D3.1a – Focus Report on economic impacts

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About this report

This deliverable analyses the impacts of the decarbonization efforts taken by countries on a global basis, with a higher degree of attention to the EU-28 countries, under three pathways – the Status-quo, the REEEM and the Paris agreement – between 2011 and 2050. While the Status-quo pathway assumes low ambition targets for the emission reduction until 2050, reflecting the actual state of the NDCs and the Paris agreement pathway assumes that each region in the world takes measures consistent with the 2° target, the REEEM pathway assembles the main assumptions from this project to how the world will develop in the coming years and presents an intermediary emissions path in between the other two pathways. This report's objective is to assess the economic impacts of pursuing different reduction targets and main challenges to ensure economic growth.

REEEM partners

About REEEM

REEEM aims to gain a clear and comprehensive understanding of the system-wide implications of energy strategies in support of transitions to a competitive low-carbon EU energy society. This project is developed to address four main objectives: (1) to develop an integrated assessment framework (2) to define pathways towards a low-carbon society and assess their potential implications (3) to bridge the science-policy gap through a clear communication using decision support tools and (4) to ensure transparency in the process.

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Abbreviations

AEEI	Autonomous Energy Efficiency Index
BaU	Business-as-Usual
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
ETP	Energy Technology Perspectives
ETS	Emissions Trading System
ESD	Effort Sharing Decision
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GVA	Gross Value Added
NEWAGE	National European Worldwide Applied General Equilibrium

1. Introduction

In harmony with global treaties aimed on reducing human caused climate change, such as the Kyoto Protocol and the Paris Agreement, the European Union has a long term roadmap to become a low-carbon economy, which set targets towards reducing its greenhouse gas (GHG) emissions progressively up to 2050. The main climate targets are set in the following strategies: 2020 climate and energy package [1], 2030 climate and energy framework [2] and the 2050 low-carbon economy [3]. The main target of these plans is for the EU to cut GHG emissions, by 2050, to 80% below 1990 levels. Additionally, there are milestones for 2020, 2030 and 2040 of reducing the emissions bellow 20, 40 and 60% below 1990 levels, respectively.

In order to achieve its emissions targets, one of the main European tools is the EU emissions trading system (EU-ETS), which operates in 31 countries (EU-28 plus Iceland, Norway and Liechtenstein) and is responsible for limiting emission from heavy, energy-intensive installations, as well as the airlines operating between these countries, covering around 45% of the EU's GHG emissions [4]. The EU-ETS is planned to last, at least, until 2030, when its target is to cut 43% of the GHG emissions of the sectors within it compared to 2005 levels, plus a milestone of 21% lower than 2005 levels by 2020.

For the sectors not covered by the EU-ETS, the 28 countries in the EU took binding annual targets until 2020 towards cutting GHG emissions under the Effort-sharing decision (ESD). The targets differ between countries and depend on Member States' relative wealth, measured by GDP per capita. For 2020, the richest countries took obligation to reduce GHG emissions by 20%, while the least wealthy countries can increase their emissions up to 20% compared to 2005 levels. The sectors covered by the ESD will collectively contribute to a reduction of 10% by 2020 and of 30% by 2030, compared to 2005 levels.

As it is expected, the environmental targets in the EU inflict certain costs to its economy, e.g. in the form of emission allowances (ETS), investments to increase the efficiency of current technologies and R&D for innovation. These costs will certainly affect the European society, as it may increase electricity costs and interfere with the competitiveness of the European industry in the international arena. This work aims precisely on understanding the economic impacts of policies focused on reducing GHG emissions.

This work is part of the REEEM project, which aims at gaining a clear understanding of system-wide implications of energy strategies in support of the EU transition towards a low-carbon economy. Among several activities, this project developed key pathways that describe ways in which the World can develop in the coming years, where each of these pathways was built with the support of stakeholders. Through the usage of the Computable General Equilibrium (CGE) model NEWAGE, three different pathways are analyzed, each one with a different level of CO_2 emissions reduction, in a way that it is possible to assess the economic impacts of increasing environmental ambition. More than being a standalone report, the results obtained here will also serve as input for the other project partners, which will allow us to complete one of the project's goal, develop an integrated assessment framework, and understand the European energy transition not only through an economic point of view, but also through the usage of resources, energy production, health impacts and popular acceptance.

2. Methodology

2.1. Modelling framework

In order to analyze different emission reduction targets inside and outside of the EU-28, the numerical model NEWAGE (National European Worldwide Applied General Equilibrium) was applied. NEWAGE [5] is a recursive-dynamic general equilibrium model with special focus on the energy sector. It describes the macro-economy through production functions and depicts interdependencies between different sectors within an economy as well as interdependencies among different economies.

NEWAGE covers the entire World, however, most countries are aggregated into regions. In total, there are 18 regions, 9 within Europe, 9 outside of Europe. Similarly, production sectors are represented at certain aggregation level. There are 5 sectors belonging to primary energy generation and electricity, 6 sectors belonging to the energy-intensive industry, 3 sectors representing the rest of the industry and 4 sectors representing the rest of the economy. Within the electricity sector, 18 generation technologies are included. Production possibilities are represented through constant elasticity of substitution (CES) production functions. Appendix A.2 presents detailed information regarding NEWAGE's regional and sectorial, as well as the CES nesting for sectorial and electricity production.

While energy system models are generally better suited to analyze the energy sectors in detail, they lack the relations with other sectors and are not able to assess overall macro-economic costs. With NEWAGE the impact of different policy interventions in macro-economic indicators, such as GDP growth, employment or competitiveness can be assessed. Therefore, NEWAGE is a valuable tool for the analysis of economic impacts and, hence, was chosen as the most suitable modeling framework for this work.

2.2. Model limitations

Despite being able to represent the relationship between sectors in the economy, NEWAGE has limitations that influence the final results of this analysis and have to be explained. The main drawbacks from the model can be divided in two categories, lack of endogenous technology development and inability to internalize positive externalities caused by environmental policies.

The first limitation refers to NEWAGE's flexibility when facing high energy costs. The actual version lacks endogenous technology development, which translates as the capacity to invest on increasing the efficiency of production technologies, making them consume less energy for the same output. In the case of the electricity sector, it means that through investments in research and development there is a reduction in the capital cost or the fuel consumption to produce one unity of energy. In order to overcome this limitation, NEWAGE utilizes exogenous assumptions for the technology development from 2011 and 2050 through the autonomous energy efficiency increases (AEEI) parameter, which is better explained in section 4.3. For this work the same set of AEEI was applied in all pathways, meaning that regardless of the environmental ambition, the technology development happens in the same pace.

Finally, in the present state of NEWAGE, the model looks into the gains and losses from any policy measure solely as a matter of profit and costs. For this work, it means that the model is not capable of accounting for the non-financial benefits brought by environmental policies, such as increased air quality or lower water pollution.

It is important, therefore, to understand that due to its limitations the figures produced by NEWAGE, especially for economic development, are rather pessimistic. This effect is explained by the fact that the model fails to account for non-financial gains from tighter emission targets, such as higher life quality and faster technology development.

2.3. Model assumptions

Although NEWAGE covers the whole economy and all world regions, reality is still far too complex to be captured adequately. Consequently, and as in any other numerical model, several assumptions on certain boundary conditions are employed. For the sake of transparency, the main assumptions are revealed, documented and justified in the next paragraphs.

Elasticity of Substitution (EoS)

A central assumption influencing the choice of production factors and technologies are the EoS parameters. They define how easily production factors, e.g. capital and labor, or different technologies, e.g. solar and wind electricity, can substitute each other[1]. Substitution parameters vary between 0 and infinity, with a value equal to 0 meaning substitution is not possible. The higher the elasticity value, the easier it is to substitute the two respective factors. The elasticity parameters in NEWAGE are mainly based on Beestermöller (2016) [5] and are summarized in Table 5 to 8 in appendix A.1.

CO_2 emission trajectory

Moreover, the CO_2 emission trajectory is a central assumption for the pathways, since each one is composed of different regional emission targets. This parameter sets the maximum volume of CO_2 that each region is allowed to produce per year. A detailed overview of all the CO_2 emission paths implemented for this work can be found in the sources cited in appendix A.2.

Further assumptions

In addition to the aforementioned assumption, the following sources were used for a number of assumptions:

- GTAP 9 Data Base [6]
    - Trade and energy data on year 2011
- Electricity Information 2013 [7]
    - Electricity generation per country on the year 2011
- EU Reference Scenario 2016 [8]
    - GDP growth for the EU-28 regions between years 2011 and 2050
    - CO_2 emission for the EU-28 regions between years 2011 and 2050
- The Great Shift: Macroeconomic projections for the world economy at the 2050 horizon [9]
    - GDP growth for the non-EU-28 regions between years 2011 and 2050
    - CO_2 emission for the non-EU-28 regions between years 2011 and 2050

[1] A graphic illustration of this CES structure can be found in the appendix A.1

Regions in NEWAGE

As mentioned before, there are 18 regions in NEWAGE, from which nine are located within the EU-28. Since several indicators will be presented according to the region they belong, Table 1 depicts the regions that are part of the EU-28, indicating their code used in NEWAGE and in several figures in this work. Table 2 presents the remaining regions. For more information regarding the regional disaggregation in NEWAGE, Figure 20 from Appendix A.2 presents a detailed map highlighting the regions in NEWAGE.

Table 1: NEWAGE regions within the EU-28

NEWAGE CODE	REGION
DEU	Germany
FRA	France
ITA	Italy
POL	Poland
UKI	UK
ESP	Spain and Portugal
BNL	Benelux
EUN	Northern EU
EUS	South-Eastern EU

Table 2: NEWAGE regions OUTSIDE the EU-28

NEWAGE CODE	REGION
USA	USA
OEC	Rest of OECD
RUS	Russia
CHI	China
IND	India
BRZ	Brazil
RSA	South Africa
OPA	OPEC and Arabian World
ROW	Rest of the World

2.4. Pathways

Three pathways are constructed for the assessment of the impact of the decarbonization efforts on the environmental, economic, social and energy-sector specific indicators. These are:

- the Status-quo pathway;
- the REEEM pathway;
- the Paris agreement pathway.

The pathways are constructed in a way to reflect the developments of the relationships between the EU-28 countries and environmental ambitions taken outside the EU-28 countries in the future, meaning that the EU-28 and the world trends are considered within the pathways. Figure 1 presents the pathway matrix considering the expected EU-28 and the World trends.

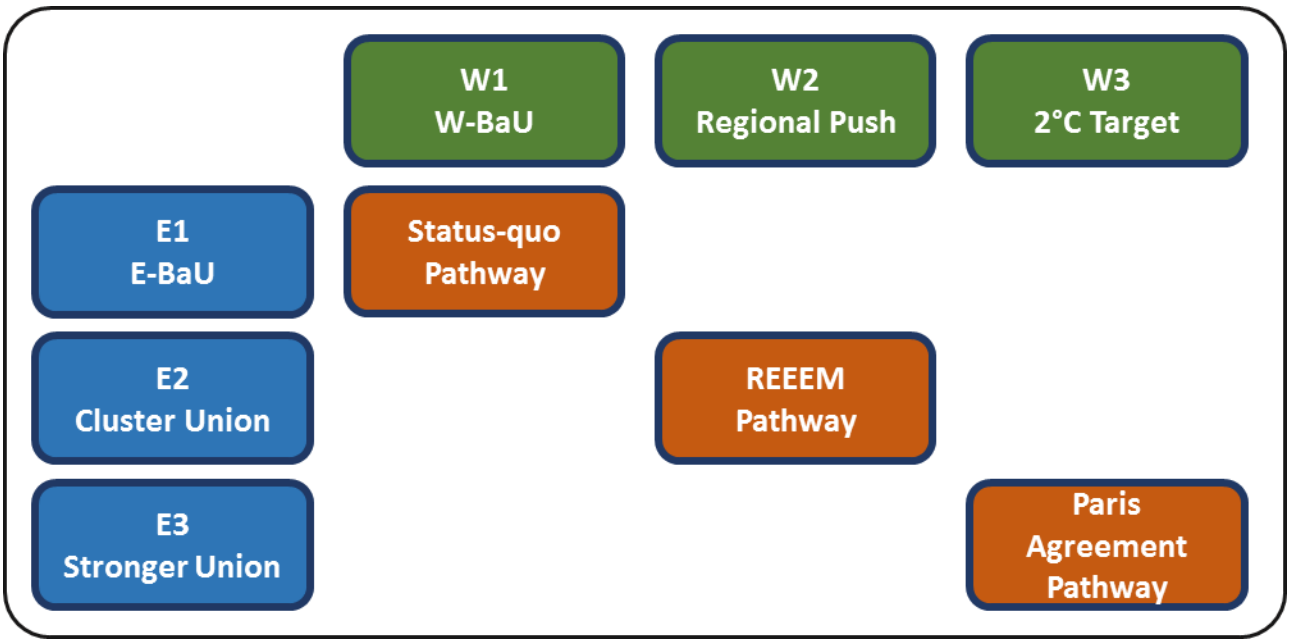

Figure 1: Matrix of pathways

2.5. Pathways definition

The process of defining pathways for this case study focused primarily on finding a wide enough range of possible World and EU states that allow for a better understanding of economic effects of environmental regulations. First, possible states were defined for the EU and the rest of the World. Finally, theses states were combined according to their environmental ambition and the pathways were created.

World dimension

The World dimension describes the level of climate ambition in regions outside the EU-28. The possible states for the World dimension can be described as follows:

Table 3: World states

W1: Business as Usual	W2: Regional push	W3: 2°C
Emissions follow the Reference Technology Scenario from the Energy Technology Perspectives (ETP) 2017 [10].	A selected group of regions follows the 2°C target scenario. Remaining regions follow the Business as Usual scenario[2].	Emissions follow the 2DS Scenario from the ETP 2017 (ETP) [10].

For the regions outside the EU-28, the emission targets were reached by means of a regional cap-and-trade system. While it is unrealistic to assume that every region in the World would follow the same approach to cut emissions, from a modelling perspective it allows to measure the impacts, on the EU-28, of different degrees of emission reduction by the regions outside of it.

European dimension

Similarly, the European dimension describes the level of climate ambition within the EU-28 member states. The possible states for the European dimension can be described as shown in Table 4. For each of the European states was assumed a different policy portfolio to reach the environmental targets.

- **Business as Usual**
  - Current ETS
    - This policy scenario represents the current state of the EU-ETS. The NEWAGE sectors included in this version of the ETS are oil refining, electricity and the energy intensive industry, except for food and tobacco.
    - The GHG reduction target was taken from the EU reference scenario 2016 [8] and it considers that in 2050 there will be a reduction of 47.4%, compared to 1990 levels.

[2] For more details, see Appendix A.2

    - Current ESD
        - This policy scenario represents the current emission reduction targets for the non-ETS sectors. The targets until 2050 were taken from the EU reference scenario 2016 [8].
- **Cluster Union**
    - ETS with 80% reduction target
        - Same sectorial reach as current ETS
        - GHG reduction target of 80% in 2050 compared to 1990 levels.
    - ESD with new targets
        - This policy scenario is part of the REEEM pathway and represents the project's assumptions for how the ESD emissions will reduce until 2050. The regional emission targets can be found in appendix A.2, Table 11.
- **Stronger Union**
    - All sectors are contained in the ETS and have a 95% GHG reduction target
        - All 18 sectors of NEWAGE are included in the ETS and participate of the cap-and-trade system.
        - GHG reduction target of 95% in 2050 compared to 1990 levels.

Table 4: European states

E1: Business as Usual	E2: Cluster Union	E3: Stronger Union
Europe follows the rationale of Scenario 1 from the White paper [11].	Europe follows the rationale of Scenario 3 from the White paper [11], meaning that selected countries have more ambitious targets. While targets for ETS sectors remain identical for members of the Cluster Union and other EU countries, the non-ETS targets differ. Membership in the Cluster Union depends on socio-economic and energy-related indicators as well as on geographic location. See Appendix A.2 for more details on the members of the Cluster Union.	Europe follows the rationale of Scenario 5 from the White paper [11], meaning that all member states increase their cooperation across all policy areas.

3. Results and Discussion

3.1. Analysis of GDP impacts

Under all the pathways analyzed, the World economy grows in the long-term as shown in Figure 2, through the development of global GDP. The efforts to decarbonize the economy, however, impact the growth rates of the World economy.

The model results suggest that under the Status-quo pathway the world GDP grows by 2.8% a year and almost triples in 2050 compared to its level in 2011. Under the REEEM pathway, the world GDP grows by 0.2% slower. Thus, it increases 2.7 fold in 2050. The results of the Paris agreement pathway demonstrate moderate annual growth rates of the World's GDP, of 2.4% a year, in other words, an increase by 2.5 times in 2050 compared to its level in 2011. Under current modelling assumptions, the global GDP losses due to stronger decarbonization efforts are:

- 1.0% under the REEEM pathway and 1.6% under the Paris agreement pathway in 2030;
- 4.0% under the REEEM pathway and 6.1% under the Paris agreement pathway in 2040;
- 9.4% under the REEEM pathway and 16.6% under the Paris agreement in 2050
- All values are compared to the Status-quo pathway results.
- These results indicate that, as the cut in emissions increases, so does the loss in global GDP.

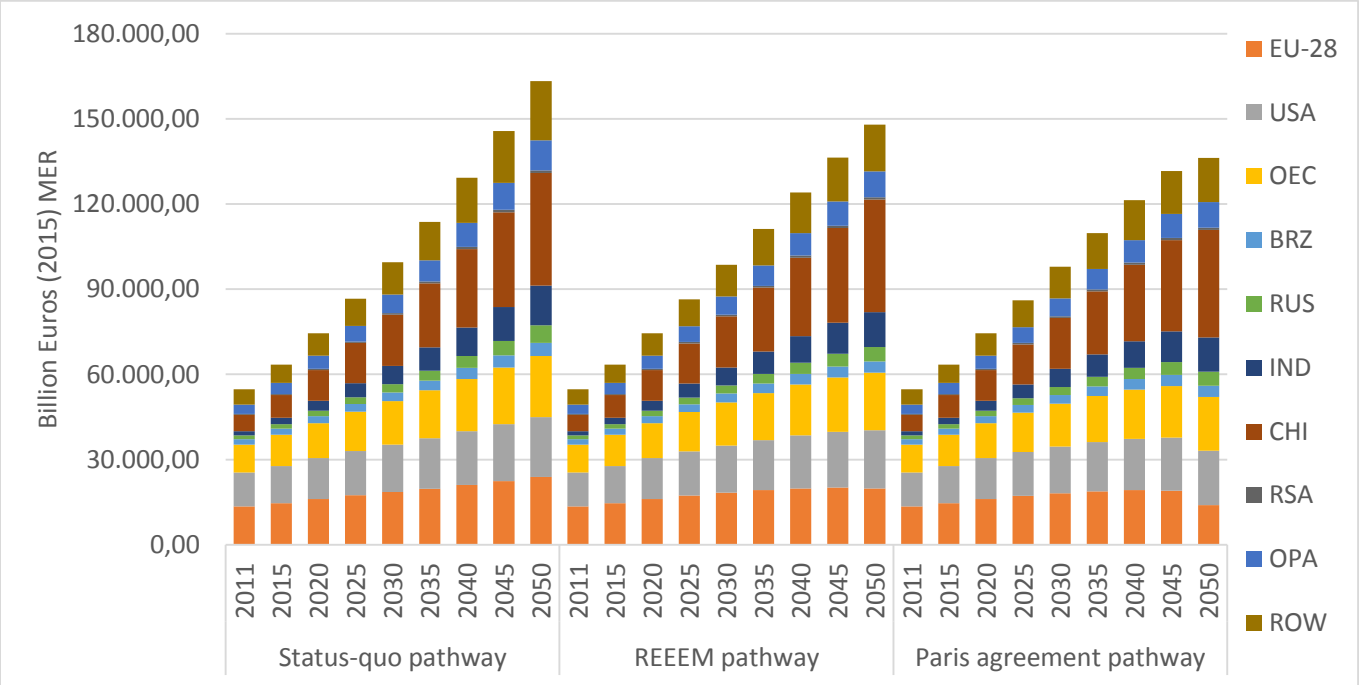

Figure 2: GDP development by countries under different decarbonization pathways during 2011–2050

The annual GDP growth rates in India, China and Russia significantly exceed the average World GDP growth rates, whereas the annual GDP growth rates in EU-28, USA, OECD and Brazil are below the average World GDP growth rates under all the pathways. Although the world leading economies – EU-28, USA and OECD – continue with significant shares of the world GDP, their contribution to it reduces. Under the Status-quo pathway, the GDP share of the EU-28, USA and OECD economies reduces by 23.7% (i.e. from 64.4% in 2011 to 40.7% in 2050), whereas under the pathways of the REEEM and the Paris agreement by 23,5 and 26,2%, respectively. Due to rapid GDP growth in China (depending on the modelled pathways, its GDP grows by 4.9–5.1% a year), its contribution to the world GDP more than double and in 2050 China creates one-fifth and more of the world GDP compared to 10.6% in 2011. The contribution of India's economy to the world GDP increases from 2,6% in 2011 to 8.5% under the Status-quo pathway, to 8.3% under the REEEM pathway and to 8.9% under the Paris agreement pathway in 2050.

It is estimated that, independently of the decarbonization pathway, growth of the global economy starts slowing down after 2020, however, at different rates. Under the Status-quo pathway, the GDP grows by 3.3% a year during 2020-2030, by 2.9% during 2030-2040 and by 2.6% during 2040-2050. The annual GDP growth rates are 3.2%, 2.6% and 2.0% under the REEEM pathway and 3.1%, 2.4% and 1.3% – under the Paris agreement pathway, respectively. China demonstrates rather high annual GDP growth rates under all the pathways and time periods analyzed:

- 2.7% (2020-2030), 2.3% (2030-2040) and 2.0% (2040-2050) – under the Status-quo pathway and the REEEM pathway, and;
- 2.7% (2020-2030), 2.2% (2030-2040) and 1.8% (2040-2050) – under the Paris agreement pathway.

In a group of presently leading economies – EU-28, USA and OECD – the annual GDP grows by 1.9% a year during 2020-2030, 1.6% a year during 2030-2040 and by 1.5% a year during 2040-2050 under the Status-quo pathway, while under the REEEM pathway the annual GDP growth rates are 1.8%, 1.3% and 0.8%, respectively. The results of the Paris agreement pathway show that the GDP of the group of presently leading economies is reducing by 0.5% a year during 2040-2050, although positive GDP growth is expected during 2020-2040.

The EU-28 economies are impacted by the decarbonization efforts too. The results of the Status-quo pathway demonstrate these countries could create a GDP of 18.5 trillion € in 2030, 21 trillion € in 2040 and 23.8 trillion € in 2050. However, the environmental actions taken by EU-28 economies under the REEEM pathway cause the GDP to grow at lower rates, where EU-28 economies create 1.1% less GDP in 2030, 5.8% less GDP in 2040 and 17% less GDP in 2050 compared to the Status-quo pathway. The Paris agreement pathway demonstrates an even more dramatic decline of GDP, where it reduces by 2.4% in 2030, 8.7% in 2040 and 41.4% in 2050. Moreover, under the Paris agreement pathway, the GDP of EU-28 economies starts declining by 3.5% a year from 2040.

GDP growth for different EU-28 economies and under the different pathways is presented in Figures 3, 4 and 5.

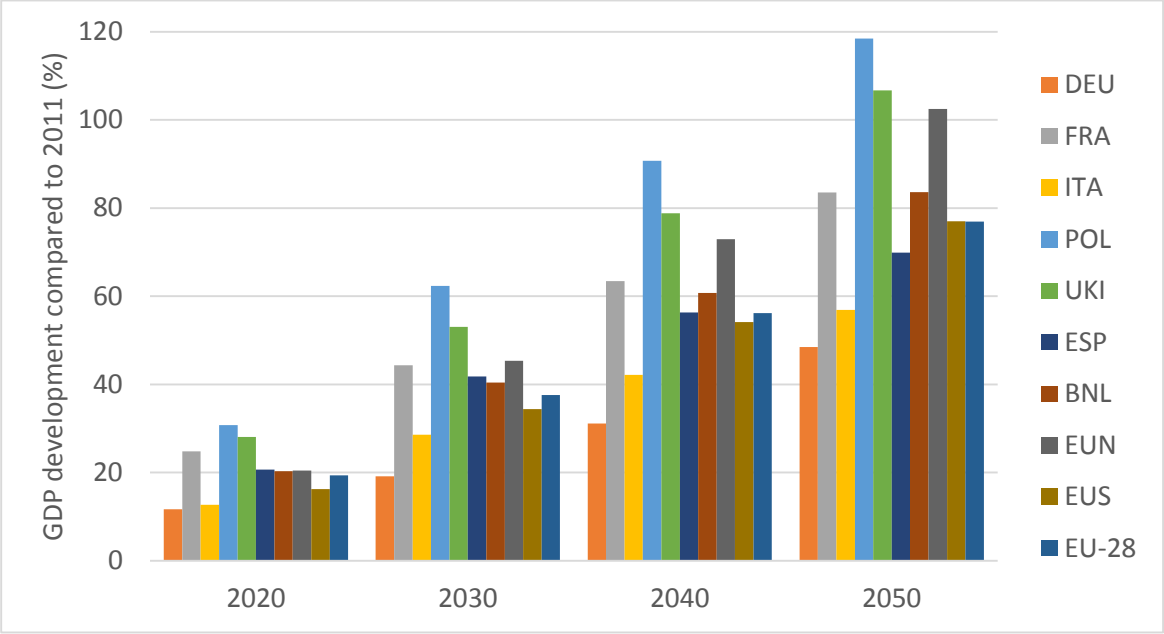

Figure 3: GDP growth in the EU-28 for the Status-quo pathway

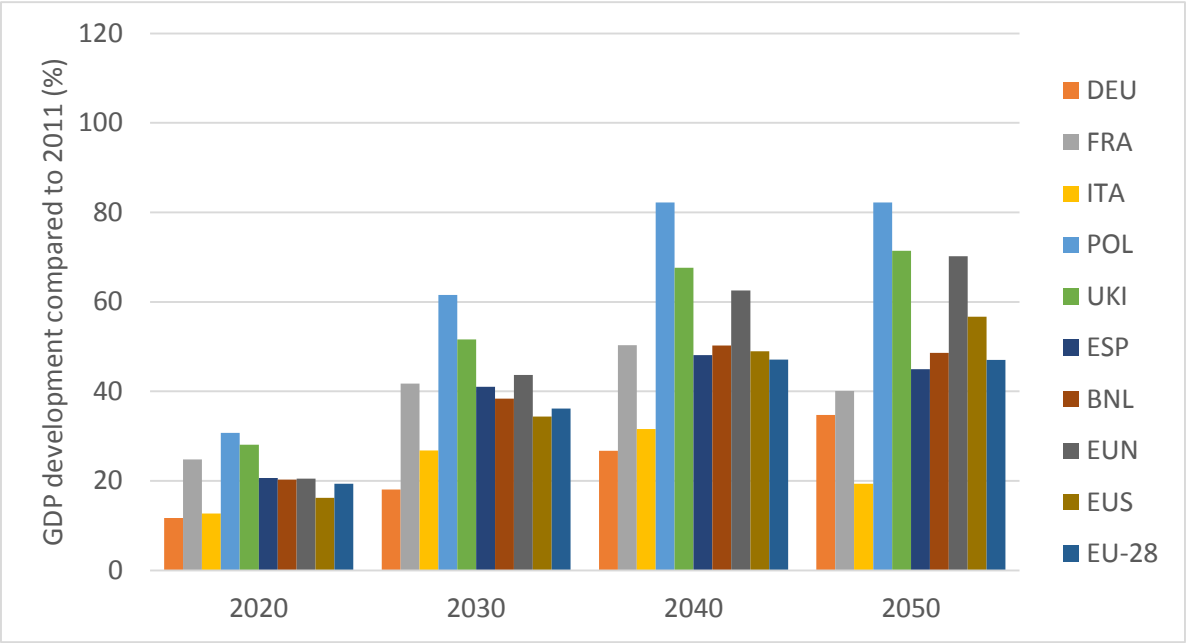

Figure 4: GDP growth in the EU-28 for the REEEM pathway

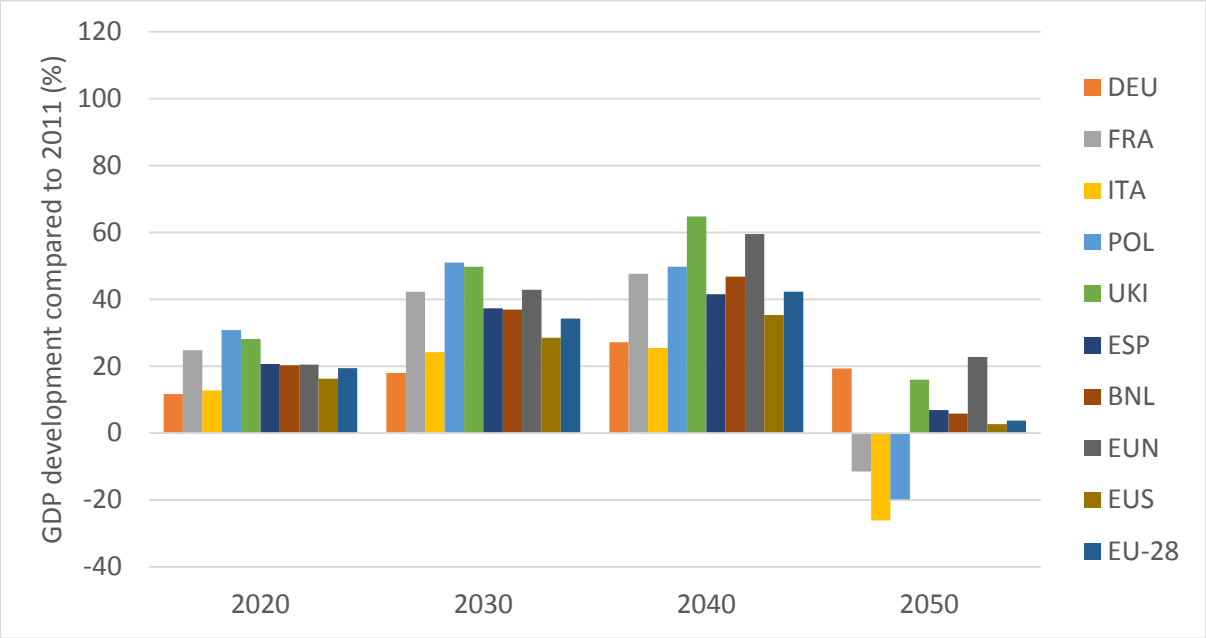

Figure 5: GDP growth in the EU-28 for the Paris agreement pathway

As it is seen in Figure 3, EU-28 economies have relatively high GDP growth potential under the Status-quo pathway until 2050. It is modelled that GDP in Poland, Great Britain and the group of EUN – Ireland, Denmark, Estonia, Finland, Latvia, Lithuania, Sweden – economies increase by 118%, 107% and 103%, respectively, in 2050 compared to its level in 2011. In the remaining EU-28 economies, the GDP increases by 48.4–83.6% in 2050 compared to its level in 2011. Under the REEEM pathway, the GDP increase is lower than under the Status-quo pathway for all EU-28 economies. GDP growth rates slowdown especially in France, Italy and Benelux economies after 2040. Under the Paris agreement pathway, in 2050 France Italy and Poland economies face lower GDP level than in 2011, while in in the group of EUS countries – Austria, Cyprus, the Czech Republic, Greece and Hungary – the GDP in 2050 is only 2.6% higher than its level in 2011.

To sum up, if considered only from the economic point of view and if positive externalities, as well as possible technology spill overs, are not included, decarbonization policies have negative impacts on economic growth in the World and especially in the EU-28. Although there are no European countries in which GDP increases as a result of stricter environmental policies, it might be observed that the performance of some countries is more stable than others'. Remarkable cases in this aspect are Italy, whose economic performance is among the worst under all three pathways, and the United Kingdom, which is always among highest growth. On the contrary, Poland is strongly affected by the strict environmental policies imposed by the Paris agreement pathway, while under the Status-quo and the REEEM pathways it demonstrates the most significant growth in 2050. An example of resilience in face of decarbonization is Germany, which demonstrates relatively modest growth in all the pathways, and strict decarbonization policies have a lower negative impact on its GDP growth.

The inclusion of positive externalities or additional effects that have an impact on GDP and other macroeconomic indicators through non-economic channels (e.g., GDP impacts of diseases caused by the pollution) might change the picture for better. Nevertheless, the present analysis shows that decarbonization policies have costs which result in GDP losses, and the degree of the impact on the economy depends both on the economic structure of the country, the policy design and the GHG reduction target.

3.2. Analysis of welfare impacts

Next, it is shown how decarbonization efforts impact the welfare and its developments in different world regions outside of the EU-28. Figures 6, 7 and 8 depicts Welfare development for the three pathways.

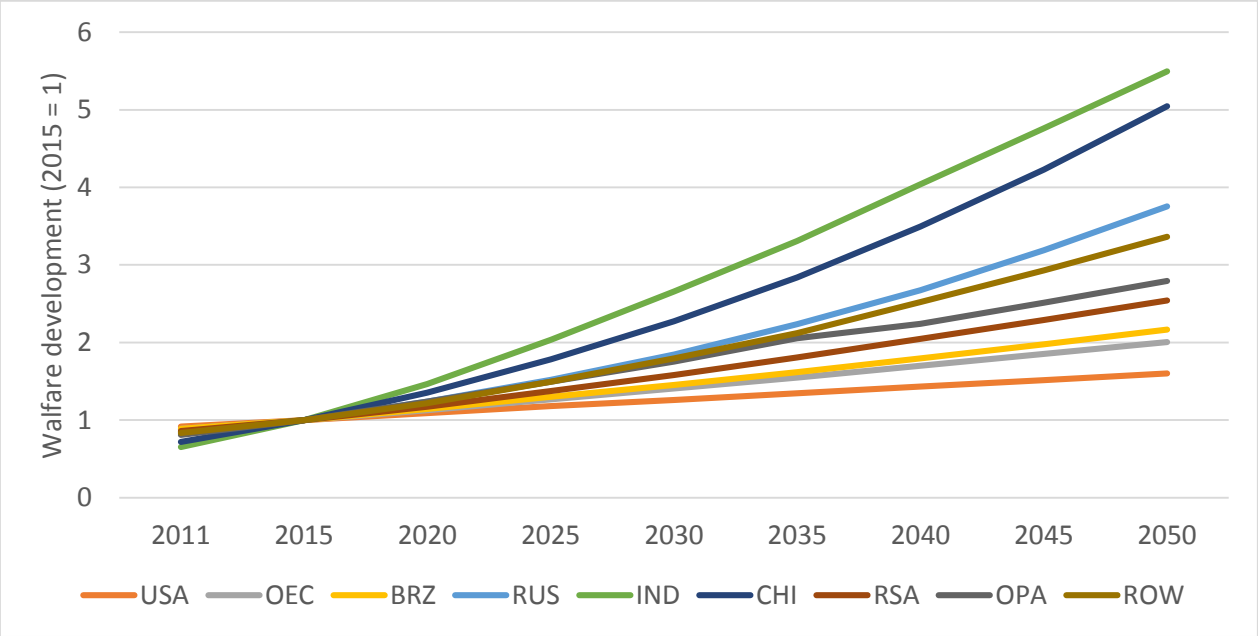

Figure 6: Welfare development in Status-quo pathway – regions outside of the EU-28

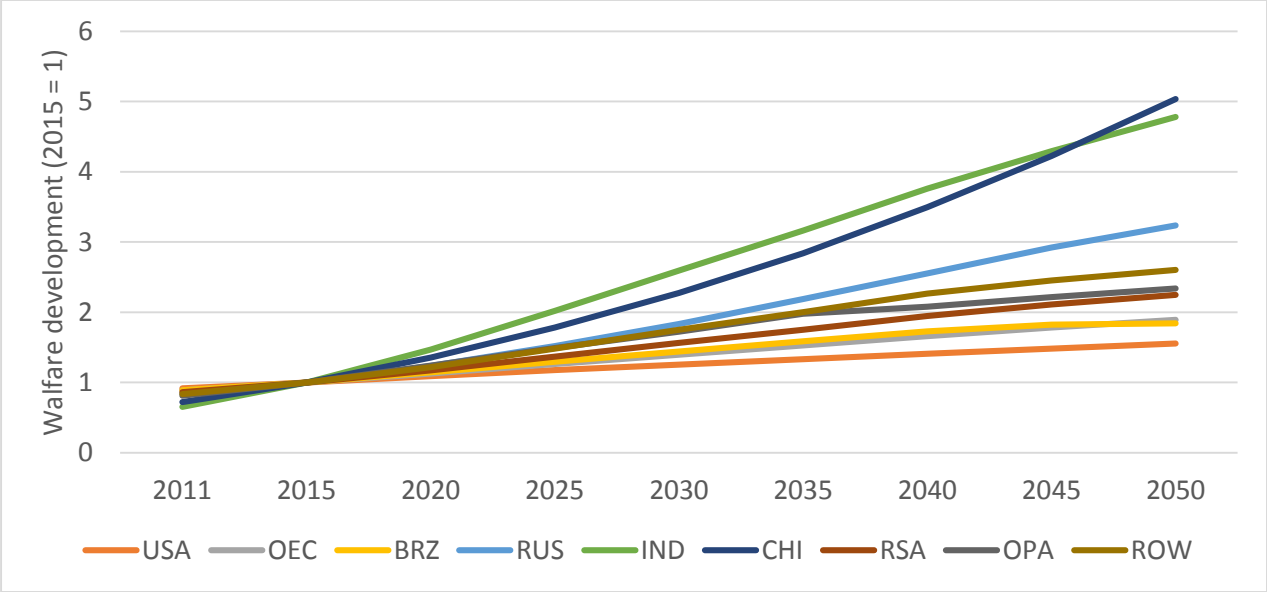

Figure 7: Welfare development in REEEM pathway – regions outside of the EU-28

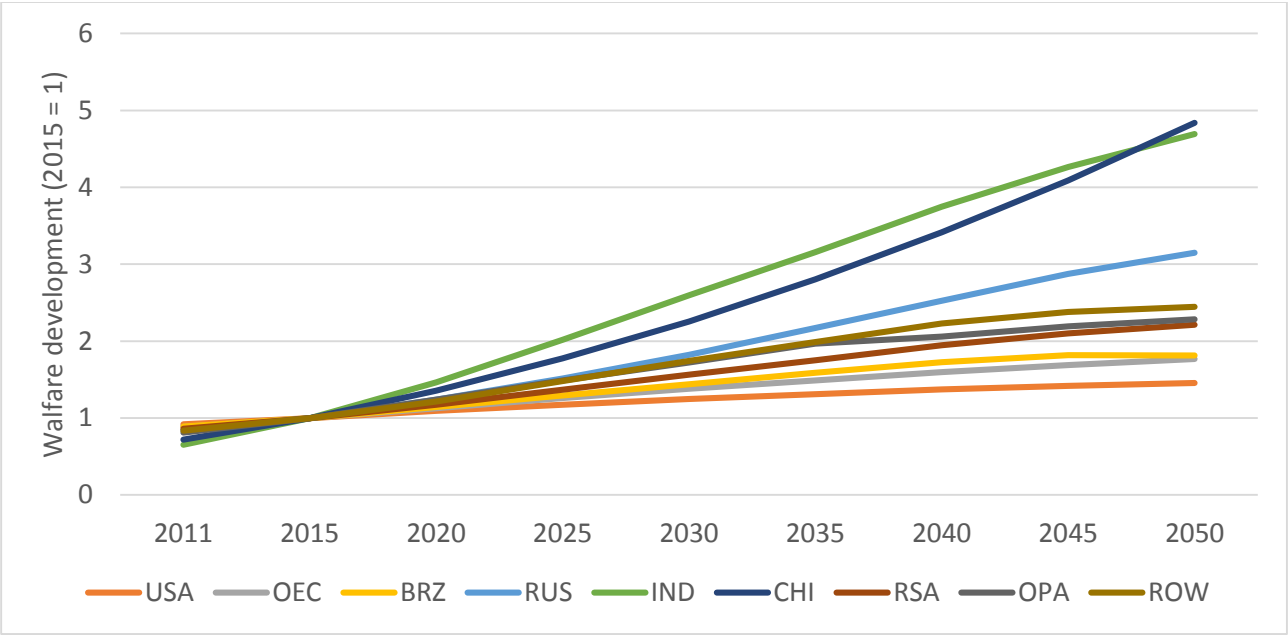

Figure 8: Welfare development in the Paris agreement pathway – regions outside of the EU-28

The figures show that, despite the emissions cut, welfare continues to grow in every pathway analyzed. However, the decarbonization efforts do have a certain influence on the rate in which welfare develops. The Status-quo pathway demonstrates the highest positive welfare changes till 2050. Under this pathway welfare is the most improving in India and China, where it could increase by 5.5 and 5.1 times, respectively, in 2050 compared to 2015. The lower welfare development is seen in the USA, where in 2050, it improves only by 60% compared to its level in 2015. In other world regions, positive welfare changes are expected too, varying in a range between 2.0 to 3.8 times in 2050 under the Status-quo pathway.

The REEEM and the Paris agreement pathways show slightly more moderate welfare improvements in the world regions, i.e. from 1.5 up to 5.0 times in 2050 compared to 2015. On either cases, welfare mostly improves in India and China. Again, the Paris agreement pathway demonstrates that the lowest welfare improvements are achieved in USA, OECD and Brazil. In Russia, welfare changes remain rather stable and are of about 3.2 times higher in 2050 than in 2015 under either pathway.

By comparing the welfare development on the three pathways, it is possible to see that certain regions are more affected than others by higher emission cuts. India, for instance, despite having one of the largest growths among all regions and for all pathways, is clearly much more affected than China, who, in return, has a minor welfare reduction between the status-quo and Paris agreement pathways. Other regions that are highly impacted are the group of ROW countries, OPA countries and Russia, while USA and OECD are much less affected. Nevertheless, every region faces a decrease in welfare growth when higher emission cuts are considered.

In EU-28 countries welfare improvements are much more dependent on the decarbonization efforts than in other world regions, as shown on Figures 9, 10 and 11.

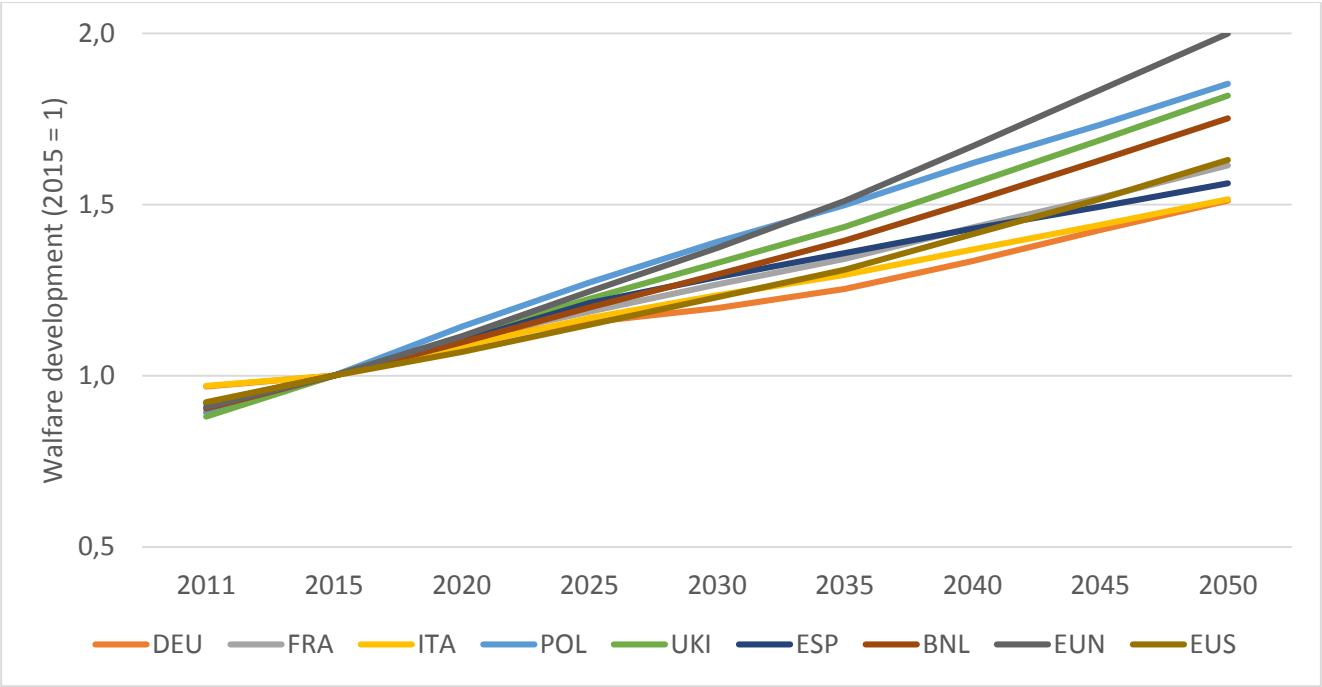

Figure 9: Welfare development in the Status-quo pathway – EU-28

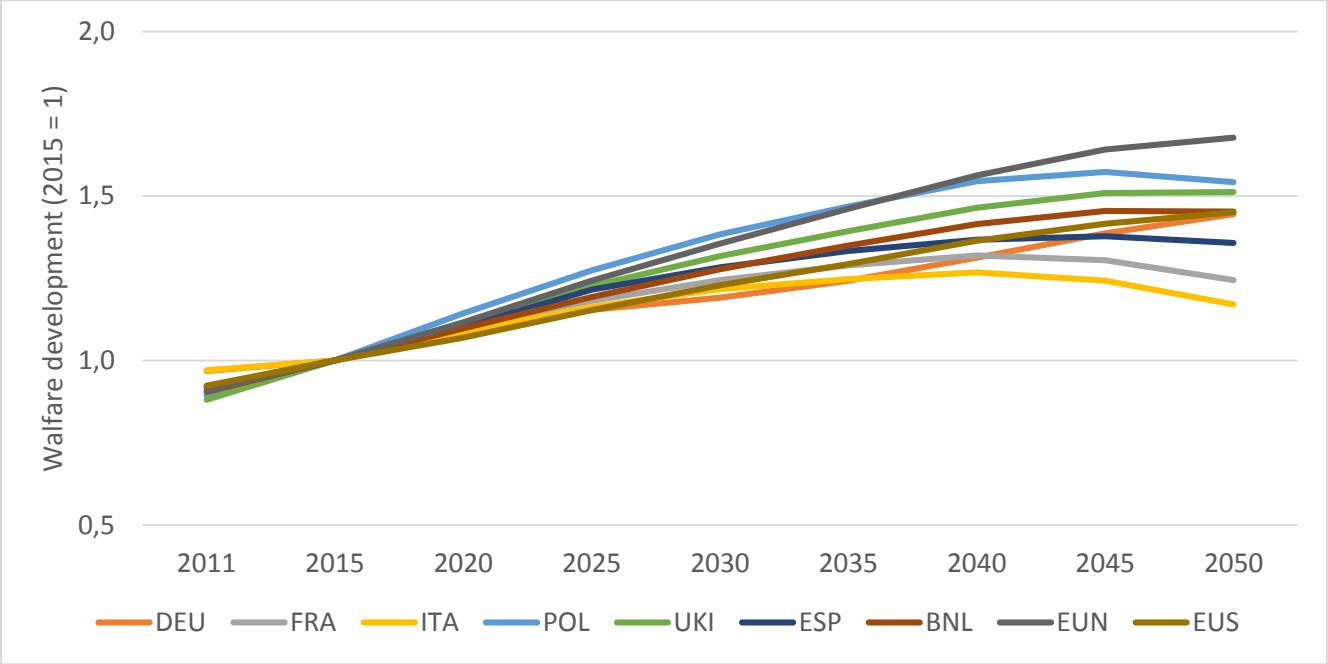

Figure 10: Welfare development in the REEEM pathway – EU-28

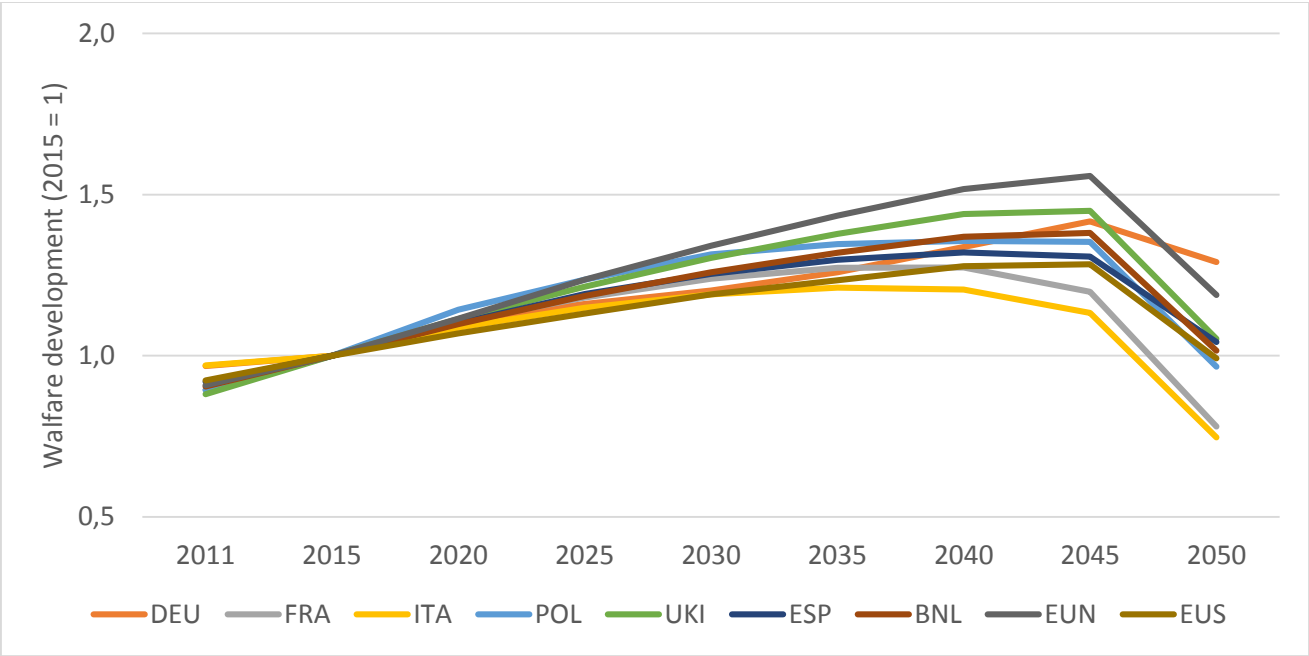

Figure 11: Welfare development in the Paris agreement pathway – EU-28

The Status-quo pathway, shown in Figure 9, demonstrates that there is a general positive tendency for the development of welfare in all EU-28 countries, meaning that welfare improves in each EU-28 country up to 2050, compared to 2015. It is expected that welfare improvements in the group of EUN countries (Ireland, Denmark, Estonia, Finland, Latvia, Lithuania and Sweden) are the highest, but the lowest in Germany, Italy and Spain.

For both the REEEM and Paris agreement pathways, the welfare increases until 2040 for every region in the EU-28. After this year, the effects vary depending on the region and pathway. On the REEEM pathway, Italy, France, Poland and Spain and Portugal face welfare reduction, while the remaining regions see the opposite effect, with increasing welfare. In the Paris agreement pathway, however, every region in the EU-28 faces welfare reduction between 2045 and 2050, with Germany having the lowest reduction and Italy and France the highest.

The comparison of welfare changes for the different pathways suggest that the intensity of the emissions cut creates proportional welfare reductions. Additionally, welfare reductions increase in the long-term, when the emissions cut reach its higher degree. Under the REEEM pathway (in comparison to the Status-quo pathway) the highest welfare reductions (by rank) are expected in France, Italy, the group of EUN economies, Poland, Great Britain and Benelux, while the lowest – in Germany, the group of EUS economies and Spain. Under the Paris agreement pathway, namely, Poland, France, the group of EUN economies, Italy, Great Britain and Benelux experience the largest welfare reductions, but the lowest welfare reductions are seen in Germany. Again, from the perspective of welfare reductions, the Paris agreement pathway is at least favorable for EU-28 economies.

It can be said that, subject to the environmental policies, welfare development is limited in all world regions according to the chosen emission targets in 2050. Moreover, in the case of several EU-28 regions, there could be welfare reductions after 2040 and the strictest environmental policies, under the Paris agreement pathway, are expected to cause the highest welfare reductions in comparison to the Status-quo pathway and the REEEM pathway.

3.3. Analysis of employment impacts

The impact of decarbonization efforts on employment in EU-28 countries is presented in Figures 12, 13 and 14.

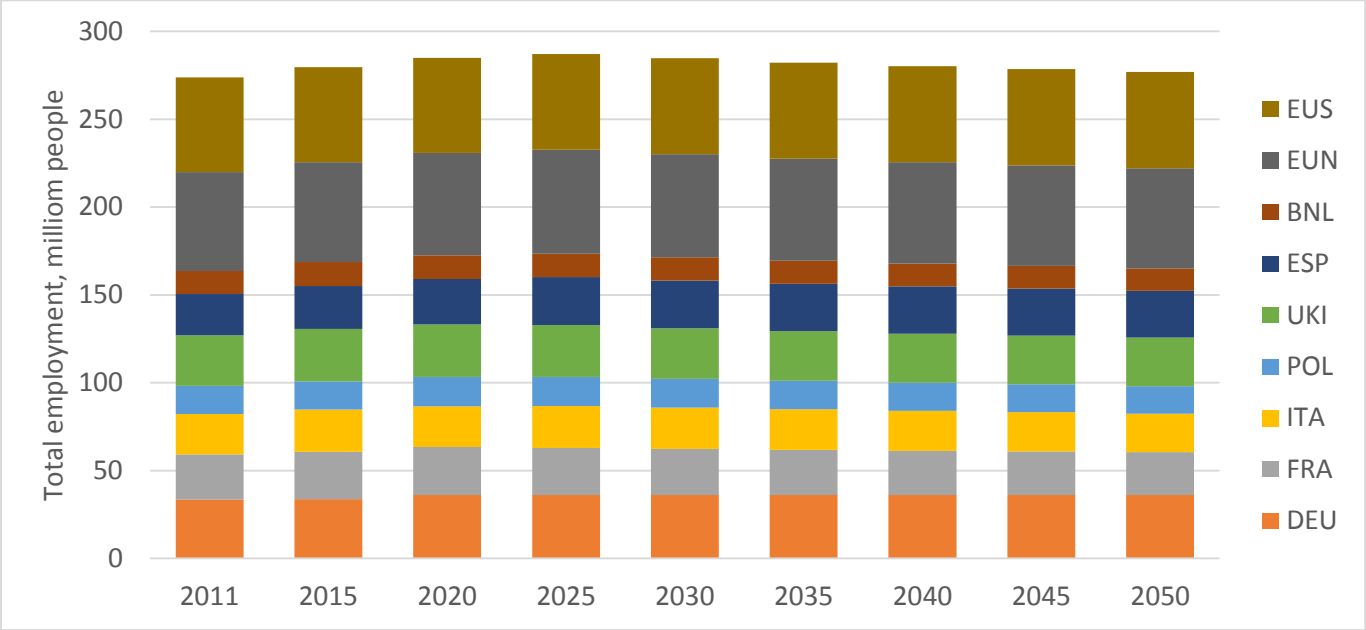

Figure 12: Development of total employment in EU-28 countries during 2011–2050 under the Status-quo pathway

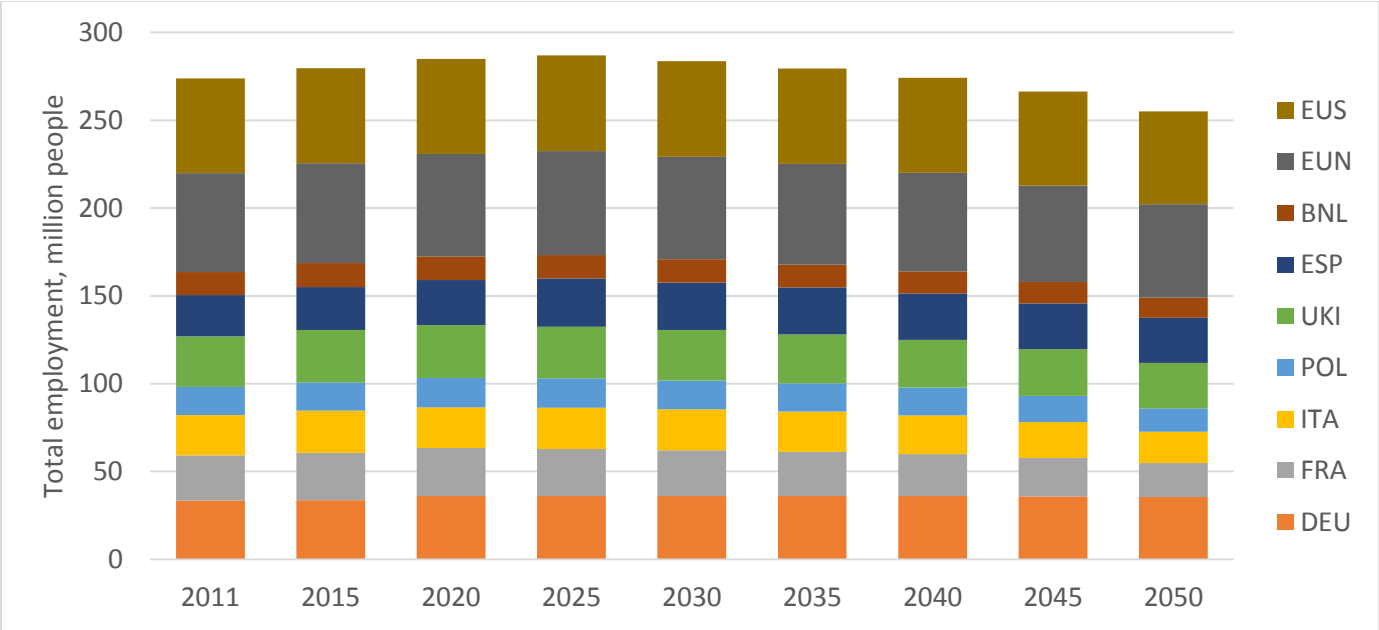

Figure 13: Development of total employment in EU-28 countries during 2011–2050 under the REEEM pathway

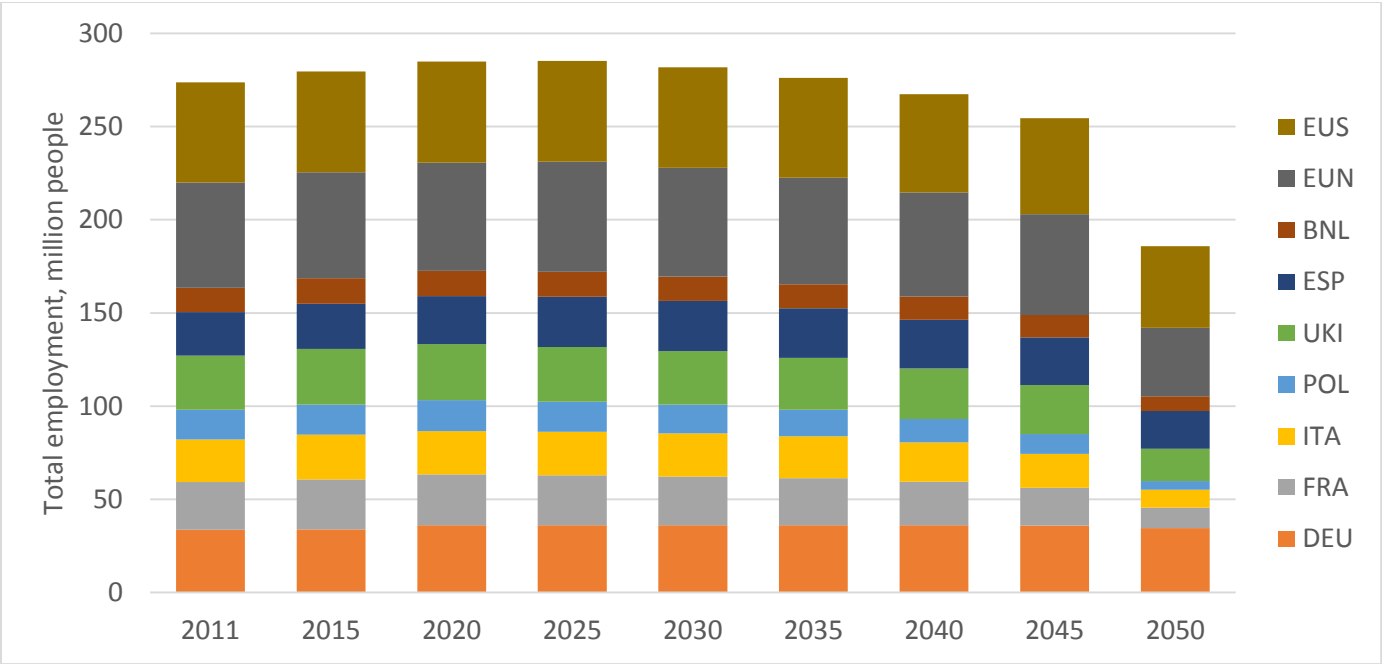

Figure 14: Development of total employment in EU-28 countries during 2011–2050 under the Paris Agreement pathway

Under all the pathways analyzed, employment increases by 0,3% a year in the group of EU-28 countries during 2011–2025 and then starts decreasing. Under the Status-quo pathway employment decreases by 0.1% a year during 2025–2050, while under the pathways of the REEEM and the Paris agreement – by 0.5% and 1.7% a year, respectively. Thus, totally 276.9 million people are employed under the Status-quo pathway in 2050, in comparison – 284.7 million people in 2030 and 280.2 million people in 2040. Under the pathways of the REEEM and the Paris agreement 7.9% and 32.9% less people are employed in 2050, respectively, compared to the Status-quo pathway value. Germany – the largest employer in EU – is a country which even subject to strong decarbonization efforts avoids employment reductions till 2035. Additionally, it has the lowest employment decreases during 2040–2050. Implementation of tight environmental policies in other EU-28 countries cause employment reductions in these countries.

The largest employment reduction can be seen under the Paris agreement pathway (in comparison to the Status-quo pathway) in 2050. Under this pathway, employment losses are highest in the group of EUN countries, France, Italy, Poland, the group of EUS countries and Great Britain. The reduction in these countries is of 20.3, 13.6, 12.2, 10.88, 10.89, 10.4 million people in 2050, respectively. In Benelux countries and Spain and Portugal, there are job losses as well, but they are almost twice lower than in the aforementioned countries, i.e. account for 4,8 million people and 6.3 million people, respectively. Employment losses increase in time, i.e. they are the lowest in 2030, but the highest in 2050 under the REEEM and the Paris agreement pathways.

The results suggest that decarbonization efforts have a negative impact on employment development in EU-28 countries in the long-term, i.e. they cause employment reductions in these countries. Moreover, subject to stronger decarbonization efforts, as the Paris agreement pathway demonstrates, the employment reductions become major in long-run.

3.4. Analysis of impacts on trade balance of industry

The trade balance of the industry of the group of EU-28 countries is impacted by the decarbonization efforts, as Figure 15 shows.

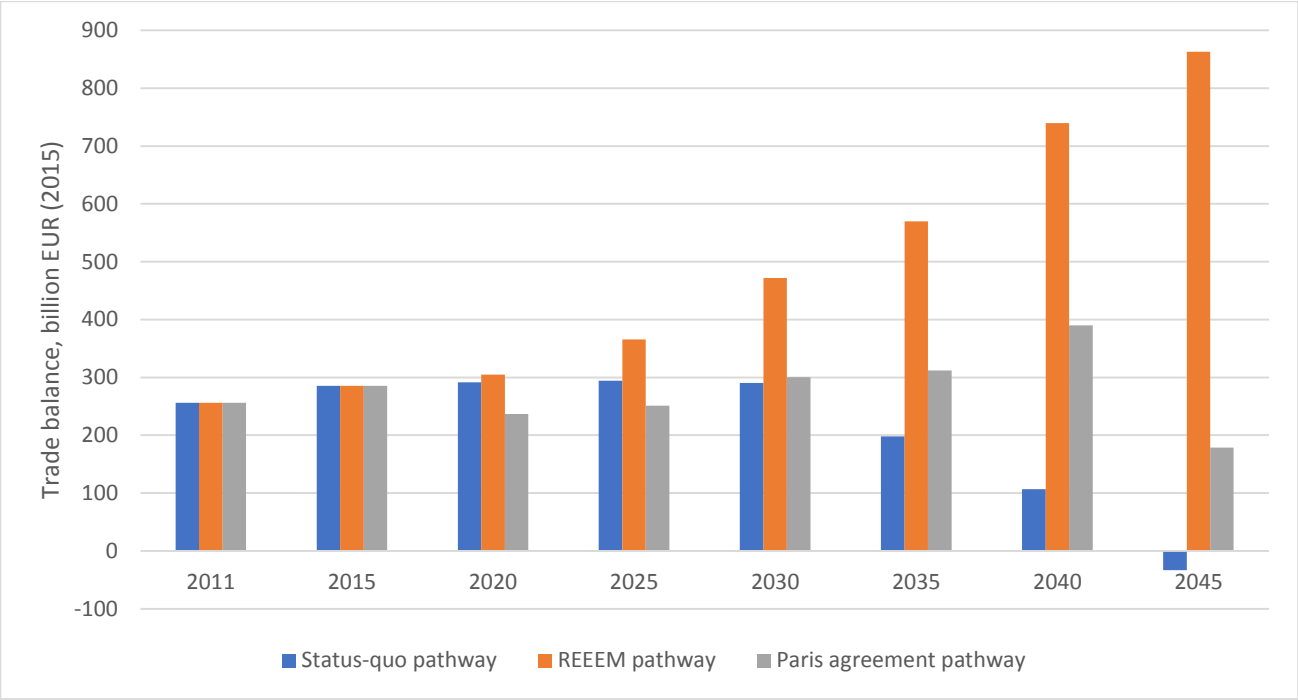

Figure 15: Development of trade balance in EU-28 during 2011–2050 under different pathways

As it is seen in Figure 15, under the Status-quo pathway the positive trade balance of the group of EU-28 countries decreases from 2030 and becomes a deficit in 2050 meaning that the region becomes more dependent upon imports of industrial goods and services outside the EU. This effect is mostly possible because the regions outside of the EU, while facing less stringent emission targets, can provide cheaper goods.

For the other two pathways, however, the results indicate that there is a surplus on the trade balance of industrial sectors until 2050.Under the REEEM pathway it increases by 3.3% a year and accounts for 862.8 billion EUR in 2050. Under the Paris agreement pathway trade balance surplus increases by 1.4% a year during 2011–2045 and then decreases by 54.3% between 2045 and 2050, accounting for 178.4 billion EUR in 2050. The EU-28 profit from higher environmental ambitions outside of its borders. The surplus in these two pathways can be explained by the higher emission cuts outside the EU-28, but in the REEEM pathway the surplus is higher because the countries facing more ambitious targets compete in the same sectors as the EU and the remaining countries, while not facing higher costs to decrease emissions, end up consuming more goods from the EU. In the Paris agreement pathway, since all countries in the world are obliged to reduce their emissions, it is possible to see a lower surplus, since the volume of sales decrease.

Under all the pathways and time periods analyzed, the trade balance of the industrial sectors is negative (deficit) in the UK and in Spain and Portugal (except, under the REEEM pathway in 2050), as Figure 16 presents. However, European decarbonization efforts, together with higher emission cuts outside of the EU, cause reductions in UK's

trade balance deficit both under the Paris agreement pathway (by 67.7 billion EUR compared to the Status-quo pathway value in 2050) and under the REEEM pathway (by 161.1 billion EUR compared to the Status-quo pathway value in 2050). In the case of Spain and Portugal, increasing the emission cuts in the EU, together with higher environmental ambition on the remaining regions, contribute to a surplus of 14.8 billion EUR in 2050, under the REEEM pathway, while trade balance deficit tends to increase under the Paris agreement pathway, reaching 56.7 billion EUR in 2050.

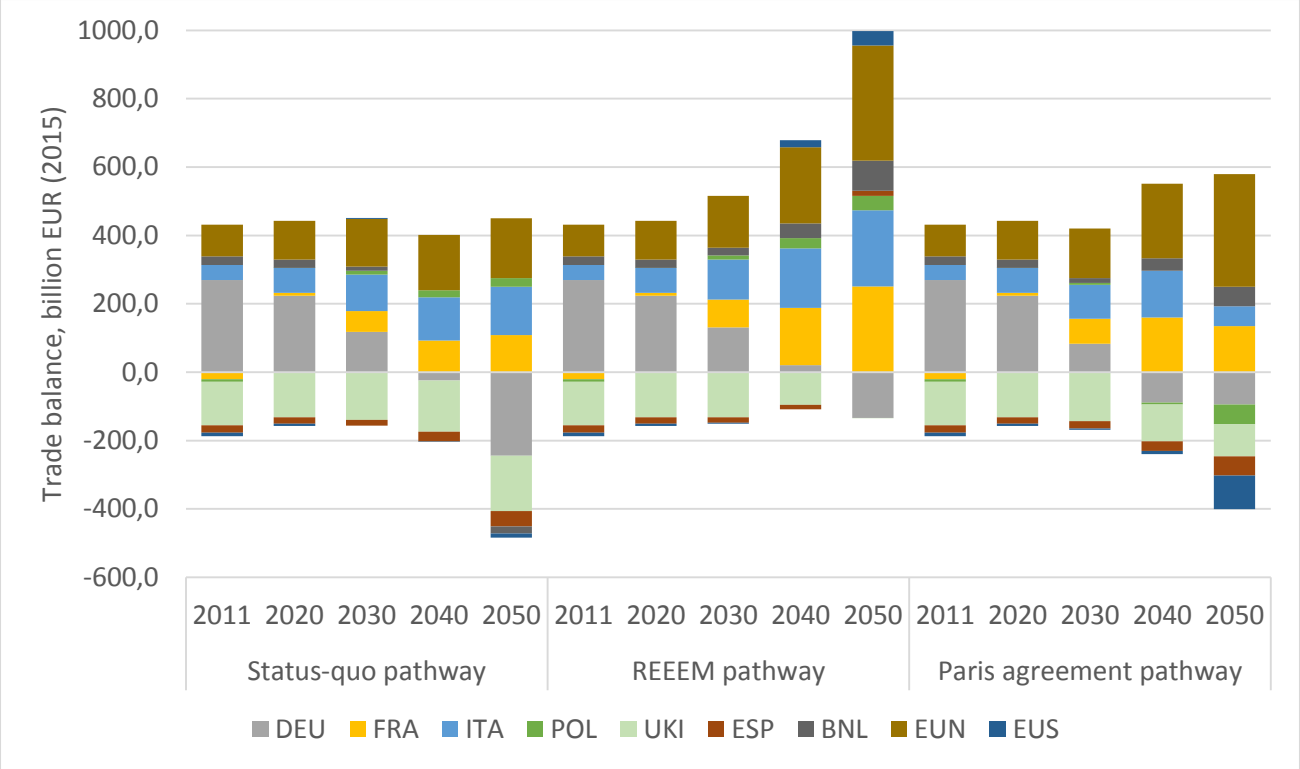

Figure 16: Development of trade balance by EU-28 country and under different pathways

By comparing the REEEM to the Status-quo pathway it is possible to classify the EU-28 regions in relation to the impacts caused by the decarbonization efforts on their trade balance. For France, Italy, Poland, Benelux and the group of EUN countries, there is an increase in the trade balance surplus under the REEEM pathway compared to the Status-quo pathway between 2011 and 2050. The case of Germany shows that, while decarbonization may not cause a surplus, it may at least reduce its trade balance deficit. For the group of EUS countries, decarbonization efforts may transform the trade balance status from deficit (under the Status-quo pathway) to surplus (under the REEEM pathway).

Generally, in EU-28 countries, the trade balance increases under the REEEM pathway in comparison to the Paris agreement pathway. Moreover, under the Paris agreement pathway, the trade balance surpluses increase only in France, Benelux and the group of EUN countries, however, at lower scales than the REEEM pathway. The case of Italy demonstrates that tight decarbonization efforts taken under the Paris agreement pathway force the trade balance surpluses to decrease compared to the Status-quo pathway.

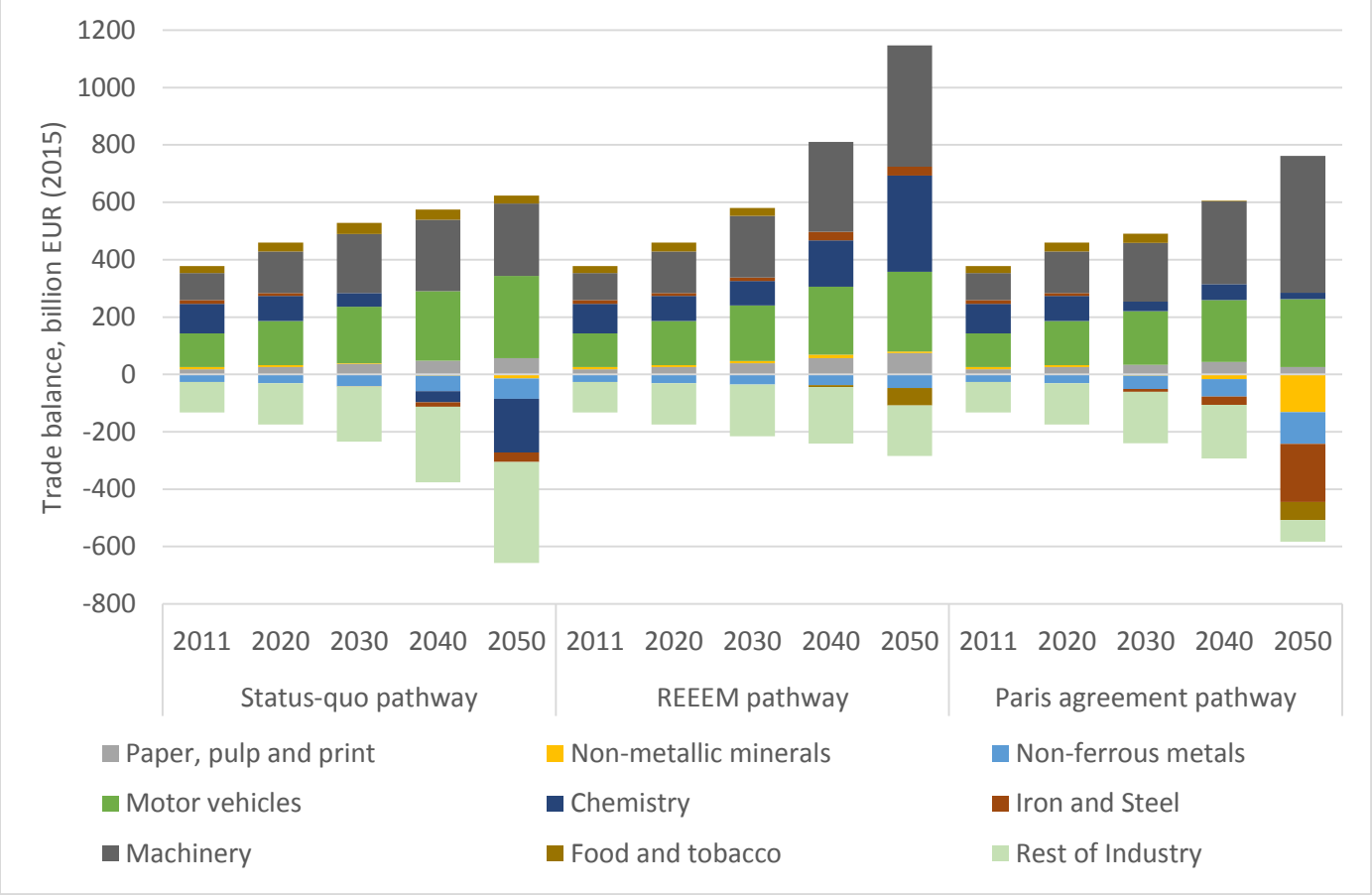

Figure 17: The status of trade balances of different branches of industry in EU-28 under different pathways

As it is seen in Figure 17, where the trade balance is shown according to the industrial sectors of NEWAGE, under the Status-quo pathway, industries of food and tobacco, motor vehicles, machinery, paper, pulp and print maintain trade balance surpluses, which increase by 0.4%, 2.3%, 2.6% and 2.9% a year respectively until 2050. In the energy intensive sectors of non-metallic minerals, chemistry and iron and steel, however, the tendency is for a decrease of the trade balance, reaching deficit by 2050. For the non-ferrous metals and the rest industries, trade balance deficits are expected to happen during all time steps and they increase by 2.6% and 3.1% a year, respectively.

Under the REEEM pathway, EU-28 industries demonstrate increasing trade balance surpluses in 2050, except the sectors of food and tobacco, non-ferrous metals and the rest of industries. While for the food and tobacco sector it is expected a deficit only for the years of 2045 and 2050, for the non-ferrous metals and the rest of industry the deficit can be seen for every time step. This trade surplus for most sectors, including some energy intensive sectors can be explained by the fact that in this pathway other developed nations, like Canada, the USA and Japan, are also facing higher emission cuts and, thus, have increased energy cost.

Under tight decarbonization efforts taken in the Paris agreement pathway, all energy intensive sectors are negatively impacted with a reduction on their trading balance. The only sector from the aforementioned group that does not go into deficit in 2050 is chemistry, but its trade balance gradually decreases year after year. Even with the negative impact on energy intensive sectors, the EU-28 maintains a trading surplus until 2050 in the Paris Agreement pathway due to the machinery and motor vehicles sectors, which are capable of overcoming the deficits from other sectors.

Finally, the results indicate that the trade balance of the different industrial sectors from NEWAGE in the EU-28 are positively impacted by the decarbonization efforts taken under the REEEM and the Paris agreement pathways, since there is a trade surplus in all the years between 2011 and 2050. However, stronger decarbonization efforts taken under the Paris agreement pathway can decrease the surplus obtained in the REEEM pathway and have a strong negative impact on the trade balance of energy intensive sectors, i.e. non-metallic minerals, iron and steel, non-ferrous minerals and chemistry. There are two main effects that can be observed through these results, first, the positive impact of decarbonization measure outside of the EU, while the emission cut target within is kept at 80% from 1990 levels in 2015, which causes a higher global demand for European goods. Second, in the Paris agreement, it is possible to see that even for a World where every country outside of the EU is cutting emissions according to the 2°C target, a 95% emission cut target would impose a high burden for the energy intensive industries, especially between 2045 and 2050, causing deficits in these sectors.

4. Conclusions

In this work, the impact of different decarbonization efforts were analyzed using specific economic indicators between 2011 and 2050. The chosen indicators are GDP and welfare development, total employment and trade balance. The selected pathways, namely Status-quo, REEEM and Paris agreement, allow for assessing the impacts of gradually increasing environmental ambitions within and outside the EU and help identify not only the winners and losers of environmental policies, but also when the impacts appear.

The results of the GDP development analysis under different pathways show that economy will continue to grow in the EU-28 and other World regions until 2040. After that year, there is a clear difference between the regions outside and inside the EU-28. For the outside group, as the environmental ambition increases from status-quo to the Paris agreement, GDP growth slows down, but continue to grow, while for the group of countries inside it, the total GDP remains practically stagnant between 2040 and 2050 for the REEEM pathway and decreases at the Paris Agreement pathway.

The analysis of welfare development indicates that welfare will improve (grow) in the EU-28 and other world countries under different pathways until 2040, just as seen in the GDP impacts, and changes in welfare growth are minor under the REEEM and the Paris agreement pathways. For the regions outside of the EU-28, welfare continues to grow in every pathway, while for the regions within the effect is rather mixed for the REEEM pathway, where some regions see welfare growth and others not. For the Paris agreement pathway, the welfare decrease for every European region after 2040.

The analysis of total employment reveals that it will increase until 2030 in the EU-28 under all the pathways and reach its peak. The peak is reached in this year mostly due to the stabilization of the European population growth. After this year, however, total employment will either stabilize or decrease, depending on the pathway. The results indicate that that the highest employment losses are expected under the Paris agreement pathway, and the lowest under the REEEM pathway.

For the trade balance of EU-28 industrial sectors, the results indicate a stable surplus until 2030 for the Status-quo pathway, followed by a gradual decrease until it reaches a deficit in 2050. Due to the combined effects decarbonization efforts inside and outside of the EU-28 taken under the REEEM and Paris agreement pathway, there is always a trade balance surplus for all time steps. Moreover, the results of the REEEM pathway demonstrate significantly increasing surplus of trade balance up to 2050, while the results of the Paris agreement disclose that from 2045 the surplus of trade balance starts reducing. The EU-28 industrial sectors will most likely benefit from the decarbonization efforts taken by other regions.

Although a variety of metrics were chosen for this analysis, there are some key trends common to all of them. The main one is the fact that in every indicator, except for the trade balance, their development in both the REEEM and Paris pathway tend to keep very close to the status-quo pathway development until 2040, indicating that the critical years come after this point. For the trade balance, it is possible to see a roughly similar development for the three pathways until 2030, but afterwards the status-quo develops worse than the other two. This effect is significant because it highlights that, until 2040, the emissions cut within the EU-28 will play a rather small role on the economic development of the region. After this year, however, aiming for a 95% GHG emission reduction in 2050, compared to 1990 levels, might bring high negative impacts to the European economy.

These results should not discourage ambitious environmental targets from the EU-28, but rather suggest that after 2030, but especially after 2040, there should be an alternative, or at least a reform, to the ETS as the main European measure to reduce emissions, since it was a constant in every pathway. Furthermore, as shown through the trade balance results, having the international community committed to high emission cuts have positive effects over the European economy, as more countries have to face a burden similar to the one in Europe.

Finally, NEWAGE's limitations should not be forgotten as they have effects of the final results. One important example is the usage of the same exogenous AEEI curves within all the pathways, which neglects the hypothesis that, under the necessity to cut a higher amount of GHG emissions, there would be a higher amount of research dedicated to improve the energy efficiency of different technologies and, thus, balancing the costs brought by the ETS and other environmental policies. Additionally, it is currently not able to internalize increase in quality of life brought by emission cuts, resulting in higher welfare.

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A.1 Modeling framework

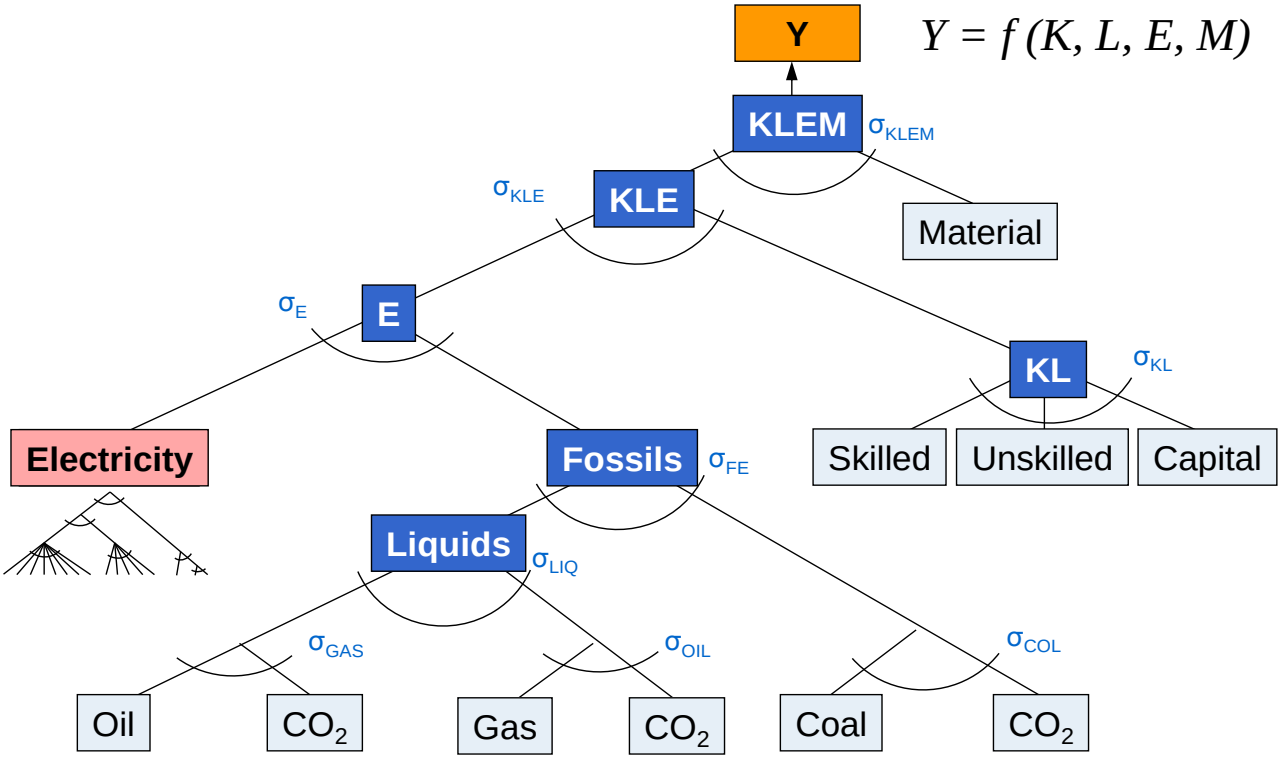


Figure 18: CES structure in NEWAGE for the production sectors

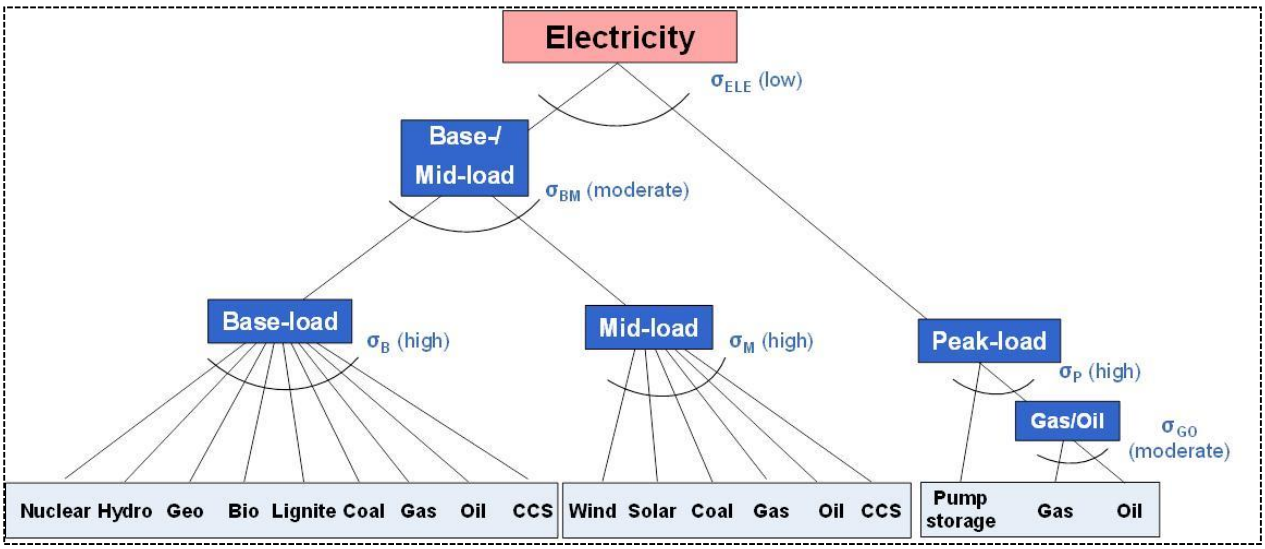


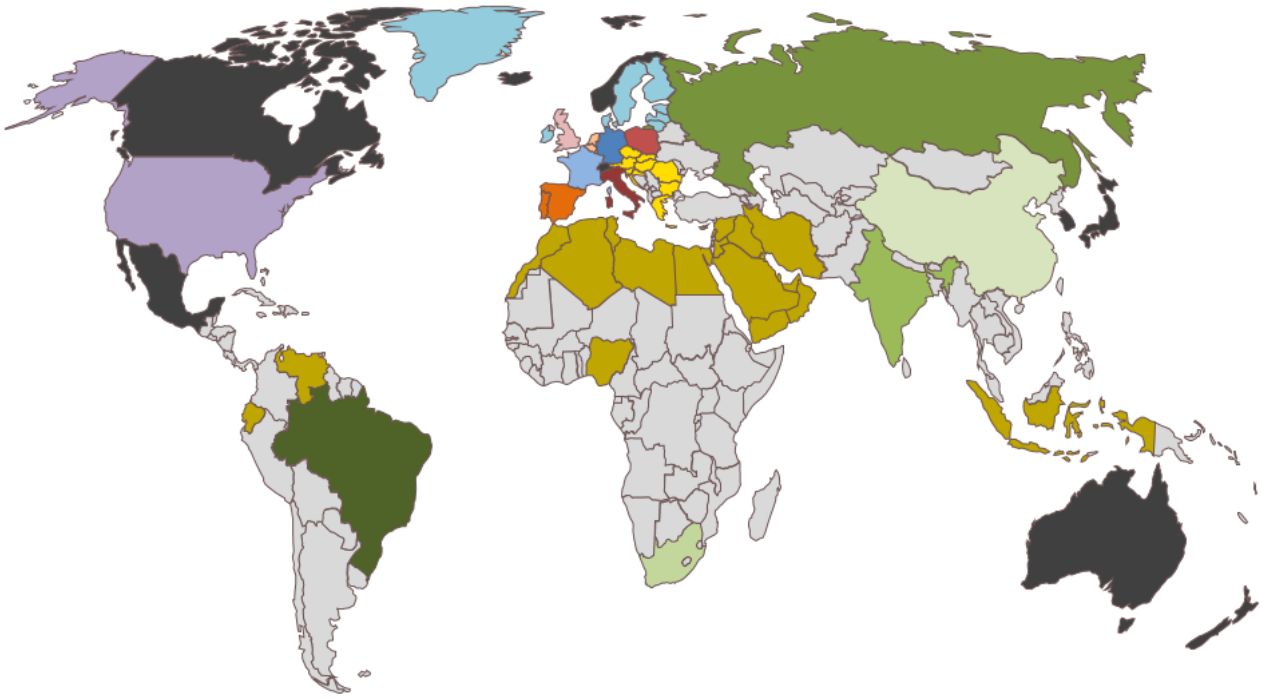
Figure 19: CES structure in NEWAGE for electricity production

Table 5: List of production sectors in NEWAGE

No.	Sector	Group
1	Coal	Energy production
2	Natural gas	Energy production
3	Crude oil	Energy production
4	Oil refining	Energy production
5	Electricity	Energy production
6	Iron & Steel	Energy intensive industries
7	Non-ferrous metals	Energy intensive industries
8	Non-metallic minerals	Energy intensive industries
9	Paper, pulp & print	Energy intensive industries
10	Chemicals	Energy intensive industries
11	Food & Tobacco	Energy intensive industries
12	Motor vehicles	Other manufacturing
13	Machinery	Other manufacturing
14	Rest of industry	Other manufacturing
15	Buildings	Rest of the economy
16	Transport	Rest of the economy
17	Agriculture	Rest of the economy
18	Services	Rest of the economy

Table 6: Technology portfolio available at the electricity sector of NEWAGE

No.	Load	Technology
1	Base	Nuclear
2	Base	Hydro
3	Peak	Hydro
4	Base	Geothermal
5	Medium	Solar
6	Medium	Wind
7	Base	Hard Coal
8	Medium	Hard Coal
9	Base	Brown Coal
10	Base	Oil
11	Medium	Oil
12	Peak	Oil
13	Base	Gas
14	Medium	Gas
15	Peak	Gas
16	Base	Biomass
17	Base	CCS
18	Medium	CCS



EU-28

1. Germany
2. France
3. Italy
4. Poland
5. UK
6. Spain + Portugal
7. Benelux
8. Northern EU
9. South-Eastern EU

OECD (non-EU)

10. USA
11. Rest of OECD

BRICS

12. Brazil
13. Russia
14. India
15. China
16. South Africa

Remaining

17. OPEC and Arabian World
18. Rest of the World

Figure 20: Regional disaggregation in NEWAGE. Each region in the model has its own color in the map

A.2 Assumptions

Table 7: Substitution elasticities in NEWAGE for consumption

CES parameter	Substitution elasticity between	Value
$\sigma^{C\text{-}ENE}$	energy and non-energy-goods aggregate	0,5
$\sigma^{C\text{-}NE}$	non-energy-goods	1
$\sigma^{C\text{-}E}$	energy carriers (electricity, gas, oil, coal)	1
$\sigma^{C\text{-}GAS}$	gas and CO_2 emissions	0
$\sigma^{C\text{-}OIL}$	oil and CO_2 emissions	0
$\sigma^{C\text{-}COL}$	coal and CO_2 emissions	0

Table 8: Substitution elasticities in NEWAGE for industry production

CES parameter	Substitution elasticity between	Value
σ^{KLEM}	material and capital-labor-energy	0
σ^{KLE}	Capital, labor and energy	0,5
σ^{KL}	capital, skilled and unskilled labor	1
$\sigma^{KL\text{-}refOil}$	capital, skilled and unskilled labor	0,2
σ^{LAB}	skilled and unskilled labor	0,5
σ^{E}	electricity and fossil fuels	0,1
σ^{FE}	Liquid and solid fossil fuels	0,5
σ^{LQD}	gas aggregate and oil aggregate	2
σ^{OIL}	oil and CO_2 emissions	0
σ^{COL}	coal and CO_2 emissions	0
σ^{GAS}	gas and CO_2 emissions	0

Table 9: Substitution elasticities in NEWAGE for electricity production

CES parameter	Substitution elasticity between	Value
σ^{ELE}	base-, mid- and peak-load	0,8
σ^{PL}	electricity generation technologies peak-load	5
σ^{OG}	Peak-load gas and oil turbines	2,5
$\sigma^{BM\text{-}EU}$	base- and mid-load for EU28 regions	5
$\sigma^{BM\text{-}RoW}$	base- and mid-load for non-EU28 regions	4
σ^{BL}	electricity generation technologies base-load	8
σ^{ML}	electricity generation technologies mid-load	5

Table 10: Substitution elasticities in NEWAGE for trade

CES parameter	Substitution elasticity between	Value
σ^{A}	Armington Elasticity (substitution between local production and imported goods)	4
σ^{IM}	imported goods from different countries	8
σ^{TS}	imported good and associated transport service	0

Table 11: Emission reduction targets for the REEEM pathway – in the EU

	Targets for 2020 (compared to 2005)	*Targets for 2030 (compared to 2005) - Proposal*	*Target for 2050 (compared to 2005) – REEEM clusters*
EU-28 ETS	-21%	-43%	-83%
	Effort sharing decision	*Effort sharing decision*	*Effort sharing decision*
France	-14%	-37%	-80%
Portugal	1%	-17%	-80%
Spain	-10%	-26%	-80%
Italy	-13%	-33%	-80%
United Kingdom	-16%	-37%	-80%
Austria	-16%	-36%	-80%
Germany	-14%	-38%	-80%
Netherlands	-16%	-36%	-80%
Belgium	-15%	-35%	-80%
Luxembourg	-20%	-40%	-80%
Austria	-16%	-36%	-80%
Denmark	-20%	-39%	-80%
Sweden	-17%	-40%	-80%
Finland	-16%	-39%	-80%
Ireland	-20%	-30%	-80%
Poland	14%	-7%	-50%
Czech Republic	9%	-14%	-50%
Bulgaria	20%	0%	-60%
Romania	19%	-2%	-60%
Estonia	11%	-13%	-60%
Latvia	17%	-6%	-60%
Lithuania	15%	-9%	-60%
Croatia	11%	-7%	-60%
Hungary	10%	-7%	-60%
Greece	-4%	-16%	-60%
Slovakia	13%	-12%	-60%
Slovenia	4%	-15%	-60%
Cyprus	-5%	-24%	-60%
Malta	5%	-19%	-60%
EU-28	-9%	-30%	-75%

Regional Push

The Regional Push scenario can be translated as the mutual work of several regions that, together, concentrate at least half of the global emissions and have the economic means to pursue emission targets that are consistent with the 2 °C target[3], or at least more ambitious than the current policies[4].

Since the EU-28 has specific emission targets, Table X depicts only the emission targets of regions outside of the EU that pursue a higher emission cut than the current policies in the Regional Push World state.

Table 12: Emission targets for regions outside of the EU-28 pursuing emission cuts higher than the current policies for the Regional Push World state

Region	CO2 emission targets in 2050
USA	Halfway between 2 °C target and current policies
China	2 °C target
Japan	Halfway between 2 °C target and current policies
Republic of Korea	2 °C target
Canada	Halfway between 2 °C target and current policies
Mexico	Halfway between 2 °C target and current policies
Australia	Halfway between 2 °C target and current policies
Norway	80% reduction compared to 1990 levels
Switzerland	80% reduction compared to 1990 levels
New Zealand	2 °C target
Iceland	2 °C target

[3] According to the emission path presented in 2DS from [10]
[4] According to the emission path RTS from [10]