in 2030 and 2050 under the NDC-LTS and 1.5°C scenario

Fig. 6 presents the results for the simulations in which labour market is fixed and with lump-sum transfers to households of carbon revenues (LS fixed in Table 2). In line with previous work (Vandyck et al., 2016), 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 CurPol scenario, particularly due to the strong activity reduction of the coal sector.

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. Because 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. Electrification and bioenergy as core mitigation options offer increasing employment opportunities, particularly in the electricity production and agriculture sectors, with the latter, as a labour-intensive sector, absorbing jobs under both scenarios in 2050.

We note that service-oriented sectors face growing labour demand under both scenarios, but such growth is slightly lower than the one projected in our Current Policies scenario. In this respect, the NDC-LTS and 1.5C scenarios also represent a certain reindustrialisation of the global economy driven by significant investments and structural changes prompted by the energy transition.

4. Conclusion

This paper finds that the NDC and LTS pledges stabilise global GHG emissions over the next decades, leading to declining emissions by 2050. While delivering on these aims results in an increase of global mean temperature of 1.8°C at the end of the century (with current policies in excess of 3°C), substantial further actions are needed to limit global warming to the Paris Agreement targets. Achieving well below 2°C and pursuing efforts to reach a 1.5°C temperature increase above preindustrial levels by the end of the century requires immediate action, which implies important impacts on the global macro economy, with a shift in investment and a transition of the labour market out of fossil fuels and towards sectors that can deliver clean energy.

We note that 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. The current modelling framework does not include these dimensions, which would potentially reduce the total costs of the climate policy scenarios.

Another limitation of our study is that we do not take into account the territorial dimension of certain sectors. For instance, while the number of fossil fuel jobs might be small on the aggregate regions considered in this study, it may be concentrated at sub-regional level (e.g., NUTS 2 level, describing the basic regions typically considered for the application of regional policies). The same rationale applies to other sectors, such as agriculture, with clusters at the sub-regional level. Finally, the effects of the energy transition within sectors are not fully captured in the current model structure, including structural changes in supply chains, such as those in the production of Internal Combustion Engine (ICE) vehicles to Electric Vehicles (EVs), and are a potential source of developments in the modelling framework and future studies.

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Supplementary material - Energy-economy implications of the Glasgow pledges: a global stocktake of COP26

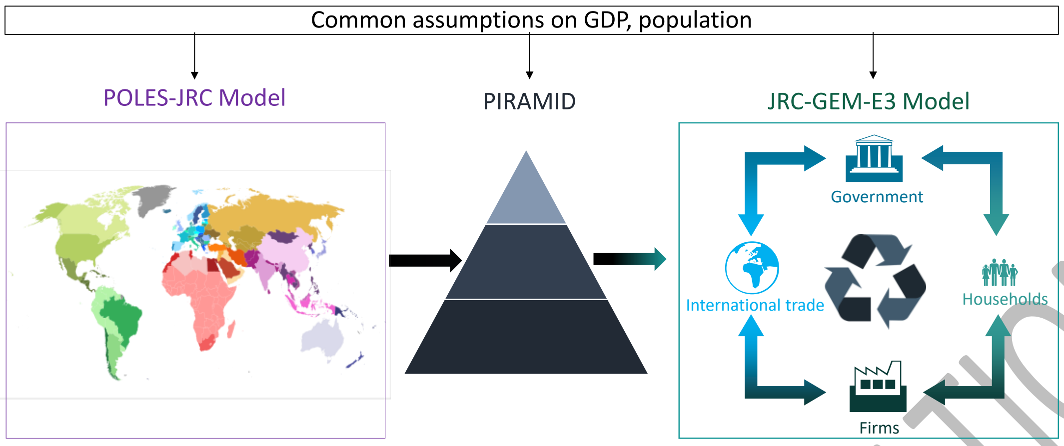

Fig. S.1. Modelling toolbox. Bottom-up energy system and top-down global economic modelling combined.

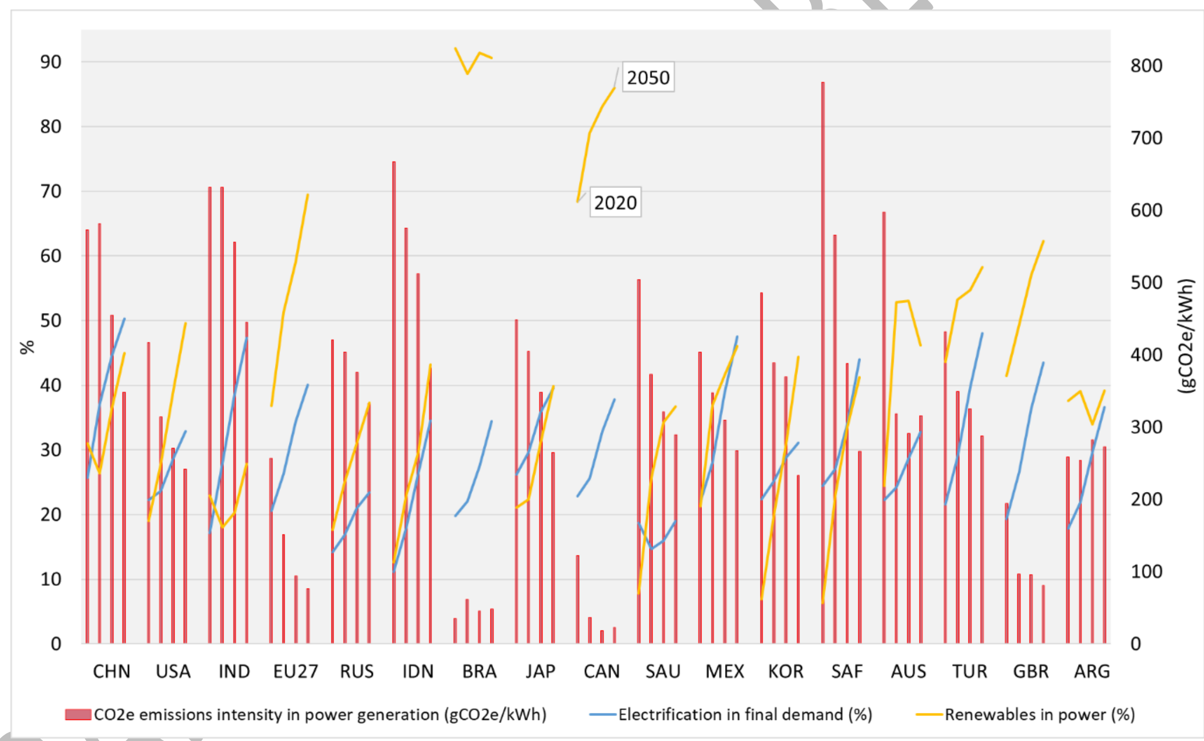

Figure S.2 – Share of electrification in final demand and renewables in power generation (%), and CO2 emissions intensity (gCO2e/kWh) by selected countries/regions in the CurPol scenario.

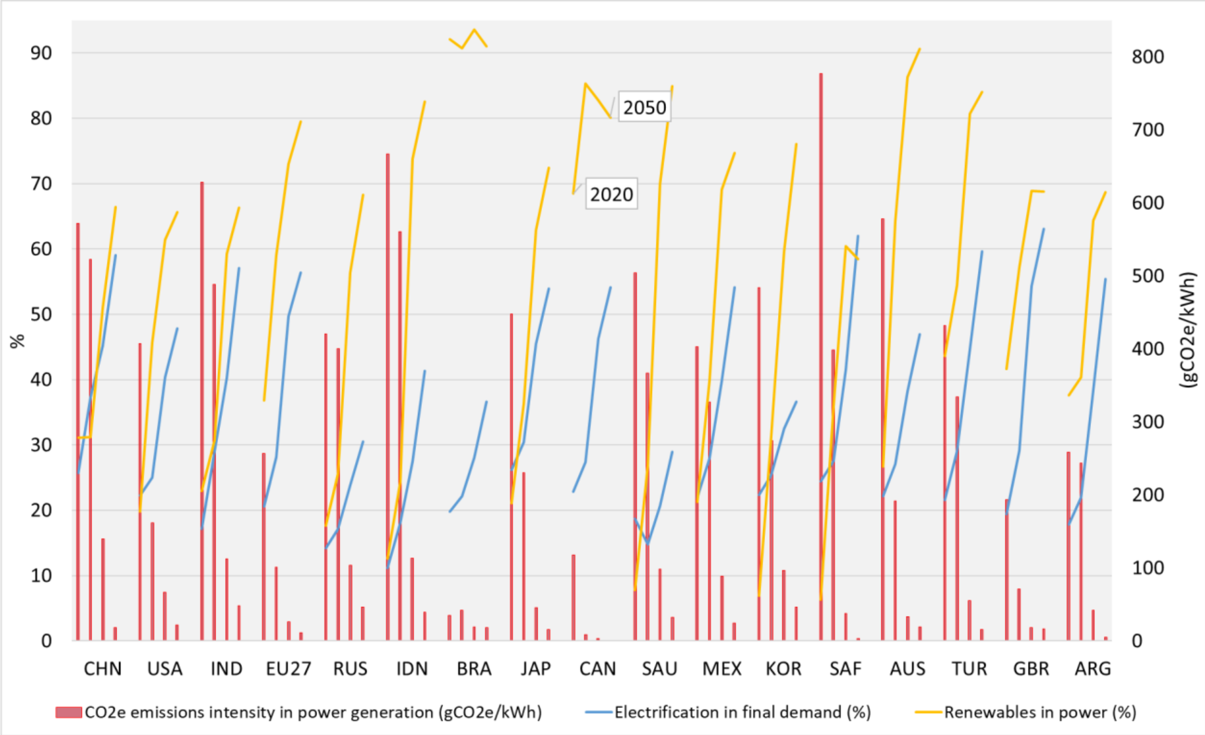

Figure S.3 – Share of electrification in final demand and renewables in power generation (%), and CO2 emissions intensity (gCO2e/kWh) by selected countries/regions in the NDC-LTS scenario.

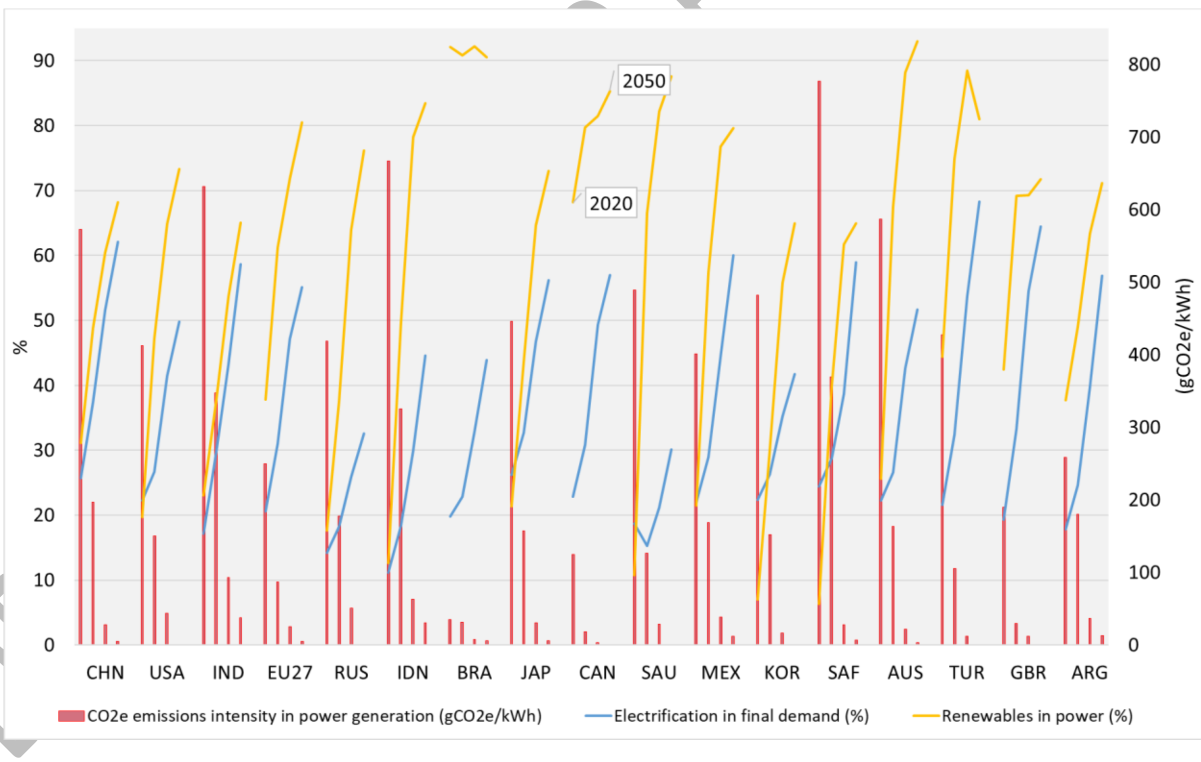

Figure S.4 – Share of electrification in final demand and renewables in power generation (%), and CO2 emissions intensity (gCO2e/kWh) by selected countries/regions in the 1.5C scenario.