Exploring the distributional impacts of the European Energy Transition

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 five scenarios – the Reference, Coalitions for a Low Carbon Path, Local Solutions, Paris Agreement - EU and the Paris agreement – between 2011 and 2050. The Reference pathway assumes low ambition targets for the emission reduction until 2050. In comparison to the previous focus report on economic impacts, this report explores the impacts of the energy transition, and more specifically carbon taxation, on different income groups in the EU-28, which shines a light on topics such as changes on consumption, income development and tax incidence on different income groups.

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 line with the REEEM project that aims at gaining a clear understanding of the system-wide implications of energy strategies leading to a competitive low-carbon EU energy society, this report focuses on exploring and describing the economic impacts of such strategies. The different strategies are analysed in terms of several parameters and on different levels of aggregation.

Households are an increasingly important actor in the energy transition process, and they are being transformed from relatively passive consumers to active market participants. However, the energy transition itself, as well as policy measures that support it, is considered to be regressive, placing a larger burden on poor than on wealthy households. It might be argued that the success of the energy transition lies in the active participation of different groups of society. Rising income inequality might even discourage some groups of society from taking an active role in the decarbonisation process. Therefore, this report focuses on the incidence of carbon pricing, more specifically due to a cap and trade system, on different income groups and analyses its effects on their consumption and welfare. For the analysis of different income groups, factors specific to these groups are highlighted, such as the composition of household consumption, the level of income dedicated to energy goods and carbon taxes and income development On a regional and European level, indicators such as GDP development and GVA are utilized to complete the analysis.

The report compares a reference scenario with the three main pathways of the REEEM project:

- *Coalitions for a Low Carbon Path* aiming at 83% GHG reduction in ETS sectors and 50-80% GHG reduction in non-ETS sectors on the national level in 2050 compared to 2005 levels
- *Local Solutions* Pathway that in addition to Coalitions for a Low Carbon Path Pathway conditions foresees extra European targets for households, transport, and services
- *Paris Agreement* Pathway that aims at 95% GHG reduction in 2050 compared to 1990 levels

These pathways were derived from months of discussions with stakeholders, project partners, and researchers, mainly during workshops organized by the REEEM team, and they include assumption across different areas including household behaviour, economy evolution, policies and technology development.

In this research, we employ a Computable General Equilibrium (CGE) model named NEWAGE (National, European, World Applied General Equilibrium). The model, by means of Constant Elasticity of Substitution (CES) has the advantage of accounting for the relationship between different sectors of the economy and is capable of indicating the burden imposed by carbon pricing. Specifically, for this project, the model was extended in order to account for different income groups in society and, thus, reflect the different incidence of carbon pricing for each group. The application of this new feature together with the existing 18 sectors of the model used to describe the different production sectors of the economy, the world divided into 18 regions, 9 of them in Europe, and a detailed description of the energy sector allows for a thorough analysis of environmental and energy policies in the EU.

The improved modelling framework allows for a better understanding of the effects and impacts of energy strategies on European society.

2. Literature review

Consequences and causes of global warming have been recognized by most of the world countries today. According to the Intergovernmental Panel for Climate Change (IPCC), anthropogenic emission of greenhouse gases has contributed to rising in global temperature, rise in sea levels and more frequent occurrence of extreme weather events [1]. The Paris Agreement puts forward a global plan to limit the growth in global temperature below 2ºC and pursuing the efforts to limit it to 1,5ºC to prevent the consequences of further dangerous climate change.

Recent work on the economic consequences of climate change provides quantification on the possible costs of inaction. One strand of research has investigated the historic relation between economic growth and changes in surface temperature by employing econometric methods. Using detailed data on a global scale where the unit of observation was one unit latitude by one unit longitude cell, Nordhaus [2] finds a negative relation between economic output and mean surface temperature. Using the estimated parameters and assuming an increase in the average temperature of 3ºC and decrease in precipitation, he forecasts a reduction of economic activity between 0,9% and 3%. Based on the panel data of 100 most populous countries, Horowitz [3] estimates that the rise in the surface temperature of 1ºC would reduce the world GDP between 2,7% and 4,2%, with the best estimate of 3,8%. Hsiang [4] investigates the impact of variation of surface temperatures on the output of 28 Caribbean basin countries. After controlling for the effect of cyclones he finds that a 1°C rise in surface temperature is associated with a contemporaneous decrease in GDP of 2,5%. He also finds that higher surface temperature is associated with a statistically significant decrease in economic output in three of seven economic sectors. Dell et al [5] find large and negative effects of higher temperatures on economic growth: they estimate a 1°C rise in temperature in a given year reduces economic growth in that year by about 1.3%, though the relationship is not robust for rich countries. The possibility that climate change does not have an adverse effect on rich countries has prompted some researches to investigate this issue a bit deeper. Burke et al [6] address this issue and by using historical data and analyse whether country-specific deviations from growth trends are non-linearly related to country-specific deviations from temperature and precipitation trends, after accounting for any shocks common to all countries. They find country-level economic production is smooth, non-linear, and concave in temperature, with a maximum at 13°C. Both rich and poor countries exhibit similar non-linear responses to temperature. Therefore, the link between rich countries and temperature change is weaker primarily because rich countries exhibit lower temperatures. Lemoine and Kapnick [7] also find that future warming could raise the expected rate of economic growth in rich countries, reduce the expected rate of economic growth in poor countries, and increase the variability of growth by increasing the climate's variability.

Another strand of research has focused on assessing the costs of implementing the measures to combat climate change. Adams [8] investigates the impact of the introduction of the ETS scheme in Australia. By using a CGE model coupled with an electricity generation model they assess that the ETS scheme would result in a real GDP and a consumption loss of 1.3% and 1.4% respectively by 2030. Real wages would decline by 3.3% and CO_2 emissions would be reduced by 21% compared to the baseline scenario. In a similar work, Adams et al [9] analyse the impact of carbon pricing on the Australian economy that is determined within the global emission trading scheme. They find that such global ETS scheme which results in 25% lower emission in 2030 would result in a reduction of GDP by 1.1% compared to a base case scenario, together with a reduction in household disposable income by 2.3% and real private consumption by 1.3%. They also show that carbon pricing adversely affects most of the industries, though it has positive effects on some, notably forestry, electricity generation from renewables and electricity generation from gas (move away from coal) as well as iron, steel, and aluminium which become more internationally competitive due to cheaper raw material. Lu et al [10] assess the impact of the introduction of a carbon tax on Chinese economy. They find that a carbon tax of up to 300 Chinese Yuan per ton of CO_2

(approximately 30 EUR) results in a relatively modest reduction of GDP of 1,1% compared to the scenario without the carbon tax. In a similar work, Guo et al [11] investigate the impact of the introduction of a carbon tax. Like the previous work, they also find negative effects of a carbon tax on most of the economic sectors as well as overall GDP and returns to labour and capital.

As the research has shown that schemes to limit the emission of CO_2 into the atmosphere such as carbon tax or emission trading scheme entail a reduction in GDP growth and consumption, a question regarding the distributional impacts of such schemes arose. Goulder [12] emphasizes the importance of revenue recycling and tax interaction effect, both representing a fiscal interaction effect when assessing the cost-effectiveness of climate change policy. Revenue recycling refers to returning the revenues collected by climate change measures back to the economy, whilst tax interactions refer to the impact of climate policies on returns on factors of production. While the revenue recycling effect is self-explanatory, the tax interactions argument states that climate policy measures increase the cost of carbon-related goods hence driving up the prices. This reduces the real wage of workers as well as returns to the owners of capital employing carbon-related inputs, both of which represent an efficiency loss. The efficiency loss could be reduced or even mitigated by using appropriate fiscal policies such as reduction of marginal tax rates on labour and capital, providing a lump sum transfers to households, or some combination of the above, depending upon the goals of the policymakers. Work by Tran et al [13] analyses the impact of emission reduction in Australia by 2020 by using a static CGE model. Without revenue compensating mechanisms they find a decline in Australia's GDP by 0,285%-0,3% by 2020 as well as a decrease in welfare for all 20 household categories. To address the issue of welfare loss of different households, they assess the use of direct lump-sum transfers, government transfers and reductions in income tax. They find a trade-off between efficiency and equity. While income tax policies are the most efficient in the sense that they achieve the highest reductions in the GDP loss, they are the least equitable as they benefit mostly the wealthiest households. On the other hand, lump-sum transfers aid the poorest households, while government transfer policy aids the most middle-income households. Caron et al [14] provide a five-model assessment of distributional impacts of carbon pricing in the US. To alleviate distributional impacts on different households they evaluate the efficiency and equity (progressivity) of lump sum household transfers, capital, and labour tax reductions. They find that lump sum transfer to the household consumer are progressive, but come at the greatest costs, while capital tax reductions are mostly regressive and help the richest households. Labour tax credits are somewhere in between these two measures. Nevertheless, the authors conclude that by using a creative approach such as lump-sum transfers to the poorest households and capital tax reductions, the policymakers can reduce the progressivity of carbon pricing at rather a low cost.

In summary, the research up to date provides us with the following conclusions. First, the historic effects of climate change on economic growth have been documented and they affect not only the level but also the rate of economic growth. Second, unmitigated climate change results in significant negative environmental consequences that have negative repercussions on economic growth. Third, to mitigate the economic consequences of climate change, policymakers should enact policies that will eliminate and hopefully reverse the effects of climate change. But these policies come at the cost and they are regressive in nature, mostly hurting poor households. Fourth, policymakers have different options of revenue recycling mechanisms which can be either efficient but inequitable (mitigation of negative effects of climate policies on economic output at the lowest costs but hurting poor households) or equitable but inefficient (a measure that aid more poor households than rich but come at a higher cost).

Our paper adds to the current debate in several aspects. To our knowledge, this is the first comprehensive paper that addresses the consequences of the Paris Agreement on European economies taking into account different pathways other global economics might take vis-à-vis Paris agreement. In this sense, it expands the existing literature by making a multi-regional analysis on selected EU countries between the years 2011 and 2050 considering different emission targets inside and outside of the EU.

3. Scenarios

For this report, there are two main components for the definition of scenario, first the carbon cap and trade scheme in the EU-28, which includes the regions selected to be part of it, selected sectors (ETS, non-ETS or specific sectors such as Iron and Steel) and the reduction targets (80% or 95% reduction in 2050 compared to 1990 levels, for example). The second component is the emission reduction targets of the regions outside of the EU-28. In order to make the understanding of the different emission targets easier, Figure 1 depicts the aggregate emission targets of the EU-28 and Rest of the World for the different pathways.

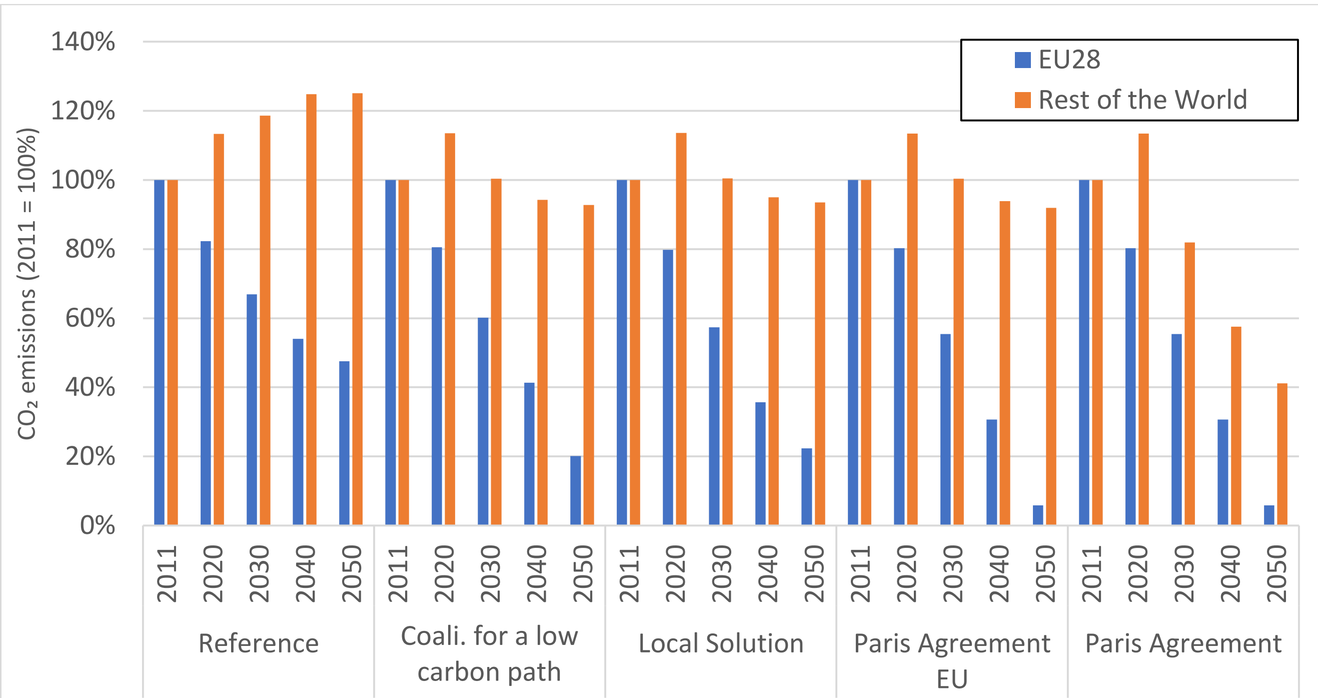

Figure 1: CO_2 emission targets in the EU-28 and Rest of the World compared to 2011 levels for all sectors. Source: Authors

3.1. Reference Scenario

The Reference Scenario, which in this context is a Business-as-usual scenario, unites a set of assumptions for different parameters in regions outside and inside the European Union. Its assumptions range from CO_2 emission limits, GDP development and employment development.

As the main reference for CO_2 emissions, emission targets and GDP in the EU we utilize the EU Reference Scenario 2016 [15] as the main source. The emission figures from the remaining regions are based on the Reference Technology Scenario (RTS) from the Energy Technology Perspectives 2017 [16]. In this scenario, for the ETS sectors in the EU, we assume a 62% CO_2 emissions reduction target in 2050 compared to 2005 levels and no targets for the remaining sectors, resulting in an overall reduction of CO_2 of 43%. There are no reduction targets for the Non-EU regions.

3.2. Coalitions for a Low Carbon Path

The Coalitions for a Low Carbon Path assumes a more active position of the EU and most of the remaining regions, however, with different degrees of ambition. In the EU, for instance, the overall CO_2 emissions reduction in 2050 is 80% compared to 1990 levels, which is reached by two different policies. On the European level, there is an 83% reduction target in 2050 compared to 2005 values for the ETS sectors, while for the remaining sectors there are national reduction targets ranging from 50 to 80%, which together result in a 75% overall reduction in 2050 compared to 2005 levels. For detailed information regarding the emissions targets see Appendix A.2 Cluster Union.

For the regions outside of the EU, the targets are diverse and represent what we call a "Regional Push" scenario. The pathway consists of a small group of regions willing to decrease their emissions of GHG and to intensify their efforts against climate change. Within this block, there are three distinct reduction targets. The first represents regions whose target are in line with the EU, simply to reduce 80% of the emissions in 2050 compared to 1990 levels. The second group is formed by the regions willing to reach the necessary emission levels consistent with a 2 °C target and the third group is formed by the regions whose target is the mean average between current policies and 2 °C target. For a detailed list of regions that are part of the Regional Push and their targets, consult Appendix A.2.

3.3. Local Solutions Pathway

In the Local solutions pathway, the main assumption is that the main driver for the energy transition will come from the consumers, who will move towards locally generated energy, such as wind turbines and solar panels, due to a sense of urgency of avoiding climate change. While the ETS and national non-ETS targets remain the same as in the Coalitions for a Low Carbon Path Pathway, the higher willingness form consumers to produce local and renewable energy is modelled as a tighter emissions' cap on the households, transportation, and commercial sectors. Table 1 depicts the exact targets from Local Solutions Pathway in comparison to the other pathways.

3.4. Paris Agreement Pathway

The Paris Agreement Pathway, as the name suggests, sets the targets for both EU and non-EU regions in line with the commitments signed in the Paris Agreement. More specifically, the emissions are derived from the 2DS scenario from ETP 2017 [16], that were defined to limit the rise of global temperature to 2 °C. In this pathway, the EU has one cap-and-trade system that groups all the sectors of the economy, not only the ETS sectors, but also includes residential, transportation, and services.

Finally, one last pathway was created to assess the effects on the European economy of the case where the EU follows a 95% reduction target alone while the remaining regions follow the Regional Push scenario. The objective of this extra pathway is to enable the assessment of the specific impacts that higher global emission reduction might have over, for example, industrial production and consumption in Europe. This decarbonization pathway is named "Paris Agreement – EU" to specify that the Paris Agreement targets are being followed mostly in Europe.

Table 1: Description of analysed scenarios. Source: Authors

	Reference Scenario (REF)	Coalitions for a Low Carbon Path (CL)	Local Solutions (LS)	Paris Agreement – EU (PA_EU)	Paris Agreement (PA)
ETS sectors	62% reduction in 2050[1]	83% reduction in 2050[1]	83% reduction in 2050[1]	95% reduction in 2050 compared to 1990 levels	95% reduction in 2050 compared to 1990 levels
non-ETS sectors	no targets	50 to 80% reduction in 2050[1] Extra European targets: • Industry	50 to 80% reduction in 2050[1] on the national level Extra European targets: • Residential • Transport • Services		
Remaining regions	No targets	**Norway and Switzerland**: 80% reduction in 2050 compared to 1990 levels **Remaining OECD**: mixed ambition levels (see A.2 "Regional Push") **China**: In Line with the 2°C target **Remaining countries**: No targets	**Norway and Switzerland**: 80% reduction in 2050 compared to 1990 levels **Remaining OECD**: mixed ambition levels (see A.2 "Regional Push") **China**: In Line with the 2°C target **Remaining countries**: No targets	**Norway and Switzerland**: 80% reduction in 2050 compared to 1990 levels **Remaining OECD**: mixed ambition levels (see A.2 "Regional Push") **China**: In Line with the 2°C target **Remaining countries**: No targets	In line with the 2°C target

[1] Compared to 2005 levels

4. Methodology

4.1. Modeling Framework

To analyse the different decarbonization pathways mentioned above, we apply the numerical model NEWAGE. NEWAGE is a recursive-dynamic general equilibrium model with a particular 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. There are 18 regions in total, 9 within Europe. Similarly, production sectors are represented at certain aggregation level also. There are 5 energy production sectors, 6 energy-intensive industry sectors, and 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.1 presents detailed information regarding NEWAGE's regional and sectoral structure, as well as the CES nesting for sectorial and electricity production.

While energy system models are generally better suited to analyse the energy sectors in detail, they usually consider a fixed demand which does not respond to policy shocks, lack the relationship with other sectors and are not able to assess overall macro-economic costs. With NEWAGE the impact of different political interventions on macro-economic indicators, such as GDP growth, employment or competitiveness can be assessed. Therefore, NEWAGE is a valuable tool for the analysis of carbon leakage and its' effect on competitiveness and hence was chosen as the most suitable modelling framework for this case study.

In addition to the representation of production sectors and detailed energy technologies, NEWAGE also depicts households and government as one single entity, named a representative agent. This block is endowed with capital, labour, natural resources (oil, natural gas, coal) and CO_2 certificates, it receives taxation revenue from production (including VAT), consumption, international trade and CO_2 certificates and decides whether to spend its gross revenues in consumption or investments. As much of the improvements to the model were made in the direction of disaggregating the representative agent into government and a number of income groups, representing households, Figure 2 illustrates NEWAGE's architecture, presenting a diagram of how the different blocks are interconnected before the disaggregation of the representative agent was implemented.

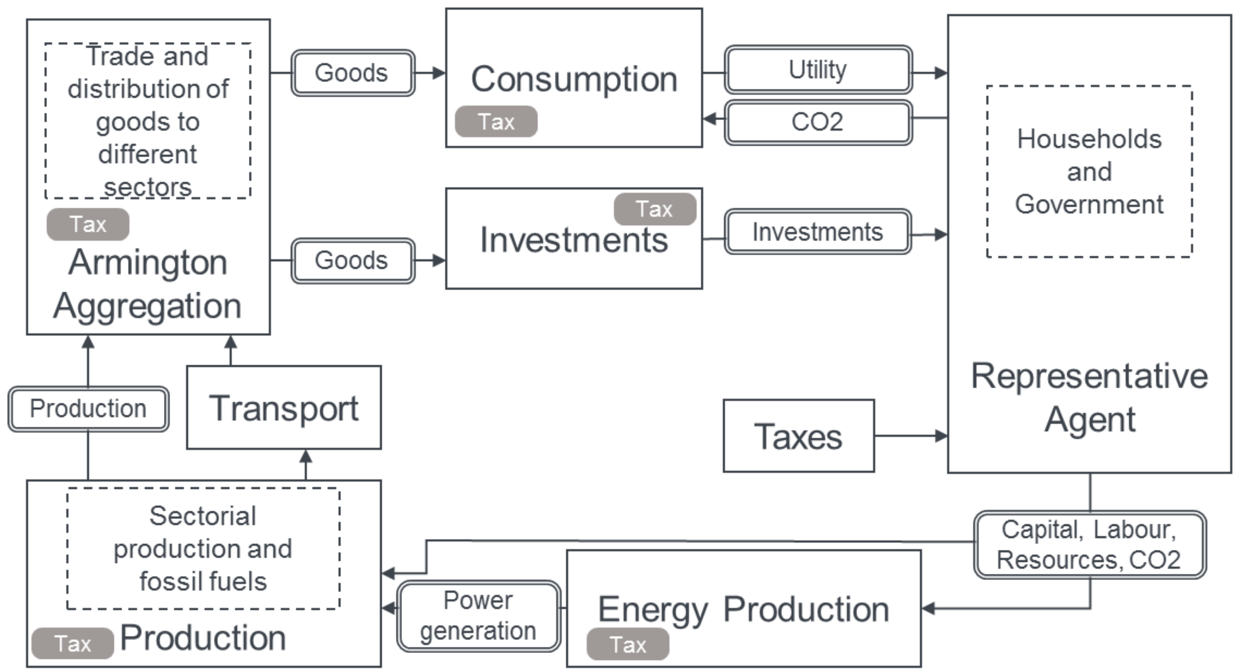

Figure 2: Diagram representation[2] of NEWAGE's production and demand blocks prior to disaggregation. Source: Authors

4.2. Model's limitations

Despite being able to represent the relationship among different sectors of the economy, the NEWAGE has some limitations that influence the results of the analysis. The main limitations can be divided into 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. 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 unit of energy. To surpass this limitation, NEWAGE utilizes exogenous assumptions for the technology development from 2011 and 2050 through the Autonomous Energy Efficiency Index (AEEI) parameter, which was developed based on the energy efficiency provided by the EU Reference Scenario [15] For this work the same set of AEEI was applied in all pathways, meaning that regardless of the environmental ambition, the rate of technology development remains the same.

Finally, in the present version of NEWAGE model, the model sees the gains and losses of any policy measure solely as a matter of profit and costs. It means that the model is not capable of accounting the non-financial impacts brought by different pathways, such as increased air quality and lower water pollution, in the cases where emission levels decrease, or higher temperatures, in the case where countries fail to reduce emissions.

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[2] Square blocks represent economic actors, arrows represent the flow of money between actors and double lined squares with curved corners represent in which form the money is transferred between blocks

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

4.3. Modelling assumptions

Although NEWAGE covers the whole economy and all world regions, the 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, as described in what follows.

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 labour, or different technologies, e.g. photovoltaics and wind turbines, can substitute each other[3]. 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 primarily based on Beestermöller (2016) [17] and are summarized in Table 8 to Table 11 in appendix A.3 .

Further assumptions

In addition to the assumption above, we use the following data sources for additional assumptions:

- GTAP 9 Data Base [18]
    - Trade and energy data for the year 2011
    - Social accounting matrix
- Electricity Information 2013 [19]
    - Electricity generation per country for the year 2011
- EU Reference Scenario 2016 [20]
    - 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 [21]
    - 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
- The Great Shift: Macroeconomic projections for the world economy at the 2050 horizon [21]
    - 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

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

4.4. Disaggregation of households in income quintiles

As mentioned before, NEWAGE possesses one block representing both government and households, named Representative Agent. For the realization of this report, one of the tasks, as well as one objective of the REEEM project, and the main improvement to the model was to disaggregate this block into six new blocks: one for the government and five for each income quintile. More specifically, the households were divided into five groups according to their income, each of the groups with the same number of people, or approximately 20% of the population, and sorted **from lowest income (hh1) to highest income (hh5)**, as shown on Figure 3. No distinction between urban and rural population was made and the calculus for income included gains from labour, capital and government subsidies.

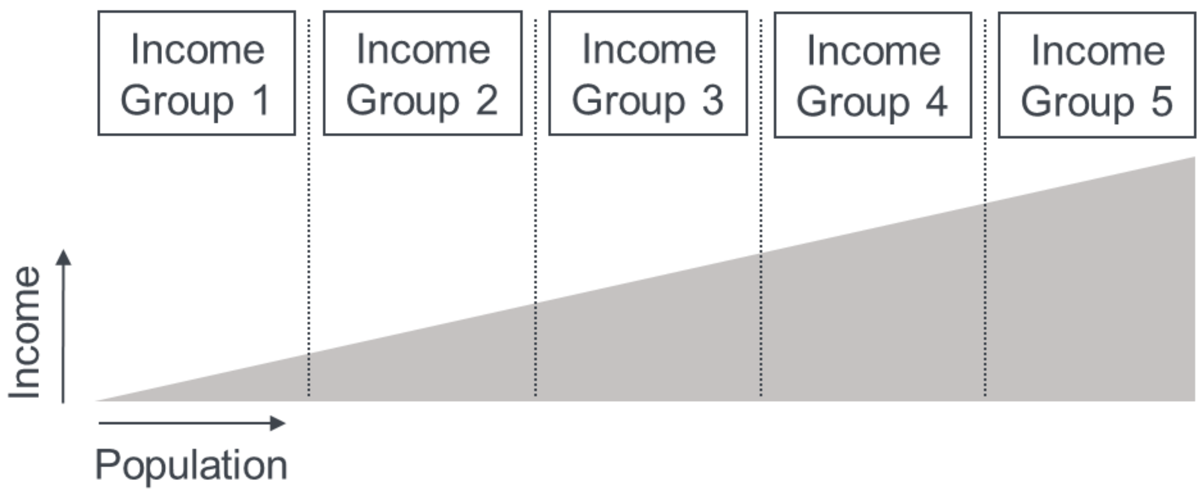


Figure 3: Graphical representation of the income groups division. Source: Authors

In order to perform the disaggregation of the household sector into five income groups, the first step was to separate the consumption of the representative agent between government and households, creating one block for each of these two agents. This task was executed by accessing the GTAP 9 [18] database to access the consumption values for both agents and, later, implementing the two blocks in place of the original representative agent. Following, as the data available for consumption and income sources was aggregated on a national level, it was necessary to use Eurostat's Household Budgets Survey (HBS) and Survey on Income and Living Conditions (SILC) to obtain data regarding the expenditure of households and their sources of income.

With the implementation of the six blocks representing the government and five income groups, the last step was to add the channels that allowed for income flow between these blocks. The flow represents the taxation of income, both from labour and capital, from the households to the government, and the payment of social benefits and pensions from the government to the household. Figure 4 shows a detailed representation of the new process of collecting and distribution of tax revenues, in which the government receives tax revenues, as well as revenues from CO_2 certificates and income taxes payed by the households and, in return, distributes the net revenues to the households according to the shares that each income group is endowed to receive. Figure 5 shows a diagram of the new state of NEWAGE, in comparison to Figure 2.

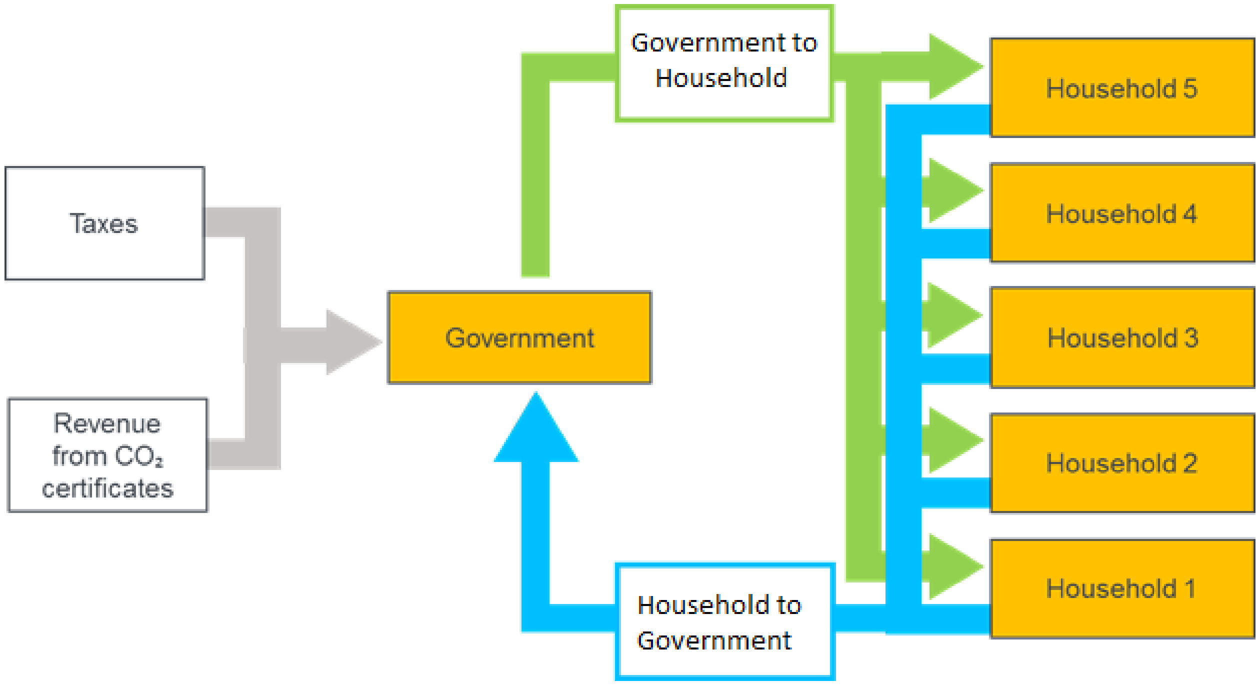


Figure 4: Detailed flow of taxes and CO_2 certificates' revenues. Source: Authors

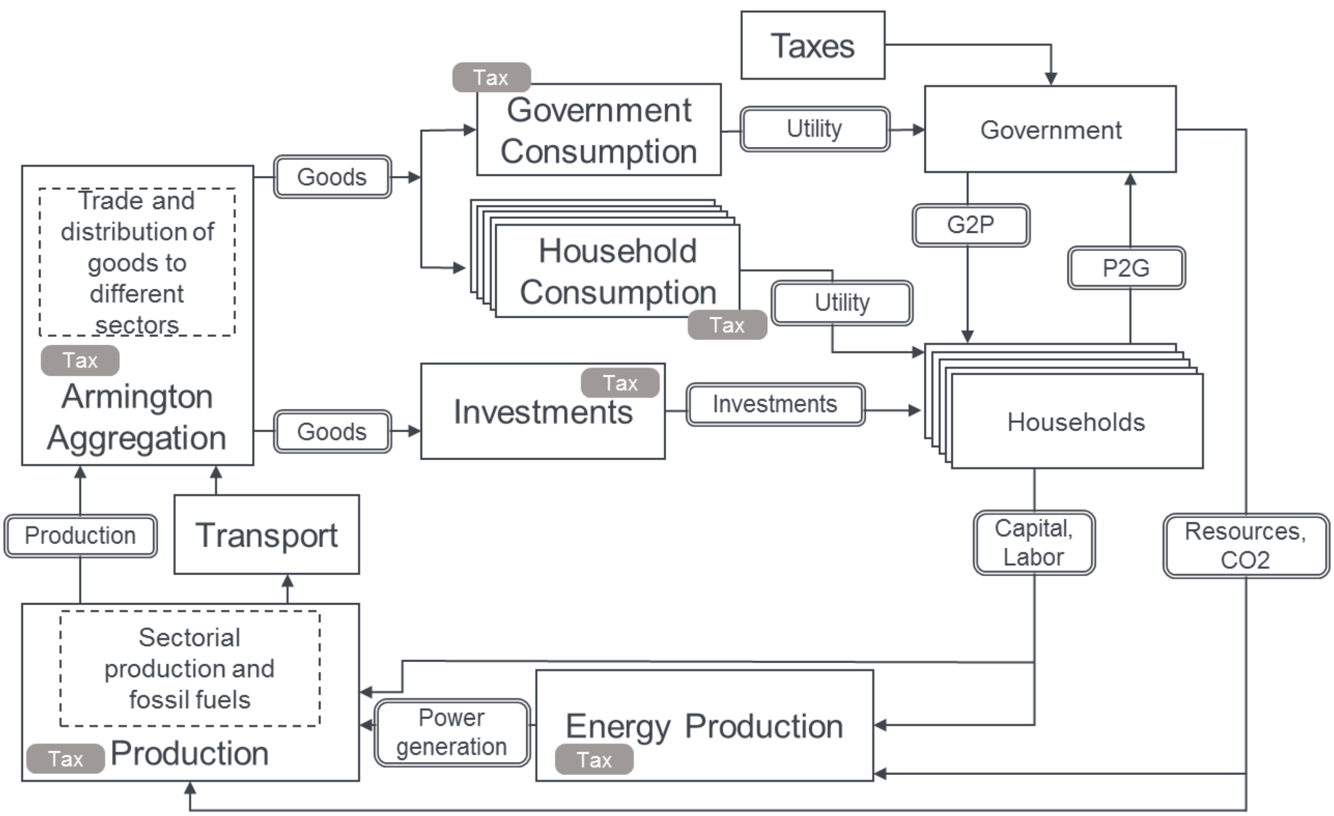


Figure 5: Diagram representation of NEWAGE's production and demand blocks with disaggregation of Government and Income Groups. Source: Authors

As mentioned, the main information source for household disaggregation was microdata of SILC and HBS surveys. The Access to Eurostat microdata covering Household Budget Survey [22] and Survey on Income and Living Conditions [23] was been granted to the Lithuanian Energy Institute by Eurostat to be used in the REEEM Project. All the results of calculations using the datasets and conclusions are provided by the authors of this report and not those of Eurostat, the European Commission or any of the national statistical authorities whose data have been used.

The first data processing step was the calculation of expenditure and income in different household groups of NEWAGE regions. To ensure confidentiality of respondents and to make our calculations comparable to other datasets, all indicators are calculated at decile level and aggregated to quintiles just before implementing in NEWAGE model. To group individuals covered by the dataset to deciles, equivalized disposable income[4] has been calculated by dividing net income of a household by the equivalised household size (the number of adult equivalents in the household). Equivalised household size has been calculated using modified OECD scale in which the first adult is equal to 1, the second and each subsequent person aged 14 and over is equal to 0.5, and each child aged under 14 is equal to 0.3. Finally, decile groups have been formed taking into account equivalised income, household size, and sample weight.

The same methodology has been applied for both SILC and HBS datasets. In the case of HBS dataset, Monetary net income (total monetary income from all sources minus income taxes, EUR_HH095) variable represented households' disposable income, while total disposable Household Income (HY020) has been used for SILC dataset.

The disaggregation of consumption expenditures by deciles was carried out assuming that total expenditure by commodity remains the same as that in the aggregated version of NEWAGE. This assumption ensures the consistency of the model that relies on fully balanced GTAP data. Different consumption levels in different deciles were included as proportions of the total consumption expenditure calculated from HBS.

The proportions between consumption expenditure on different commodities within decile are least certain mainly due to data inconsistency and different classifications: The HBS survey deals with the Classification of individual consumption by purpose (COICOP[5]) categories while NEWAGE model uses aggregated GTAP commodity classification. To make the two datasets consistent, a mapping matrix was developed. This matrix maps every commodity in NEWAGE model with one or more COICOP categories in HBS. For instance, it is assumed that "oil" in NEWAGE is represented by "Fuels and lubricants for personal transport equipment" and "Liquid fuels" in HBS. To avoid data inconsistency problems, iterative scaling was performed by fixing total consumption by commodity and total consumption expenditure per household decile.

Income disaggregation was performed following income categories represented in the new structure of NEWAGE. For this, the most similar income categories were selected in SILC survey. In some cases, it was possible to get rather a good fit with the microdata (e.g., for skilled labour income), while for return on capital microdata served just as a proxy since SILC survey covers the income from rental of a property or land and interest, dividends, profit from capital investments in unincorporated business only. To get more comprehensive and

[4] Eurostat (2018). Definition of equivalised disposable income. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Equivalised_disposable_income

[5] For more information, see https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Classification_of_individual_consumption_by_purpose_(COICOP)

balanced picture of income and consumption expenditure, aggregate propensities to consume by income quintile were calculated using household budget survey microdata and implemented in income disaggregation by using income taxes as a balancing element.

By the end of the disaggregation process, the average composition of gross income and the relative income level from the 5 income groups in the EU-28 is depicted inFigure 6. The figure indicates that the lowest income group has a higher share of its gross income coming from payments from the government, or tax revenues, and the highest income group has the largest share of its gross income from capital revenues, followed by labour payments from skilled labour. Additionally, the figure also illustrates the difference between gross income levels, where the richest 20% households have a gross income 7,6 times higher than the poorest 20% of households.

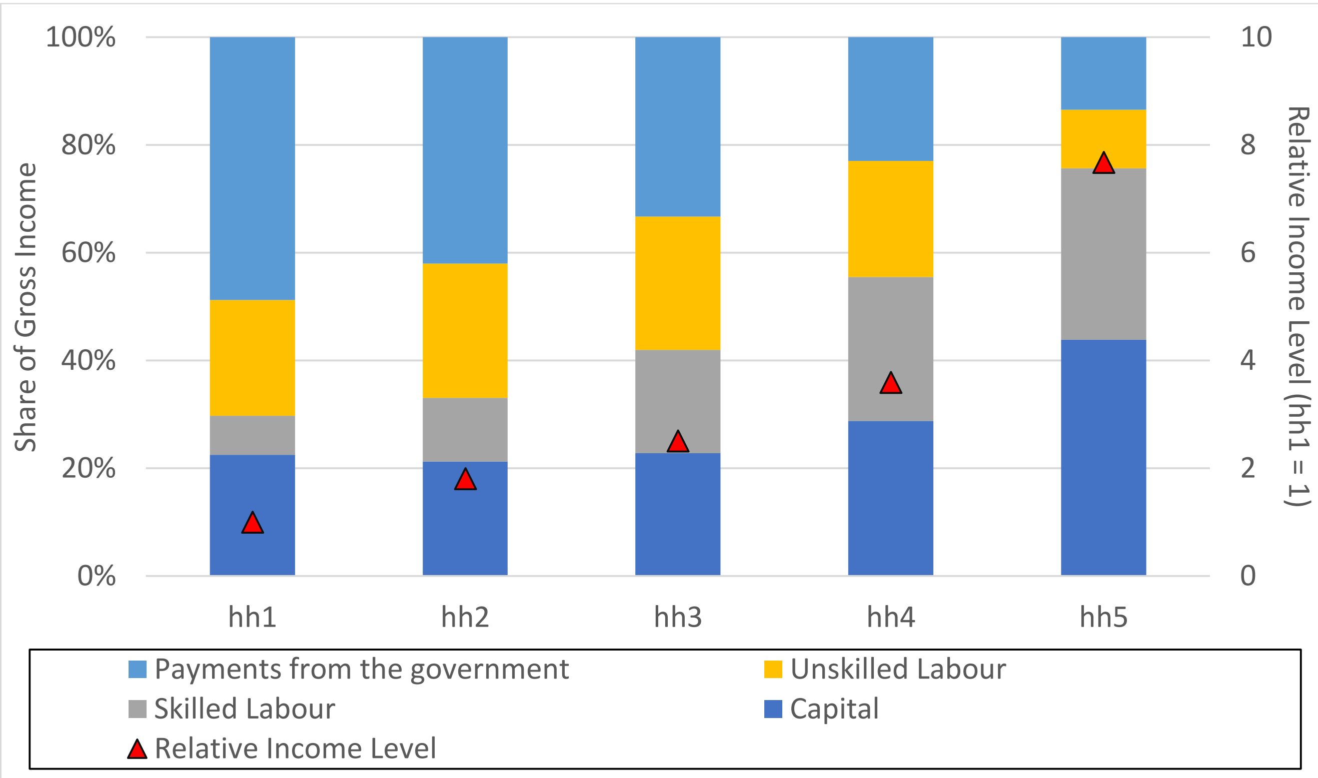


Figure 6: Average composition of gross income from the five income groups and relative income level. Source: Authors

5. Results

In this section, we present the main results of the economic analysis performed with NEWAGE. This chapter is divided into two sections: Macro Economy and Analysis of income groups, where the first refers to main macro-economic parameters, such as GDP and GVA. The second section focusses on parameters that are specific to the analysis of different income groups, such as consumption, the share of income dedicated to energy products, the incidence of carbon pricing and net income.

5.1. Macro Economy

5.1.1. GDP

Figure 7 depicts the relative GDP development of the EU between 2011 and 2050 for the five pathways that were analysed. It shows that regardless of the pathway, there is positive economic growth, which in 2050 varies between 55% for the Paris Agreement pathway and 73% for the Reference scenario. In addition, until 2040 the maximum difference between the lowest and highest GDP development is 6%, where Reference scenario represents the upper limit and Local Solutions and Paris Agreement the lower limit, indicating that all the pathways behave in a similar way during the short and medium term, having the highest discrepancies appearing after 2040.

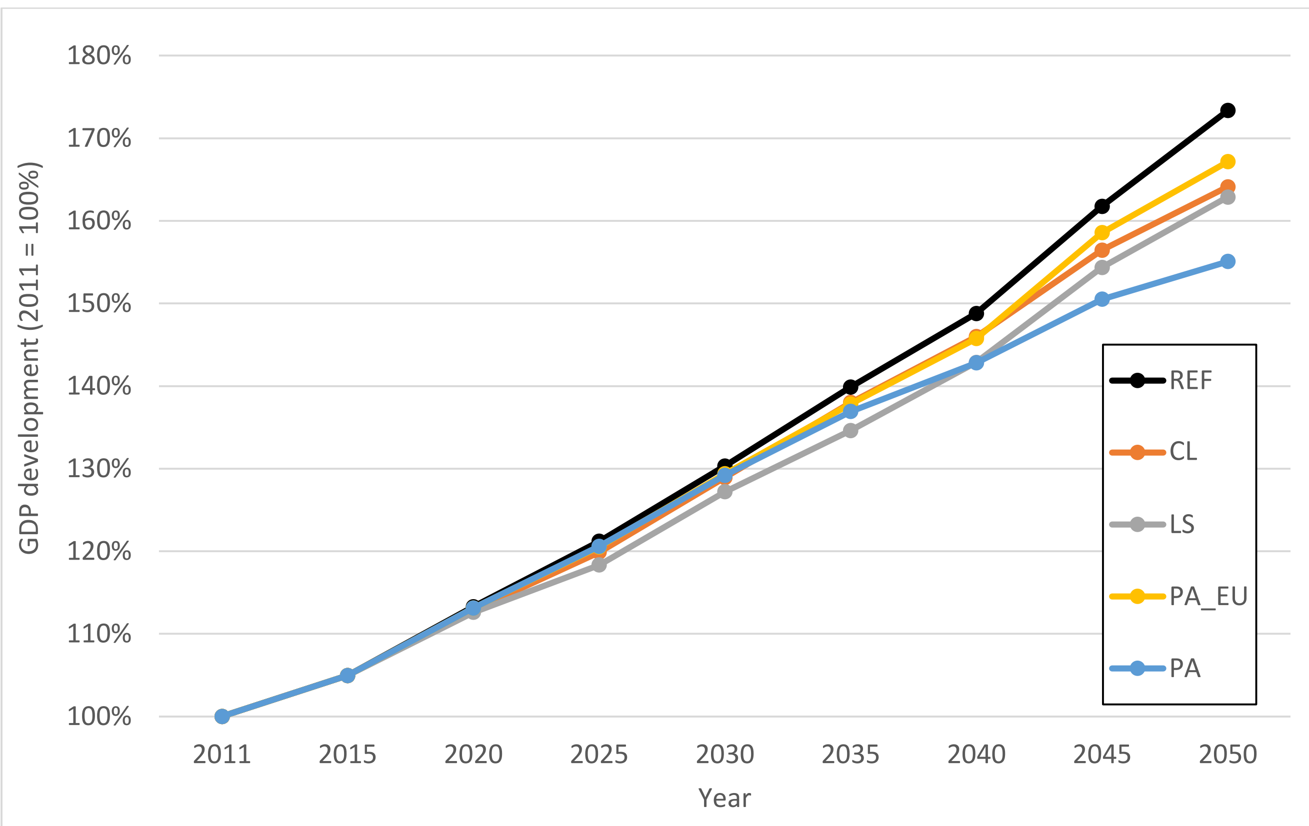


Figure 7: GDP development of the EU-28 relative to 2011. Source: Authors

Looking more specifically to the counterfactuals we see that the GDP development in the Paris Agreement – EU pathway is most of the time superior, or at least equal to the remaining pathways, despite the fact that the CO_2 reduction targets in the EU are stricter in this case. The pattern suggests that its CO_2 cap and trade scheme is more cost effective than the ones presented in Coalitions for a Low Carbon Path and Local Solutions pathways. Additionally, Paris Agreement pathway has a very similar development to the Paris Agreement-EU pathway until 2035, when its GDP growth slows down as a consequence of the lower economic activity in the remaining regions of the world that have to invest more in CO_2 emission abatement measures and, thus, reduce their consumption of EU exports, as shown on **Figure 8**, reducing the European industrial production and GDP.

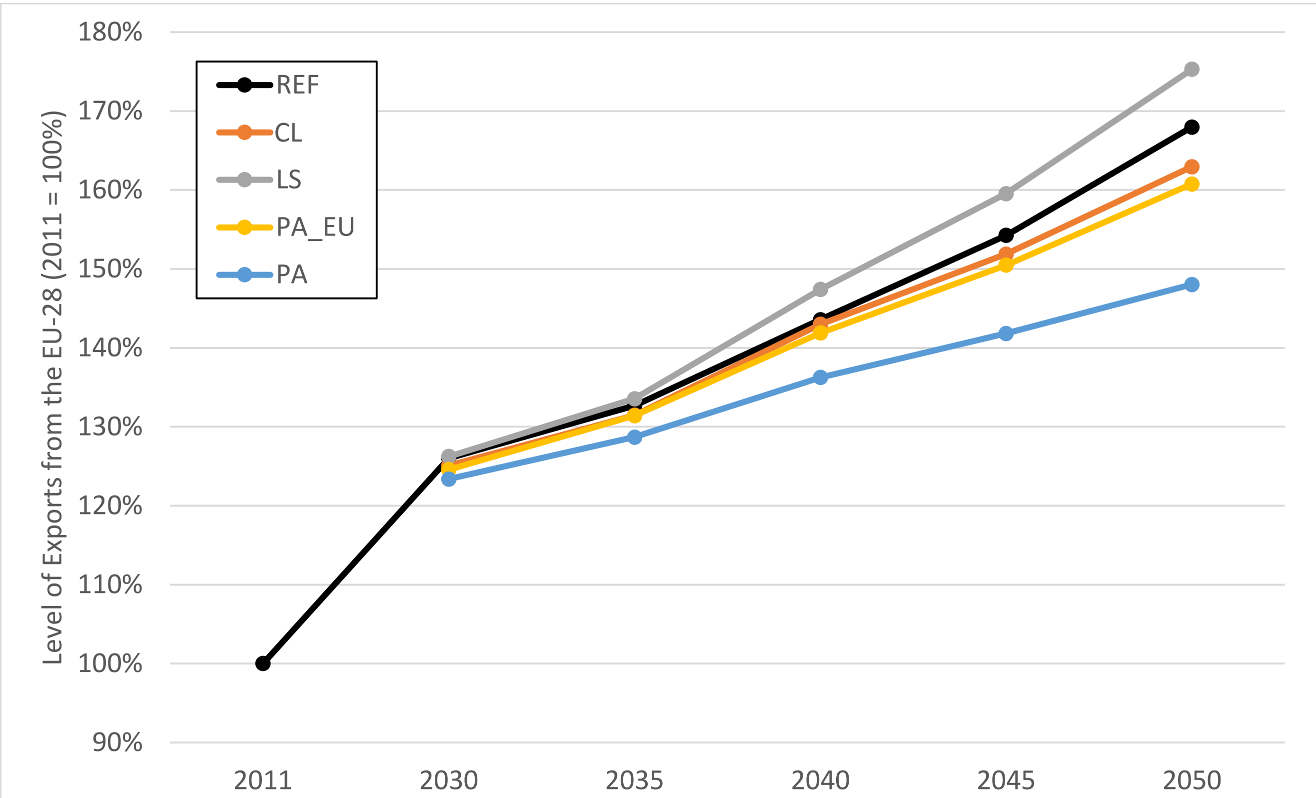


Figure 8: Level of Exports from EU-28 compared to 2011. Source: Authors

When it comes to the Coalitions for a Low Carbon Path and Local Solutions pathways, the results indicate the former to have a higher GDP development, increasing 64% in 2050 compared to 62% increase of the latter. Although these numbers are still lower than the Paris Agreement-EU pathway, it is important to note that the difference between these two pathways is that in the former there is a higher burden on the industry while in the latter, the burden is on transportation, residential and services sector. This effect indicates that placing a higher burden on the industry is more effective than the other option for GDP growth, however, as shown inFigure **8**, it also leads to lower exports.

Figure 9, which presents the GDP growth in the rest of the World until 2050, depicts the effects of reducing CO_2 emissions outside of the EU. The results indicate that in the Paris Agreement pathway, where non-EU regions pursue higher emission cuts, these efforts are translated into slower economic growth after 2035. Consequently, in 2050 the aggregated GDP of the non-EU regions varies between 188% for the Paris Agreement-EU to 149% for the Paris Agreement pathway. As aforementioned, this slower economic growth in the rest of the World affects the EU by reducing the European GDP growth from 67% for the Paris Agreement-EU pathway to 55% in the Paris Agreement pathway between 2011 and 2050.

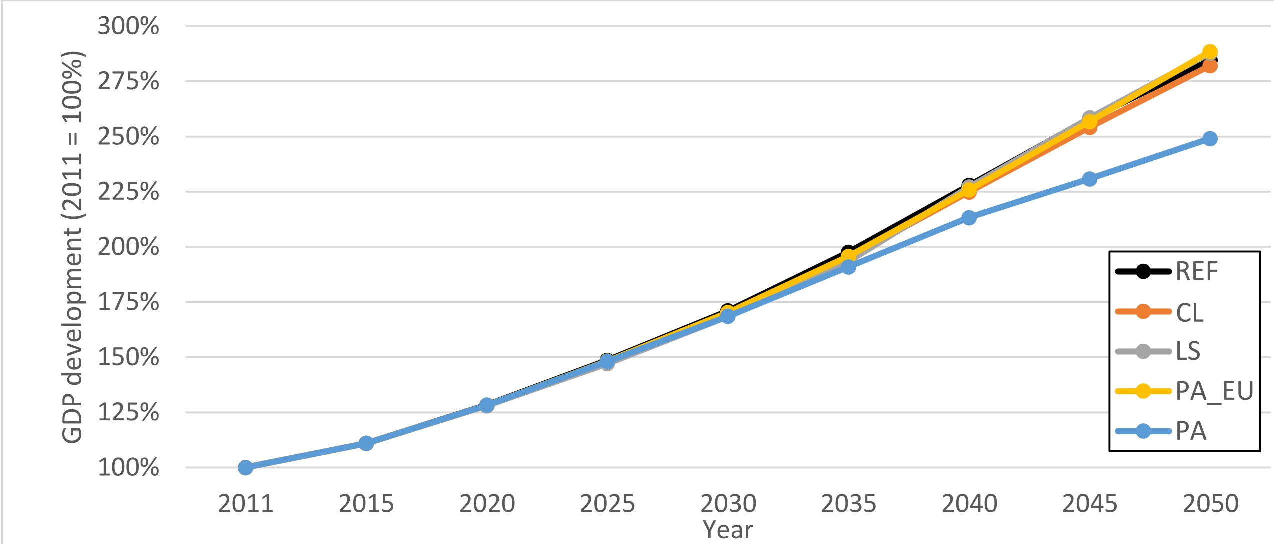


Figure 9: Aggregated GDP development of the rest of the World (non EU-28). Source: Authors

Figure 10 depicts the average variation of GDP and CO_2 emissions in the EU in the five-years interval and indicates that in pathway Paris Agreement-EU the European GDP grows 5.9% and reduces its CO_2 emissions on average 23.6% every five years, being the most efficient of the counterfactuals. Scenario Paris Agreement, although having the same average European CO_2 emissions reduction, has a lower average European GDP than Paris Agreement-EU of 5%, again due to lower economic activity in the rest of the world. The European GDP growth in the Coalitions for a Low Carbon Path is 5.7%, slightly higher than the 5.6% of the Local Solutions pathway, but the reduction of CO_2 emissions is 15.7%, against the 14.9% of the Local Solutions pathway. These results indicate how important the CO_2 cap and trade scheme is to reduce emissions while maintaining economic growth.

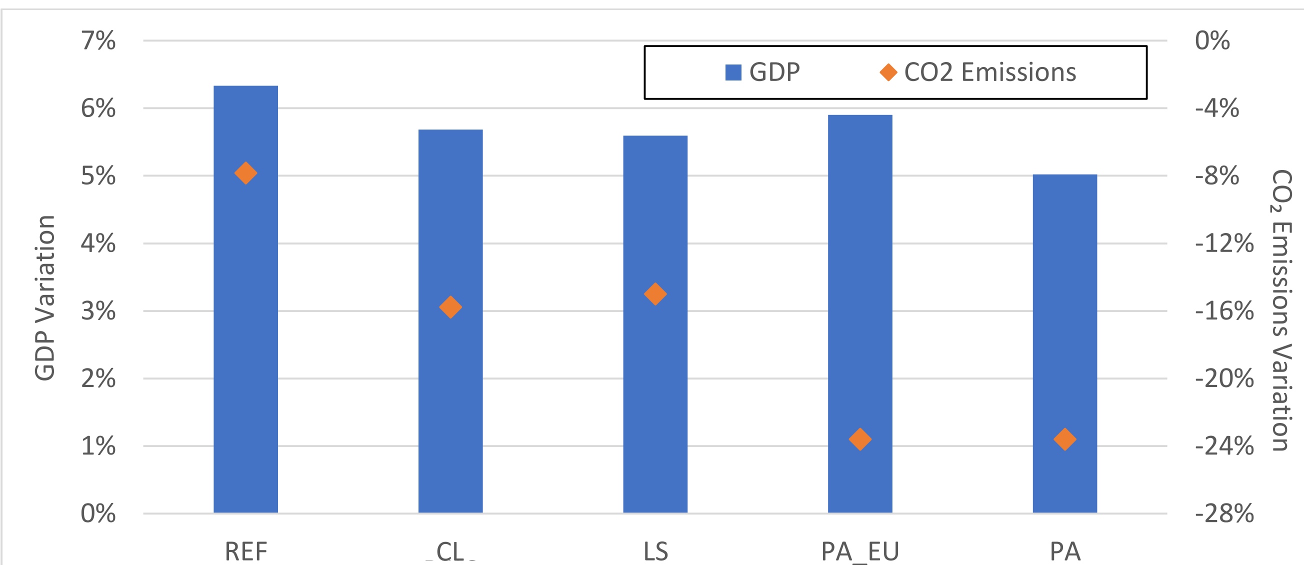
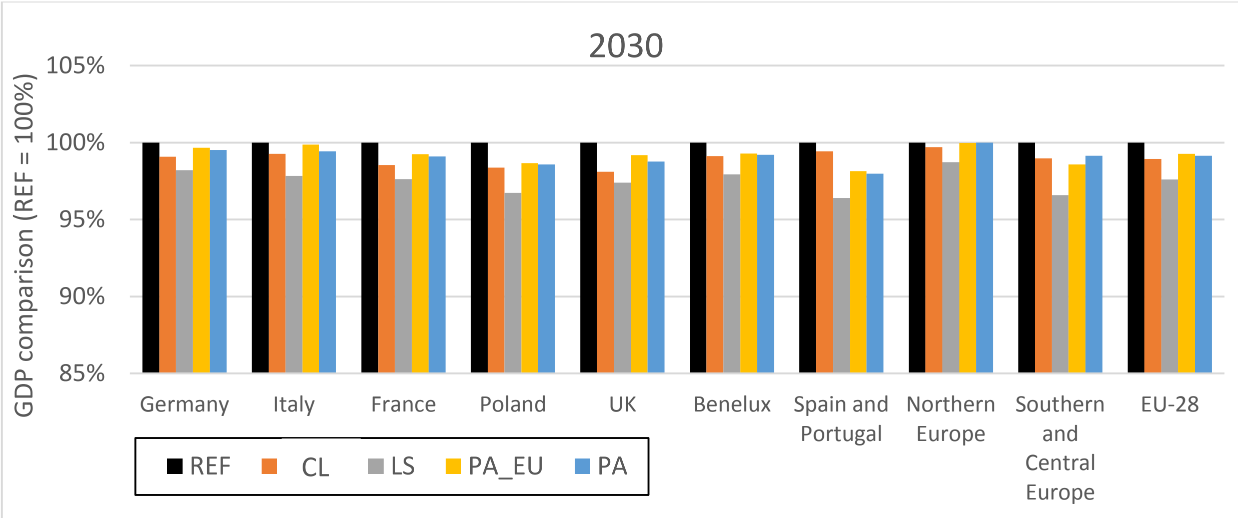


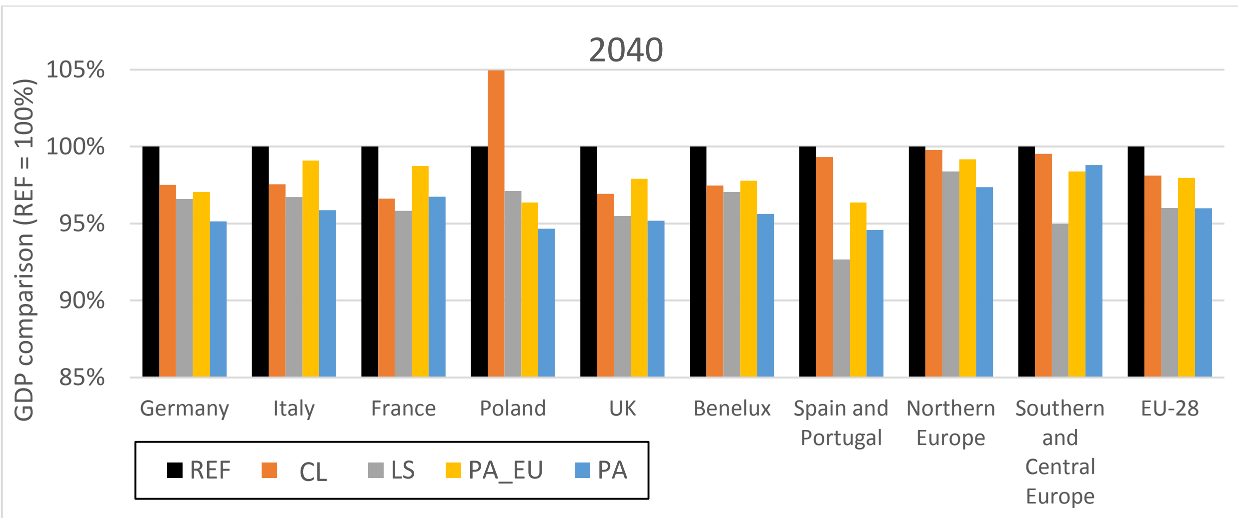
Figure 10: Average time-step (five-years) variation compared to the previous time-step of GDP and CO_2 emissions between 2015 and 2050 in the EU-28. Source: Authors

In a closer look of the effects of each pathway in specific regions, we use Figure 11 to depict the difference between Reference scenario and the other counterfactuals for the nine EU-28 regions modelled in NEWAGE for three different years: 2030, 2040 and 2050. The results indicate that in 2030 the Local Solutions pathway has the lowest GDP level among all regions, between 96.6% of Reference scenario for Southern and Central Europe and 98.72% of Reference scenario for Northern Europe, and Coalitions for a Low Carbon Path, Paris Agreement-EU and Paris Agreement being very close to each other, but already lower than the Reference scenario. It is interesting to note that in 2030, for the Northern European Region, there is barely any difference between REF, Paris Agreement-EU, and Paris Agreement due to the already high share of renewable energy in these countries.

In 2040, as the CO_2 cuts increase, the differences between pathways and regions become more apparent. Poland, in 2040, and Southern and Central Europe, in 2050, see higher GDP levels under the Coalitions for a Low Carbon Path due to their lower reduction targets in that pathway, while Portugal and Spain, despite having higher reduction targets, are also better off in the Coalitions for a Low Carbon Path, indicating that they might struggle with the CO_2 cap and trade scheme of the Paris Agreement and Paris Agreement-EU pathways. The remaining regions have either close GDP levels in the Coalitions for a Low Carbon Path and Paris Agreement-EU pathways, such as Germany and Northern Europe, or higher levels under Paris Agreement-EU. Additionally, the difference between Paris Agreement-EU and Paris Agreement, due to lower economic activity in other regions of the world is more apparent and the highest difference is found in Italy, which varies between 99.1% of Reference for the Paris Agreement-EU and 95.9% of Reference for Paris Agreement.

In the final year depicted in Figure 11, 2050, the highest GDP level of the counterfactuals is often under the Paris Agreement-EU pathway, with the exception being Poland and Central and South-Eastern Europe, which are better off under the Coalitions for a Low Carbon Path, again due to their lower CO_2 reduction targets in this case. In this last time-step it is possible to see that instead of Local Solutions, Paris Agreement pathway presents the lowest GDP level for every region. Additionally, the higher difference between Paris Agreement-EU and Paris Agreement is again in Italy, 97.2% of Reference for the first case and 87.9% for the second, showing a difference almost twice as much as in 2040.





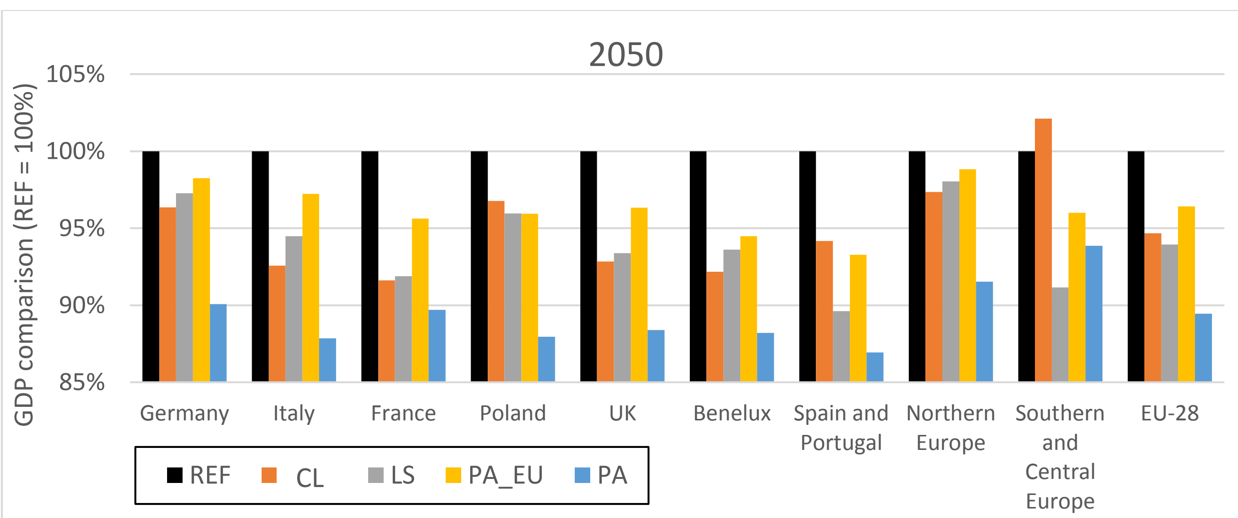


Figure 11: GDP comparison between Reference scenario and counterfactuals (Upper: Year 2030, Middle: Year 2040, Lower: Year 2050). Source: Authors

5.1.2. GVA

Figure 12 shows changes in Gross value Added (GVA) created in energy intensive and other manufacturing industries as well as in service sector of EU-28 under different pathways analysed for years 2030 and 2050 (in comparison to 2011).

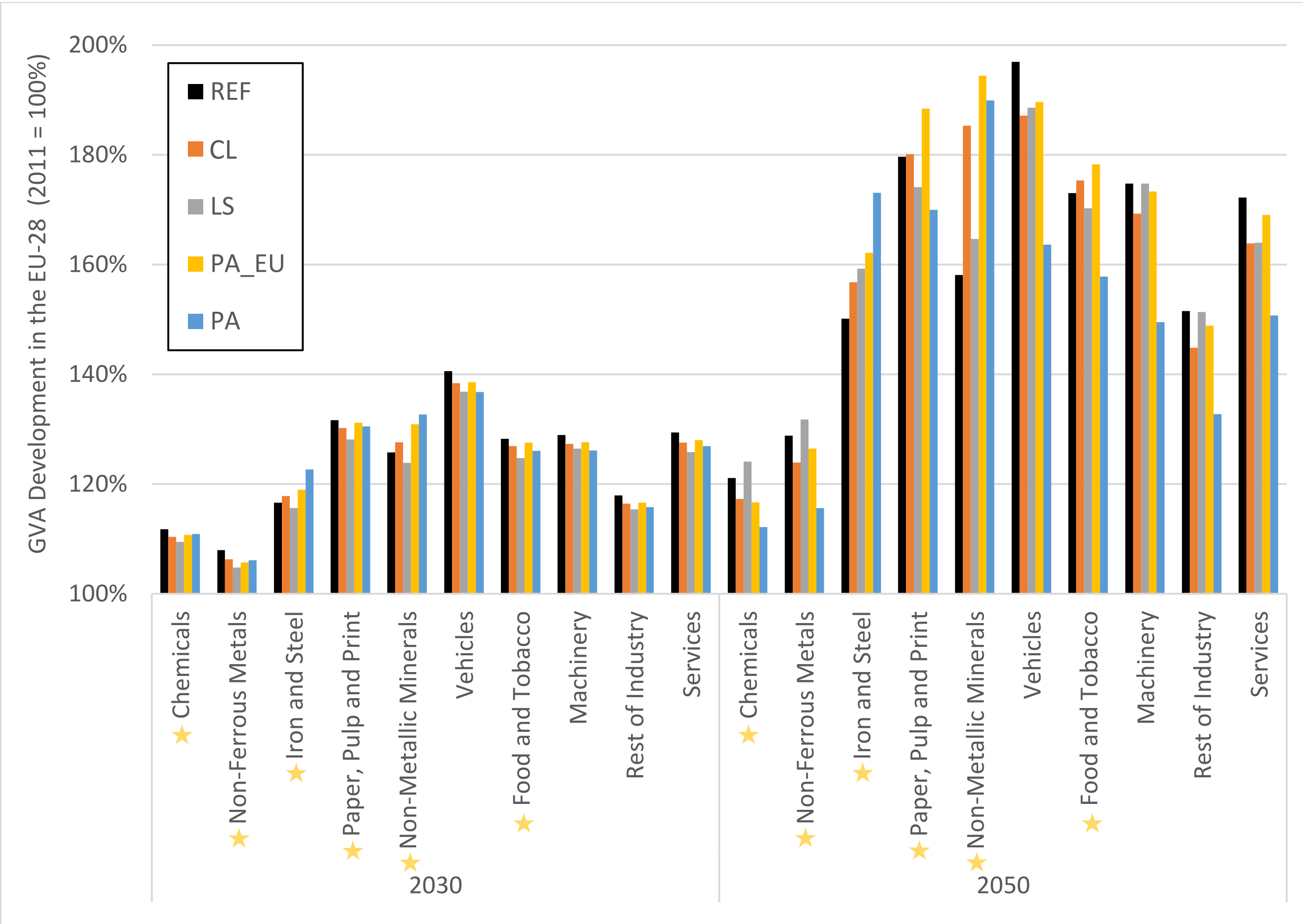


Figure 12: Changes of GVA created in energy intensive and other manufacturing industries as well as in service sector in EU-28 under different pathways (energy intensive sectors are marked with a start). Source: Authors

Over the time, the energy intensive industries demonstrate a potential to increase their GVA under all the pathways. Additionally, non-metallic minerals, paper, pulp and print, food and tobacco and iron and steel demonstrate the highest GVA increase potential under all the pathways analysed. In detail, the GVA from the non-metallic minerals industry increases by 57.8% (Reference scenario) to 63.7–94.1% (alternative pathways) in 2050 disclosing relevant net gains to be achieved under all the alternative pathways analysed. These gains can be explained by the fact that the European non-metallic minerals sector has a global reach, especially cement, flat glass and bricks [24], and as countries outside of the EU increase their environmental protection actions, it is expected that the cost of energy in these regions also increase, making the European products more competitive. The Iron and Steel industry follows the same trend, as its GVA increase rates are from 50.6% (Reference scenario) to 57.1–72.7% (alternative pathways).

Despite high GVA creation potential in the remaining energy intensive industries, the net gains are pathway dependent. In particular, only the Paris Agreement-EU pathway is advantageous to pulp, paper and print, as the

GVA increases by 88.3% in comparison to 79.5% under the Reference scenario. Both the Paris Agreement-EU and the Coalitions for a Low Carbon Path are favourable for GVA creation in food and tobacco industry as the GVA increase rates are of 78.2% and 75.3%, respectively, in comparison to 72.8% under the Reference scenario.

The GVA increase potential is the weakest in chemicals and non-ferrous metals industries. Here GVA increase rates are rather slow. In detail, the GVA increases only by 12.3% (Paris Agreement pathway) to 24.0% (Local Solutions pathway) in chemical while it grows by 14.6% (Paris Agreement pathway) to 31.3% (Local Solutions pathway) in non-ferrous metals industry in 2050. Only under the Local Solutions pathway the net gains of GVA are achieved in that industries while losses are expected from the remaining alternative pathways. This effect can be explained by the fact that the two sectors are mainly focused on the European market, as extra-EU exports accounted for 28% of total sales from the European chemical's sector in 2017 [25] and as for 2011 the non-ferrous metals sectors was facing trade deficit in most of its sub-sectors [26], which added to increasing competitiveness from foreign countries, lead to lower growth potential.

The GVA creation potential in other manufacturing industries, including motor vehicle, machinery and rest of industry, is significant. It is expected that the GVA increases by 63.4% (Paris Agreement pathway) to 96.8% (Reference scenario) in the motor vehicle industry, by 49.5% (Paris Agreement pathway) to 74.7% (Reference scenario) in the machinery industry but by 21.3% (Reference scenario) to 57.8% (Paris Agreement pathway) in the rest of industry. The lower GVA growth under the Paris Agreement pathway is directly connected to the fact that the goods produced by these sectors are sold directly to consumers, which in this pathway have to pay a higher share of their income to energy goods both inside and outside of the EU, decreasing the demand for these items, and leading to a lower GVA growth.

The Service sector, the largest economic sector in EU-28, demonstrates potential for GVA growth as well. Under the Reference scenario the GVA increases by 72.2% in 2050 while its growth potential under the alternative pathways is lower. Under the Paris Agreement pathway, the GVA increase rate is estimated to be the lowest (50.7%). Additionally, since this sector represents the largest share of the economic production in the EU-28, it is possible to see that its development is quite similar to the European GDP, which has the highest growth under Reference, followed by Paris Agreement – EU, Coalitions for a Low Carbon Path, Local Solution and Paris Agreement.

Thus, the analysis of GVA development in EU-28 for years 2030 and 2050 showed that in the long-term energy intensive and other manufacturing industries as well as service sector have GVA growth potential under various levels of decarbonization efforts. Following, the carbon taxation utilized in the Paris Agreement-EU pathway could significantly improve the GVA creation opportunities in pulp, paper and print, non-metallic minerals, food and beverages and the rest of industries, while the Local Solutions could essentially facilitate development of GVA in non-ferrous, chemistry and machinery industries. Finally, when global action towards climate protection increases, as depicted under the Paris Agreement, the general tendency is for GVA growth to stay close to the values from the Reference scenario in 2030 and to slow down in 2050.

5.2. Analysis of income groups

5.2.1. Share of consumption dedicated to energy goods

It is expected that CO_2 cap-and-trade policies will increase the prices of fossil fuel and electricity, as polluting technologies would be penalized with a higher price on their emissions. This section aims at understanding the impact of such taxation in the four different counterfactuals by understanding the change in the share of consumption dedicated to energy goods (EG), including CO_2 pricing, in the five income groups over time. In addition, the development of the absolute expenditure on EG by each group will be displayed to determine if households are paying more or less for the energy they consume.

The share of consumption dedicated to EG by income group in the EU-28 can be seen in Figure 13, where the development of expenditures on EG is also displayed. To create this figure, we calculated the average share of EG in total consumption for each of the nine regions into which the EU-28 was divided in the NEWAGE model and for each income group. The EG in this context includes expenditures on electricity, natural gas, oil products, coal and the respective amount paid for the CO_2 cap and trade system on each of the fossil fuels. Finally, the years 2011, 2030, 2040 and 2050 were chosen to be depicted so it is possible to examine the starting point of the analysis together with prospects for the short, medium and long terms.

As shown in Figure 13, in 2011 the average share of total consumption for EG in the EU-28 varies between 7.6% in the lowest income group (hh1) and 6.2% in the highest income group (hh5). As time progresses, this share decreases for every scenario and income group, however, the highest decline occurs in the Reference scenario, from 7,6% to 4,4% in the lowest income group (hh1) and from 6.2% to 3.2% in the highest income group (hh5). In parallel, it is possible to see that the expenditure on EG for this scenario also decreases as time progresses, indicating a reduction in the demand for energy, caused by increasing energy efficiency. The reduction of expenditure has a low variation among income groups, as in 2050 the lowest income households (hh1) pay on average 96% of what they were paying in 2011 and the highest income households (hh5) pay 93%.

Coalitions for a Low Carbon Path and Local Solutions pathways have similar results due to their similar CO_2 targets and cap and trade schemes. While the share of EG in total consumption decreases with time, the expenditure with EG first stays stable, around the same level as 2011, and starts increasing after 2040, reaching its peak in 2050. The fact that expenditure increases with decreasing share of consumption dedicated to EG indicate that the net income of all the households is also increasing, so much that it is able offsets the higher expenditure and even consume more of other goods and, thus, decrease the share of total consumption on EG. As it happened in the Reference scenario, the change in expenditure in EG varies among income groups, and in this case the lowest income groups (hh1) experience the largest increase, of 28% for Coalitions for a Low Carbon Path and 27% for Local Solutions, while for the highest income groups (hh5) these values are 21% for Coalitions for a Low Carbon Path and 19% for Local Solutions.

Finally, Paris Agreement-EU and Paris Agreement pathways also present similar results since they have the same CO_2 reduction targets and cap and trade schemes for CO_2, but present some variation in the late time steps, especially in 2050. In the last time step, for the Paris Agreement-EU pathway, the highest income group (hh5) experiences a larger increase of expenditure on EG in the amount of 32%, in comparison to 30% of the lowest income group (hh1). In the meanwhile, for Paris Agreement pathway the increase of EG expenditure is kept more stable across income groups and around 29%. It is worth noting that while expenditure for EG decreases as we move from Paris Agreement-EU to Paris Agreement pathway, the share of consumption for EG increases for every income group, which is a consequence of the slower economic growth seen on Paris Agreement. The reasoning here is that despite the decrease in energy spending, when compared to Paris Agreement-EU pathway, the lower income level in Paris Agreement pathway does not allow for increasing the consumption of other goods and, thus, the share of consumption of EG in total consumption is higher.

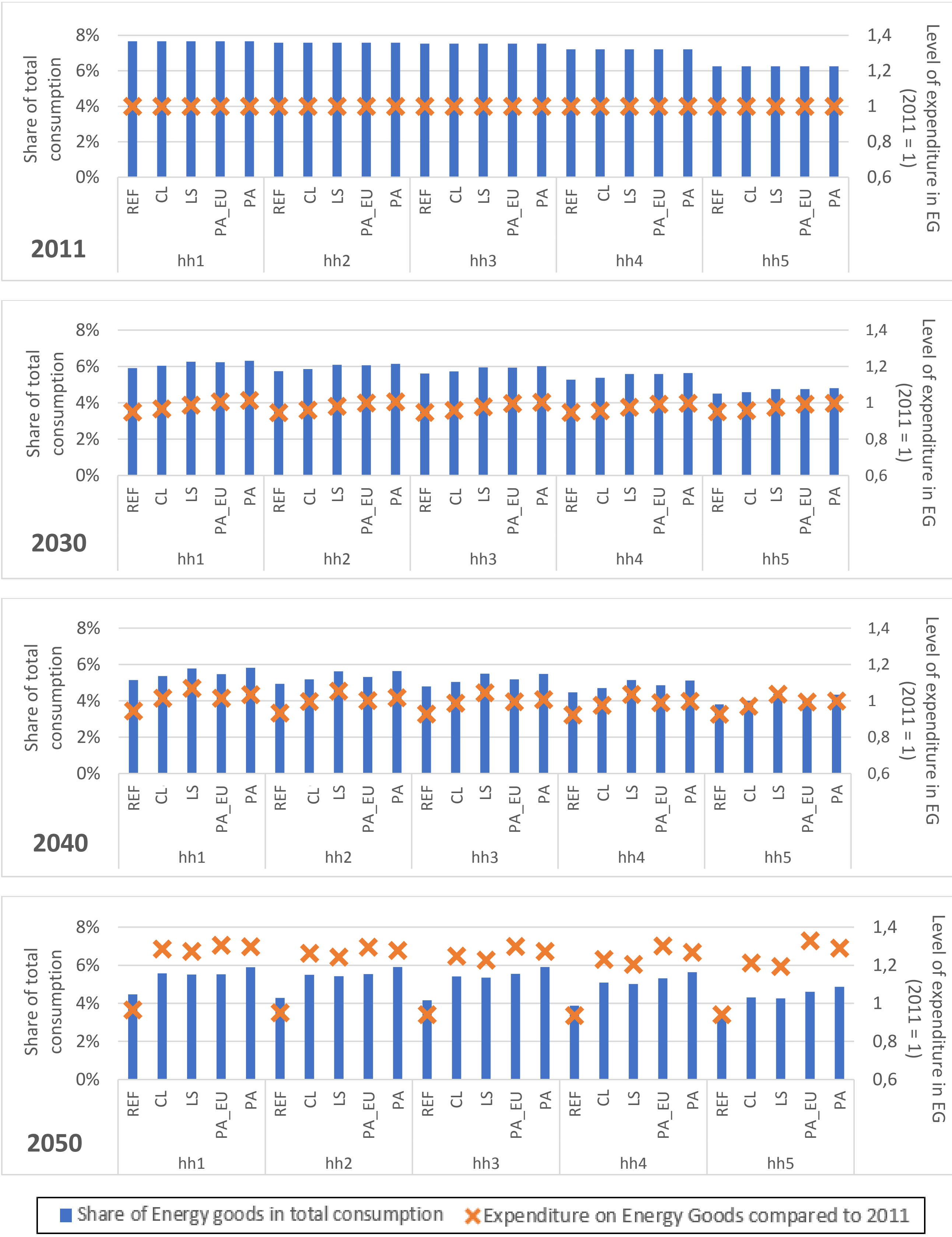


Figure 13: Share of EG in total consumption versus expenditure on EG for selected years in the EU-28. Source: Authors

Figure 14 shows the average distribution of specific energy goods in the EU-28 in 2011, 2030, 2040 and 2050 for the lowest (hh1) and the highest (hh5) income groups. It shows that in 2011 the highest income group already consumes a higher share of fossil fuels that the lowest income group and this pattern is kept throughout all the times-steps. Additionally, since the highest income groups can afford higher energy costs, they end up consuming a higher share of energy goods consumption with oil products and, also, with the respective CO_2 payments. On the other hand, the lowest income group consumes a higher share of electricity and lower share of oil products and CO_2 payments. Finally, the results indicate that the Paris Agreement-EU and Paris Agreement pathways lead to the lowest share of fossil-fuel among energy goods in the highest income group, while for the lowest income groups the shares are quite close among all the counterfactuals. Finally, it is possible to perceive a drastic increase in the share of CO_2 payments as part of the energy goods from 2040 to 2050, which is caused by a rapid increase of the carbon price and elevates the expenditure on EG, as seen in Figure 13.

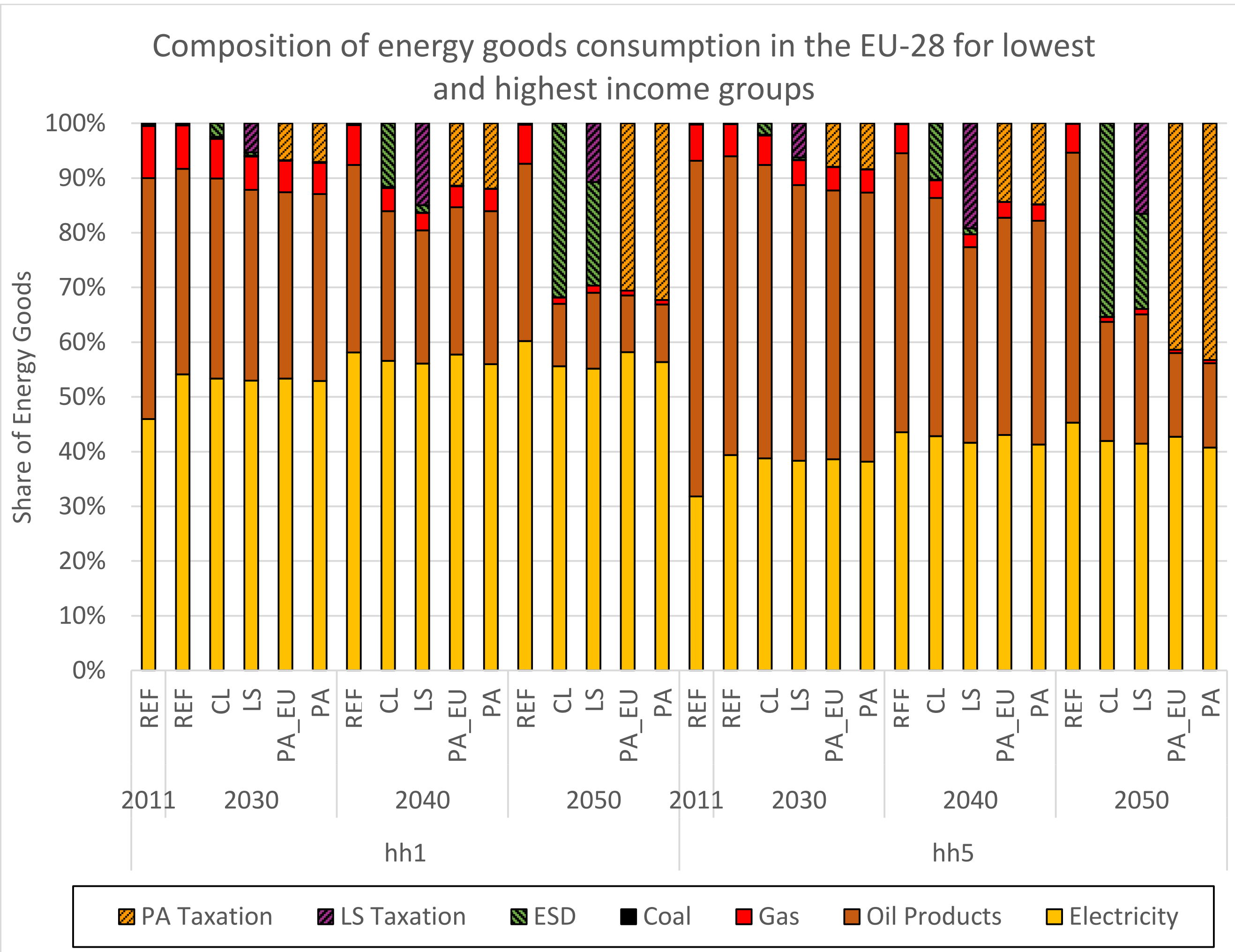


Figure 14: Consumption of specific EG in the EU-28 according to income level. Source: Authors

5.2.2. Income development for different income groups

The development of gross income is depicted in Figure 15, where the values are shown relative to 2011, disaggregated between the lowest (hh1) and highest (hh5) income groups for years 2011, 2030, 2040 and 2050 and for all pathways in the EU-28. The results indicate that the development of gross income is similar to the growth of GDP for the counterfactual pathways, where Paris Agreement-EU pathway exhibits the highest growth, of 70% and 68% for highest and lowest income groups respectively and Paris Agreement pathway exhibits the slowest growth, of 56% and 52% for highest and lowest income groups respectively. In contrast to the development of the GDP, the development of gross income in the Reference scenario is not higher than in the counter-factual pathways, as it can be seen in Figure 7.

It can be seen from the results that for years 2030 and 2040, the income development is higher for the highest income group in every pathway, however, the difference is always higher for the Reference scenario. Following, in the year 2050, the Reference scenario has again a higher income for the highest income group, while for the counterfactuals the growth of income for the two income groups is either equal, as seen on the Coalitions for a Low Carbon Path, or higher for the lowest income group, for the remaining counterfactuals. This behaviour matches the results shown in Figure 14 where the highest income groups, especially in the year 2050, dedicate a higher share of the consumption of energy goods to CO_2 payments. The results depicted in Figure 15 suggests that carbon cap and trade has the potential to work as a tool for preventing the growth of income inequality because lower income households have a high share of their gross income from government payments, as shown in Figure 6. With that in mind, it is possible to understand that by increasing carbon payments, and thus the payments from government to households, even with each income group receiving the same amount of payments, the low income households will be the main beneficiary from it and see the highest increase in gross income.

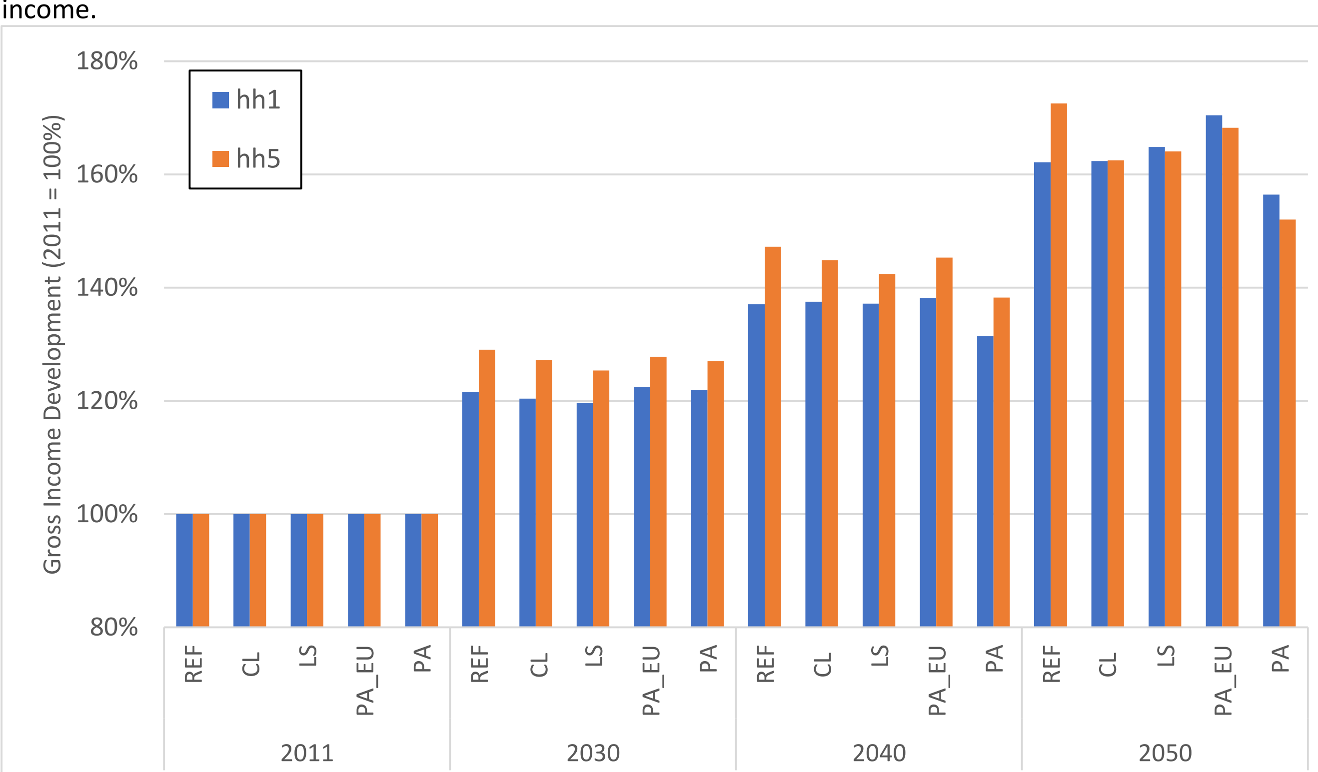


Figure 15: Development of gross income for the lowest (hh1) and highest (hh5) income groups. Source: Authors

5.2.3. Incidence of carbon pricing in different income groups

Figure 16 shows on the primary axis the average share of the gross income of the lowest and highest income groups in the EU-28 dedicated to the payment of carbon on the fossil-fuels they consume and on the secondary axis the ratio between the values displayed in the first axis. Through the results displayed in this figure it is possible to see that in every year and each scenario, the lowest income group has to use more of their gross income to pay for carbon, although the ratio between the two groups decreases as time progresses. In addition, for 2030 and 2040, the ratio between what the two income groups pay is the highest for the Coalitions for a Low Carbon Path and around 3.6, while in 2050 pathway Local Solutions has the highest ratio, of 3.1, followed by 2.9 in the Coalitions for a Low Carbon Path and 2.7 in Paris Agreement-EU and Paris Agreement pathways. The results suggest that the Coalitions for a Low Carbon Path leads to higher imbalances when charging for CO_2 payment to distinct income groups, and the Paris Agreement-EU and Paris Agreement cap and trade system leading to fewer imbalances.

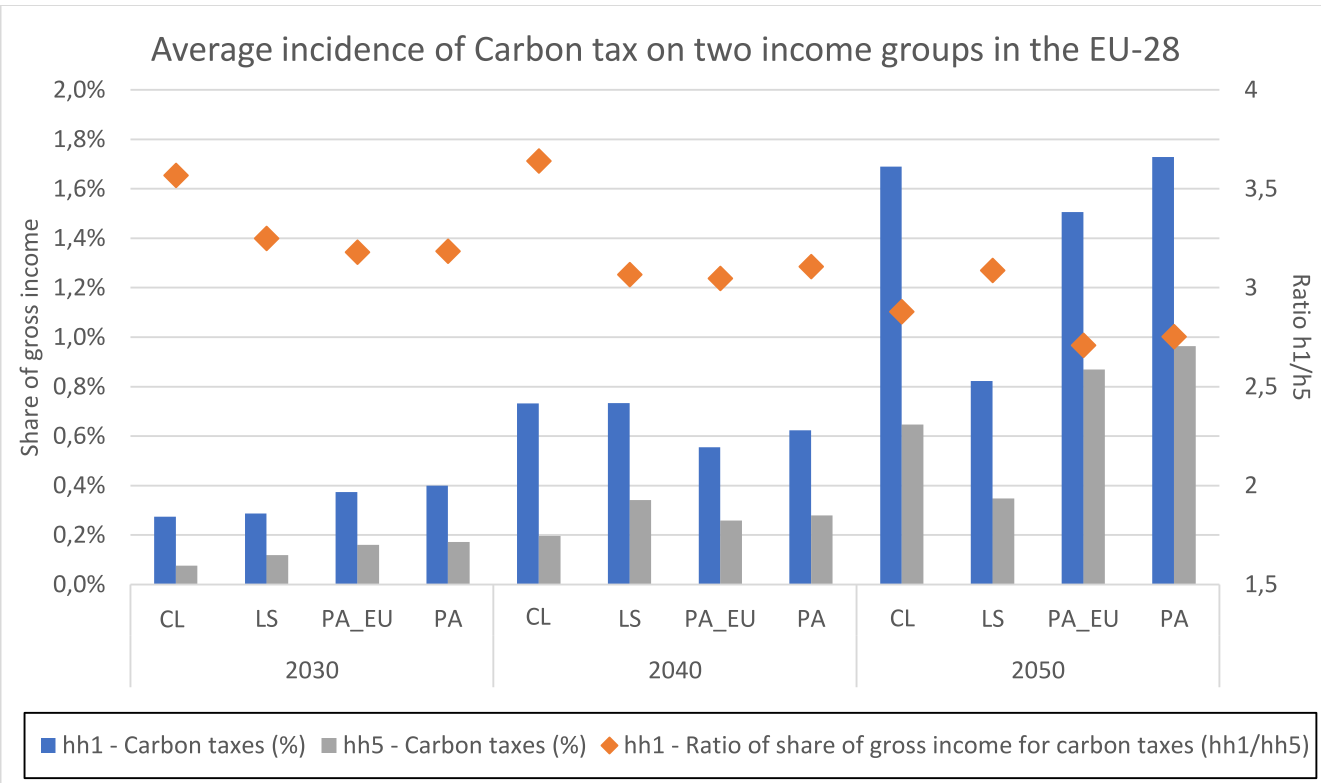


Figure 16: Average share of gross income dedicated for two income groups in the EU-28 versus the ratio between these two groups (hh1/hh5). Source: Authors

6. Conclusions

Throughout this report different aspects of decarbonization pathways were analyzed, from economic growth, with parameters such as GDP and GVA, to impacts on different income groups, through the display of changes on consumption pattern, income development and incidence of carbon payments. The analysis was based on a Reference scenario and four counterfactuals: Coalitions for a Low Carbon Path, Local Solutions, Paris Agreement – EU and Paris Agreement. They differed between one another in aspects such as sectoral coverage of carbon cap and trade scheme, reduction targets for 2050 and international cooperation against climate change. This section summarizes the main insights found for each decarbonization pathway.

Coalitions for a Low Carbon Path

- **Economy – GDP:** The GDP development of the EU-28 in this pathway is quite similar to the Reference scenario until the year 2040, when GDP grows 45% compared to 2011, 3% less than the Reference. On the year 2050 the total growth is of 64%, 10% less than Reference. Poland, Portugal and Spain the Central and South-Eastern European countries have higher GDP growth in this pathway than in any of the counterfactuals.
- **Economy – GVA:** Since there is a higher burden on industry, sectors that are not energy intensive, such as Machinery, Vehicles and rest of the industry, perceive a lower GVA growth on the year 2050 in comparison to the Local Solutions and Paris Agreement – EU pathways. Nevertheless, GVA grows for every sector, ranging from 17% in Chemicals to 87% in the Vehicles' sector.
- **Society – Consumption of energy goods:** While the share of consumption dedicated to energy goods decreases for every income group, the level of absolute expenditure increases after 2040 and in 2050 it is 28% higher than 2011 for lowest income group and 21% higher than 2011 for the highest income group.
- **Society – Income development:** Until 2040 the income of the highest income increases more than the lowest, being 7% higher in both 2030 and 2040. In 2050, however, when carbon payments are at their highest levels, the growth of income for both groups, compared to 2011 levels, is the same.
- **Society – Incidence of carbon payments:** This pathway presents the highest difference between the share of gross income dedicated to carbon payments between the lowest and highest income groups for years 2030 and 2040, when the lowest income group uses 3.6 times more of its gross income than the highest income group. This difference drastically decreases in the year 2050, to 2.9 times, but Coalitions for a Low Carbon Path remains with the second highest difference between the two groups.

Local Solutions

- **Economy – GDP:** The GDP development of the EU-28 in this pathway is lower than the Reference scenario for most years starting in 2025 and very similar to the Coalitions for a Low Carbon Path in 2045 and 2050. In the last time-step, GDP grows 63% compared to 2011, 1% less than the Coalitions for a Low Carbon Path. Additionally, this pathway has a lower reduction of CO_2 emissions than Coalitions for a Low Carbon Path, despite having a lower GDP growth (see Figure 10), indicating that this specific carbon cap and trade scheme is less efficient.
- **Economy – GVA:** In this pathway there is GVA growth for every sector, but the clear winners are Chemicals, Non-ferrous metals, Machinery and Rest of industry, which either outpace the growth from

the Reference scenario or match it. GVA growth in 2050 compared to 2011 varies between 24% for Chemicals and 88% for Vehicles.

- **Society – Consumption of energy goods:** While the share of consumption dedicated to energy goods decreases for every income group, as in the Coalitions for a Low Carbon Path, the level of absolute expenditure increases after 2040 and in 2050 it is 27% higher than 2011 for lowest income group and 19% higher than 2011 for the highest income group, the lowest increase among all counterfactuals.
- **Society – Income development:** Until 2040 the income of the highest income group increases more than the lowest, being 5% higher in both 2030 and 2040. In 2050, however, when carbon payments are at their highest levels, the income for the lowest income group grows 64%, compared to 2011, or 1% more than the richest income group.
- **Society – Incidence of carbon payments:** This pathway presents the second highest ratio of gross income dedicated to carbon payments between the lowest and highest income groups for years 2030, of 3.25 times, and the highest in 2050, when the lowest income group uses 3 times more of its gross income than the highest income group. On the other hand, this pathway also presents the lowest share of gross income dedicated to carbon payments in 2050 among all counterfactuals, ranging from 0.8% to 0.35% for the lowest and highest income groups respectively.

Paris Agreement – EU

- **Economy – GDP:** The GDP development of the EU-28 in this pathway is the highest among the counterfactuals and the highest difference to the Reference scenario is on year 2050, when it grows 67% compared to 2011, 6% lower than the Reference scenario. Additionally, according to Figure 10, this is the most efficient pathway, as it provides the highest GDP growth with the highest reduction of CO_2 emissions.
- **Economy – GVA**: In this pathway, sectors such as Iron and Steel, Paper, pulp and print, Non-metallic minerals and Food and tobacco see higher gains than in the Reference. GVA growth in 2050 compared to 2011 varies between 16% for Chemicals and 94% for Non-metallic minerals
- **Society – Consumption of energy goods:** While the share of consumption dedicated to energy goods decreases for every income group, as in the Coalitions for a Low Carbon Path, the level of absolute expenditure increases after 2040 and in 2050 it is 30% higher than 2011 for lowest income group and 32% higher than 2011 for the highest income group, the highest increase among all counterfactuals. Additionally, since this pathway experiences some of the highest increases of income, the share of total consumption dedicated to energy goods is in the same levels as Coalitions for a Low Carbon Path and Local Solutions pathways, because the higher income still allows the households to consume more of other products despite the higher expenditure on energy.
- **Society – Income development:** Until 2040 the income of the highest income group increases more than the lowest, being 5% higher in 2030 and 7% higher in 2040. In 2050, however, when carbon payments are at their highest levels, the income for the lowest income group grows 70%, compared to 2011, which is the highest growth for this income group in this year, 2% more than the richest income group, the second highest growth for this group in this year.
- **Society – Incidence of carbon payments:** This pathway presents the lowest ratios of gross income dedicated to carbon payments between the lowest and highest income groups for all years, varying between 3.18 times in 2030 to 2.7 in 2050.

Paris Agreement

- **Economy – GDP:** The GDP development of the EU-28 in this pathway is the lowest among the counterfactuals and the highest difference to the Reference scenario is on year 2050, when it grows 55% compared to 2011, 18% lower than the Reference scenario. It is important to notice, however, that the only difference to this pathway and Paris Agreement – EU is the global cooperation for climate protection, and thus the rest of the World also has a lower GDP growth, of 150%, which is 37% lower than the growth in Reference scenario.
- **Economy – GVA:** This pathway presents lower GVA growth than Paris Agreement – EU for every sector, except for Iron and steel, a sector in which the highest GVA growth in 2050 is for pathway Paris Agreement, indicating that in the case where all the regions follow their INDCs, the Iron and steel industry in Europe will become more competitive. Nevertheless, for the remaining sectors, it is possible to perceive the impact of lower economic activity around the world, as the GVA growth is lower than Paris Agreement-EU.
- **Society – Consumption of energy goods:** While the share of consumption dedicated to energy goods decreases for every income group, as in the Coalitions for a Low Carbon Path, the level of absolute expenditure increases after 2040 and in 2050 it is 29% higher than 2011 for lowest income group and 28% higher than 2011 for the highest income group, the second increase among all counterfactuals. Additionally, since this pathway experiences some the lowest increases of income, the share of total consumption dedicated to energy goods is higher than in pathway Paris Agreement – EU, because the higher expenditure together with lower income growth impose a burden on the households which make them cut consumption in other sectors.
- **Society – Income development:** Until 2040 the income of the highest income group increases more than the lowest, being 5% higher in 2030 and 7% higher in 2040, as in Paris Agreement – EU. In 2050, however, when carbon payments are at their highest levels, the income for the lowest income group grows 56%, compared to 2011, 4% more than the richest income group.
- **Society – Incidence of carbon payments:** This pathway presents the lowest ratios of gross income dedicated to carbon payments between the lowest and highest income groups for all years, varying between 3.18 times in 2030 to 2.7 in 2050, the same as in Paris Agreement - EU. However, households pay a larger share of their income to carbon payments compared to Paris agreement – EU, where the lowest income group pays 1.7%, against 1.5% from Paris Agreement-EU and the highest income group pays 0.96% against 0.86% of the Paris Agreement-EU.

After analysing all pathways, the results indicate that there is no case in which every parameter is better than another, but each yields success across at least one parameter. However, it is important to recognize the importance of two factors: the carbon cap and trade scheme and the participation and commitment of countries outside of the EU in the Paris Agreement. The importance of the carbon cap and trade scheme can be shown in Figure 10, where pathway Paris Agreement – EU has the highest GDP growth and highest reduction of CO_2 emissions as all sectors are included in the same cap-and-trade scheme. On the other hand, the EU is still in a connected world where greater action and expenditure by other countries on climate protection decreases their consumption of European goods, which results in lower GDP growth in the EU-28 area, as shown by the Paris Agreement pathway.

The results also indicate that there are beneficial aspects for Europe to pursue higher CO_2 reductions than the rest of the world as the GDP for Coalitions for a Low Carbon Path, Local Solutions and Paris Agreement-EU only start to diverge from the Reference scenario after 2040 and reaches a 10% difference in 2050. Besides the economy, adding a carbon cap and trade system also decreases the difference of income growth between the lowest and the highest income groups. Moreover, besides the fact that the Paris Agreement pathway has the lowest GDP growth among the pathways, the global analysis reveals that that other regions will also face slower GDP growth with the benefit of reaching the targets in line with the Paris Agreement such that the environmental gains should outweigh the slower economic development. Finally, it was shown that after year 2035, when the emission targets become more stringent, the GDP growth of the counterfactual pathways slow down compared to the Reference scenario. These results indicate that removing the last CO_2 emissions from the European economy might be a challenge by means of a cap-and-trade system because, by that point in time, the CO_2 certificates will face a severe scarcity and the price may end up being too high. Therefore, alternatives to the cap-and-trade system need to be evaluated / assessed and brought into force in time to remove the last CO_2 emissions from the economy without harming it.

Regarding the distributional impacts, it was shown that the carbon price paid by different income groups is regressive meaning that the share of income dedicated to the carbon payments decrease as income increases. This indicates, that poorer households will have a higher propensity to reduce their emissions than richer as the carbon price will constitute a higher share of their budget. On the other hand, the results demonstrate that redistributing the revenues from carbon certificates can work as a tool to decrease income inequality, because the poorer households have a higher share of their income coming from government payments and would therefore observe higher gross income growth than richer households.

As for future research based on the questions raised by this work, there are a few aspects that should be further studied. First, as it was shown that non-European countries have a great influence over the economic development of the EU’s economy, the development of different pathways regarding environmental policies implemented outside of the EU and how to respond to them appropriately is especially important in a time of political instability and disagreements with countries such as the United States, Russia and China. Secondly, it is crucial for a better understanding of the real impacts of policies to internalize environmental gains and losses as the costs of environmental measures, or lack thereof, would be more clearly perceived in economic parameters such as GDP and trade balance. Finally, this report considered that all pathways would have the same revenue recycling scheme for the carbon certificates and, as it was shown that redistributing this revenue to the households can have positive effects on diminishing income inequality, new recycling schemes with a focus on low income households should be further studied.

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A.1 Modeling framework

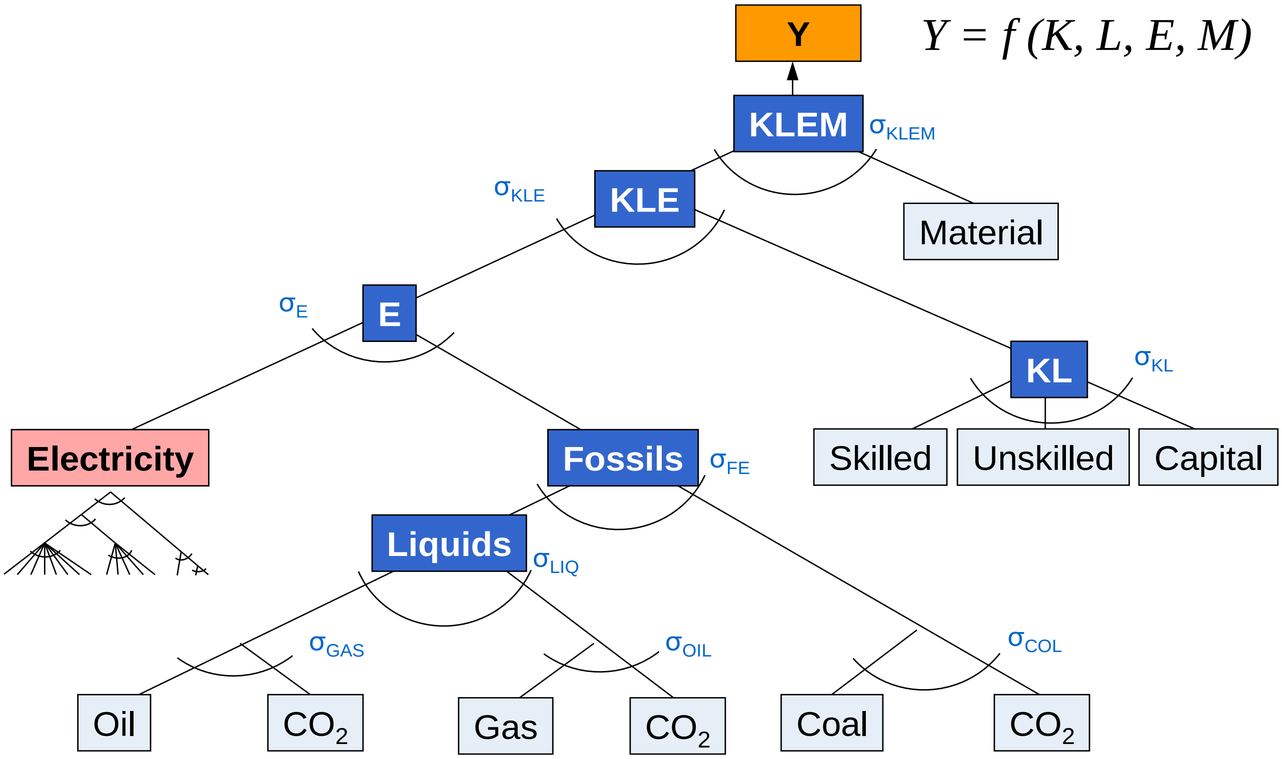

Figure 17: CES structure in NEWAGE for the production sectors

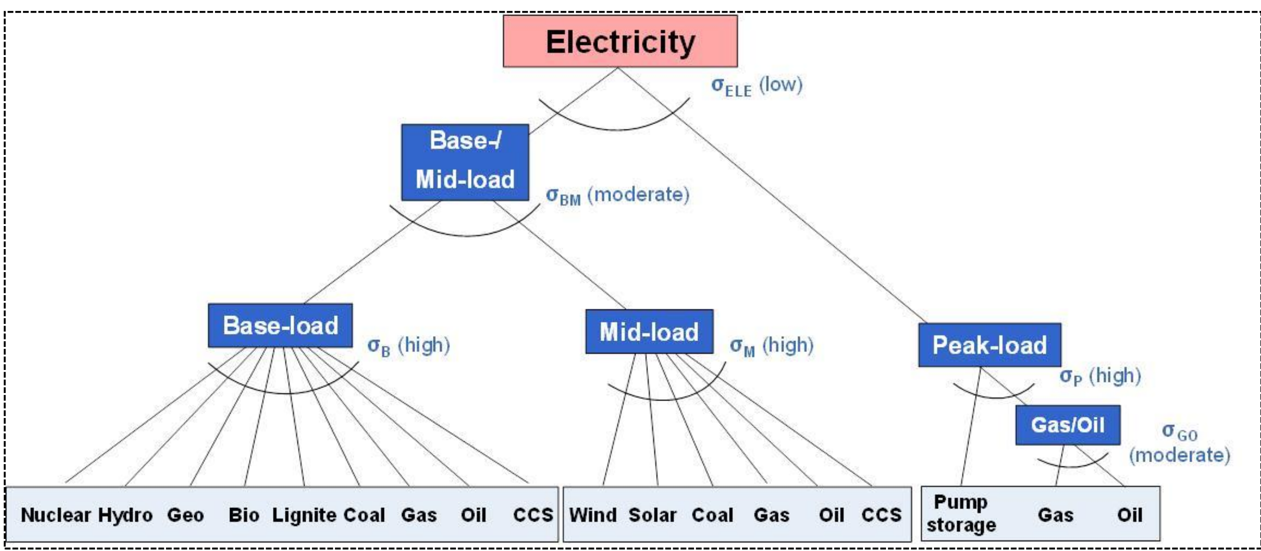

Figure 18: CES structure in NEWAGE for electricity production

Table 2: 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 3: 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

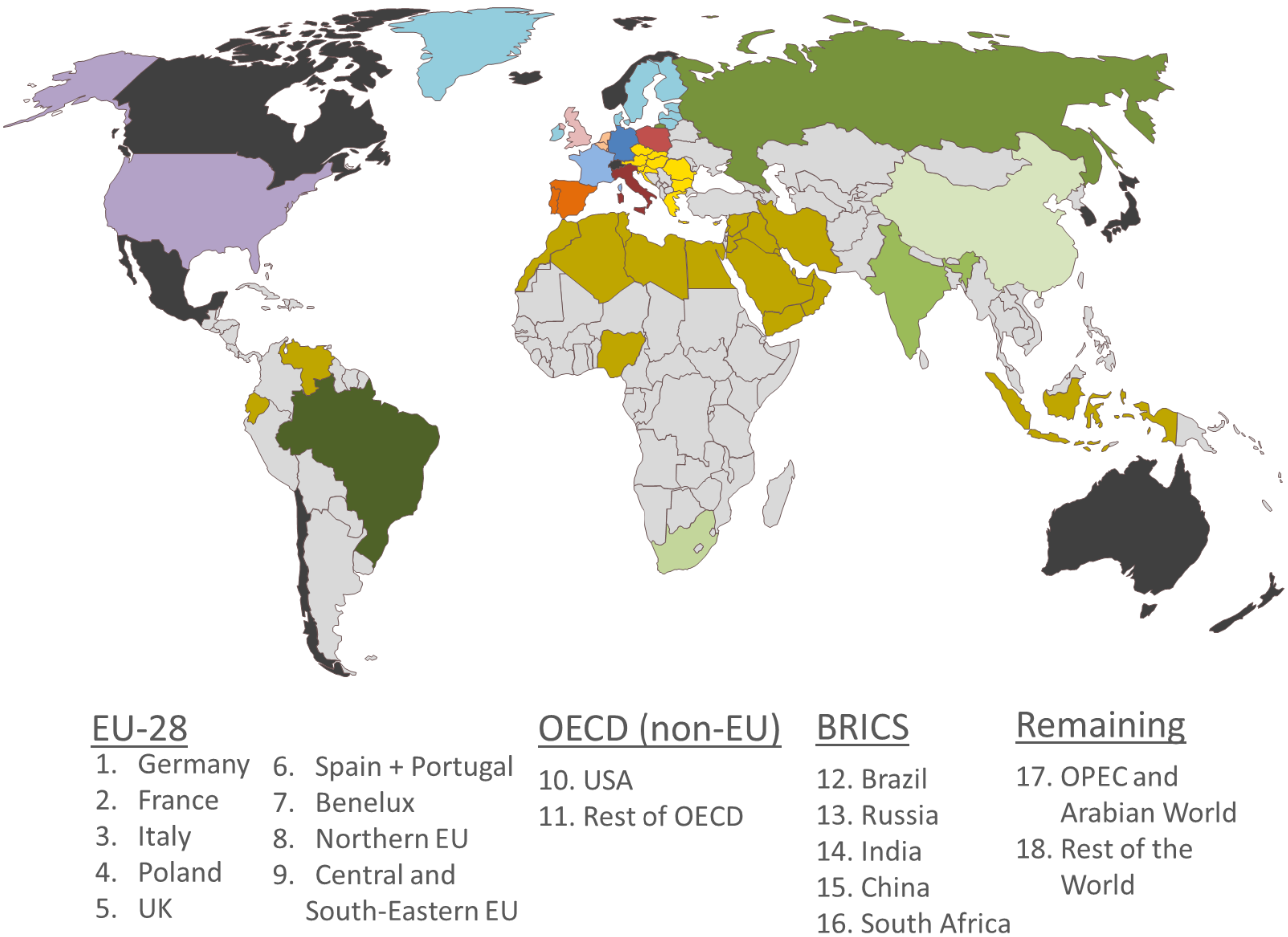

Figure 19: Regional disaggregation in NEWAGE. Each region in the model has its own colour in the map

Table 4: Description of European regions in NEWAGE that are not single countries.

NEWAGE Region	Countries
Spain + Portugal	Portugal, Spain
Benelux	Belgium, Luxembourg, Netherlands
Northern EU	Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Sweden
Central and South-Eastern EU	Austria, Bulgaria, Croatia, Cyprus, Czech Rep., Greece, Hungary, Malta, Romania, Slovakia, Slovenia

A.2 Assumptions

Table 5: 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 6: 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 7: 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 8: 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

Cluster Union

Table 9: 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) –*
EU-28 ETS	-21%	-43%	-83%
	Effort sharing decision (ESD)	Effort sharing decision (ESD-new)	Effort sharing decision (ESD-new)
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[6], or at least more ambitious than the current policies[7].

Since the EU-28 has specific emission targets, Table 15 depicts only the emission targets of NEWAGE's regions outside of the EU that pursue a higher emission cut than the current policies in the Regional Push World state.

Table 10: Emission targets for regions outside of the EU-28 pursuing emission cuts higher than the current policies for the Regional Push World state

Region	CO_2 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

[6] According to the emission path presented in 2DS from [16]
[7] According to the emission path RTS from [16]