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Working Paper

Fragmented Landscape of European Policies in the Energy Sector: First-Mover Advantages

CESifo Working Paper, No. 9093

Provided in Cooperation with:

Ifo Institute – Leibniz Institute for Economic Research at the University of Munich

Suggested Citation: Govorukha, Kristina; Mayer, Philip; Rübhelke, Dirk (2021) : Fragmented Landscape of European Policies in the Energy Sector: First-Mover Advantages, CESifo Working Paper, No. 9093, Center for Economic Studies and Ifo Institute (CESifo), Munich

This Version is available at:

<https://hdl.handle.net/10419/235463>

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Impressum:

CESifo Working Papers

ISSN 2364-1428 (electronic version)

Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH

The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute

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Editor: Clemens Fuest

<https://www.cesifo.org/en/wp>

An electronic version of the paper may be downloaded

- from the SSRN website: www.SSRN.com
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Fragmented Landscape of European Policies in the Energy Sector: First-Mover Advantages

Abstract

In order to achieve the commonly agreed emission reduction target, the European Commission developed binding national targets for each member state until 2030 and called upon the member states to submit National Energy and Climate Plans to ensure increased transparency for the respective national targets and strategies. An analysis of these plans shows that some of the emission reductions set at the national level prescribe a more ambitious decarbonisation than the EU-wide limits. However, since a transformation to a climate-friendly system requires considerable investment, the question arises as to why some states apparently want to be in the vanguard. We find that countries may have an incentive to outperform other states in the development of a low-carbon electricity system in order to pass on part of the transformation costs to neighbouring countries.

JEL-Codes: C600, Q400.

Keywords: electricity, utilities, thermal generation, unilateral action, climate policy.

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Highlights

- Despite continuous efforts towards an integrated European power system, the energy policy landscape of the member states is fragmented.
- Setting progressive national emission reduction targets demonstrates strategic decision-making and could influence the energy policies of neighbouring member states.
- First-mover advantages can be a decisive driving force for the transformation of European energy systems.

1. Introduction

The European Union (EU) has adopted an ambitious legislative framework under the Energy Union (EC 2018a) that aims to support the achievement of the EU's 2030 environmental targets and even to exceed its commitments under the Paris Agreement. As the European Commission (EC) points out (EC 2019a): "These targets are not ceilings but rather floors, and with the right incentives they can even be surpassed." The 2030 national reduction targets are defined for each member state (EC 2018b). In order to increase transparency and coordinate the planning of public and private investments, the EC required each member state to draw up a National Energy and Climate Plan (NECP) and to describe its current and planned policies and targets under five major dimensions: (i) *decarbonization* (including greenhouse gas emissions and renewable energy), (ii) *energy efficiency*, (iii) *energy security*, (iv) *internal energy market* and (v) *research innovation and competitiveness* (EC 2019b).

A careful inspection of the reported NECPs reveals that some member states' targets significantly exceed the joint targets for emissions abatement obligations and renewable energy deployment. Individual countries have set themselves far more stringent targets than those specified within the EU framework. In practice, achieving the national decarbonization targets in the electricity sector involves various technological and regulatory strategies such as increasing renewable energy production, carbon capture and storage (utilization) (CCS(U)) technologies, and expanding demand-side management potentials and smart grids. However, political decisions to deploy or phase out particular generation technologies, such as coal-fired or nuclear power plants, decisively influence national electricity systems.

In the light of ambitious unilateral national policies in the European landscape, two important questions arise. First, why do some member states commit to targets that exceed jointly adopted objectives? Second, how do such national targets affect highly interconnected electricity systems such as that of the EU?

European electricity markets are a highly integrated system with respect to both infrastructure and regulation. Developments in one market often influence neighboring markets. Hence, any analysis of one country's energy policy must consider possible effects on neighboring member states. In this study, we compare how Europe's electricity markets perform when countries broadly adhere to jointly agreed-upon mitigation targets, and when single countries (or country groups) aim for stricter abatement strategies. We focus on national energy policy goals and decarbonization strategies, evaluating how electricity production structures will change and what influence they will have on greenhouse gas emissions. Finally, we attempt to identify economic reasons why individual countries make greater contributions to climate protection than the EU framework stipulates.

2. NECPs - A closer look of the countries considered

The EC has begun to establish NECPs for 2021–2030 (EC 2019b). These documents provide information on member states' national targets and their progress toward climate protection. The plans share a common structure that is designed to improve comparability and lead to better cross-border cooperation and efficiency gains. The member states' national plans describe their goals for energy efficiency, renewables, greenhouse gases, emission reductions, interconnections, and research and innovation. The EC aims to monitor the member states' progress toward these targets and to establish a legally binding framework (EC 2019a). Next, the EC "will take stock of the final plans and confirm whether they are consistent with the Union's 2030 targets or whether further efforts might be needed" (EC 2019a, 2). Having submitted their final NECPs in 2019, member states must provide progress reports every two years (EC 2018a).

Although the EU strives for a higher level of market integration with unified regulations, our analysis of the published reports shows that national energy markets and regulatory frameworks deviate considerably. Differences arise from several factors: (i) national emission reduction targets, (ii) promotional measures or bans, and (iii) renewable energy targets.

Decarbonization strategies, and particularly sector-level emission reduction targets, are a major part of every NCEP. Under dimension (I), *decarbonization*, the collective GHG reduction targets are reported for both the sectors inside the EU emission trading system (ETS) and non-ETS sectors. Among the ETS sectors, power generation represents a significant share of greenhouse gas emissions and, consequently, significant potential savings: in 2019, the sector accounted for 31% of overall ETS CO₂ emissions¹ (EEA 2020a). In the discussion below, we will focus on the specific aspects that drive the divergence of national policies.

(i) *Emission reduction targets*

If met, the EU's collective emission reduction targets formulated in the 2030 Climate and Energy Framework would reduce emissions by 40% by 2030 compared to 1990 levels. Sectors included in the EU ETS are subject to a 43% cut, and non-ETS sectors² will need to reduce emissions by 30% (both compared to 2005 levels). A single EU-wide cap will replace individual national caps starting with the third phase of the EU ETS. The allocation of national reduction obligations to the member states is based on "considerations of fairness and solidarity" and defined by the EC (2018a, 26). The reduction obligations of member states with a GDP per capita above the EU average are adapted in proportion to "reflect cost-effectiveness in a fair and balanced manner" (ibid). For several member states, the national

¹ Item "combustion of fuels" to the sum of all ETS sectors.

² The sectors not included in the EU ETS, however, are subject to individual national obligations. Those cuts are regulated by the Effort Sharing legislation and are based on the respective Member State's relative wealth.

policy objectives stated in the NCEPs appear to deviate significantly from the targets listed in this regulation (Figure 1). Table 1 shows the sector-specific emission reduction targets for the energy sector. Comparing the NCEP targets and reported progress with the binding reduction levels stated by the Regulation 2018/842 is possible only to a limited extent. This limitation reflects the calculation basis of the greenhouse gas emission sources and sectors in the respective reports (see the footnote of Table 1).

(ii) *Technology-specific bans*

Several EU member states have implemented technology-specific bans. The nuclear accident of Fukushima caused an extensive public and political discussion on the future of nuclear power in Europe. In Germany, this discussion resulted in a planned phase-out of nuclear energy by 2022. However, the reaction to this incident varied across EU member states. While Germany declared a moratorium on nuclear power stations, the UK stood by its decision to expand its nuclear power capacity. As of 2019, 14 member states have nuclear reactors (IAEA 2020a). Of those 14 states, four plan to phase out nuclear power or to block the construction of new reactors. A similarly fractured picture emerges in the case of coal-fired power plants. Nine member states announced a complete phase-out of coal-fired power plants, while in several countries with a historically significant share of coal in their electricity mix (e.g., Germany), a coal phase-out became part of the political discussion. Phasing out coal-fired power plants is usually linked to concerns about climate change. In terms of climate protection, an alternative approach to a complete phase-out is the deployment of carbon capture and storage (CCS) or carbon capture and utilization (CCU) technologies. However, the implementation of CCS has proved to be complicated. In many cases, it is accompanied by a high level of public opposition (see e.g., Vögele et al. 2018, Upham and Roberts 2011). Table 1 provides an overview of the status of the national phase-out plans and technology-specific bans of individual EU member states as well as renewable energy expansion targets and planned greenhouse gas (GHG) emission reductions. The NECPs contain estimates for baseline developments *with existing measures* (WEM) and for more ambitious targets *with additional measures* (WAM).

Table 1: Overview of national policy goals and objectives set on EU level

State	Bans [share of production]	Year	RES share total (in electricity gen.)		Carbon budgets (Energy ¹)	Reduction below 2005 levels WEM (Energy ¹)		Reduction below 2005 levels (Total ²)		Regulation (EU) 2018/842 ³
			WEM	WAM		WEM	WAM	WEM	WAM	
			2030 [%]	2030 [%]	2005 [MtCO ₂ e]	2030 [%]	2030 [%]	2030 [%]	2030 [%]	
Austria	Coal ⁴	2020	36 (23)	46-50 (100)	16,3	-60		-36		-36
Belgium	Nuclear	2025	36		29,4	+2	+5	-15	-23	-35
Czech Rep.	-		22 (17)		63,2	-33		-30	-22	-14
Denmark	Coal	2030	55 (109)		23,2	-43	-47	-43	-69	-39
France	Coal	2022	38 (40)		66,7	-10	-40	-19	-46	-37
	Nuclear [50%]	2035								
Germany	Nuclear	2023	54 (53)	65 (62)	379,4	-34	-54	-28	-41	-38
	Coal	2038								
Great Britain	Coal	2025	(50)	(54)	214,4	-68		-45	-48	-37
Italy	Coal	2025	30		159,1	-49	-65	-34	-44	-33
Netherlands	Coal	2030	23		68,2	-73	-79	-31	-46	-36
Poland	Coal [60%]	2030	23 (32)		178,5	-16		-18		-7
Portugal	Coal	2030	47		25,5	-93	-95	-65	-55	-17
Norway	-		-			-12		-40		-68 ⁵
Spain	Coal	2030	26	30	126,6	-62	-82	-33	-49	-26
	Nuclear	2040								
Sweden	Coal	2022			10,8	-33				-40
	Nuclear	2040								

¹ Reductions are given for IPCC sector Energy 1.A.1 and estimated with the base of 2005 where necessary; some countries reported reductions with a base of 1990 (EEA 2020b).

² Total (without LULUCF and aviation).

³ Reduction of GHG emissions below 2005 levels: greenhouse gas emissions from the IPCC categories of energy, industrial processes and product use, agriculture and waste pursuant to Regulation (EU) No 525/2013 excluding greenhouse gas emissions from the activities listed in Annex I to Directive 2003/87/EC.

⁴ Hard coal and lignite if given.

⁵ For Norway, this target is defined under Annex IV to the European Economic Area Agreement.

Sources: (EC 2019b, 2018a, 2009)

(iii) Renewable energy targets

A similar fractured picture emerges when considering expansion targets for renewable energies. The Renewable Energy Directive (EC 2009) stipulated that renewable energy should cover 20% of gross final energy consumption by 2020. Individual targets were set for the respective member states, taking into account the starting point of renewable capacities and the national potential for energy production from renewable sources. In 2018, a revised Renewable Energy Directive (EC 2018c) entered into force. This directive raised the target for renewable energy share to 32% of final energy consumption by 2030. However, this updated version does not set country-specific minimum limits for 2030. Instead, the targets for 2020 are considered minimum contributions to the new 2030 framework, while the EU-level target is intended to give member states flexibility to "meet their greenhouse gas reduction targets in the most cost-effective manner in accordance with their specific circumstances, energy mix and capacity to produce renewable energy" (EC 2018c, 83). Figure 1 shows the national

targets for RES deployment (left) and emission reduction (right) as stated in the respective NCEPs in comparison to (EC 2009) and (EC 2018b).

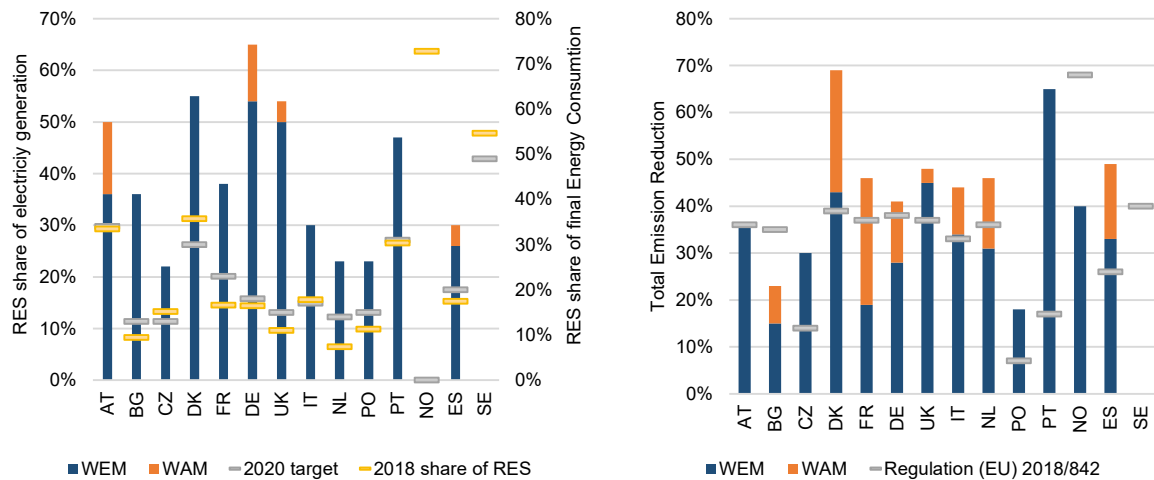


Figure 1: National RES development and emission reduction targets

Sources: Own compilation, based on (EC 2009, 2019b, 2018a, Eurostat 2019).

(iv) Summary

The national targets for emission reductions and expansion paths for renewable energies differ considerably. As the examples above show, the current system of national energy policies across member states is fractured. Individual targets and national political orientation significantly affect the structure of regional electricity markets. Despite the EU's efforts, a fragmented system has developed at the national level; it is uncertain to what extent individual countries meet common targets or implement climate measures that exceed these objectives. As the international integration of European electricity markets increases, this could lead to unexpected interactions.

3. Methods and analysis setting

3.1. Literature review

Climate change is a global problem. Therefore, it is to be expected that various actors prefer and pursue different political measures to address it. Consequently, this problem has also been considered in various settings by the scientific community. Weissbart (2018) analyzed the effects of member state cooperation to reduce GHG emissions to achieve the decarbonization targets of European power markets. The author applied a cooperative game approach to a bottom-up European power market model, analyzing the total system costs of regions coordinating to maximize welfare under their respective climate targets. He concluded

that all EU member states' cooperation was necessary to reach the common 2050 emission reduction target cost-effectively.

Several studies have addressed the consequences of technology-specific phase-out strategies. Osorio et al. (2020) investigated the risks of Germany's plan to phase out coal-fired power plants in the context of the EU ETS. Matthes et al. (2019) emphasized that this may encourage fossil fuel-based electricity production in neighboring countries. De Menezes and Houllier (2015) and Bruninx et al. (2013) analyzed the effect of Germany's national policies to increase wind generation and phase out nuclear energy on the interconnected European power markets. De Menezes and Houllier (2015) showed that price shocks can be transferred between the regions, and the effect is constrained only by the available transmission capacity. The authors concluded that after the decommissioning of eight nuclear power plants in Germany in 2011, price volatility increased across EU markets, proving that the first mover can significantly affect interconnected regions. In the case of unilateral actions in the energy sector, these positive effects at national level are limited by the negative impact on the competitiveness of energy-intensive industries (e.g. analysing consequences of unilateral action for Sweden by Sarasini (2009)). On the national level, first-movers can stimulate competitiveness introducing technological innovation and setting standards – these advantages are highlighted by the *Porter hypothesis* (Porter and Van der Linde 1995). It stipulates that the enforcement of progressive environmental standards can be more advantageous than adapting to foreign technological and political conditions in the follow-up. However, the same argument can lead to a *technology lock-in* - e.g. deployment of CCS(U) projects that do not correspond to the future choice of capture technologies, transport capacity or demand on gas composition (Stigson, Hansson, and Lind 2012).

Several studies have focused on the global climate agreement and the stringency of GHG emission reduction targets and long-term mitigation efforts (Böhringer, Rosendahl, and Storrøsten 2017, Juergens, Barreiro-Hurlé, and Vasa 2013, Paltsev 2001). These studies have analyzed the fragmented climate policy regimes emerging from unequal carbon prices across different regions of the world. The higher costs of delayed action outweigh the seemingly intuitive decision to postpone measures and thus avoid the short-term costs of progressive climate policy (Arroyo-Currás et al. 2015). This may explain why some countries find it beneficial to move forward unilaterally.

Hoel (1991) highlighted two possible arguments for unilateral actions to reduce emissions taken by a country. First, they are supposed to contribute – albeit only slightly – to climate protection and, second, there is a symbolic effect that may influence other countries to follow this "good" example.

Hoel (1991) himself challenged the first argument, showing that unilateral action may influence the outcome of international environmental negotiations, inducing even higher total emissions.

It is a standard result in the theory of public goods (Cornes and Sandler 1996) that unilateral abatement action would – at least to some degree – be offset by other countries' increases in emissions in response to the unilateral action (Vögele et al. 2019). However, this threat of carbon leakage³ has not prevented the implementation of several unilateral abatement initiatives in recent years. This might be partly due to effects (e.g., information transmission and technological progress)⁴ of unilateral action that could cause other countries to pursue stricter targets and counter carbon leakage (Arroyo-Currás et al. 2015). Behavioral influences are also among these effects, and Schwerhoff et al. (2018) stressed the importance of reciprocal behavior in this context.⁵ This reciprocity aspect is consistent with the second argument presented above, implying that leaders wish to provide a good example.⁶

In contrast, in the present study, we consider a case where those taking unilateral action have a more ambivalent view of others' behavior. On the one hand, leaders would benefit from others following their action; from a climate protection point of view, any action is beneficial for all. On the other hand, other countries' delays in transitioning could mitigate the leader's transition costs. We particularly consider this second aspect of the ambivalent perspective of the ambitious country in this paper. We will see how these arguments are supported by the modeling framework and analysis of the total costs of the unilateral action - the transformation of the power sector under more stringent climate policy.

3.2. Analysis setting

Contributing to climate change mitigation can be regarded as providing a global public good. Consequently, the incentive to freeride will impair mitigation contributions from the perspective of individual countries, leading to sub-provision. As described above, EU legislation established country-specific targets that consider member states' economic capacities in order to provide a fair and balanced framework. Nevertheless, some member states have committed themselves to even more stringent targets. Therefore, the question arises as to why some member states commit themselves to targets that go beyond the joint objectives and what effects that has on a highly interconnected electricity system.

This analysis will focus on the national energy policies of Germany, France, and their neighboring countries. The selection of these markets is based on two dimensions: (i) their relative significance within the European electricity markets and (ii) the divergence of national

³ Carbon leakage is defined as the additional CO₂ emissions of countries subject to a weak carbon policy compared to the CO₂ reduction achieved by pioneer regions with more ambitious policies.

⁴ See, for example, Buchholz, Dippl, and Eichenseer (2019) and Eichenseer (2020) for such effects.

⁵ Buchholz and Sandler (2016) included elements of behavioural economics in the standard model of public good provision and show that unilateral actions may then no longer be ineffective.

⁶ Buchholz, Buchholz, Cornes, and Rübbelke (2014) investigated members of a subgroup of countries cooperating by reciprocally matching their public good contributions. In doing so, the subgroup takes a leader position in the game of public good provision.

energy policy between them. The French and German markets rank highest in terms of overall electricity generation, and together they accounted for 47.4% in 2019 of gross electricity generation within the EU (Eurostat 2019). Due to Germany's geographical location, its electricity market is highly interconnected with neighboring markets. Furthermore, in the context of the *Energiewende*, Germany strives for ambitious targets regarding the development of renewable energy capacities. At the same time, it is pursuing a complete phase-out of nuclear power generation.

Contrary to its determined emission reduction targets, a nuclear phase-out could increase the need for fossil-fueled balancing capacities (see, e.g., (Bruninx et al. 2013, Knopf et al. 2014)). However, coal-fired generation will also be phased out and will be eliminated no later than the end of 2038 under the Act to Reduce and End Coal-Fired Power Generation (KvbG 2020). This limits balancing options and demands the further transformation of the German power sector. In France, on the other hand, a significant share of electricity is provided by nuclear reactors. As of 2018, 71.6% of electricity was supplied by nuclear power plants (IAEA 2020b). However, France plans to cut its reliance on nuclear power to 50% by 2035. Given this fractured regulatory and policy framework, we aim to evaluate potential distorting effects on electricity markets by applying a bottom-up linear optimization model of the European electricity market.

3.3. Model description

Our partial-equilibrium bottom-up model EMME⁷ features the EU-28 states, including Norway and Switzerland. We endogenously modeled electricity dispatch and investment in generation capacities by minimizing total system costs. Total system costs consist of overall variable generation costs and investment costs. Generation is subject to hourly demand (Equation 2). In the model, the demand is an exogenous input and is given as a price-inelastic time series in hourly intervals.

$$\min Cost = \sum_{h,i,d} [Pr_{h,i,d} \cdot Cst_{i,d}^{var}] + \sum_{i,d} (G_{i,d}^{inv} \cdot Cst_{i,d}^{inv}) \quad \forall h, i, d \quad (1)$$

$$Pr_{h,i,d} \leq G_{h,i,d} \quad \forall h, i, d \quad (2)$$

with:

- h specific hour of the year [-]
- i electricity generation technology index [-]
- $Cst_{i,d}^{var}$ variable generation costs [€/MWh]

⁷ A more detailed description of the model is provided in (Govorukha et al. 2020).

- $Cst_{i,d}^{fix}$ quasi-fixed annual costs (e.g. labor costs) [€/MW]
- $Cst_{i,d}^{inv}$ investment costs (annuity recalculated from overnight costs) [€/MWe]
- $Pr_{h,i,d}$ electricity production [MWh]
- $G_{h,i,d}^{inst}$ installed generation capacity at the beginning of the period [MW]
- $G_{h,i,d}^{inv}$ invested generation capacity of gas, lignite, and coal [MW]
- $G_{h,i,d}$ total generation capacity [MW]

Equation (3) describes the energy balance constraint.

$$\sum_i Pr_{h,i,d} + \sum_k I_{h,k,d} - \sum_k I_{h,d,k} = D_{h,d} \quad \forall h, i, d, k \quad (3)$$

where

- $I_{h,k,d}$ electricity imports from country k to d , and $I_{h,d,k}$ electricity exports from d to k [MWh]
- hourly electricity demand [MWh]

The existing cross-border net transfer capacity restricts electricity transfers between two nodes:

$$I_{h,k,d} \leq NTC_{k,d}; \quad I_{h,d,k} \leq NTC_{d,k} \quad \forall h, i, d, k \quad (4)$$

Variable renewable generation is determined via exogenous generation profiles, described in Equation (5), while the actual availability of fossil-fueled generation technologies is determined by Equation (6):

$$G_{h,v,d} = G_{h,v,d}^{inst} \cdot \varphi_{h,v,d} \quad \forall h, v, d \quad (5)$$

$$G_{h,r,d} \leq (G_{h,r,d}^{inst} + G_{h,r,d}^{inv}) \cdot \alpha_{h,r,d} \quad \forall h, r, d \quad (6)$$

with

- $\varphi_{h,v,d}$ exogenous generation profiles for variable technologies r [-]
- $\alpha_{h,i,d}$ technological availability factors for dispatchable technologies i [-]

$$\sum_{hr,i} \left(\frac{e_i}{ef_{i,d}} \cdot Pr_{h,i,d} \right) = cb_d \quad \forall h, i, d \quad (7)$$

with

- e_i emission coefficient [t CO₂/MWh] for each technology i [-]

- $ef_{i,d}$ specific efficiency coefficient [%] for each technology i [-]
- cb_d carbon budget of a country d

To facilitate the modeling and decrease solution time, we used simulated representative wind, solar, and load time series for each country generated with the *tsam* algorithm presented in (Kotzur et al. 2018).

As described in the previous section, decarbonization commitments and RES expansion targets vary significantly across member states. Table 1 compares the national goals described in the NECPs to the objectives defined in EU regulations. Some member states aim for a reduction in overall carbon emissions that exceeds the jointly adopted EU targets (e.g., Denmark, United Kingdom, Portugal) already in the WEM scenarios (Table 1). In contrast, others show that the common emission reduction targets will be challenging to achieve, and additional measures will be necessary. Moreover, some countries have introduced technology-specific bans and phase-out plans that could further aggravate the situation.

We implement the NECPs' targeted emission abatements as national carbon budgets by relating the percentage reduction to the emission levels of 2005, shown in the column "Carbon Budgets (Energy)" in Table 1. Due to the electricity market's structure, we adopt national RES targets as indicative benchmarks rather than explicit capacity constraints.

Both WEM and WAM estimations were implemented in the model design. In order to assess the implications of individual precursors, this study compares the possible effects of single countries' pursuit of ambitious energy and climate policy goals with a situation in which either all member states (represented by WAM estimations) or none (represented by WEM estimations) adhere to more stringent goals. As described above, this study focuses on the electricity markets of Germany, France, and their neighboring countries. Hence, we considered the combinations in Table 2.

Table 2: Combinations of leading (WAM) and lagging countries (WEM)*

Member State	Scenarios							
	c_0	c_de	c_fr	c_1	c_2	c_3	c_4	c_n
France			x	x			x	x
Germany		x		x		x		x
Others**					x	x	x	x

* Countries following WAM are indicated with "x", a blank field represents WEM

**Other countries, as given in Table 1, except for DE and FR.

4. Analysis

The modeling framework allows individual countries to invest in all available generation technologies unless there are explicitly formulated political goals for the phase-out of individual technologies (as described in Table 1). In countries where there is a partial ban that limits only

a certain share of coal and nuclear-based generation in the national generation mix (e.g., France and Poland), investments are limited to the respective level.

4.1. Analysis of total expenses in the power sector

We implemented the targeted national carbon budgets from the NECPs given in the column "Carbon Budgets (Energy)" in Table 1. The analysis assumes that countries have the choice between the two development paths referred to in the NECPs as WEM and WAM and that they consider other member states' strategies when choosing between the paths.

Each player's total system costs tc_d are defined as the country's d total expenses for the provision of electricity. Each country seeks to minimize those expenses. tc_d are composed of variable generation costs $Cst_{i,d}^{var}$, investments in new generation capacities, and the value of net exports $\sum_k I_{h,k,d} \cdot p_{h,d,k}^{im} - \sum_k I_{h,d,k} \cdot p_{h,k,d}^{ex}$. Investment costs are calculated as the total quantity of newly built generation capacity $G_{i,d}^{inv}$ (measured in MW) multiplied by the investment costs $Cst_{i,d}^{inv}$ (measured as annuity payment in $\frac{EUR}{MW}$) of the generation technology i installed within the modeling horizon. The value of interregional trade is defined as the difference of electricity imports $I_{h,k,d}$ and exports $I_{h,d,k}$ multiplied by the regional market-clearing prices in the exporting $p_{h,d,k}^{im}$ and importing $gp_{h,d,k}^{im}$ regions, respectively. These prices are derived from the shadow prices of the regional market-clearing constraints. The total regional expenses are calculated as follows:

$$tc_d = \sum_{h,i,d} [Pr_{h,i,d} \cdot Cst_{i,d}^{var}] + \sum_{i,d} (G_{i,d}^{inv} \cdot Cst_{i,d}^{inv}) + \left(\sum_k I_{h,k,d} \cdot p_{h,d,k}^{im} - \sum_k I_{h,d,k} \cdot p_{h,k,d}^{ex} \right) \quad \forall h, i, d, k \quad (8)$$

By comparing different cases in which Germany, France, and the neighboring countries pursue more (WAM) or less ambitious (WEM) energy and climate policy goals, we can determine the effects on the total national expenses of a state (Table 3).

Table 3: Differences in the value of total expenses across countries and scenarios (billion euros)

	c_0	c_de	Δ to c_0	c_fr	Δ to c_0	c_1	Δ to c_0	c_2	Δ to c_0	c_3	Δ to c_0	c_4	Δ to c_0	c_n	Δ to c_0
DE	15.15	10.43	-31%	16.19	7%	10.48	-31%	17.10	13%	10.71	-29%	17.85	18%	10.76	-29%
FR	12.22	13.81	13%	11.48	-6%	12.78	5%	13.82	13%	14.77	21%	12.75	4%	13.40	10%
Other	66.24	71.69	8%	66.38	0%	73.15	10%	63.47	-4%	71.19	7%	64.24	-3%	72.93	10%
Sum	93.61	95.93	2%	94.05	0%	96.41	3%	94.39	1%	96.67	3%	94.85	1%	97.09	4%

Figure 2 provides an overview of the total expenses of Germany, France, and the neighboring countries (as described in Equation 8) in relation to the decision of the respective other actors.

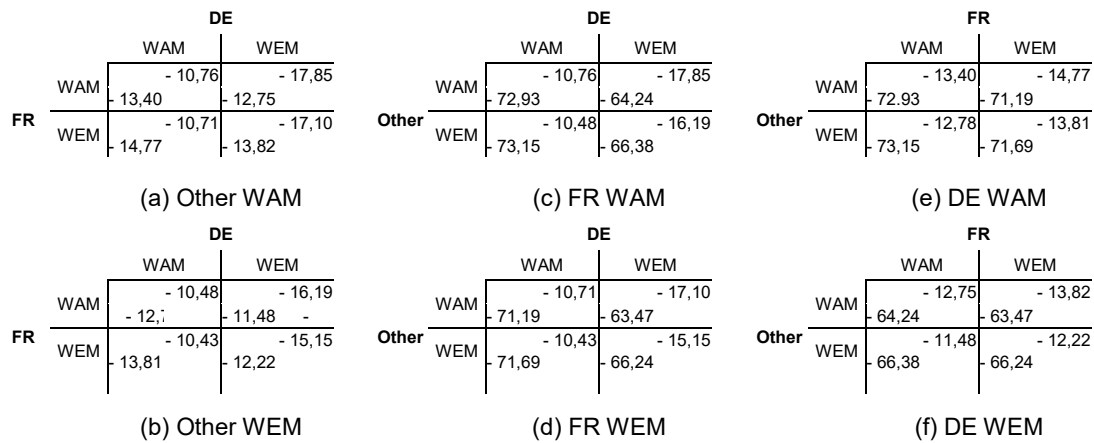


Figure 2: Payoff matrixes (billion euros)

Aiming for a more ambitious reduction in carbon budgets is the more advantageous strategy in all combinations (Figure 2). However, the expenses depend on neighboring countries. If other countries delay their advanced policies, a forerunner can potentially reach their WAM targets at lower costs. This can be illustrated by the case of Germany. When other member states choose WAM (Figure 2a), Germany's expenses are lowest if France lags behind. Germany's costs are approximately EUR 53 million lower than when France chooses WAM as well. Similarly, if France and other member states only enforce existing measures, it is advantageous for Germany to choose WAM (see Figure 2b). In this case, Germany's expenses decrease by EUR 56 million. In our model, if Germany alone pursues more ambitious climate goals (Figure 2b, lower left quadrant), it saves EUR 335 million compared to the situation in which everyone chooses WAM (Figure 2a, upper left quadrant). Hence, when fewer countries also follow the WAM strategy, Germany can spend less to achieve WAM goals. In general, the same conclusion is correct for France and the remaining member states as well.

Yet, an examination of total expenses shows that the configuration in which all countries select WEM represents the most favorable alternative overall (Table 3). From an individual player's perspective, however, it is always beneficial to unilaterally deviate from that strategy. It is more beneficial to adopt the WAM strategy if others choose WEM; this can be seen if we compare the total expenses for choosing WAM between the upper row of Figure 2 (a, c, e) and the lower row (b, d, f).

The results show that forerunners have an incentive to push ahead with the transformation of their own electricity sector while other countries lag behind. Moreover, it is disadvantageous for forerunners if other countries pursue ambitious climate goals at the same time. At first glance, this result appears counterintuitive since a transformation of the power sector toward a low carbon system is associated with high costs. This finding can be explained by investigating Figure 3, which provides a breakdown of the total national expenses for electricity

provision. In Germany, the overall sum of investments in new capacity hardly reacts to the climate strategy of neighboring countries. This can be seen by comparing overall investments in the configurations c_{de} , c_1 , c_3 and c_n with the configurations c_0 , c_{fr} , c_2 , and c_4 . A similar picture emerges when considering variable generation costs. Both variables appear to be driven mainly by Germany's own energy and climate policies. However, an analysis of electricity trade shows that Germany can produce considerable revenues from exporting electricity, especially if it follows a more ambitious climate policy under WAM. When renewable energy sources are abundant in Germany, fossil fuel power plants in neighboring countries are forced out of the market due to the merit order effect. On the other hand, Germany only relies on imports for balancing purposes for a few hours a year.

Thus, our results indicate that if one country proceeds on its own, neighboring countries may indirectly share the costs of decarbonization. The effects of increasing the share of variable renewable generation are the focus of many studies (see, e.g. Hirth and Ueckerdt 2013). Researchers have paid particular attention to the fact that negative spot market prices have appeared more regularly since Germany deployed more renewable energy sources. The occurrence of negative prices as a result of the expansion of renewable energies may appear to contradict the findings above. However, negative prices remain the exception rather than the norm. In 2019, negative prices occurred for 211 hours. This corresponds to approximately 2.5% of the trading period of that year (BNA 2019). Moreover, Germany generates substantial revenues from exporting electricity; in 2019, together with the dramatic increase in wind capacity, net electricity exports amounted to about EUR 1.2 billion (Fraunhofer ISE 2020). Moreover, there is no clear evidence that average export prices were lower than import prices. Therefore, the results are congruent with the lessons of the past, at least for medium-term developments up to the year 2030. If Germany implements additional measures, the revenues from exports will rise considerably (Figure 3). The difference between c_0 and c_{de} is explained by an interplay of increased investment costs compensated by revenues from net exports: more power is sold to neighboring countries. Additionally, there is a decrease in the expenses on inland electricity production, which itself is caused by changes in the pattern of interregional trade.

It is essential to add that we do not assume support mechanisms for wind and solar. In the case of offshore wind, there is already strong evidence of the technological competitiveness of the projects coming into operation in 2021–2023 (Jansen et al. 2020). In our model, wind and solar investments are pushed by stricter carbon budgets, which raises the endogenous cost of emissions, defined as a shadow price of the carbon budget constraint (e.g., in c_{de} for Germany, it is roughly EUR 76 per ton of CO₂ in 2030).

It is often argued that forerunners in climate policy can encourage other players to join climate change mitigation actions and treaties. We show that a different picture emerges from the

consideration of strategic decision-making. If no binding uniform framework exists, the two aspects discussed below could be of more importance than a mere "role model" function of the pioneer.

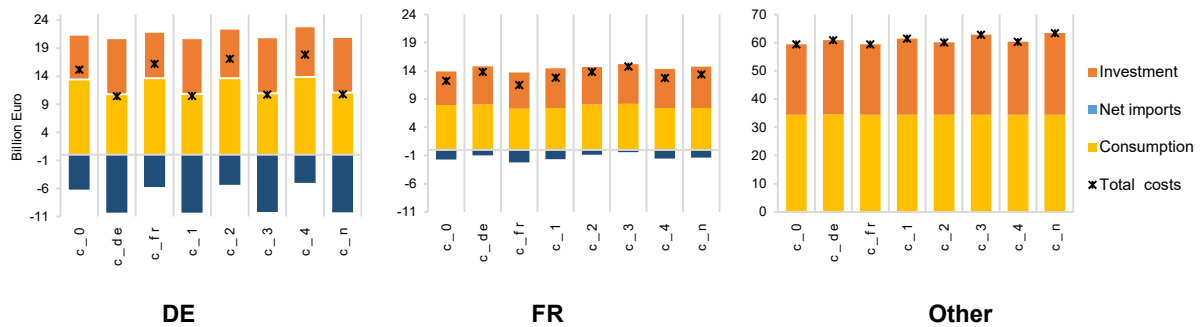


Figure 3: Decomposition of total costs in a million EUR

This section examined the rationale for unilateral action and found two key trends: (1) the "race to the top," in which the decarbonization of one market can be partially carried out on the shoulders of neighboring markets if they do not themselves implement more stringent measures at the same pace; and (2), when more countries take a more ambitious path, the cost of implementing more ambitious targets rises for all actors.

4.2. Prices

In this section, changes in wholesale electricity prices are related to the results of the total system costs determined in the previous chapter. Tighter carbon budgets for the power sector increase the mean values of electricity prices; compare the box plots for scenarios c_0 and c_n in Figure 4, where means are marked as crosses. Price means for most countries tend to be higher in the scenario where each country follows the WAM strategy, with higher variance and more persistent occurrence of hours with high prices across the interconnected regions. Table A1 of the Appendix shows the variances of wholesale prices between the scenarios. If only Germany and France strive for more advanced policies, the average prices in the neighboring countries increase along with the prices' variance. This effect is only limited by the available interconnection capacities between neighbors, with Germany retaining the position of a net exporter. The increase in price variance can be explained by the investments in the c_1 scenario, which increase the expansion of photovoltaics and wind. France continues to invest in nuclear power, but decommissioned nuclear capacities are being replaced by both new nuclear power plants and renewable energy facilities, gradually reducing the total nuclear fleet. These developments in the generation mix shift more expensive (in terms of variable costs) gas and coal-fired capacity to the right side of the merit order. The increase of variable renewables in the mix for most hours of the year increases the price volatility, which is transferred to the interconnected regions. These findings are consistent with the arguments of

de Menezes and Houllier (2015) that price shocks can be transferred between regions. Another notable effect is that hours with high price peaks in neighboring countries are reduced in the WEM scenario. As the density plots in Figure 4 show, the prices for most hours of the c_1 scenario are distributed more densely in the range of middle and high prices. Additional information about changes in the variance in wholesale electricity prices can be found in the Appendix, Table A 1.

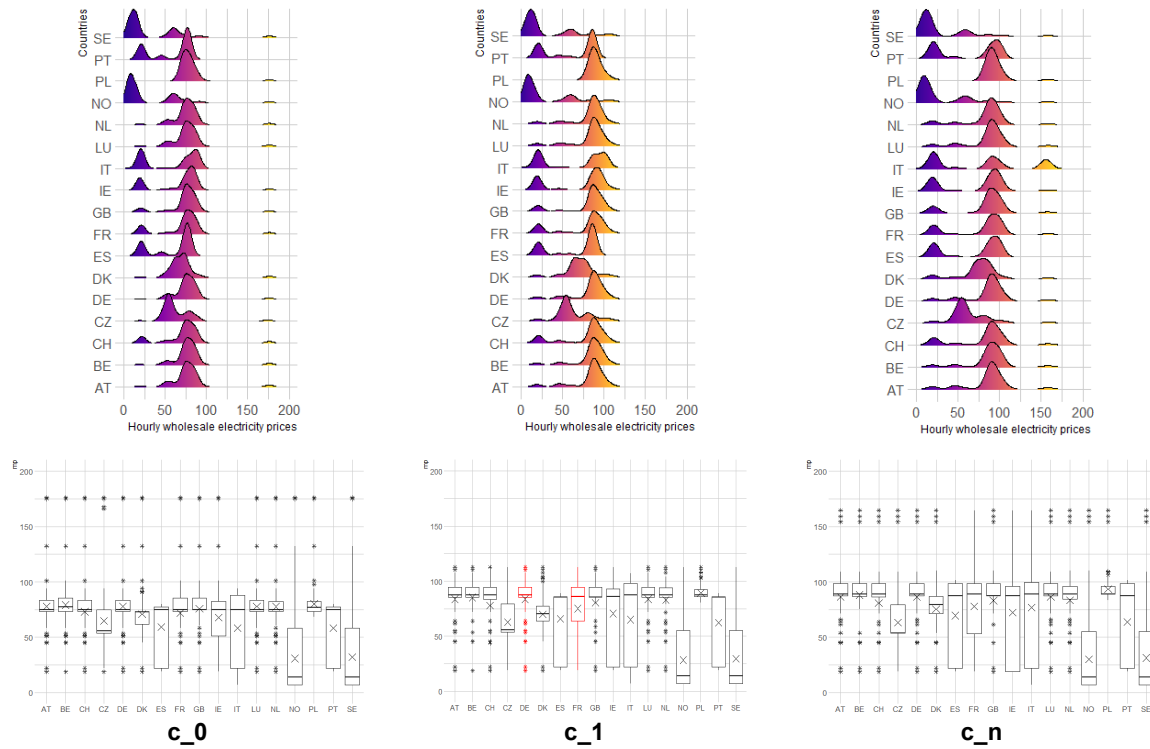


Figure 4: Wholesale electricity prices (€/MWh) in 2030

It is important to note that in the current formulation of the model, wholesale prices are influenced by the constraints imposed on the national carbon budgets (Figure 5). This places additional endogenous costs on emissions from fossil fuel electricity generation. Therefore, the prices reflect both the variable costs of electricity generation and the costs of more stringent policy targets for emissions in the electricity sector.

4.3. Emissions

As noted in the previous section, the constraint imposed on the national carbon budgets in Equation 7 creates an endogenous shadow price on the emissions of fossil fuel electricity production. The shadow prices can be interpreted as marginal abatement costs for the power sector in the respective region. Figure 5 shows the marginal abatement costs for all scenarios and member states in the modeling scope. The data behind the figure can be found in the Appendix, Table A3. They are compatible with the prices found in recent scientific studies and

sector-specific publications (Osorio et al. 2020, ENTSO-E 2019). As expected, the scenario c_0 shows lower regional marginal abatement costs for most countries. On the other hand, the scenario c_n , which has the highest total reduction of CO₂ emissions in the electricity sector, shows the highest shadow prices among all scenarios.

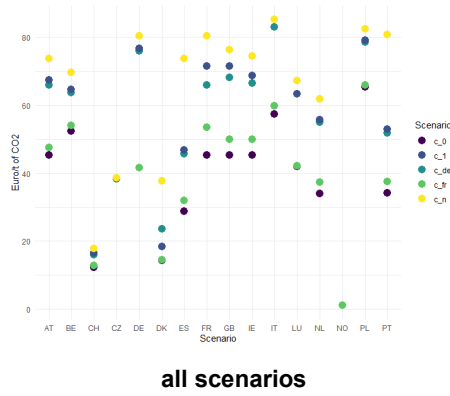


Figure 5: Marginal abatement costs in 2030

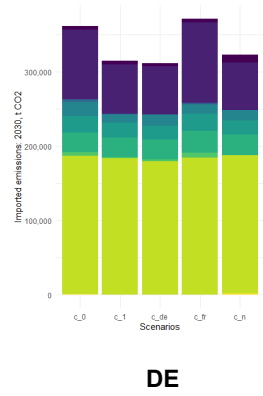


Figure 6: Imported emissions in 2030

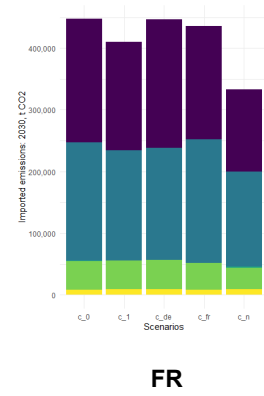


Figure 6 shows the estimated imported emissions as a total volume of imports multiplied by the emissions intensity of total electricity generation in the exporting country during the import period. Most of Germany's imported emissions come from Poland's fossil-fueled generation capacity, and this share remains relatively stable across the scenarios. The higher share of emissions imported from Belgium can be explained by the country's national strategy of expanding gas-fired capacity in the face of the nuclear phase-out in 2025. Interestingly, the value of imported emissions for Germany in c_{fr} is comparable to c_0 . Similarly to the Belgian case, this can be explained by the French reduction of nuclear generation capacity and expansion of gas-fired generation.

1.1. Investment

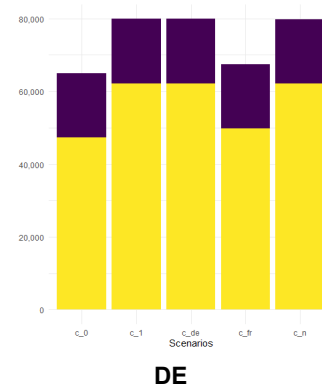
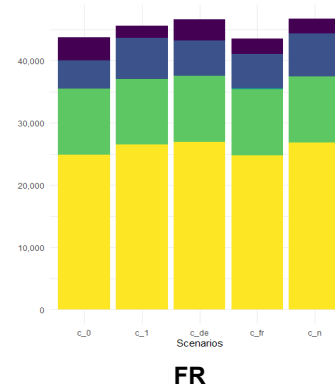
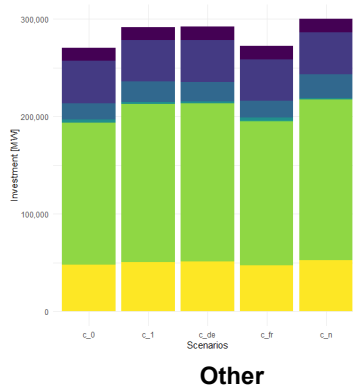


Figure 7: Investment [MW]

Scenario c_n , with additional extended measures that tighten carbon budgets for the power sector, causes more investments in renewable capacity, and in particular wind and PV, across

the selected European countries (Figure 7). Consequently, the total expansion of generation capacities is also highest in scenario c_n . Interestingly, the tightening of the German carbon budget alone has a comparably strong effect on the overall investment of other countries, with France having only a limited impact in c_{fr} . This can be explained by the substantial expansion of interconnection capacity envisaged in the Entso-E TYNDP of 35.5 GW net transmission export capacity from Germany in 2030, which is the largest planned expansion volume among the European countries discussed here. Further information about the investment costs and technology choices applied in the model can be found in the Appendix, Table A2.

5. Discussion and conclusions

In this study, we implemented a linear optimization model of the European electricity market to find a partial-equilibrium solution for different policy regimes. The model produced valuable and comprehensible results on regional investments, the development of wholesale electricity prices, and endogenous marginal abatement costs. Some limitations of the model stem from simplifications made to gain tractability, and these limitations must be considered with caution when interpreting the results. The total system costs alone are not a sufficient indicator of the different transition paths of the power sector because they can be rigid to structural changes. Therefore, an analysis of the marginal abatement costs, investment patterns, and imported emissions was applied to fill this gap.

The present analysis addresses only the European power sector, neglecting the other sectors of the EU ETS. It would be worthwhile to carry out a similar analysis that includes these sectors and the new support mechanisms that will come into force with Phase IV of the ETS in 2021 to counter the risk of carbon leakage.

This analysis is based on the NCEPs and reflects the pursuit of the EU's climate protection goals for 2050 and its own ambitions at the national level. The NCEPs are subject to uncertainty, in contrast to the existing binding EU regulations, which have strictly defined nationwide commitments to reduce CO₂ emissions in the electricity sector and to expand renewable energies. However, the NCEPs provide new and valuable insights into the current and upcoming changes in the energy sectors of EU member states.

As outlined in the introduction, this study aimed to analyze the possible motives for unilateral strict climate policies in European countries. Eight scenario groups were analyzed, highlighting the unilateral action of either Germany, France, or their simultaneous commitment to advanced climate protection goals. Additional scenarios helped to show changes in neighboring countries and their interest in pursuing more or less ambitious climate policies. The analysis of the total cost of operating and transforming the national electricity sectors revealed two main trends that explain the pursuit of unilateral commitment: (1) the costs of

early action can be redistributed to a certain extent to neighboring markets that do not have the ambition to pursue more stringent climate policies; and (2) the total costs spent by all member states increase as more countries accede to advanced policy regimes. On the national level, the effect of these two trends is considerably determined by the role (net exporter or net importer) of the country in the European electricity market, its interconnection capacity, and the structure of its generation mix.

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Appendix

Table A 1: Variance in wholesale electricity prices

		DE	FR	GB	NL	BE	DK	SE	LU	PL	CZ	AT	CH	IT	ES	NO	IE	PT
2030	c_0	470	431	595	426	441	442	125	47	303	514	470	755	951	613	130	102	639
2030	c_1	566	105	794	553	493	516	120	566	219	588	566	923	1331	846	125	131	895
2030	c_de	548	102	758	538	474	509	122	548	223	580	548	909	1307	836	127	126	884
2030	c_fr	482	631	603	440	450	449	124	482	294	526	482	772	983	639	1290	104	667
2030	c_n	738	130	954	779	661	719	140	738	259	653	738	1117	2742	1162	142	150	1284

Table A 2: Investment cost assumptions behind the scenarios

	Life-time	Overnight costs*	O&M annual costs	Overnight costs	Overnight costs
	[Years]	[2015 EUR/kW]	[2015 EUR/kW]	[2015 EUR/kW]	[2015 EUR/kW]
		2020	2020	2025	2030
Nuclear	40	5.580,0	148,7	5.468,4	5.301,0
Coal (conventional)	30	1.209,0	40,56	1.209,0	1.209,0
Coals (CCS)	30	2.4400	171,2	2.440,3	2.440,3
Lignite (conventional)	30	1.395,0	40,5	1.395,0	1.395,0
Lignite (CCS)	30	2.626,0	171,2	2.626,3	2.626,32
Gas (CCGT)	30	744,0	22,5	744,0	744,0
Gas (OCGT)	30	37,0	18,0	372,0	372,0
GAS (CCGT +CCS)	30	1.271,0	90,1	1.271,3	1.271,31
Wind (onshore)	20	1.153,0	39,6	1.095,5	1.026,3
.	20	2.550,0	108,1	669,6	641,7
Wind	20	1.153,0	39,6	976.500,0	976.500,0
Photovoltaics	20	697,0	11,7	2.185.500,0	2.185.500,0

*The cost estimations are based on the projections of current and prospective costs of electricity generation (Schröder et al. 2013) and adjusted to the trends given in De Vita et al. (2018).

Table A 3: Marginal abatement costs in 2030 (data behind the Figure 5 Marginal abatement costs in 2030)

		DE	FR	GB	NL	BE	DK	LU	PL	CZ	AT	CH	IT	ES	NO	IE	PT
2030	c_0	41,50	45,30	45,30	34,07	52,28	14,27	41,97	65,26	38,41	45,30	12,37	5,73	28,81	11,68	45,30	34,25
2030	c_de	75,93	65,90	68,13	54,93	63,71	23,71	65,90	7,85	38,48	65,90	16,00	8,29	4,58	11,29	6,65	51,77
2030	c_gb	41,50	45,30	45,30	34,07	52,28	14,27	41,97	65,26	38,41	45,30	12,37	5,73	28,81	11,68	45,30	34,25
2030	c_fr	4,16	53,36	49,76	37,48	5,40	14,60	42,09	65,95	38,30	47,49	12,78	59,83	32,11	12,02	49,76	37,66
2030	c_1	76,55	71,47	71,47	55,74	64,61	18,74	63,37	79,03	38,37	67,30	16,47	85,06	46,79	NA	68,64	52,82
2030	c_2	41,91	48,20	48,20	41,91	54,87	25,38	42,36	65,43	38,13	4,78	12,94	2,42	48,20	NA	48,20	54,29
2030	c_3	77,28	68,98	68,98	59,42	66,92	39,34	64,06	79,66	38,71	68,98	16,75	22,73	68,98	NA	68,98	75,76
2030	c_4	43,20	61,15	55,04	43,20	57,85	29,33	43,59	66,66	38,15	49,12	13,50	25,01	55,04	NA	55,04	61,35
2030	c_n	8,04	8,04	7,63	61,88	69,49	37,79	67,24	82,28	38,70	73,69	17,80	20,36	73,69	NA	7,44	80,62