Horizon 2020 Societal challenge 5:
Climate action, environment, resource efficiency
and raw materials

COP21 RIPPLES

COP21: Results and Implications for Pathways and Policies for Low Emissions European Societies

GA number: 730427, Funding type: RIA

Deliverable number (relative in WP)	Deliverable 2.4.
Deliverable name:	Report on comparing sectoral and technological transformation in national NDC and 2°C/1.5°C pathways
WP / WP number:	WP 2/ Task 2.4. Disaggregating the assessment of NDCs and 2°C/1.5°C scenarios to provide insights into the required action to be on track to 2°C/1.5°C
Delivery due date:	Month 20 (July 2018)
Actual date of submission:	31/07/2018
Dissemination level:	Public
Lead beneficiary:	CNRS
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Estimated effort (PM):	10
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1. Changes with respect to the DoA

Given that the literature on 1.5°C scenarios has emerged very late and that no publicly available database exists to date for these scenarios, the analysis of 1.5°C scenarios is very limited, contrary to what was envisaged in the DoW.

2. Dissemination and uptake

This research paper will provide input into several policy briefs designed to enhance uptake of the main messages, notably in relation to the first set of COP21 RIPPLES narrative which is concerned about the advantages and disadvantages of increasing ambition in the short term.

3. Short Summary of results (<250 words)

The present contribution goes beyond traditional 'gap analysis', in terms of aggregate emissions, to provide a systemic analysis of the 'transformation gap' between national NDC and 'well below 2°C'/1.5°C scenarios. We use the decarbonisation wedges methodology elaborated by Mathy et al. (2018) which allows quantifying the impact of contrasted sectoral development assumptions and of potential structural change of the economy on mitigation strategy analysis. The methodology is applied to five EU countries: Germany, Italy, France, Poland and UK and to global mitigation scenarios.

Results show the diversity in mitigation actions between Western European countries and Eastern European countries where strong growth of economic and sectoral activities and the coal-intensive energy system raise major mitigation issues.

Whether at the level of European countries or at the global level, the contribution of the decarbonisation of energy carriers increases over time and takes an important role in emission reductions after 2030 as the introduction of new energy vectors necessitates time for development of new infrastructure. The techno-economic feasibility and realism of the high level of energy decarbonisation required after 2030 in NDC scenarios is questionable: carbon capture and storage (CCS) and coal/gas substitution are massively required only after 2030 to decarbonise the power sector. Additional demand-side mitigation actions, the penetration of renewables and an early but gradual decrease in coal capacity in the power sector are the major additional wedges needed to increase NDC ambition before 2030.

This work provides methodological lessons for improving low-carbon scenario modelling approaches and highlights the need to make assumptions on the evolution of sectoral activities more transparent and to systematise the development of contrasted alternatives on structural transformation assumptions.

4. Evidence of accomplishment

A report is submitted and uploaded in the COP21 RIPPLES website.

Abstract

In this deliverable, we provide systematic ex-post analysis of the national scenarios produced at a national level and collated in task 2.1 of the COP21 RIPPLES project, supplemented with national scenarios produced with the POLES global energy system. For this purpose, we use the decarbonisation wedges (DW) methodology elaborated by Mathy et al. (2018). The methodology splits forecast energy-related emissions up to 2050 into 10 decarbonisation wedges with six DWs on the demand side (energy efficiency and decarbonisation of energy carriers in buildings, transport and industry) and four DWs in the power sector (coal/gas substitution, renewables, nuclear, carbon capture and sequestration (CCS).

The present contribution goes beyond traditional 'gap analysis', in terms of aggregate emissions, to provide a systemic analysis of the 'transformation gap' between national NDC and 'well below 2°C'/1.5°C scenarios. The DW allows quantifiying the impact of contrasted sectoral development assumptions and of potentiel structural change of the economy on mitigation strategy analysis. We apply the methodology to global mitigation scenarios and to five EU countries: Germany, Italy, France, Poland and UK that represent on aggregate 2/3 of current EU emissions.

Results show the diversity in mitigation actions between Western European countries and Eastern European countries where strong growth of economic and sectoral activities and the coal-intensive energy system raise major mitigation issues.

One main issue highlighted by the analysis is that whether at the level of European countries or at the global level, the contribution of the decarbonisation of energy carriers increases over time and takes an important role in emission reductions after 2030 as the introduction of new energy vectors necessitates time for development of new infrastructure. The techno-economic feasibility and realism of the high level of energy decarbonisation required after 2030 in NDC scenarios is questionable: CCS and coal/gas substitution are massively required only after 2030 to decarbonise the power sector. Additional demand-side mitigation actions, the penetration of renewables and an early but gradual decrease in coal capacity in the power sector before 2030 are the major additional wedges needed to increase NDC ambition.

This work also provides methodological lessons for improving low-carbon scenario modelling approaches and highlights the need to make assumptions on the evolution of sectoral activities more transparent and to systematise the development of contrasted alternatives on structural transformation assumptions.

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1. Introduction

The Paris agreement is based on implementation of Nationally Determined Contributions (NDC). This framework has two direct implications. First, this bottom-up approach demands an understanding of the domestic dimension of development pathways and their implications for emissions trajectories. Second, it raises the question of whether the NDCs match the global objective of the Paris Agreement to keep global warming well below 2°C, and pursue efforts to limit the increase to 1.5°C.

Extensive literature has explored this issue, leading to the general conclusion that there is a global 'emissions gap' between NDCs and 2°C trajectories: greater efforts will be needed to keep global warming below 2°C by the end of the century. So the 2030 NDC targets should be more ambitious.

The present contribution aims to go beyond traditional 'gap analysis', in terms of aggregate emissions (UNEP, 2015), to provide a systemic analysis of the 'transformation gap' between national NDC and 'well below 2°C'/1.5°C scenarios. For this purpose, we use the decarbonisation wedges (DW) methodology elaborated by Mathy et al. (2018). This entails index decomposition analysis (IDA), which quantifies the contribution of the various mitigation options in scenarios. The methodology splits forecast energy-related emissions[1] up to 2050 into 10 decarbonisation wedges with six DWs on the demand side (energy efficiency and decarbonisation of energy carriers in buildings, transport and industry) and four DWs on the supply side (all these wedges refer to the power sector: coal/gas substitution, renewables, nuclear, carbon capture and sequestration (CCS)).

The specificity of the DW approach is the focus on activity levels, as it allows to consider the "structural transformation gap" effects and to quantify the impact of contrasted sectoral development assumptions and of potentiel structural change of the economy on mitigation strategy analysis.

Using the DW methodology we perform systematic ex-post analysis of the national scenarios produced at a national level and collated in task 2.1 of the COP21 RIPPLES project, supplemented with national scenarios produced with the POLES global energy system.

We apply the methodology to global mitigation scenarios and to scenarios for 5 EU countries (Germany, Italy, France, Poland and UK that represent on aggregate 2/3 of current EU emissions) produced at a national level and collated in task 2.1 of the COP21 RIPPLES project.

This information will provide a detailed understanding of the required transformation of the energy system across energy supply, transformation and consumption, and reveal the direction of future technological deployment. This methodology will be applied to NDC pathways and to 'well below 2°C'/1.5°C pathways and will enable us identify the energy system transformation gap between NDC and 'well below 2°C'/1.5°C pathways according to DWs at the national level.

[1] Only CO_2 emissions from energy are considered, which includes CO_2 emissions from combustion of fuels in energy industries (electricity or heat generation for example), manufacturing industries (emissions from fuel combustion in coke furnaces is included), transport, residential and service sectors, etc. It does not include fugitive emissions from fuels, emissions from industrial processes such as mineral industry (iron and steel, cement, glass, chemicals, etc.), and emissions from forest land, cropland, etc. (cf IPCC definitions).

In the second section, we describe the DW methodology and the scenarios to which we apply the methodology. The third section presents the national results for Germany, France, Italy, Poland and the UK. The fourth section analyses the aggregation of results and the fifth compares results at the EU-5 level with DWs at the global level relying on scenarios built with the POLES model. The sixth section discusses the results in a policy and a methodology perspective.

2. Methodology and scenarios

2.1 Decarbonisation Wedges Methodology

The decarbonisation wedges methodology (Mathy S., *et al.,* 2018) goes beyond the traditional gap analysis by quantifying the contribution of different mitigation options. This methodology can be used at global, regional or national, as well as at sectoral scales. We describe this methodology in the following.

Various methods are available for analysing the factors explaining the evolution of emissions, such as econometric regression or decomposition analysis. IDA is widely used for this type of study (Wang et al., 2005; Xu and Ang, 2013) and, as detailed in Ang (2004), these methods can be grouped into four main types: Laspeyres, Shapley/Sun, Logarithmic Mean Divisia Index (LMDI), and other Divisia Index methods. While other decomposition methods leave a residual term in the decomposition results, the LMDI methodology presents an ideal decomposition without residue.

In the general formulation of LMDI (see Ang, 2005) emissions at year *t* C^t can be broken down as $C^t = X_1^t \times X_2^t \times \ldots \times X_n^t$,

With the variation of emissions being:

$$\Delta^{tot} = C^T - C^0 = \Delta^1 + \Delta^2 + \cdots + \Delta^n, \text{ with } \Delta^k = \frac{C^T - C^0}{\ln(C^T) - \ln(C^0)} \times ln\left(\frac{X_T^k}{X_0^k}\right) \qquad \text{(Eq. 1)}$$

As the total emissions evolution in a country is the sum of emissions evolution in building (B), transport (T), industry (I) and electricity (E), $\Delta^{tot} = \Delta^B + \Delta^T + \Delta^I + \Delta^E$, we apply the LMDI methodology to each of the four sectors. In the sectors with a final energy demand (*s*=*B*, *T* or *I*), the Kaya identity is written at period *t:*

$$C_s^t = \frac{C_s^t}{FE_s^t} \times \frac{FE_s^t}{ACT_s^t} \times ACT_s^t = DECARB_s^t \times EFF_s^t \times ACT_s^t \qquad \text{(Eq. 2)}$$

With C_s^t the sectoral emissions in sector *s* at time *t*, FE_s^t the final energy consumed in the sector, and ACT_s^t the sectoral activity indicator. Any evolution of emissions in the sectors can then be broken down into three effects:

1. an energy carbon-content effect: $DECARB_s^t = \frac{C_s^t}{FE_s^t}$;

2. an energy-efficiency effect : $EFF_S^t = \frac{FE_S^t}{ACT_S^t}$;
3. an activity effect: ACT_S^t.

In the power sector decomposition reveals the specificity of decarbonisation strategies in this sector. As two-thirds of world electricity is still generated using fossil fuel, mostly coal, when choosing a decarbonisation pathway in the power sector, two main families of strategies are possible: either to organise a direct transition from CO_2 intensive conventional fossil fuels to clean energy technologies, or to switch from coal to gas prior to full penetration of decarbonised energies. Large availability of unconventional resources in some regions and changes in the relative prices of energy resulting from higher carbon values (because of proactive international climate policy) will encourage such coal/gas substitution in the electricity sector in the short to medium term. But the compatibility of this option with full decarbonisation of the energy system during the second half of the 21st century is questionable. We consequently consider the following decomposition of CO_2 emissions in the power sector:

$$C_E^t = ELEC^t \times [FF^t \times (Coal\_FF^t \times e_C^t \times CC^t + (1 - Coal\_FF^t) \times e_G^t) + (1 - FF^t) \times e_{NC}^t] \quad \text{(Eq. 3)}$$

With:

- $ELEC^t$ total electricity generation
- FF^t the share of conventional sources of fossil fuels in the electricity mix to account for the penetration of low-carbon power generation technologies in the mix
- $Coal\_FF^t$ and $Gas\_FF^t = 1 - Coal\_FF^t$ the respective coal and gas shares within the fossil fuel mix to account for coal/gas substitution
- e_C^t and e_G^t the emission rates of electricity with conventional coal and conventional gas
- e_{NC}^t the emission rate of electricity with decarbonised energies

Low-carbon power generation technologies include renewables and nuclear energy that do not directly emit CO_2 and carbon capture and sequestration (CCS) with very low CO_2 emissions as follows: $C_{CCS}^t = ccs_C^t \times CCS_C^t + ccs_G^t \times CCS_G^t$. with CCS_C^t and CCS_G^t the production of electricity using CCS with coal or gas respectively; and ccs_C^t and ccs_G^t the emission rates of CCS plants with coal and gas.

Considering that negative emissions can be projected by models in ambitious climate policy scenarios (especially in the power sector) and are a very common outcome of IAMs after 2040 due to massive penetration of biomass with CCS technologies (BCCS), the DW methodology includes BCCS among low-carbon power generation technologies. Such negative emissions are written $C_{BCCS}^t = bccs_C^t \times BCCS_C^t$, with $bccs_C^t$ the negative rate of emission of BCCS technologies and $BCCS_C^t$ the production of electricity with BCCS technologies.

Total emissions from electricity generation are then:

$$C_E^t = ELEC^t \times [FF^t \times (Coal\_FF^t \times e_C^t + (1 - Coal\_FF^t) \times e_G^t) +] + (ccs_C^t \times CCS_C^t + ccs_G^t \times CCS_G^t) + (bccs_C^t \times BCCS_C^t) \quad \text{(Eq. 4)}$$

$$C_E^T - C_E^0 = \Delta^{ACT\_E} + \Delta^{SUBST\_E} + \Delta^{DECARB\_E} + \Delta^{CE\_E} \quad \text{(Eq. 5)}$$

Four effects are then considered in the power sector: i) Δ^{ACT_E}, the activity effect ; ii) Δ^{SUBST_E}, the coal/gas substitution effect; iii) $\Delta^{DECARB_E}$the decarbonised-technology penetration effect (taking into account emissions from CCS); iv) Δ^{CE_E}, the carbon-emissions content of conventional fossil fuel plants, which refers to the carbon content of primary fossil energies used to produce one unit of electricity. This last effect aggregates the energy-efficiency evolution of conventional fossil-fuel plants and the evolution of the carbon content of coal and gas that may differ according to region and time.

The size of Δ^{DECARB_E}, the decarbonised-technology penetration effect, is directly related to the aggregate share of clean-energy technologies in the generation mix. We attribute the contribution of each clean-energy technology according to its share in the additional generation of clean-energy technologies. This allocation is computed for each decarbonised technology. The contribution of CCS is decreased by the amount of residual emissions C_{CCS}^t and the contribution of BCCS is increased by the negative emissions the BCCS technology absorbs.

At the economy-wide level, the aggregation of Equations 2 and 4 leads to the following decomposition[2]:

$$\Delta^{tot} = C_T - C_0 = \sum_{s \in \{B,T,I\}} (\Delta^{ACT\_S} + \Delta^{EFF\_S} + \Delta^{SUBST\_S}) + \Delta^{ACT\_E} + \Delta^{SUBST\_E} + \Delta^{DECARB\_E} + \Delta^{CE\_E} \quad \text{(Eq. 6)}$$

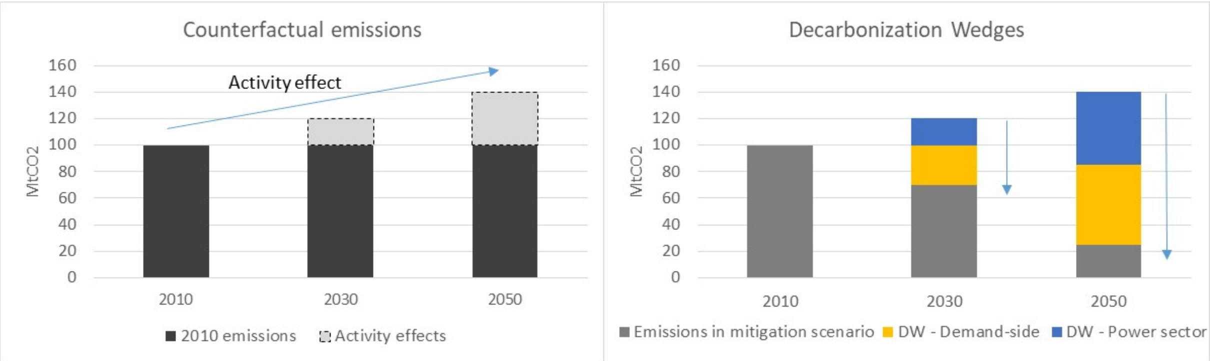
In the following, as it was not possible to gather required data in all the scenarios considered in the report, we do not consider energy efficiency for the thermal generation of electricity. In all we consider in the following 10 DWs with six DWs on the demand side (energy efficiency and decarbonisation of energy carriers in buildings, transport and industry) and four DWs on the supply side (all these wedges refer to the power sector: coal/gas substitution, renewables, nuclear, carbon capture and sequestration (CCS)).

2.2 DW Interpretation

The DW method, which does not rely on a baseline scenario, makes it possible to estimate the wedges in relation to a fictitious counterfactual scenario. For each mitigation scenario there is a counterfactual scenario. It is a projection of CO_2 emissions considering the evolution of sectoral activity indicators in the mitigation scenario between 2010 and 2050 (variations in the number of square metres, pass.km, etc.) while energy efficiency and the energy mix in each sector remain unchanged compared to 2010 (Figure 1). This is different from what is usually called a baseline or reference scenario. In a baseline or reference scenario, there is always autonomous technical change and price-induced technical progress that leads to improved energy efficiency, to the penetration of new technologies and changes in the energy-mix. The counterfactual method is really helpful for comparing mitigation requirements and strategies between two scenarios which may be computed using different models and/or different evolution of activity in sectors, and for comparing strategies between two countries, which do not have the same level of development or standard of living. This method reveals the impact on emissions of the evolution of sectoral activities.

[2] The precise formulas describing all the effects are given in Mathy et al. (2018)

Figure 1 : Schematic representation and interpretation of the counterfactual scenario and of the decarbonisation wedges



2.2 Ripples Templates: Standardised Reporting of National Decarbonisation Pathways

Each national team of the COP21 RIPPLES consortium has completed common dashboard describing its decarbonisation strategy, offering detailed, structured representation of CO_2-emissions drivers according to the same breakdown of energy demand (residential, services, passenger transport, freight transport, industry and electricity)[3].

In each sector, activity indicators reflect the evolution of demographic and socio-economic trends (population, age structure, degree of urbanisation), macro-economic indicators (GDP, household income, etc.) and lifestyles consistent with the national outlook. The industrial sector is an exception; some national teams provided detailed sub-sectoral activity indicators, but for others, only aggregate information on the evolution of industrial added-value is available. For this reason, industrial added-value has been used as the common indicator for industrial activity in all countries. Table 1 lists the data available on the national dashboards that are used for the LMDI decomposition, and the harmonised template to report national scenarios is given in the appendix.

Table 1– Variables used in the computation of the decarbonisation wedges and outputs

Sectors	Variables (inputs)	Wedges (outputs)
Residential buildings	Square metres Final energy demand Non-electricity CO_2 emissions	Energy efficiency - Residential Energy decarbonisation - Residential
Services buildings	Square metres Final energy demand Non-electricity CO_2 emissions	Energy efficiency - Services Energy decarbonisation - Services
Passengers transport	Total passenger-km Final energy demand Non-electricity CO_2 emissions	Energy efficiency - Passenger transport Energy decarbonisation - Passenger transport
Freight transport	Total tonne-km Final energy demand	Energy efficiency - Freight transport Energy decarbonisation - Freight transport

[3] The dashboard is included in the appendix.

	Non-electricity CO_2 emissions	
Industry	Value added Final energy demand Non-electricity CO_2 emissions	Energy efficiency - Industry Energy decarbonisation - Industry
Power generation	Total electricity generation and details by source and technology Total CO_2 emissions and details by source and technology	Coal/gas substitution Penetration of low carbon technologies in the power sector in which: Renewables Nuclear CCS

2.3 Typology of National Scenarios

We apply the DW methodology to a set of ambitious national and regional mitigation scenarios for the five European countries taking part in the RIPPLES project (France, United Kingdom, Germany, Italy, Poland). All the scenarios considered are consistent with at least a 2°C long-term target and are classified according to a typology of three specific profiles[4].

1. In the NDC+ (NDC to well below 2°C) family, emissions pathways are consistent with the NDC objective in 2030 and the ambition is increased after 2030 to be on track with a 'well below 2°C' target in 2050.
2. In the A2C (Accelerated 2°C) family, pathways are consistent as well with a 'well below 2°C' target but the mitigation objective of climate action is increased in the short term to reach a lower level of emission compared to NDC objectives in 2030.
3. In the 1.5C family, mitigation scenarios are consistent with 1.5°C objectives in 2050.

All the scenarios analysed are taken from the scenario database built in task 2.1. They rely on two specific modelling frameworks:

- Some were computed with national modelling tools either during the Deep Decarbonisation Pathways Project (DDPP, 2015) or others, or specifically during the COP21 RIPPLES project by national country teams;
- Some were computed with the POLES global energy model (see appendix for a description of this model and the modelling protocol used).

[4] All the assumptions of these families of scenarios are given in the scenarios narratives from COP21 RIPPLES.

Table 2: Typology of national scenarios within EU and modelling tools used

	Scenario family		
	NDC+	A2C	1.5C
Germany	Poles	from WI	from WI
France	Poles	Imaclim-France	
Italy	Times Italy	Times Italy	
Poland	MEWA	MEWA	MEWA
United Kingdom	Times UK	Times UK	Times UK

NB: other scenarios developed at the national level were available in the database, but the selection of the scenarios considered in this deliverable sought to privilege the possibility of having for a country two scenarios representing two different families of scenarios constructed with the same model.

3. Evaluation of NDC+ and A2C National Scenarios in EU

Figure 2 shows the emission pathways for the five countries considered in the analysis: Germany, France, Italy, Poland and the UK. In all these countries, the emissions in 2030 in the NDC+ scenario are higher than in other alternatives. Except for Italy, emission reductions in NDC+ are higher during the second period to compensate for this higher trend between 2010 and 2030, and 2050 emissions are lower than in the A2C alternative. NDC+ and A2C emission pathways in alternatives for Italy are on the contrary very close. In Germany, France and Poland 2010-50 carbon budget in NDC+ and A2C scenarios are close, while in UK, NDC+ carbon budget is much higher than in A2C and A2C carbon budget is much higher than in 1.5C scenario (whose emission become negative as soon as between 2030 and 2040). For the two other countries with a 1.5C scenario (Germany and Poland), emissions are much lower throughout the period.

Figure 2: Emissions in national mitigation scenarios for Germany, France, Italy, Poland and the UK

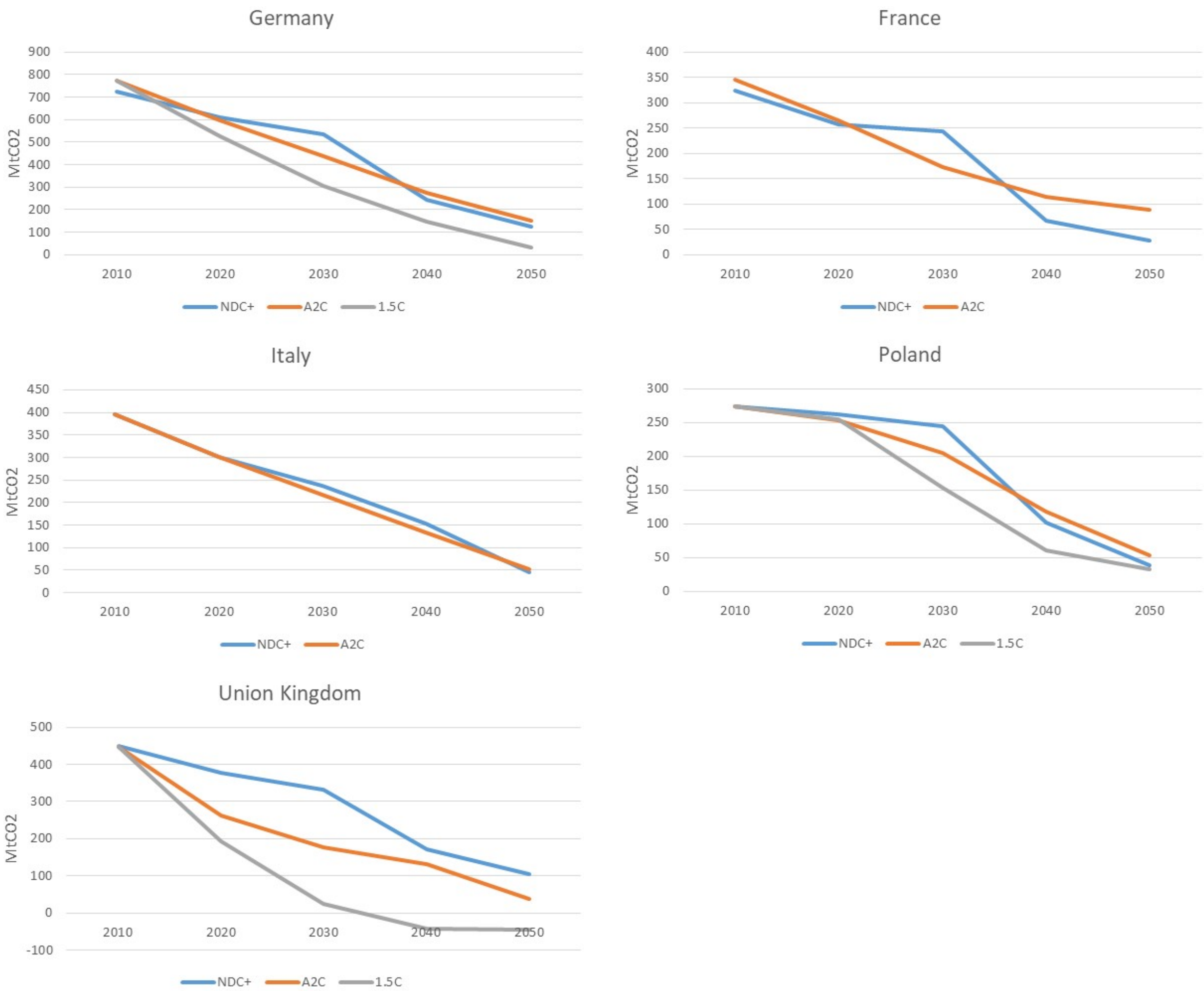


Table 3: Emission reductions in 2030 and 2050 compared to 2010 in national NDC+, A2C and 1.5C scenarios

	DEU			FRA		ITA		POL			UK		
	NDC+	A2C	1.5C	NDC+	A2C	NDC+	A2C	NDC+	A2C	1.5C	NDC+	A2C	1.5C
2030	-26%	-44%	-60%	-25%	-50%	-40%	-45%	-11%	-25%	-44%	-26%	-60%	-95%
2050	-83%	-81%	-96%	-91%	-75%	-89%	-87%	-86%	-80%	-88%	-77%	-92%	-110%

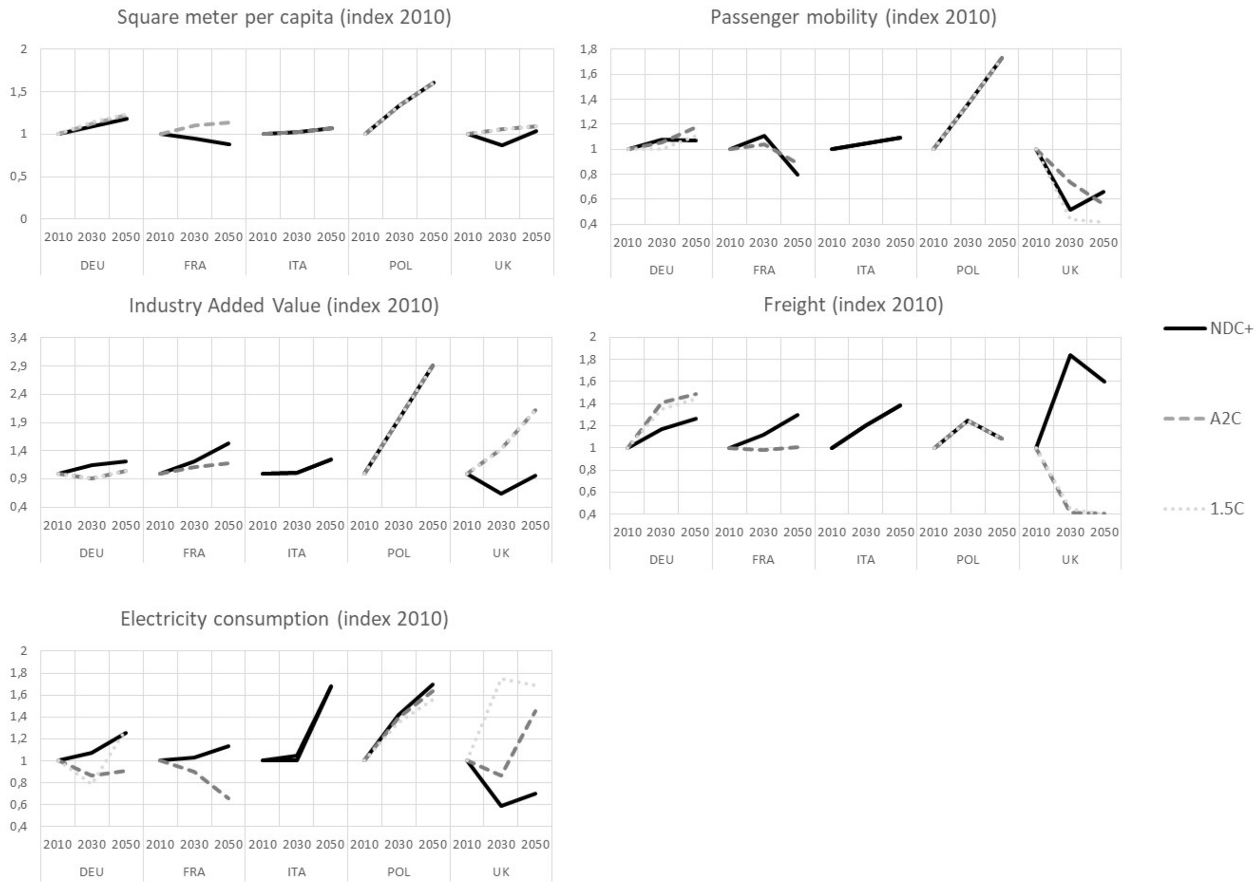
In the next section we apply the DW methodology to all these scenarios to evaluate sectoral and technological decarbonisation efforts.

3.1 The Impact of the Evolution of Sectoral Activity Indicators

We apply the DW methodology to national scenarios with a 20-year step. It measures the wedges over two time periods that are determinant in comparing NDC+ and A2C scenarios for 2010-30 and 2030-50.

Figure 3 describes the evolution of sectoral activity indicators in residential, services, passenger transport, freight transport, industry and the power sector for all scenarios and countries (for more details see the appendix).

Figure 3: Evolution of sectoral activity indicators (index 2010)



NB: Passenger mobility is measured in pass.km and freight activity in tonne.km

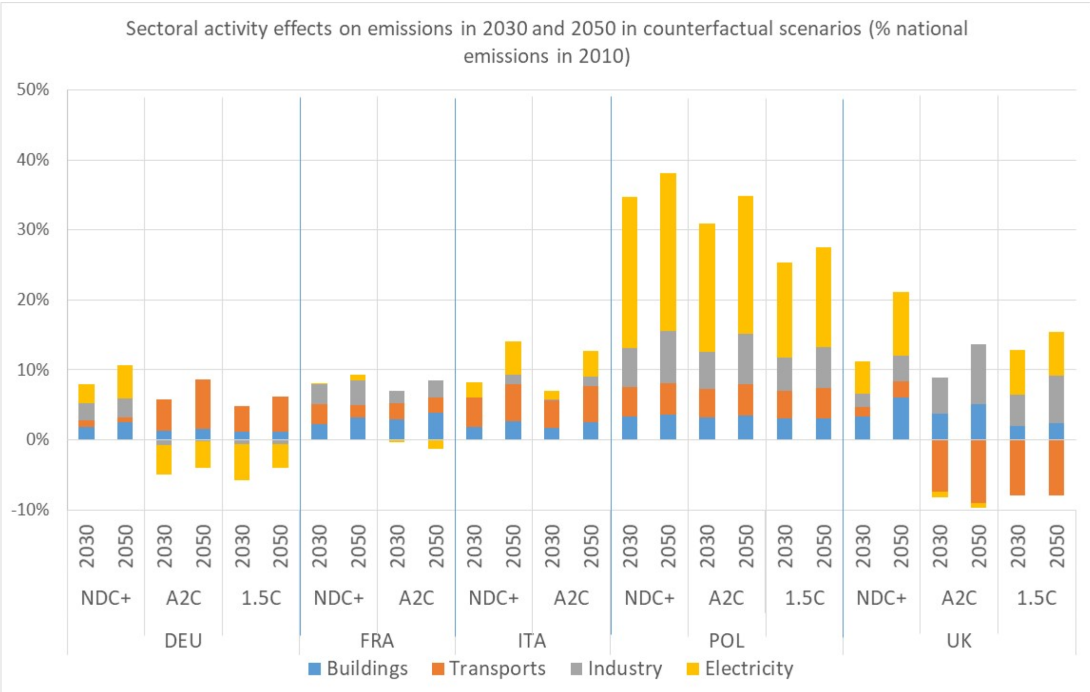
Firstly, the Italy and Poland scenarios consider the same exogenous evolution of sectoral activity indicators (except for the power sector as power generation is endogenously computed in each scenario) in all the scenario families. Second, Figure 3 highlights the important growth of all these sectoral indicators (except for freight) for Poland. This needs to be considered when analysing mitigation strategies, because such sectoral dynamics will make it necessary to implement more extensive decarbonisation actions compared to other countries with a smoother evolution of sectoral

activities. Third, since scenarios for the same country have not always been produced with the same modelling tool (Table 2) or within the same modelling exercise, it may be difficult to interpret and compare changes in sectoral activity indicators across the three scenario families.

As the sectoral activity indicators for a given country may differ in the NDC+ and A2C scenarios, there are two separate counterfactual scenarios for each country. In other words, NDC+ and A2C each have a counterfactual scenario.

Figure 4 shows counterfactual emissions induced by the evolution of sectoral activity indicators. It should be interpreted as follows: according to the NDC+ scenario for Poland, energy-related CO_2 emissions in 2030 would be 35% higher than the 2010-level taking into account changes in sectoral activity indicators in 2010 and 2030 if the energy mix in the various sectors and energy efficiency remain the same as in 2010. The yellow bar concerning the power sector shows the impact on counterfactual emissions of the additional power generation needed to meet sectoral demand in the mitigation scenario.

Figure 4: Sectoral activity effects on counterfactual emissions in 2030 and 2050 (/2010)



In Germany and the UK, sectoral contributions to counterfactual emissions are contrasted, between the NDC+ scenario and the A2C and 1.5C scenarios. This reveals the different scenario design with regard to decarbonisation strategies and the projection of sectoral activity indicators.

In Germany the main difference is due to the contribution of the power sector, which is large in the NDC+ scenario and negative in other scenarios, but with a high contribution from the transport sector. This shows that the NDC+ scenario considers a lower increase in the number of tonne.km and higher

electrification in the transport sector compared to scenarios from WI. In the A2C or 1.5C scenarios, projected power generation trends down, at least during the first period.

In the UK the A2C and 1.5C scenarios, built using the UK Times model, project a significant decrease in freight activity indicators.

In France the contribution of the power sector to counterfactual emissions is quite low as the power sector is largely carbon-free, due to the large share of nuclear energy, and the contribution of each sector is balanced.

In Italy counterfactual emissions are mainly driven by the transport sector and the power sector between 2030 and 2050, because in both alternative scenarios, power generation increases significantly.

In these four countries counterfactual emissions are approximately 10% higher in 2030 and 2050 compared to 2010 except for the UK in the NDC+ scenario in 2050.

Counterfactual emissions in Poland are really contrasted compared to other countries as they are about 30% higher in 2030 compared to 2010 in all scenarios. The power sector, which is currently carbon intensive compared to other countries, is the main contributor, but other sectors contribute significantly as well. The additional increase in counterfactual emission between 2030 and 2050 is much smaller than during the first period mainly because a smaller growth during the last twenty years of the period of the power generation and a decrease in freight activity.

Figure 3 and Figure 4 highlight the importance of considering sectoral activity trends when analysing and comparing mitigation pathways and of making allowance for actions on sectoral demands as a specific mitigation strategy.

3.2 Decarbonisation Wedges in NDC+ and A2C National Scenarios within EU

In Figure 5 DWs are aggregated into an energy efficiency effect (on the five final energy consumer sectors: residential, services, passenger transport, freight transport, industry) and an energy decarbonisation effect (in the power sector and the five final energy consumer sectors). In order to compare DW between countries these effects are expressed in relation to 2010 emissions in each country for the period 2010-30 and for the period 2030-50.

The average role of each effect (over the five countries) is summarised in Table 4.

The role of energy efficiency is nearly the same in NDC+ and A2C. During the first period the effect leads to a reduction in emissions of between 16% and 18% compared to 2010 emissions and during the second period to an additional 10% reduction compared to 2010 emissions. This is not the same with the energy decarbonisation effect. In the A2C scenario, energy decarbonisation leads to emission reductions equal to 33% of emissions in 2010. In the NDC+ scenario, energy decarbonisation plays a

smaller part during the first period (reduction equal to 20% of emissions in 2010) but much greater during the second period (reduction equal to 55% of emissions in 2010).

Figure 5 also shows the specificity of sectoral activity effects in Poland between 2010 and 2030 and its impact on emission reductions. Even if energy efficiency and energy decarbonisation are comparable to what is observed for Italy or the UK during the first period in both alternatives, the impact on net emission reductions, taking into account the activity effect is very contrasted, as emission reductions are really low for Poland in 2030 compared to 2010.

Figure 5: Activity, energy efficiency and energy decarbonisation effect and emission reductions (/2010 emissions) between 2010 and 2030 and between 2030 and 2050 in NDC+ and A2C scenarios

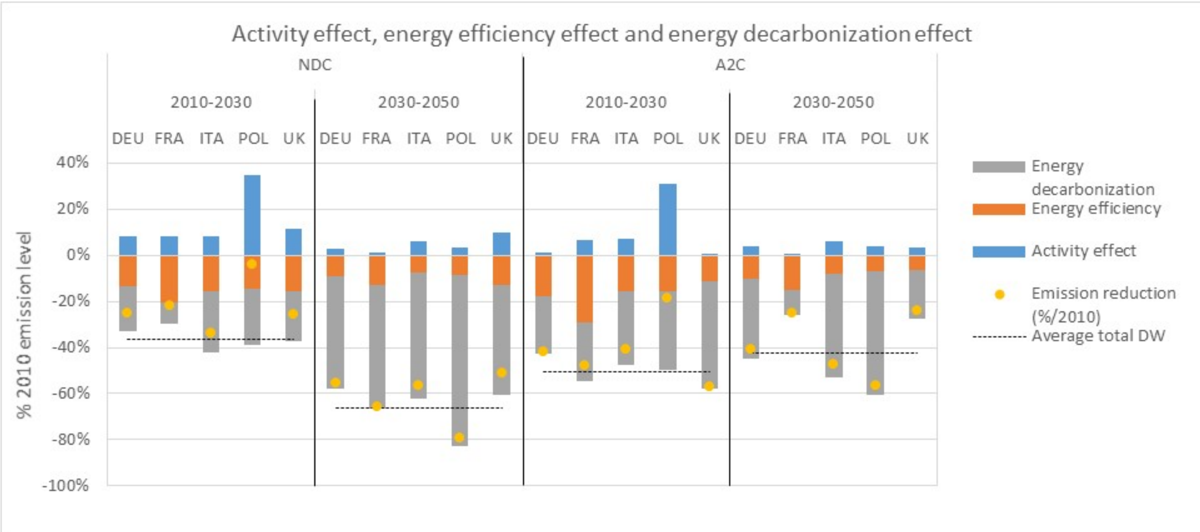


Table 4: Average impact (among the five countries considered) of the energy efficiency effect and of energy decarbonisation on emission reductions compared to 2010 emissions

	NDC+		A2C	
	2010-30	2030-50	2010-30	2030-50
Energy efficiency	-16%	-10%	-18%	-10%
Energy decarbonisation	-20%	-55%	-33%	-33%
Energy efficiency + energy decarbonisation	-36%	-65%	-51%	-43%

In the A2C scenarios, the total volume of DWs in the first (51%/2010 emissions) and second period are similar (43%/2010 emissions). This is not the same for NDC+ alternatives: DWs represent only 36% of 2010 emissions between 2010 and 2030 but 65%/2010 emissions between 2030 and 2050. This also

demonstrates that the total wedges on average for the five countries are higher in the NDC+ scenario than the A2C scenario (101% of 2010 emissions in NDC[5]+ vs 94% of 2010 emissions in A2C).

In the following we analyse sectoral contributions (Figure 6) to DW.

The contribution of the residential and service sectors to the DWs is remarkably stable for the various alternatives and periods. On average among the five EU countries, DW in these sectors represent between 10 and 12% of emissions in 2010. The other striking feature is that this stability is true on average but also for each country as the variance among the five countries is very low. These two characteristics are also verified by industry.

The contribution of transport and the power sector is more contrasted in the various scenarios, periods and countries. For example, transport plays a small role in DWs in Poland whatever the period and the alternative, whereas DWs in transport for France are very high. In the power sector, as the current energy mix is contrasted in the five countries, the role of the power sector in DW varies. It can even contribute to higher emissions, witness France during the first period of the NDC scenario. This is due to the government objective of decreasing the share of nuclear energy in power generation. In countries with coal intensive power generation (Germany and Poland), coal/gas substitution plays an important role in the second period of the NDC+ scenario. This is particularly true for Poland. In this scenario, other countries mainly consider the penetration of carbon-free technologies. In the A2C scenario, Poland is the only country to consider coal/gas substitution as a significant DW.

Figure 6: Decarbonisation wedges for the periods 2010-30 and 2030-50 and emission reduction between 2010 and 2030 and between 2030 and 2050 compared to 2010

[5] Emissions remain positive because of activity effects.

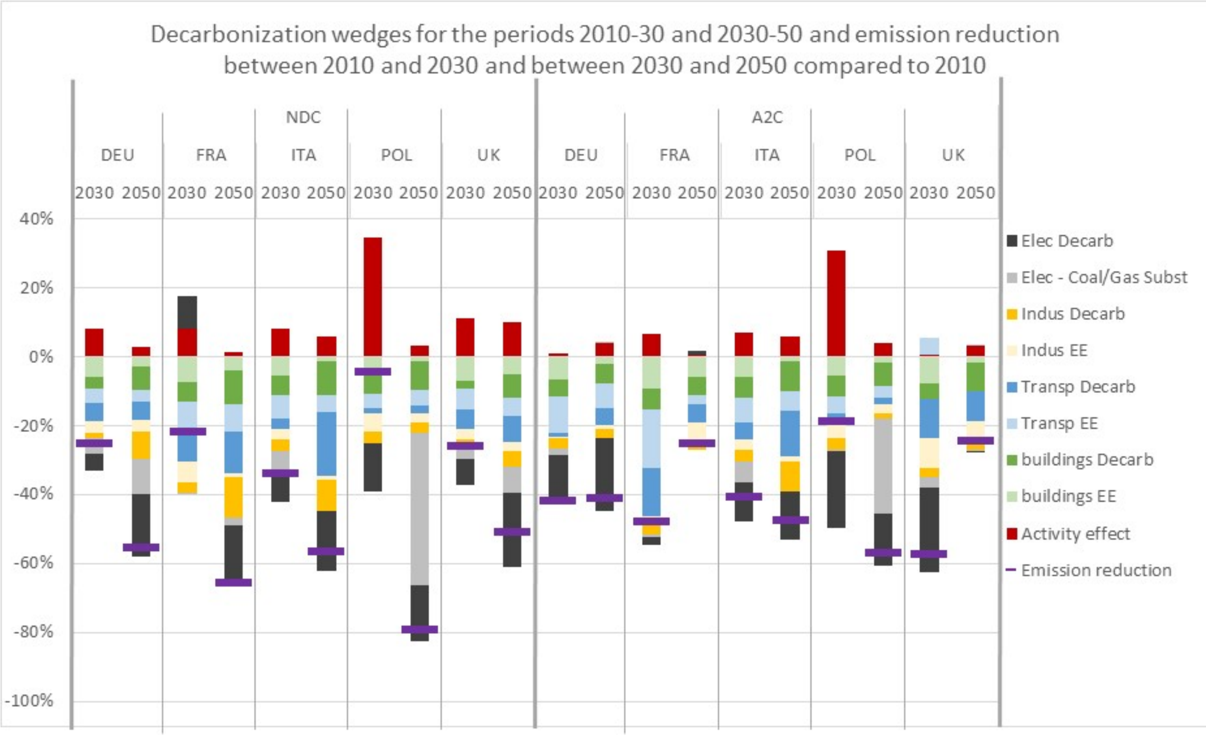


Table 5: Average sectoral contribution of sectoral DW to emission reductions (/2010 emission level)

	2010-30				2030-50			
	NDC+		A2C		NDC+		A2C	
	Average	Variance	Average	Variance	Average	Variance	Average	Variance
Building (residential + services)	-11%	2.34E-04	-12%	2.40E-04	-11%	3.13E-04	-10%	1.92E-04
Transport (passenger + freight)	-11%	1.80E-03	-14%	1.01E-02	-14%	5.00E-03	-11%	2.86E-03
Industry	-7%	3.56E-04	-7%	9.51E-04	-9%	9.23E-04	-7%	8.53E-04
Power sector	-8%	9.90E-03	-17%	8.40E-03	-31%	2.94E-02	-15%	3.22E-02

3.3 Decarbonisation Wedges in the Power Sector in the National NDC+ and A2C Scenarios

This diversity of strategy in the power sector is confirmed if we look more closely at the energy mix in the power sector in each country and each alternative (Figure 7 and Figure 8). Figure 7 details the energy mix and the evolution of CO_2 emission rates in NDC+ and A2C scenarios for the five countries throughout the period; Figure 8 compares the energy mix in NDC+ and A2C scenarios[6].

[6] For each energy generation technology (coal, gas, oil, nuclear, CCS and renewables), figure 7 shows figures equal to the difference in power generation (generation in NDC+ - generation in A2C) divided by the total power generation in 2010 in the relevant country.

In Germany the main difference is due to penetration of CCS technology after 2030, which is not considered at all in the A2C scenario, total generation in the latter being much lower than in the NDC+ scenario (~500TWh in 2050 compared to 800TWh). As a consequence, in the A2C scenario, CCS is not required and renewables produce nearly all the electricity.

In France the quantity of electricity produced is also much smaller in the A2C scenario than the NDC+ scenario (~350TWh in 2050 as against 650TWh). More nuclear energy and renewables and even CCS at the end of the period are consequently required to meet electricity demand in the NDC+ scenario. In the NDC+ scenario, the peak in 2030 in the emission rate of power generation comes from the increase in gas to bridge the gap between the decrease in nuclear and the penetration of renewables.

Things are different in the three other countries, the level of power generation being very close in the NDC+ and A2C scenarios. The difference between wedges relates to the technology required to produce carbon-free electricity earlier in the A2C scenario. For example, in Italy, in 2030, conventional gas used to produce electricity in the NDC+ scenario is replaced by renewables and CCS in A2C. In Poland, coal generation decreases earlier and more gradually in the A2C than in NDC+. On the contrary, the sharp decrease in NDC+ in coal generation after 2030 may be politically and socially impossible. In the UK the differences represent a smaller share of the quantity of electricity (20% in 2030 compared to the total power generation in 2010). In 2030, in the A2C scenario, coal generation is lower than in the NDC+ scenario, and more renewables and nuclear are required.

To sum up, two contrasted strategies emerge to bridge the gap between NDC+ and A2C in the power sector: to project a lower level of power generation that can be met with renewables only or to project the same level of power generation in NDC+ and A2C scenario that will require large penetration of carbon free-technologies and possibly CCS.

In the following, we analyse scenarios at the aggregated level comprising the five countries.

Figure 7: Energy mix in power generation and emission rate in the power sector in NDC+ and A2C scenarios for Germany, France, Italy, Poland and UK

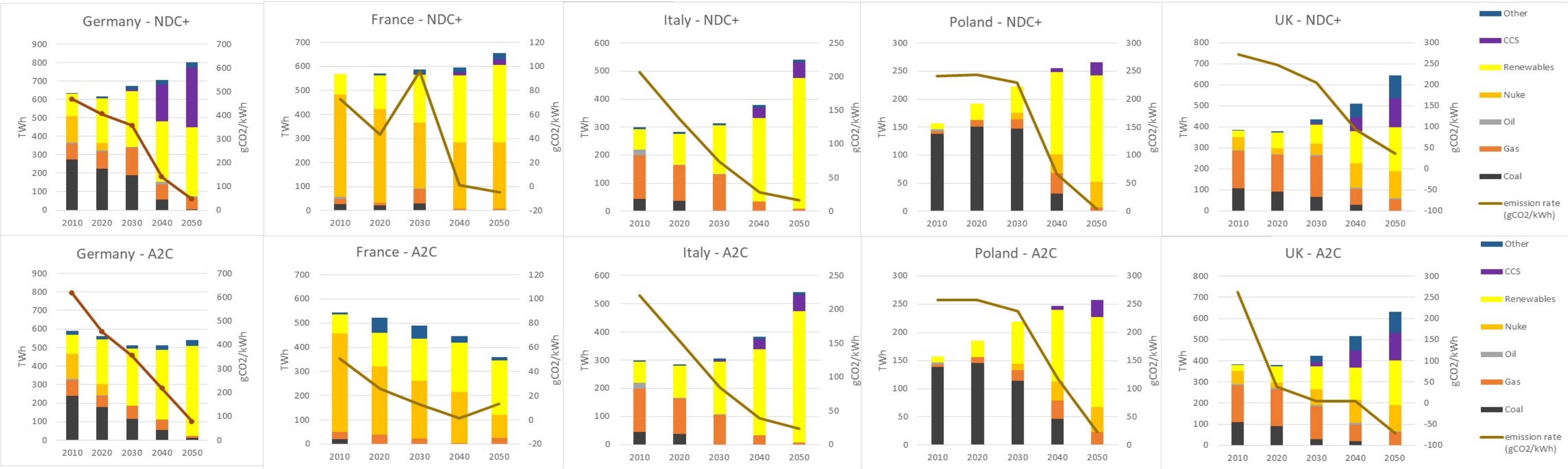
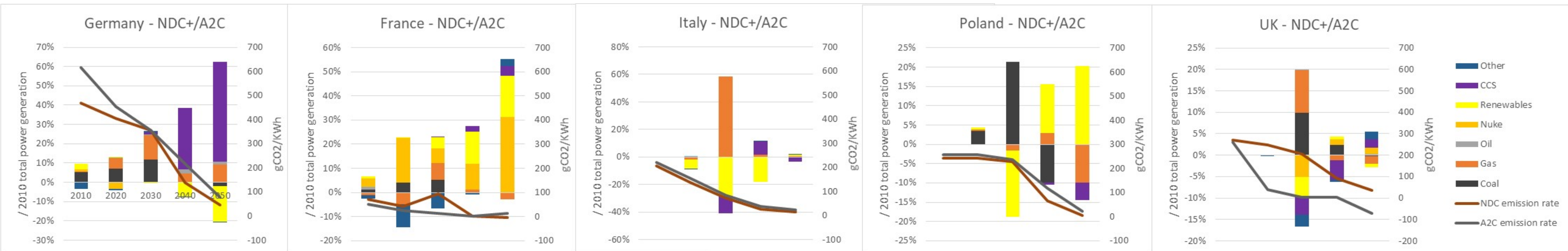


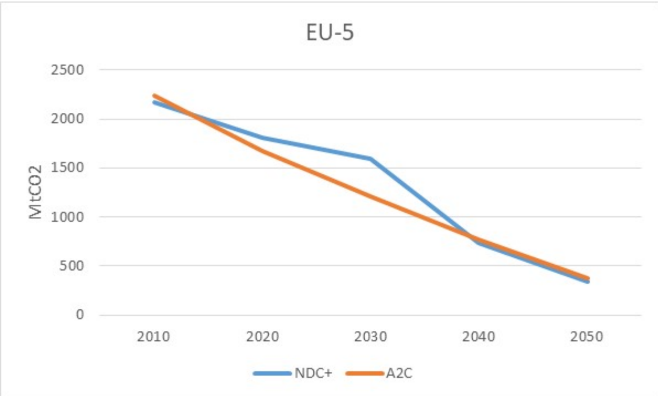
Figure 8: Energy mix difference (energy mix in NDC+ - energy mix in A2C) between NDC+ and A2C compared to the total power generation in 2010



4. Analysing the EU Strategy with NDC+ and A2C

In this section, the five national pathways are aggregated for NDC+ and A2C alternatives. Figure 9 shows the corresponding emissions for this EU-5 group of countries. They represent 67% of energy CO_2 emissions in EU28 in 2010. In both alternatives, the final level of emission reductions is approximately the same (-83% and -84% compared to 2010), but in 2030, they are equal only to -27% in the NDC+ compared to a reduction equal to -46% of 2010 emission in the A2C scenario. It is also important to note that the 2010-50 carbon budget is much higher in the NDC+ scenario than in the A2C scenario.

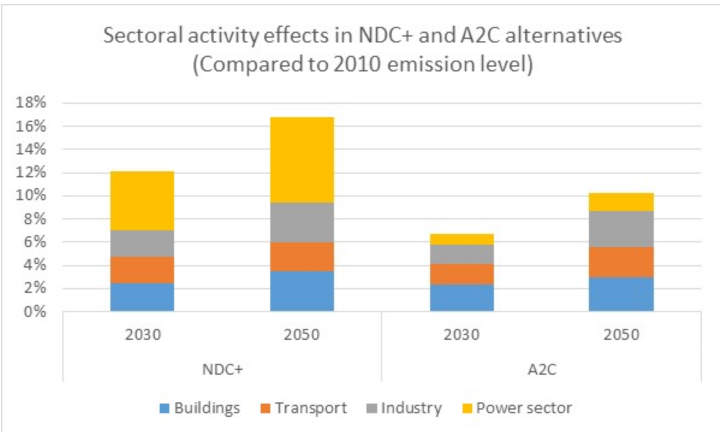
Figure 9: Aggregation of emissions in the EU-5 region for NDC+ and A2 scenarios



4.1 The Impact of the Evolution of Sectoral Activity Indicators at EU5 Level

Figure 10 shows the impact that sectoral activity indicators would have on emissions in a counterfactual scenario in which sectoral activity indicators are the same as in NDC+ and in A2C scenarios but without any evolution in energy efficiency and energy mix. In the NDC+ scenario, this would lead to 2030 emissions 12% higher and 17% higher in 2050 than in 2010 while in the A2C scenario emissions in 2030 would be 7% higher and 10% higher in 2030 and 2050 respectively. The power sector accounts for the main difference between these trends, the preceding section having shown that the power generation in the NDC+ scenario is noticeably higher in Germany and France in this scenario.

Figure 10: sectoral activity effects in NDC+ and A2C alternative at the EU-5 aggregated level

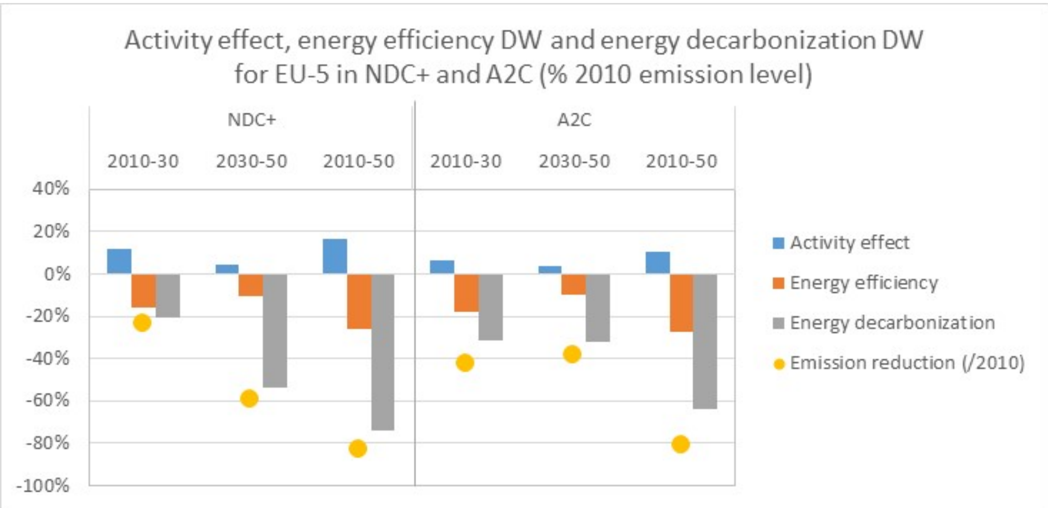


The contribution of other sectors is balanced between buildings (residential and services), transport (passenger and freight) and industry, and not markedly different in the NDC+ and A2C scenarios. It should nevertheless be noted that in Italy and Poland sectoral activity indicators for final energy consumer sectors are identical in the NDC+ and A2C scenarios.

4.2. Decarbonisation Wedges in NDC+ and A2C at EU5 Level

The aggregated impact of the DWs related to energy efficiency and of DWs related to energy decarbonisation effects is in line with observations at a national level. The contribution of energy efficiency is not contrasted between NDC+ and A2C. It constitutes a higher emission reduction driver before 2030 than afterwards. On the contrary, the impact of energy decarbonisation is very contrasted. In the NDC+ scenario, it constitutes the additional decarbonisation wedge required to reach the long term mitigation objective. The decarbonisation has to drastically accelerate after 2030, which is questionable because, given the moderate decarbonisation implemented before 2030, the economy would not be prepared to this acceleration. On the other hand, the contribution of energy decarbonisation in the A2C scenario is stable during both periods.

Figure 11: EU-5 aggregated activity, energy efficiency DW and energy decarbonisation DW in NDC+ and A2C scenarios between 2010 and 2030 and between 2030 and 2050. Emission reductions in 2010-30 and 2030-50 compared to 2010



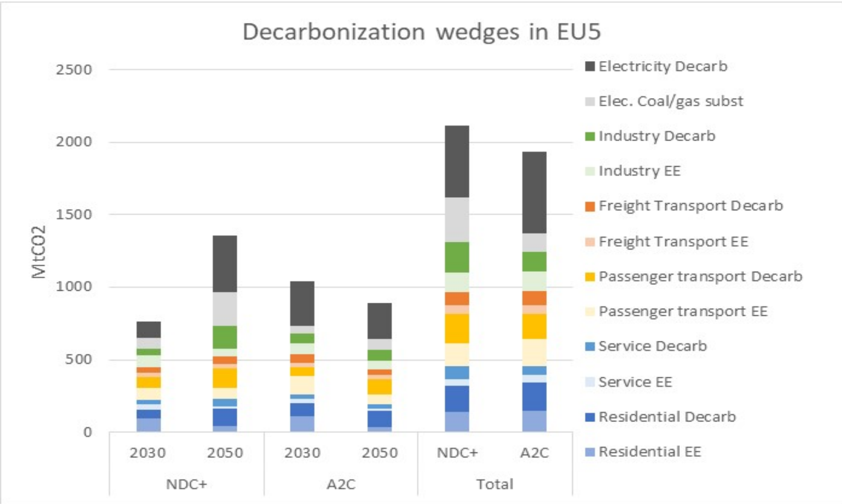
NB: 2010-50 is the sum of the two periods 2010-30 and 2030-50.

Throughout 2010-50 the main difference between NDC+ and A2C is mainly due to the additional wedge corresponding to coal/gas substitution in the power sector, which explains the higher total DW in NDC+ compared to A2C.

Total DW in final energy consumer sectors throughout the period are not very different either. Residential and service buildings and transport (passenger and freight) make a similar contribution and are the main contributors to the DWs in final energy consumer sectors.

But the distribution over time is more contrasted. In the NDC+ scenario very large quantities of DWs are mobilised between 2030 and 2050, particularly DWs in the power sector. The socio-technical feasibility of such volumes of DWs which correspond to a massive penetration of carbon-free energies must be questioned. This is all the more so as in the NDC+ scenarios, the learning by doing linked to a moderate penetration of these low carbon technologies will be low. As a result, these technologies will have a higher cost in the period 2030-40 than in the A2C scenarios.

Figure 12: Decarbonisation wedges for the periods 2010-30 and 2030-50 in the EU-5 aggregated region



4.3. Decarbonisation Wedges in the Power Sector in NDC+ and A2C at EU5 Level

In this subsection, we analyse the DW in the power sector more closely.
The first characteristic refers to the analysis of the power generation in both scenarios (Figure 13). It shows that, on the one hand total power generation is stabilised between 2010 and 2050 in A2C, while, on the other hand, power generation is 50% higher in NDC+ in 2050 compared to 2010. Other differences are observable more precisely in Figure 14 that shows the difference in power generation using coal, gas, oil, nuclear, CCS and key renewable technologies. Power generation from conventional coal (until 2030) and gas (until 2050) is much higher in NDC+ scenario. Carbon free technologies are also more necessary in the NDC+ scenario: CCS on coal and gas is only used in the NDC+ scenario; it also needs more solar after 2030 and biomass throughout the period.

This is consistent with the disaggregated DWS in the power sector.

Figure 13: Power generation in the power sector in NDC+ and A2C scenarios at the EU region level

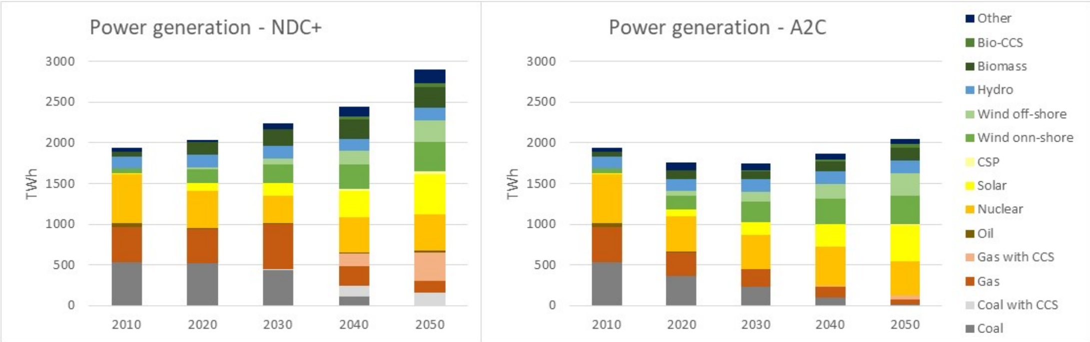


Figure 14: Differences in power generation between NDC+ and A2C (NDC+ - A2C)

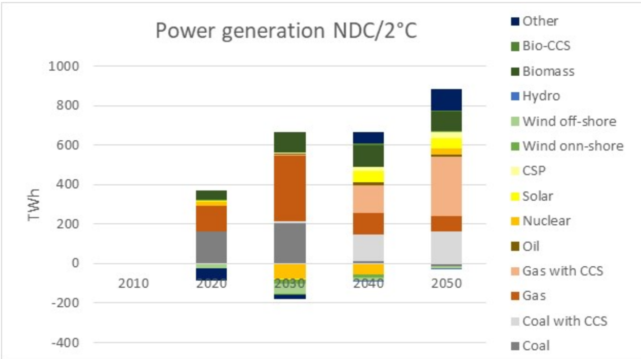
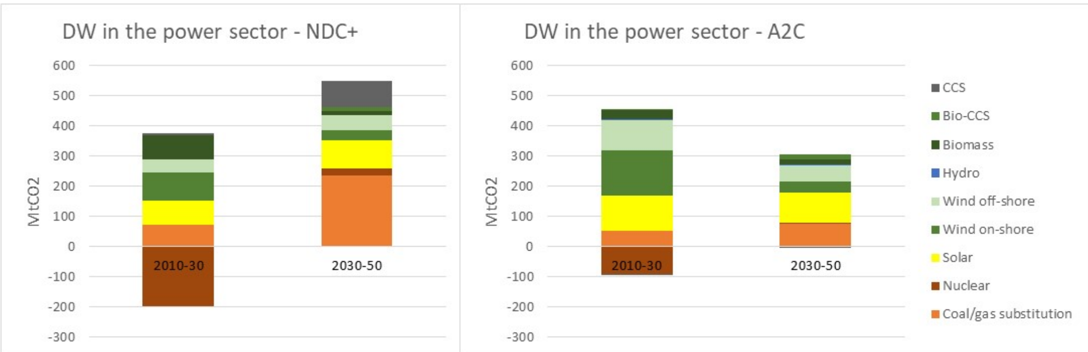


Figure 15: DW in the power sector in NDC+ and A2C scenarios at the EU region level



5. Decarbonisation at the World Level

In this section, we analyse and compare decarbonisation strategies in the NDC+ and A2C scenarios at a global level, drawing on the scenarios developed using the POLES model, described in the appendix.

5.1. The Impact of the Evolution of Sectoral Activity Indicators at the Global Level

First, we analyse the evolution of sectoral activity indicators and the impact that this evolution would have on counterfactual emissions (Figure 16). The first element that is apparent, especially when

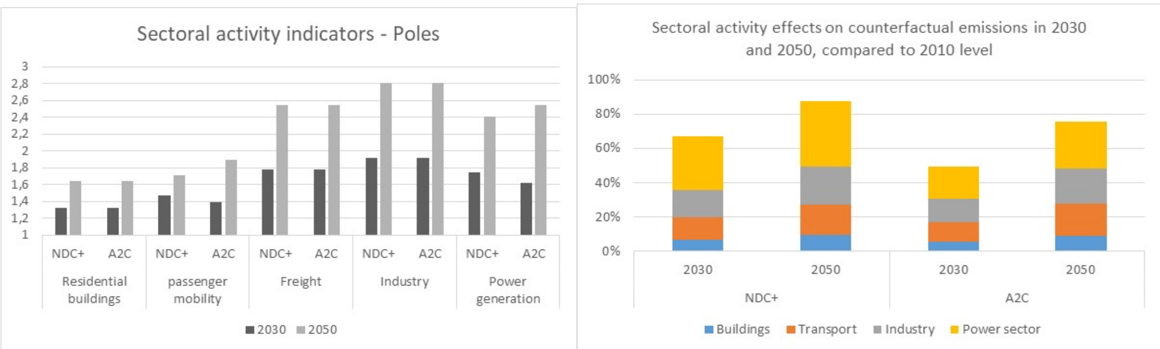
comparing with European countries and the EU-5 region, is the larger increase in sectoral activity indicators and the higher counterfactual emissions in both 2030 and 2050 compared to European trends. Counterfactual emissions in 2050 are 80% higher than emissions in 2010 in both scenarios. This very large global increase is due to the evolution of sectoral indicators. While in Europe such evolution is more driven by demographic trends than by rising living standards and economic growth, in developing and emerging countries both trends are much stronger.

Second, differences in sectoral activity indicators between NDC+ and A2C scenarios are smaller than for European countries. They are even identical for residential buildings, freight and industry. This is due to the modelling properties of the POLES model and to scenario assumptions. Passenger mobility and power generation are the only sectors to have a slightly higher evolution in 2030 in NDC+ than in A2C. This trend is reversed during the second period. This is due to the smaller constraint on emissions in the NDC+ scenario until 2030 but higher after 2030.

As a consequence, the counterfactual emissions in the NDC+ scenario are always slightly higher than those of A2C. This was also true at EU-5 level but much more markedly so, particularly because of the differences between scenarios in the power sector. The fact that scenarios at the global level rely on the same global model, POLES, also explains the smaller difference at the global level compared to what is observed for EU-5.

As a corollary, DWs would have to be higher in NDC+ than in A2C if both scenarios were to lead to the same carbon budget over time.

Figure 16: Sectoral activity indicators (index 2010) in NDC+ and A2C alternative at the global level and induced counterfactual emissions



5.2. Decarbonisation Wedges in NDC+ and A2C at the Global Level

The role of activity, energy efficiency and energy decarbonisation on emissions in NDC+ and A2C scenarios at the global level are presented in Figure 17.

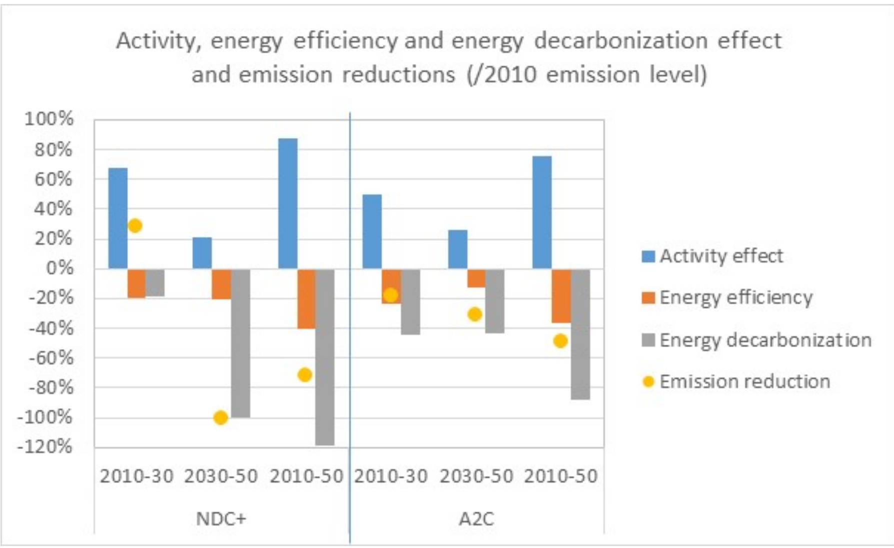
Comparing Figure 17 with the Figure 11 shows the difference in emission reduction (yellow dots) distribution between the first and the second period at the global level and at the EU-5 level. In NDC+

and A2C the constraint on emissions at a global level is less severe in the medium term (2030) than in EU-5. In the NDC+ scenario, emission reduction levels during the second period, between 2030 and 2050, at a global level are much higher than those observed at EU-5 level during the same period: the emission reduction represent 100% of the emission level in 2010. On the contrary, in A2C, the emission reduction required during the second period are much lower as they amount to 31% of emission level on 2010. This level of emission reduction is lower than the one observed in A2C at EU-5 level.

In NDC+ and A2C, between 2010 and 2030, the contribution of DWs to emission reductions (compared to 2010 emissions) related to energy efficiency (about 20%) and to energy decarbonisation (about 20% in NDC+ and 40% in A2C) at the global level appear similar to their contribution in EU-5. Nevertheless, the role of energy efficiency appears slightly higher globally than in European national scenarios, due to less efficient technologies in developing countries in particular. During this period, the main difference relies in the impact of sectoral activity on emissions during this period. The upward impact of sectoral activity on emission is particularly high as counterfactual emissions would be 66% higher than in 2010 in 2030 in NDC+, and 50% higher in A2C. In NDC+ during the first period, rising living standards in emerging and developing countries will more than offset the gains resulting from energy efficiency progress and energy decarbonisation.

Between 2030 and 2050, the role of energy efficiency remains approximately the same as in the first period. It slightly decreases in A2C. This is also more or less the case for EU-5. The projected role of energy decarbonisation in the second period in A2C is only slightly higher to what is projected in the European national scenario. The big difference comes from the energy decarbonisation wedge in NDC+ after 2030, emission reduction induced by energy decarbonisation being expected to represent the level of emissions in 2010. The realism of such a volume of DWs must be questioned

Figure 17: Aggregated activity, energy efficiency and energy decarbonisation effect, emission reductions between 2010 and 2030, between 2030 and 2050 and over the whole period, compared to 2010 emission level - NDC+ and A2C scenarios - global level.



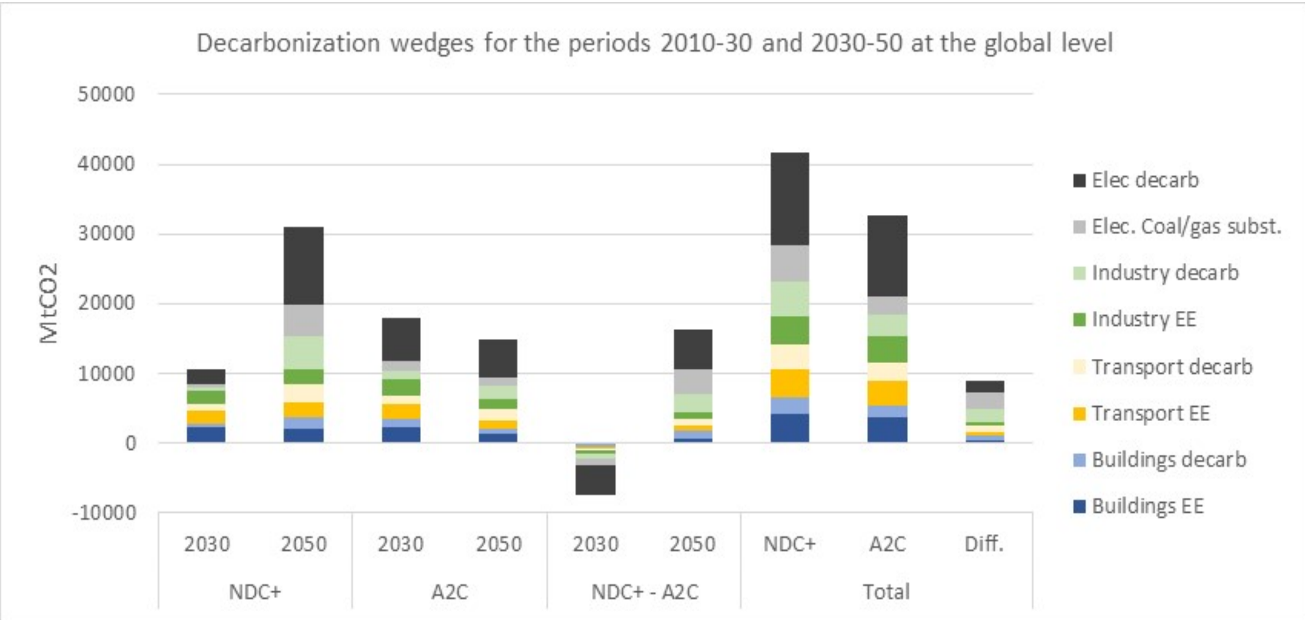
NB: 2010-50 is the sum of the two periods 2010-30 and 2030-50.

DWs at the sectoral level are balanced between the five energy consumer sectors, except in the second period of the NDC+ scenario, with industry playing a significantly larger part particularly in energy efficiency. The realism of the dramatically large role of the power sector during this second period in the NDC+ scenario (1/3 for coal/gas substitution and 2/3 for decarbonisation) is questionable.

In the A2C scenario, DW are better balanced between the first and the second period and between sectors, even if the power sector still plays the major role, in particular through energy decarbonisation.

The aggregated DW in NDC+ during the second period is more than twice the volume of DW in A2C during the second period. Differences in DW between NDC+ and A2C ('NDC+ - A2C ') show that the lower level of DW related to the penetration of carbon free technologies in NDC+ during the first period compared to A2C is more or less compensated during the second period. Nevertheless, additional DW are required in coal/gas substitution.

Figure 18: Decarbonisation wedges for the periods 2010-30 and 2030-50 in the EU-5 aggregated region



V.3. Decarbonisation Wedges in the Power Sector in NDC+ and A2C at the Global Level

We shall now look in more detail at the electricity sector and at the power generation in both scenarios (Figure 19). The difference between power generation in A2C and in NDC+ is also described. This difference is mainly marked in 2030 as it concerns around 10,000 TWh among 30-35,000 TWh

produced during this year. The difference in later years is less significant as it concerns between 2,500 and 5,000 TWh among a production higher than 40,000 TWh.

The A2C scenario involves a quicker (before 2030) and more important reduction in coal and gas generation compared to NDC+. The decrease in fossil fuel based generation is compensated by an earlier penetration of wind on-shore (that is more competitive than solar at this time) and nuclear. In NDC+, on the contrary, coal/gas substitution plays a significant role after 2030 (Figure 20).

In total, Figure 20 shows that if we aggregate the DW over the two periods, the difference between the upper DW level in NDC+ compared to A2C comes equally from renewables, CCS and nuclear power.

These results, in particular on the respective contribution of carbon-free technologies to DWs, depend of course on the specific cost assumptions for modelling these scenarios in the global POLES model. In this modelling context and at this stage, it is not possible to take into account national specificities in terms of socio-technical feasibility and beyond cost issues that may limit the penetration potential of some of these technologies. it would therefore be instructive to implement alternatives to this global scenario based both on assumptions of different penetration potential for carbon-free technologies, and on contrasting assumptions in terms of changes in sectoral activity indicators.

Figure 19: Power generation in NDC+ and A2C scenarios and differences in power generation between NDC+ and A2C (NDC+ - A2C) at the global level

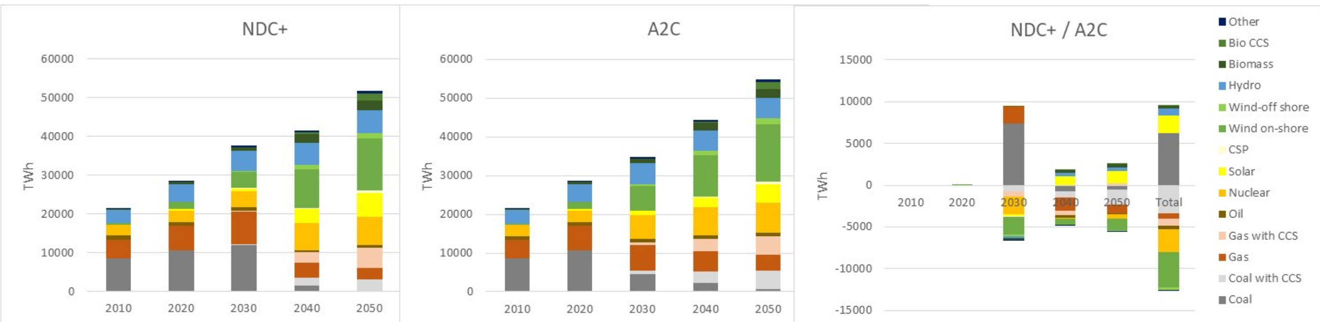
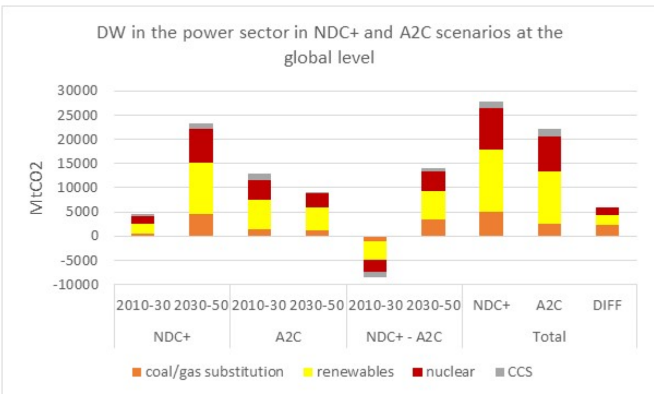


Figure 20: DW in the power sector in NDC+ and A2C scenarios at the global level



6. Discussion

In this section we summarise and discuss results from a methodological and political point of view.

6.1. Summary of Results

First, we can draw general conclusions from the results on the contributions to the evolution of projected emissions in the A2C and NDC+ scenario families of activity, energy efficiency and energy decarbonisation effects.

One originality of the approach developed in this deliverable is to make visible the contribution on the evolution of greenhouse gas emissions in ambitious mitigation scenarios resulting from the evolution of activity in energy-consuming sectors. This contribution varies greatly from one country to another reflecting alternative development patterns and must be taken into account in the analysis of mitigation strategies. Scenarios at the global level show that in NDC+ during the first period, rising living standards in emerging and developing countries, and the pursuit of consumption patterns and lifestyles in industrialised countries would more than offset at the global level the gains resulting from energy efficiency progress and energy decarbonisation. In A2C, additional early demand-side mitigation actions, and earlier energy decarbonisation drive to net emission reductions in 2030 compared to 2010. Even within the EU, contrasts in projections of sectoral activities across countries have strong implications for the analysis of mitigation strategies. In western EU countries, the activity effect is low because the evolution of sector activity is mainly driven by demographic trends. In Eastern European countries like Poland, sector activity is growing faster to catch up with the standard of living in Western Europe. As a result, even if energy efficiency and energy decarbonisation DWs are comparable to what is observed for Italy or the UK during the first period in both alternatives, the impact on net emission reductions, taking into account the activity effect is very contrasted, as net emission reductions are really low for Poland in 2030 compared to 2010. This effect for Poland and for developing countries is particularly marked during the first period. During the second period, the growth in sectoral activity indexes is slower.

The role of energy efficiency shows invariants between A2C and NDC+ families in national EU scenarios and at the global level. Its contribution decreases over time. On average in the five EU countries, energy efficiency drives to emission reductions equal to about 16 to 18% of the volume of emissions in 2010 during the first period and about only 10% in the second period. The contribution of energy efficiency is slightly higher at the global level because of less efficient technologies in developing and emerging countries.

Whether at the level of European countries or at the global level, the contribution of the decarbonisation of energy carriers increases over time and takes an important role in emission reductions after 2030 as the introduction of new energy vectors necessitates time for development of new infrastructure. The timing of energy decarbonisation is however very different in the two scenario families. In the A2C scenario, the impact of energy decarbonisation appears balanced between the two periods. In the NDC+ scenario, energy decarbonisation contributes to emission reduction equal on average for the five EU countries to 20% of the emission level in 2010, but during the second period, this contribution rises to 55%. At the global level, this contribution even amounts to 100% of 2010

emission level during the second period. This means that the amount of emission reduced thanks to the decarbonisation effects equals the total 2010 emissions. Emissions remain positive because of the increasing trend of activity. The socio and techno-economic feasibility and realism of such a high level of decarbonisation is questionable. From an economic point of view, the delay in the learning by doing induced by the moderate deployment of low carbon technologies during the first period in NDC+ scenarios will have an upward impact on the cost of NDC+ scenarios. These technologies will have a higher cost in the period 2030-40 than in the A2C scenarios.

From a sectoral point of view, Table 6 details the contribution of demand-side DWs from energy consuming sectors and of DWs in the power sector for EU-5 and at the global level. In A2C scenarios, the distribution of DWs seems very stable whatever the geographical level and the period considered: demand-side DWs represents nearly 2/3 of the DWs and the power sector only 1/3. In NDC+ scenarios, the role of the power sector is more important as it nearly represents half of the contribution. The notable exception relates to the first period in EU-5: between 2010 and 2030, DWs in the energy-consuming sectors represent ¾ of the DWs.

Table 6 : Contribution of demand-side DWs and of DWs in the power sector (% of total DW)

	NDC+				A2C			
	EU-5		World		EU-5		World	
	2030	2050	2030	2050	2030	2050	2030	2050
Electricity	24%	46%	47%	44%	35%	36%	38%	36%
Total Demand-side	76%	54%	53%	56%	65%	64%	62%	64%

At a more disaggregated sectoral level, building (residential + service) sectors and industry to the DWs is remarkably stable for the various alternatives and periods. At the EU-5 level, emission reductions in these sectors represent each between 10 and 12% of the emissions level in 2010. The other striking feature is that this stability is true on average but also for each country as the variance among the five countries is very low.

The contribution of transport and the power sector is more contrasted in the various scenarios, periods and countries. For example, transport plays a small role in DWs in Poland whatever the period and the alternative, whereas DWs in transport for France are very high. Implementing demand side wedges particularly for building and mobility implies carefully considering end-user consumption patterns, behavioural parameters, regulation design, awareness-raising campaigns and economic signals in order to achieve a better diffusion of low-carbon solutions and habits and to solve the "energy-efficiency gap" problem.

In the power sector, as the current energy mix is contrasted in the five countries, the role of the power sector in DW varies. It can even contribute to higher emissions, witness the decrease in nuclear capacity in France and Germany and the negative contribution of nuclear in the DWs in EU-5 particularly in the NDC+ scenario. The contribution of renewables sources appear as an invariant whatever the family of scenarios. On the contrary, CCS and massive coal/gas substitution are required

in the NDC+ scenario during the second period to bridge the gap in required emission reductions to be consistent with the 2°C target. Given the lifetime of coal-fired power plants and the uncertainty on the possibility to rely on CCS in the future, it should be essential to organise a rapid and irreversible reduction of coal use in the production of electricity. In EU-5, this is true particularly for Germany and Poland.

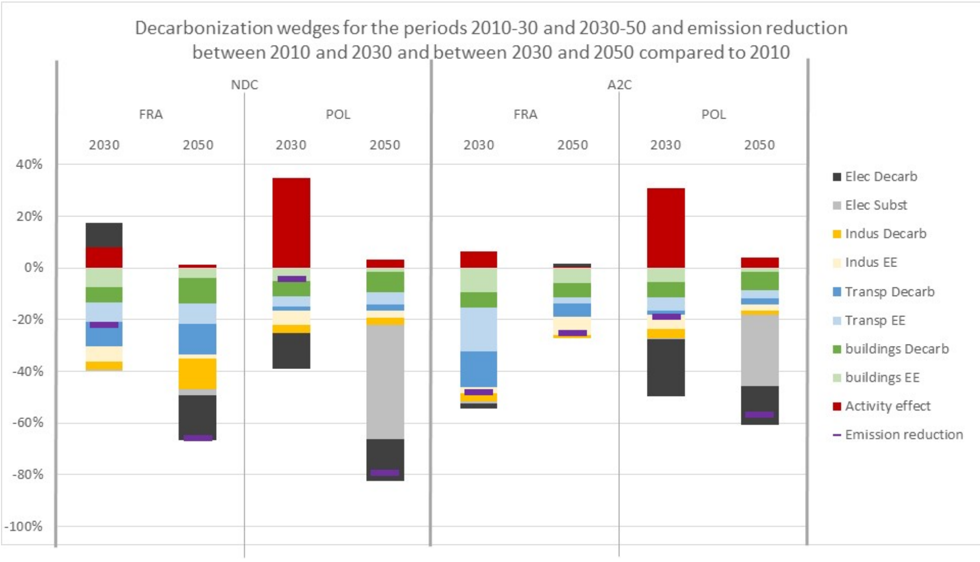
6.2. France and Poland as Examples of the Diversity of Mitigation Issues within the EU

Beyond this summary of results, the analysis highlights the diversity within EU countries in national mitigation strategies and in additional actions that would be required to bridge the gap between NDC+ pathways and A2C pathways. In the following, we focus (Figure 21The importance of the coal sector in Poland constitutes a socio-economic barrier to the low-carbon transition of the energy sector in that country. As shown in Figure 7, coal generation decreases earlier and more gradually in the A2C than in NDC+. On the contrary, the sharp decrease in NDC+ in coal generation after 2030 may be politically and socially impossible. Moreover, the delay in decreasing coal capacity in Poland during the first period of the NDC+ scenario, induce additional required DWs during the second period and particularly a very large transition from coal to gas.

One specific feature for Poland is the significant upward impact on emission in both scenarios of activity effect. In spite of DWs in NDC+ and A2C scenarios with the same aggregated volume as France, the net impact on emissions is particularly low. This calls for developing alternatives scenarios for Poland based on contrasted sectoral developments and to understand whether such alternatives can be implemented through policies.

) on the one hand on France, a Western European country with a very low carbon content energy system and on the other hand on Poland, an Eastern European country with a coal-intensive energy system. Whereas for France, DWs rely to a very large extent on DWs in the energy-consuming sectors (which is not in itself a great surprise since the electricity sector is already highly carbon-free), in Poland the role of the electricity sector is decisive.

Figure 21 : Comparison of decarbonisation wedges between France and Poland



In France, the transport sector appears as the key player to bridge the gap during the first period between an NDC+ and an A2C scenario. The role of other sectors and particularly the need for thermal retrofitting is an invariant in both scenarios.

The importance of the coal sector in Poland constitutes a socio-economic barrier to the low-carbon transition of the energy sector in that country. As shown in Figure 7, coal generation decreases earlier and more gradually in the A2C than in NDC+. On the contrary, the sharp decrease in NDC+ in coal generation after 2030 may be politically and socially impossible. Moreover, the delay in decreasing coal capacity in Poland during the first period of the NDC+ scenario, induce additional required DWs during the second period and particularly a very large transition from coal to gas.

One specific feature for Poland is the significant upward impact on emission in both scenarios of activity effect. In spite of DWs in NDC+ and A2C scenarios with the same aggregated volume as France, the net impact on emissions is particularly low. This calls for developing alternatives scenarios for Poland based on contrasted sectoral developments and to understand whether such alternatives can be implemented through policies.

6.3. The Importance of Taking into Account Alternative Sectoral Dynamics

This question of contrasting visions on the evolution of sectoral activity indicators has been particularly studied within the French scenarios developed in the Deep Decarbonisation Pathways (Mathy et al., 2015). Two 2°C consistent scenarios leading to a 75% emission reduction in 2050 compared to 2010 but with contrasted projections of sectoral activity indicators (Figure 22) were developed and assessed with the Imaclim-R France model. The DIV (for Diversity) scenarios considers the continued growth rates of activity in each of the sectors while in the EFF (for Efficiency) scenario a significant moderation of these growth rates is considered. For example, mobility activity index decreases by 10% in the long term, freight activity is stable over the period. As a consequence the need for electricity consumption

in EFF is really reduced compared to the DIV scenario. EFF is the A2C scenario considered in previous sections for France.

Figure 22 : Sectoral activity index in EFF and DIV scenarios

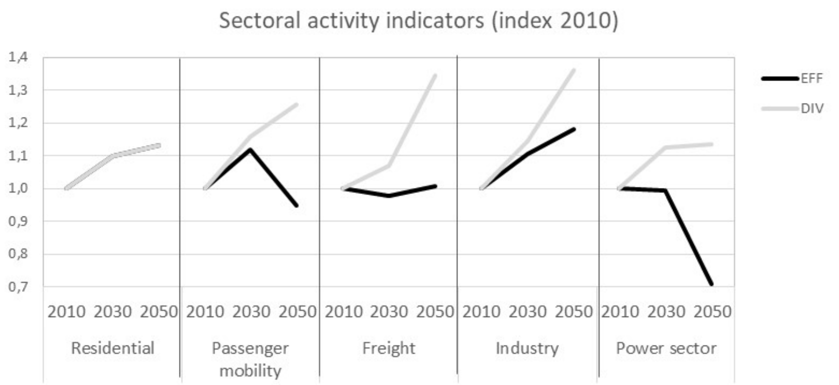
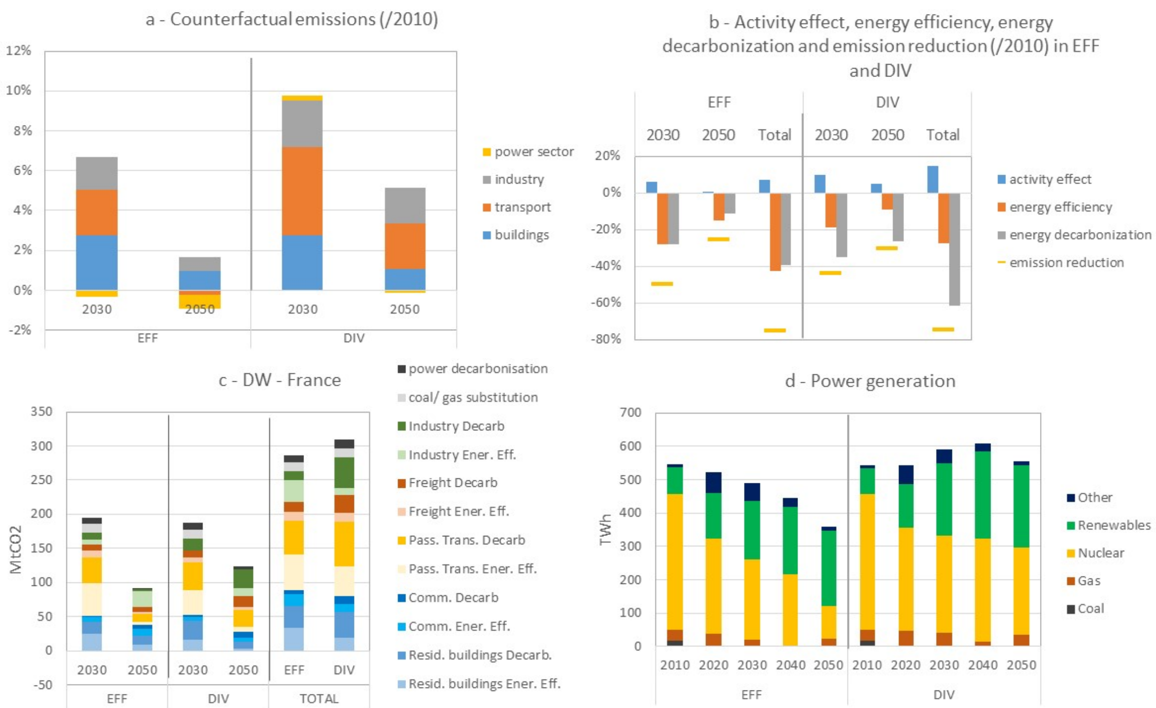


Figure 23 : Comparison of EFF and DIV scenario – a. Counterfactual emissions ; b- activity effect, energy efficiency, energy decarbonisation and emission reduction ; c – decarbonisation wedges ; d – power generation



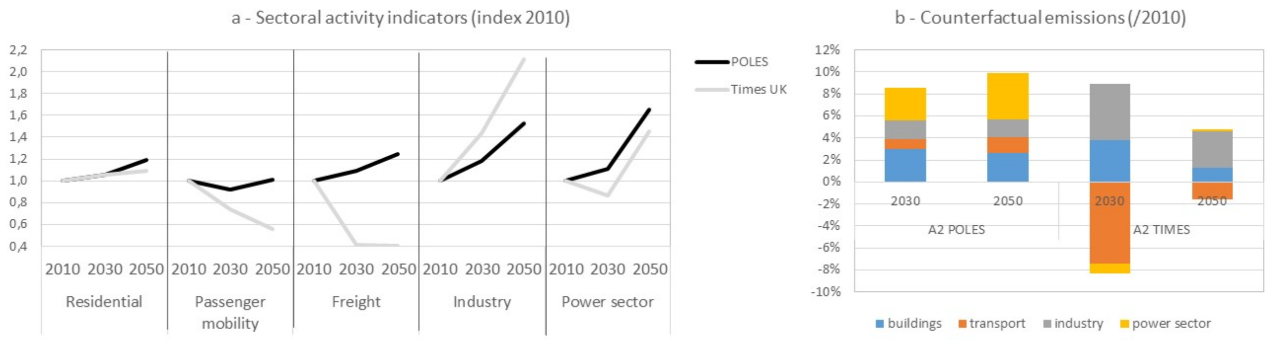
The full comparison of EFF and DIV scenarios is presented in Figure 23. The activity indicators that are differentiated between EFF and DIV result in higher counterfactual emissions (particularly in transport) in DIV and therefore a greater activity effect that must be offset by more emission reductions and therefore more DW overall. In EFF, energy efficiency plays a major role early during the first period and its contribution is higher than energy decarbonisation all over the period. On the contrary, in the

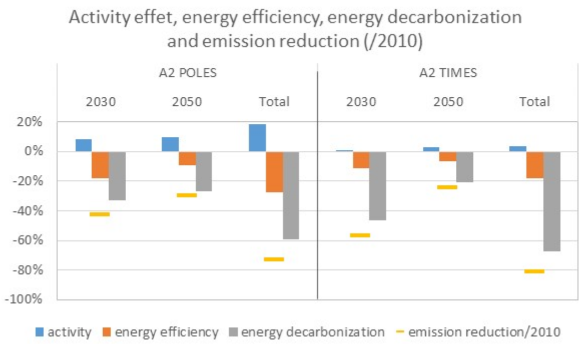
DIV scenario, energy decarbonisation plays a very important role and the higher level of power generation required induce a higher quantity of low-carbon electricity to be produced. Mathy et al. (2016) analyse dynamic management issues induced by each mitigation strategy. When choosing a pathway, it is important to have in mind that each decarbonisation option relies on the implementation of specific policies and instruments. In EFF, the main uncertainty is the ability to halve final energy demand and particularly to retrofit almost all the existing building stock in 35 years. In DIV, an increased use of nuclear energy is required. As it is not possible to be sure that the construction time of new nuclear plants could be less than 10 years, alternatives to central decarbonisation pathway options should be considered in due time in a monitoring process.

6.4. DW as a Tool for Enabling Multi-Model Comparison

One of the difficulties encountered in the analysis of the scenario database gathered in task 2.1 is the diversity of the models with which the scenarios were produced. Indeed, Poland is the only country for which three scenarios from the same model and each representing a scenario family have been produced. For the other countries, more than one models were used, which greatly complicates the analysis of mitigation strategies and especially if one seeks to compare a NDC+ scenario produced with a model with an A2C scenario produced with another model. The impact of different modelling options and of different assumptions are often difficult to disentangle. The DW approach presents the advantage to make visible some of them. To illustrate this issue, we consider the example of the A2C scenarios produced for UK: one is based on modelling with POLES and the other on the Times UK model.

Figure 24 : Comparison of sectoral activity indicators, induced counterfactual emissions, and decarbonisation wedges for UK A2C scenarios produced with POLES and Times UK





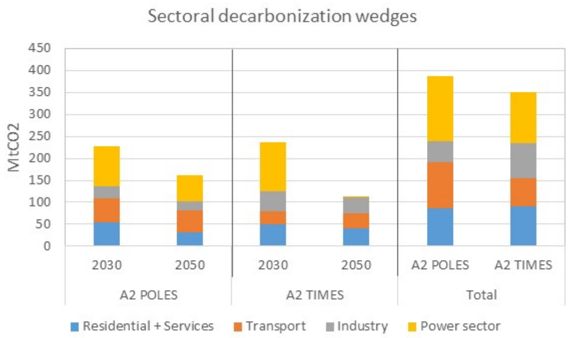


Figure 24 shows the very contrasted sectoral indicators forecast in the two scenarios: they are much higher for residential and transport in the POLES scenario but much lower for industry. Transport indicators in the Times UK A2C scenario are particualry low with a significant decrease all over the period in passenger mobility and freight. As a result, transport pulls down counterfactual emissions in the Times UK A2C scenario when all the sectors have an upward impact on counterfactual emisions in the POLES model. Of course this has an impact on mitigation strategies and on decarbonisation wedges.

One added value of the methodology is thus to make it possible to highlight contrasting visions on the evolution of sectoral activities and thus structural transformations or on the contrary a continuation of growth and consumption patterns in mitigation scenarios, as well as their impact on emissions. However, the implementration of the methodology is dependent on reporting related to sectoral indicators as proposed in the dashboard elaborated in this work and given in the appendix. This calls for more transparent scripting approaches in the choice of sectoral development hypotheses.

Conclusion

In this deliverable, we provide systematic ex-post analysis of the national scenarios produced at a national level and collated in task 2.1 of the COP21 RIPPLES project, supplemented with national scenarios produced with the POLES global energy system. For this purpose, we use the decarbonisation wedges (DW) methodology elaborated by Mathy et al. (2018). The methodology splits forecast energy-related emissions up to 2050 into 10 decarbonisation wedges with six DWs on the demand side (energy efficiency and decarbonisation of energy carriers in buildings, transport and industry) and four DWs in the power sector (coal/gas substitution, renewables, nuclear, carbon capture and sequestration (CCS).

The present contribution goes beyond traditional ‘gap analysis’, in terms of aggregate emissions, to provide a systemic analysis of the ‘transformation gap’ between national NDC and ‘well below 2°C’/1.5°C scenarios. The DW allows quantifiying the impact of contrasted sectoral development assumptions and of potentiel structural change of the economy on mitigation strategy analysis. We apply the methodology to global mitigation scenarios and to five EU countries: Germany, Italy, France, Poland and UK that represent on aggregate 2/3 of current EU emissions.

Results show the diversity in mitigation actions between Western European countries and Eastern European countries where strong growth of economic and sectoral activities and the coal-intensive energy system raise major mitigation issues.

Whether at the level of European countries or at the global level, the contribution of the decarbonisation of energy carriers increases over time and takes an important role in emission reductions after 2030 as the introduction of new energy vectors necessitates time for development of new infrastructure. The techno-economic feasibility and realism of the high level of energy decarbonisation required after 2030 in NDC scenarios is questionable: CCS and coal/gas substitution are massively required only after 2030 to decarbonise the power sector. Additional demand-side mitigation actions, the penetration of renewables and an early but gradual decrease in coal capacity in the power sector before 2030 are the major additional wedges needed to increase NDC ambition.

This work provides methodological lessons for improving low-carbon scenario modelling approaches and highlights the need to make assumptions on the evolution of sectoral activities more transparent and to systematise the development of contrasted alternatives on structural transformation assumptions.

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Appendix

1. Ripples Dashboard for Task 2.1 and task 2.3

RIPPLES: Dashboard for task 2.1 and 2.3

Color Key:
Data absolutely needed
Data needed if available

		2000	2010	2020	2030	2040	2050
Aggregate Inputs							
Population	Millions						
GDP	B$2005PPP						
GDP	B$2005MER						
Residential & service inputs							
Residential inputs							
Floor area, residential units	Msqm						
Residential final energy consumption	Mtoe						
Residential total non-electricity CO2 emissions	MtCO2						
Residential total CO2 emissions	MtCO2						
Residential final electricity	TWh						
Residential non-electricity FEC	Mtoe						
Residential district heating	Mtoe						
Residential solar thermal	Mtoe						
Residential pipeline gas	Mtoe						
Residential liquid fossil fuels	Mtoe						
Residential coal and coal gas	Mtoe						
Residential solid biomass	Mtoe						
Service inputs							
Floor area, commercial units	Msqm						
Service Value added	B$2005PPP						
Commercial final energy consumption	Mtoe						
Commercial total non-electricity CO2 emissions	MtCO2						
Commercial total CO2 emissions	MtCO2						
Commercial final electricity	TWh						
Comemrcial non-electricity FEC	Mtoe						
Comemrcial district heating	Mtoe						
Commercial solar thermal	Mtoe						
Commercial pipeline gas	Mtoe						
Commercial liquid fossil fuels	Mtoe						
Commercial coal and coal gas	Mtoe						
Commercial solid biomass	Mtoe						
Transport inputs							
Passenger transport inputs							
Total passenger kilometers traveled (PKT)	Gpkm						
Passenger kilometers - Cars	Gpkm						
Passenger kilometers - Road collective transports	Gpkm						
Passenger kilometers - Air	Gpkm						
Passenger kilometers - non motorized transports	Gpkm						
Passenger transport final energy consumption	Mtoe						
Passenger non-electricity CO2 emissions	MtCO2						
Passenger total CO2 emissions	MtCO2						
Passenger final electricity	TWh						
Passenger non-electricity FEC	Mtoe						
Passenger biofuels	Mtoe						
Passenger liquid fossil fuel	Mtoe						
Passenger natural gas	Mtoe						
Passenger hydrogen	Mtoe						
Freight transport inputs							
Freight movement	Gt-km						
Freight movement - Road	Gt-km						
Freight movement - Rail	Gt-km						
Freight movement - Air	Gt-km						
Freight transport final energy consumption	Mtoe						
Freight non-electricity CO2 emissions	MtCO2						
Freight total CO2 emissions	MtCO2						
Freight final electricity	TWh						
Freight non-electricity FEC	Mtoe						
Freight biofuels	Mtoe						
Freight liquid fossil fuel	Mtoe						
Freight natural gas	Mtoe						
Freight hydrogen	Mtoe						

Industry inputs	
Industry total inputs	
Industry value added	B 2005$PPP
Industry final energy consumption	Mtoe
Industry non-electricity CO2 emissions	MtCO2
Industry fugitive and process emissions	MtCO2
Industry total CO2 emissions	MtCO2
Industry final electricity	TWh
Industry non-electricity FEC	Mtoe
Industry steam	Mtoe
Industry coal	Mtoe
Industry coal w/ccs	Mtoe
Industry pipeline gas	Mtoe
Industry pipeline gas w/ccs	Mtoe
Industry liquid fossil fuels and other	Mtoe
Industry solid biomass	Mtoe
Industry biofuels	Mtoe
Industry sub-sectors inputs	
Cement or NMM value added	B 2005$PPP
Cement or NMM production	Mt
Cement or NMM final energy consumption	Mtoe
Cement or NMM non-electricity energy-related CO2 emissions	MtCO2
Cement or NMM final electricity	TWh
Iron & Steel value added	B 2005$PPP
Iron & Steel production	Mt
Iron & Steel final energy consumption	Mtoe
Iron & Steel non-electricity energy-related CO2 emissions	MtCO2
Iron & Steel final electricity	TWh
Mining value added	B 2005$PPP
Mining production	Mt
Mining final energy consumption	Mtoe
Mining non-electricity energy-related CO2 emissions	MtCO2
Mining final electricity	TWh
Non-Ferrous metals value added	B 2005$PPP
Non-Ferrous metals production	Mt
Non-Ferrous metals final energy consumption	Mtoe
Non-Ferrous metals non-electricity energy-related CO2 emissio	MtCO2
Non-Ferrous metals final electricity	TWh

Electricity inputs	
Power generation mix inputs	
Total power generation (electricity produced)	TWh
Final energy produced from conventional coal	*TWh*
in which coal with CCS	*TWh*
Final energy produced from conventional gas	*TWh*
in which gas with CCS	*TWh*
Final energy produced from conventional oil	*TWh*
in which oil with CCS	*TWh*
Final energy produced from nuclear	*TWh*
Final energy produced from solar PV	*TWh*
Final energy produced from CSP	*TWh*
Final energy produced from wind	*TWh*
in which wind on-shore	*TWh*
in which wind off-shore	*TWh*
Final energy produced from hydro	*TWh*
Final energy produced from biomass	*TWh*
Final energy produced from bio-CCS	*TWh*
Final energy produced from other	*TWh*
Power generation sources (energy inputs)	
Power generation sources (primary energy inputs)	Mtoe
Power generation from conventional coal	Mtoe
in which coal with CCS	Mtoe
Power generation from conventional gas	Mtoe
in which gas with CCS	Mtoe
Power generation from conventional oil	Mtoe
in which oil with CCS	Mtoe
Power generation from nuclear	Mtoe
Power generation from solar PV	Mtoe
Power generation from CSP	Mtoe
Power generation from wind	Mtoe
in which wind on-shore	Mtoe
in which wind off-shore	Mtoe
Power generation from hydro	Mtoe
Power generation from biomass	Mtoe
Power generation from other	Mtoe
Power generation CO2 emissions	
Total CO2 emissions from power generation	MtCO2
CO2 emissions from conventional coal	*MtCO2*
in which coal with CCS	*MtCO2*
CO2 emissions from conventional gas	*MtCO2*
in which gas with CCS	*MtCO2*
CO2 emissions from conventional oil	*MtCO2*
in which oil with CCS	*MtCO2*

2. Scenarios Computed with the POLES Model

The Prospective Outlook on Long-term Energy Systems (POLES) has been developed at CNRS (currently in the GAEL lab) in collaboration with the European Commission's JRC-IPTS and ENERDATA. It is a long-term recursive simulation model (up to 2100) for energy supply, demand and prices. It is a partial equilibrium bottom-up world model, based on 57 national sub-models, which allows the balance of energy supply and demand with endogenous prices. The model allows projections of energy demand and supply in each country or region, as well as the induced CO2 emissions. The scenarios provide energy and emission data for 46 countries and 11 regions worldwide, 14 fuel supply branches and 15 final demand sectors. Economic assumptions are exogenous to the model (table 1 gives GDP and population assumptions used in POLES scenarios) while the set of variables that structure the energy demand, supply and prices are endogenously estimated for each country or region and market.

We rely on two POLES scenarios: a NDC+ and an A2C scenario (see Table 1). Both scenarios are built to achieve 2°C target in 2050 with a carbon budget for the period 2010 to 2050 equal to 1,130 $GtCO_2$ (IPCC, 2014; DDPP, 2015).

Both scenarios are implemented through carbon values required to reach the carbon budget (Figure 1.a). In the **NDC+** scenario, the carbon value is adjusted until 2030, in order national emissions are consistent with NDCs objectives of the Paris Agreement. For the period 2015-2030, in the NDC+ scenario, national carbon values vary from 0 to 60.5 $/$tCO_2$ in 2030. The world average carbon price is only 11.15 $/$tCO_2$ in 2030. For the second period, 2030-2050, the carbon value is the same for all countries and increases quickly to reach 1000 $/$tCO_2$ in 2050.

In the **A2C** scenario, we follow the same logic as in GECO 2017 report (Kitous et al., 2017), we divide countries/regions in 3 groups[7] and apply three different carbon values. The carbon value for middle-income countries is twice as small that for high-income countries and forth as small for low-income countries.

In this framework, national emissions in NDC+ after 2030, and over the whole period in the A2C scenario are endogenously determined given the regional or global carbon prices required to reach the global carbon budget objectives. It is very important to have this mind for a comprehensive understanding of the following DW analyses of the 42 national scenarios considered in this report. For national scenarios relying on global modeling and on global or regional carbon values, emissions are determined by this carbon value. In national scenarios built with other modeling tools, national emissions may be quite different. This explains the very contrasted emission pathways and mitigation objectives for a given country between two scenarios in the same family.

[7] - The partition of countries in groups are given as follows: high-income countries (EU28, Switzerland, Norway and Island, USA, Canada, Japan, Australia and New Zealand, South Korea); Middle-income countries (Turkey, Russia, Brazil, rest of south America, China and South Africa); Low-income countries (the rest of the world).

*Table 1 : **GDP and demographic assumptions and carbon budget in NDC+ and A2C scenarios in 2010-2050 period***

			NDC+	A2C
	POP	GDP	CO2 budget	CO2 budget
	Growth rate		*ktCO2*	*ktCO2*
Word	0.81%	3.06%	1 128 010	1 133 813
EU28	0.03%	1.32%	96 720	93 339
USA	0.63%	1.65%	140 732	122 844
China	0.05%	4.51%	363 904	347 091
India	0.74%	5.41%	83 347	94 974
France	0.37%	1.45%	8 508	8 437
Italy	-0.02%	1.08%	10 334	10 136
United Kingdom	0.41%	1.54%	13 164	12 694
Poland	-0.28%	1.90%	8 513	8 008
Germany	-0.34%	1.01%	20 884	20 143
Brazil	0.42%	2.11%	16 553	18 115
USA	0.52%	2.84%	12 553	11 700

Figures 1.c. and 1.d. show the evolution of emissions for both scenarios built with POLES at the global and EU28 levels. This highlights the sharp decrease in global emissions under the NDC+ scenario post-2030. Before 2030, emission reductions have to be much more ambitious, but this alleviates the emission constraint during the second half of the period. A significant shock on oil and gas market appears in 2020 in A2C, both prices increase from 2020 to 2050. In the NDC+ scenario, the shock is much higher in 2030 and gas and oil prices decrease from 2030 to 2045, followed by a rebound effect from 2045 to 2050.

Figure 2 describes the primary energy consumption and electricity generation. As electrification of uses is an important mitigation strategy deployed in POLES scenarios, electricity generation increases, especially in the A2C scenario. In the NDC+ scenario, the share of renewable energy in primary energy consumption is around 47% both at the global and EU28 level in 2050. This share is 38% and 44% in A2C scenario in the World and the EU 28, respectively. The electricity generation from solar and wind is higher in the rest of the World than in the EU 28: 42% and 35% in NDC+ scenario and 36% and 40% in the A2C scenario, respectively in 2050.

*Figure 1: **Characteristics of NDC+ and A2C scenarios computed with POLES***

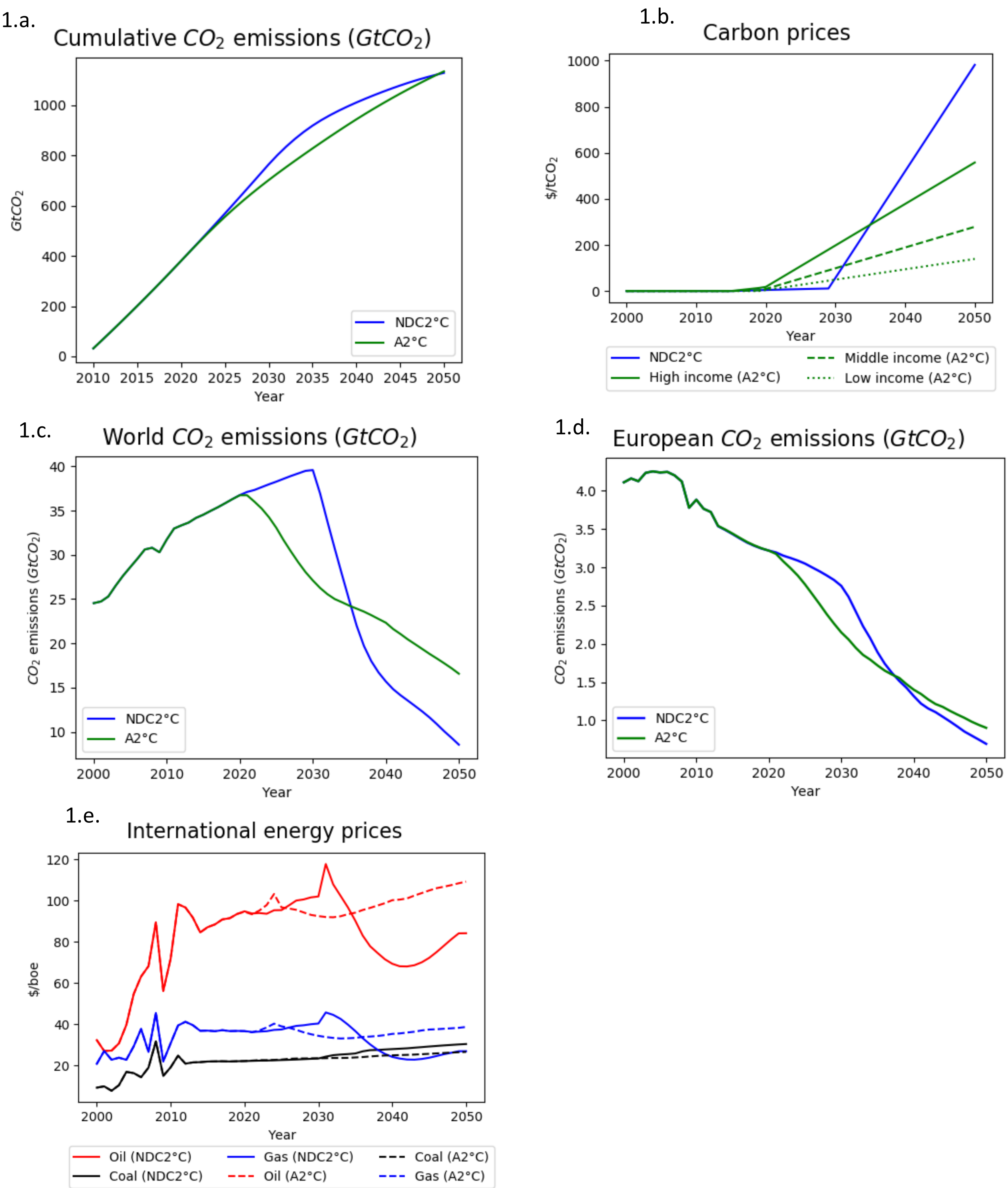
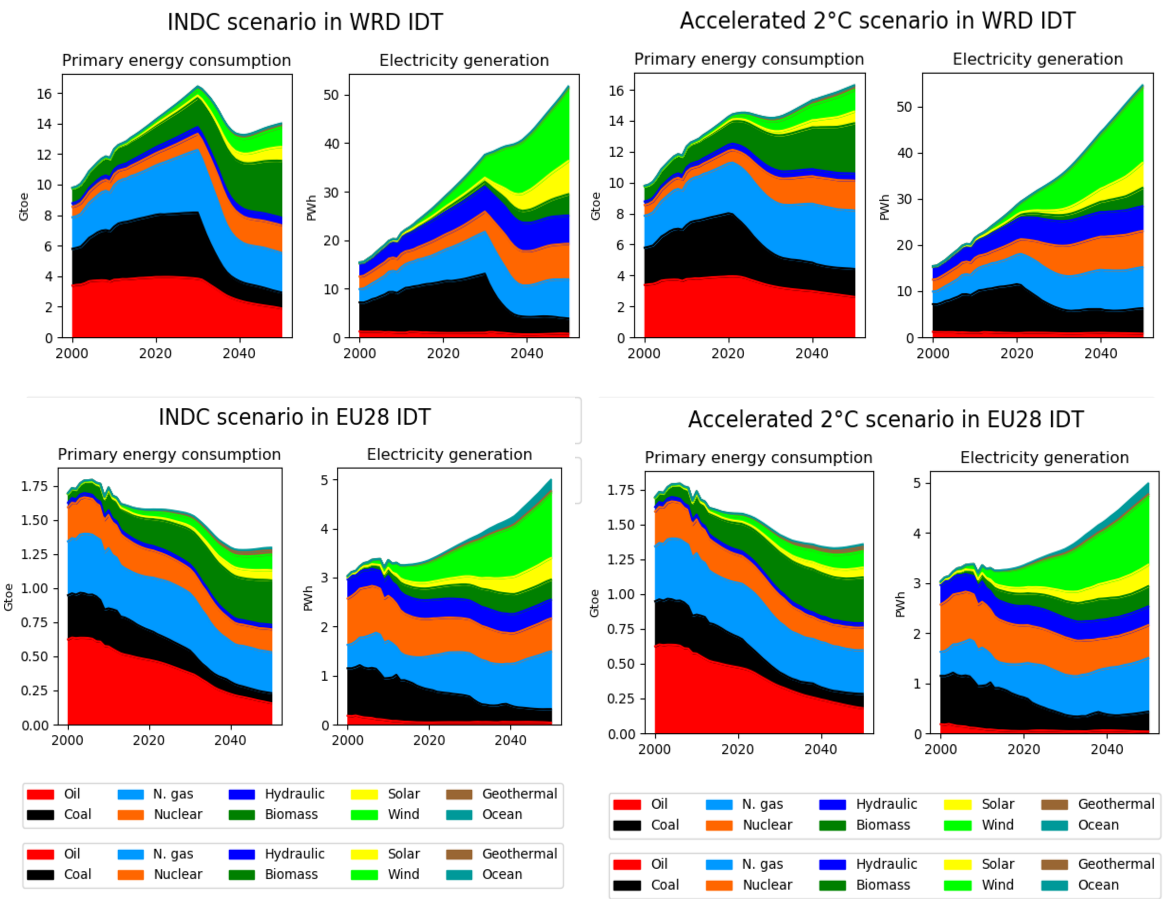
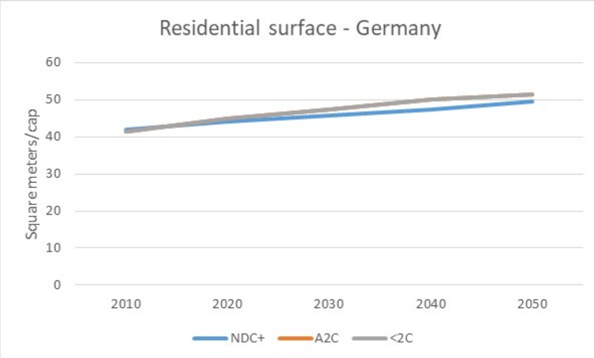


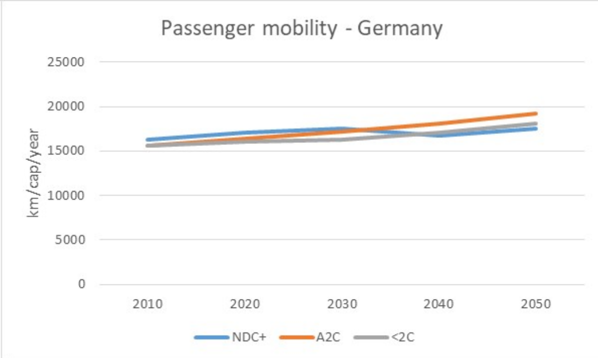
Figure 2 ***: Primary energy consumption and electricity generation in Poles scenarios***

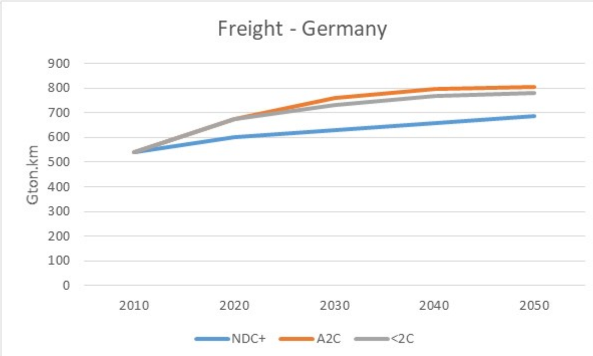


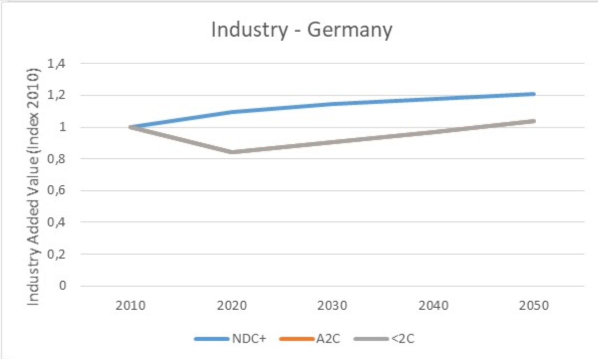
3. Sectoral Activity Indicators

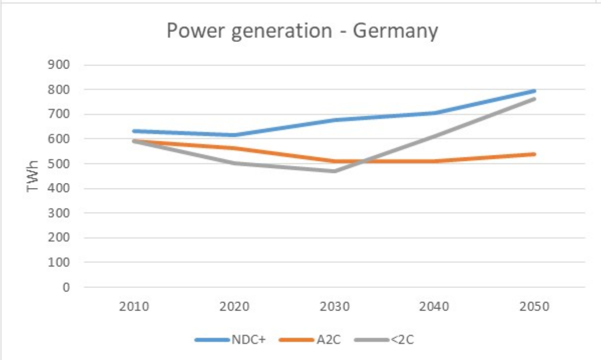
Germany – Sectoral activity indicators



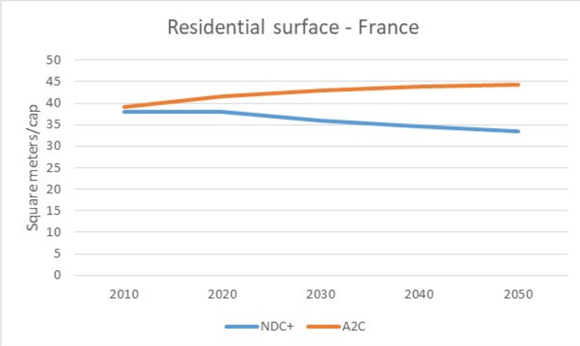


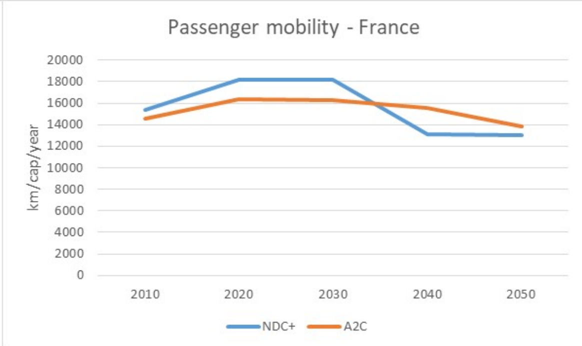


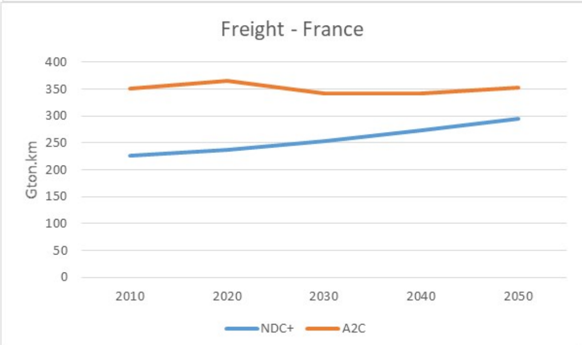


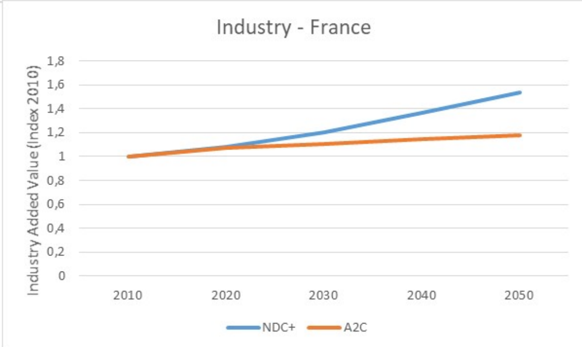


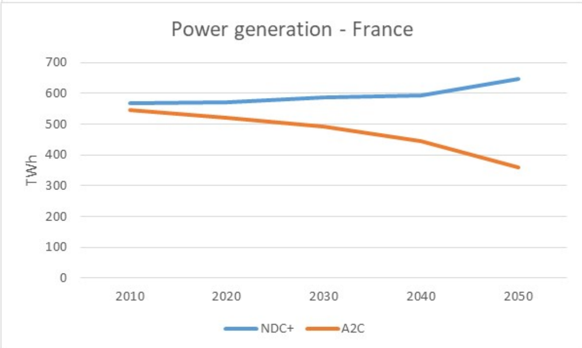
France – Sectoral activity indicators



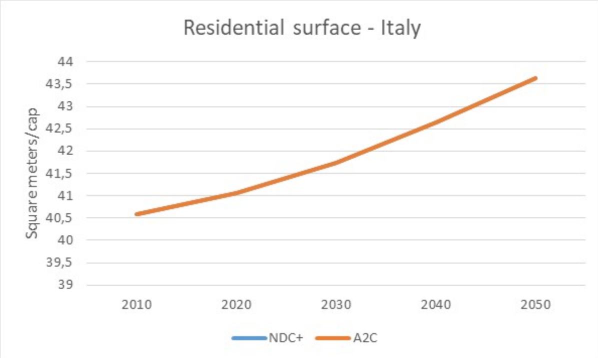


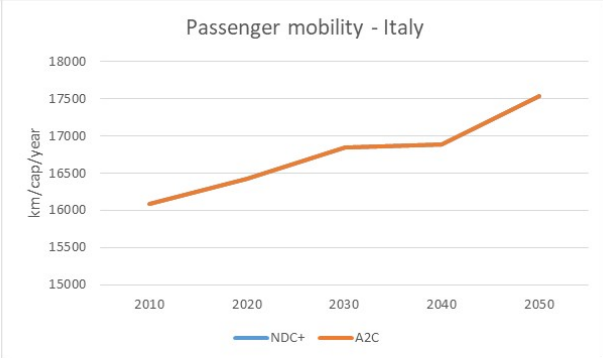


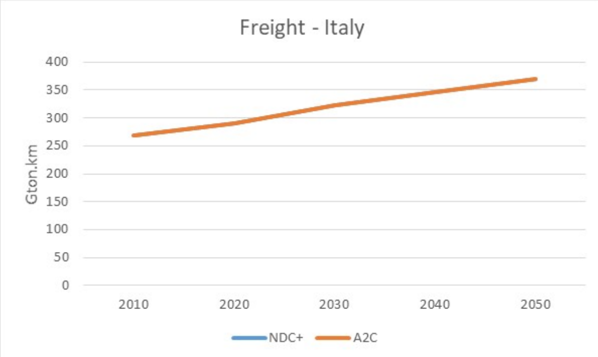


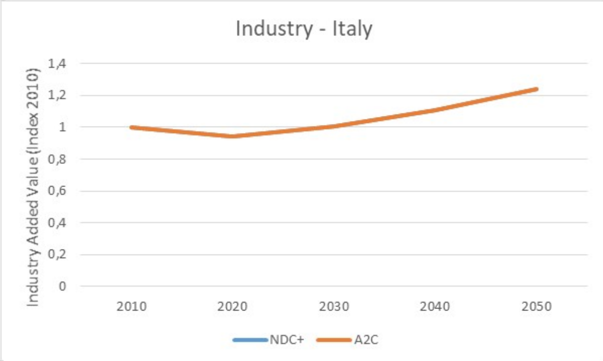


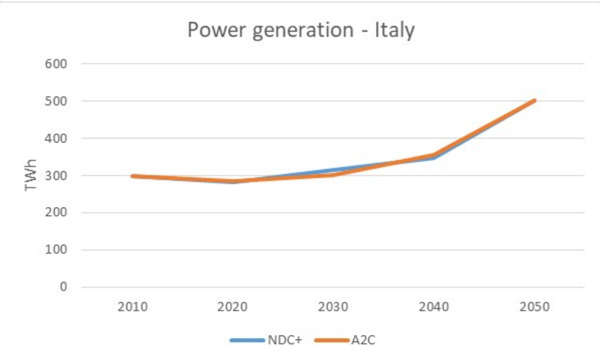
Italy – Sectoral activity indicators





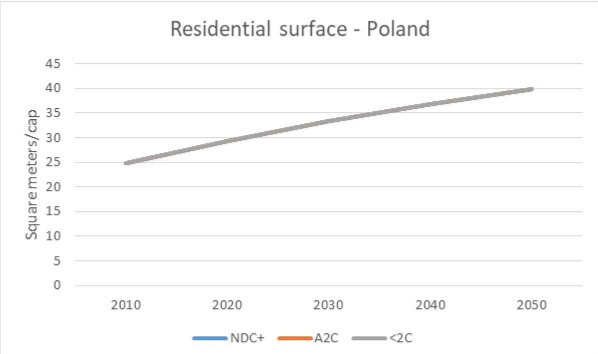


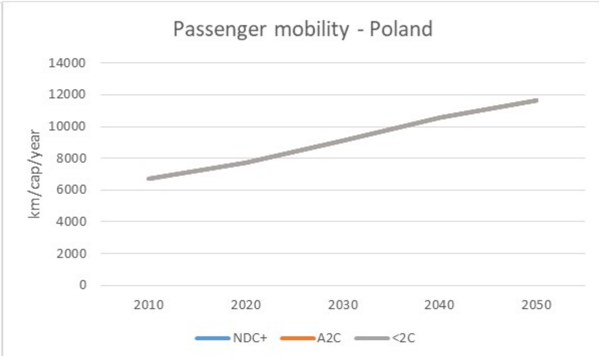


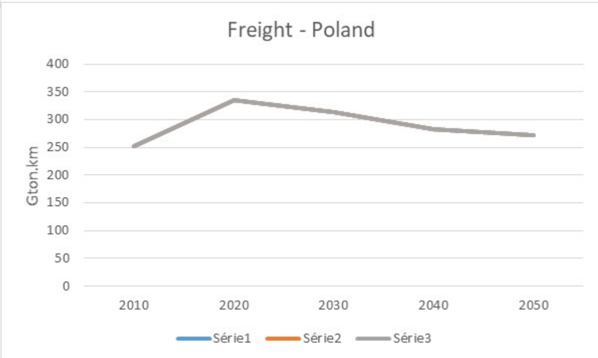


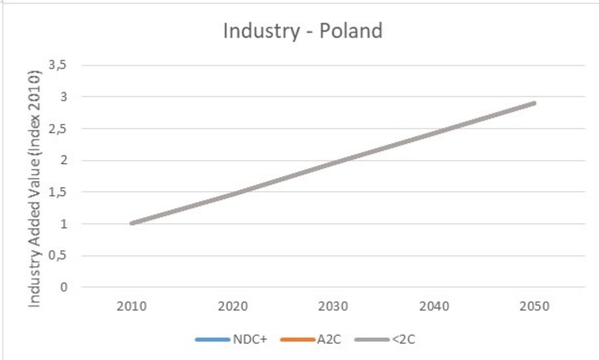
Poland – Sectoral activity indicators

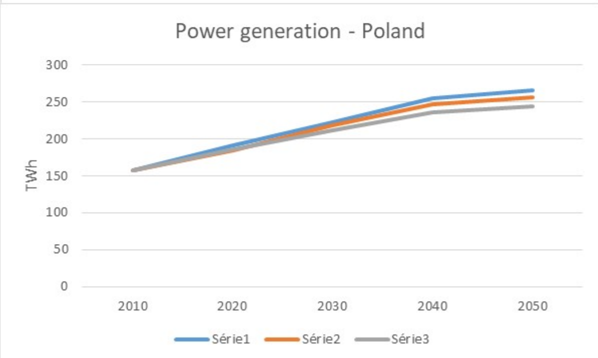
NB: the three scenarios consider the same sectoral activity indicators; this is the reason why only one curve is visible on each figure











UK – Sectoral activity indicators