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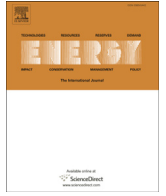
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Coal phase-out in Germany – Implications and policies for affected regions



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ABSTRACT

The present study examines the consequences of the planned coal phase-out in Germany according to various phase-out pathways that differ in the ordering of power plant closures. Soft-linking an energy system model with an input-output model and a regional macroeconomic model simulates the socio-economic effects of the phase-out in the lignite regions, as well as in the rest of Germany. The combination of two economic models offers the advantage of considering the phase-out from different perspectives and thus assessing the robustness of the results. The model results show that the lignite coal regions will exhibit losses in output, income and population, but a faster phase-out would lead to a quicker recovery. Migration to other areas in Germany and demographic changes will partially compensate for increasing unemployment, but support from federal policy is also necessary to support structural change in these regions.

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1. Coal in the context of the *Energiewende* in Germany

To achieve internationally agreed upon climate targets, all countries must achieve rapid decarbonisation of all sectors by the middle of this century [1]. Research on this topic has mostly focused on the energy sector due to its high remaining emissions, but comparatively cheap abatement potential [2,3]. Germany's *Energiewende* (energy transition) is sometimes referred to as a positive example in this context [4,5]. It originates from bottom-up initiatives by people and (a diversity of community and privately

owned) companies promoting renewable energy sources (RES) [6,7]. The sharp increase of RES from 3% in 1990 to 40% of electricity in 2018 came alongside new business concepts and the creation of around 350,000 new jobs, spread relatively evenly across the entire country (cf. Fig. 1). At the same time, employment within the coal sector decreased continuously [8,9]. The deployment of photovoltaics (PV) around 2011 was especially remarkable. As a consequence, several countries are taking Germany as a benchmark [10–12] - hoping to use their own photovoltaic potential [13–15]. Germany, however, has exhibited rather poor performance in the context of more recent European energy-transition targets [16] Figs. 8–10.

Looking at more recent trends, the image of Germany as a leader in climate policy has faded: CO₂ emissions from the German electricity sector were reduced through efficiency increases after unification (1990–1995: –14%), but have hardly changed within the

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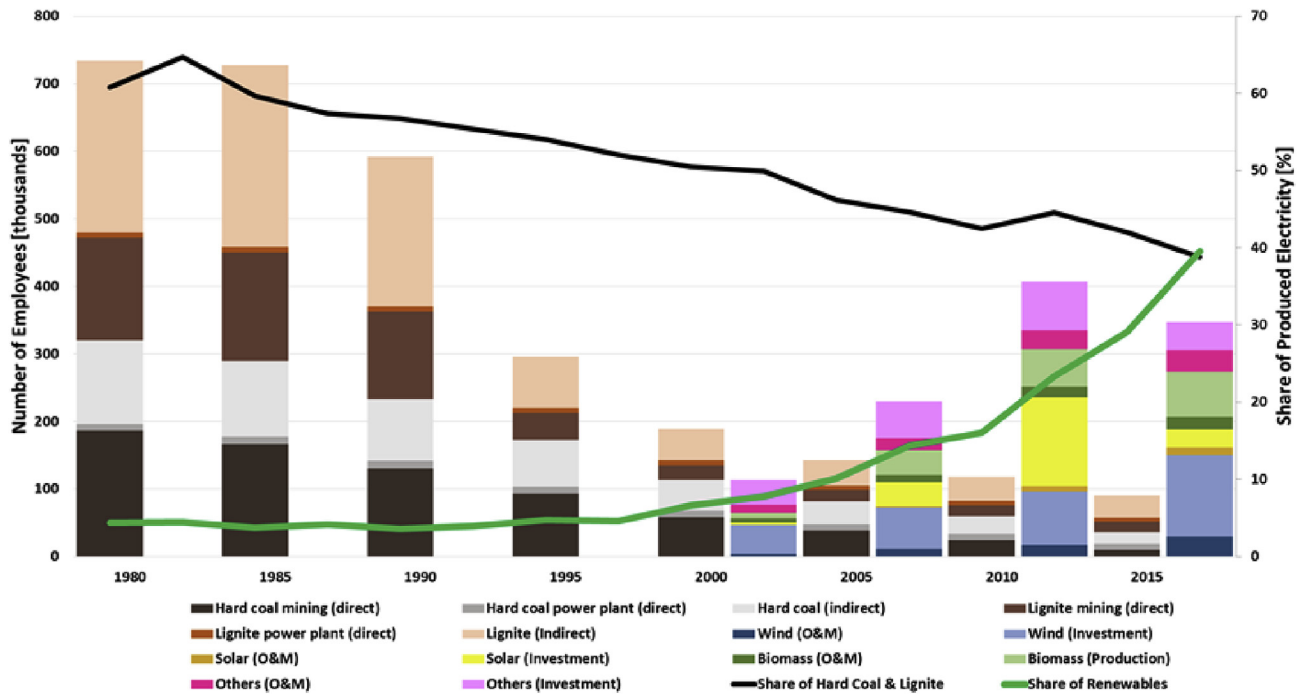


Fig. 1. Development of coal and renewable energy share employment depicted by bars and share of electricity production in Germany from 1980 to 2017 depicted by lines. Source: Own calculations and depiction based on [17]; data for RES employment only available since 2000.

last twenty years (1995–2017: –10%) [18]. Whereas in Europe the full load hours of conventional power plants has decreased [19], the increasing share of RES has not been sufficient to reduce emissions in Germany due to a decline only in nuclear and the maintenance of continuous high coal-fired electricity production [20].

Nearly forty years after the first publication on the German energy transition, Germany still remains the world's biggest producer of lignite, with lignite and hard coal providing almost 40% of its electricity [21]. As a consequence, Germany is going to miss its own climate target for 2020 by about 7% [22]. The current German government has also confined national RES growth and prevented more ambitious European emission and RES targets.

Coal-fired power plants are still among the key drivers of global warming [23,24]. Additionally, they are harmful for the environment since they emit airborne pollutants. This causes high environmental and social costs, e.g. due to impacts on human health and property. With average cost of 20.81 Euro Cents/kWh, lignite is responsible for the highest environmental costs in electricity generation. Hard coal is second with an average of 18.79 Euro Cents/kWh, followed by natural gas, with costs of 8.59 Euro Cents/kWh. On the contrary, renewable energy sources are more environmentally friendly with 0.28 Euro Cents/kWh for wind, and 1.64 Euro Cents/kWh for photovoltaics [25,26]. Within these numbers, the environmental impacts of opencast mining are not even taken into account. Lignite mining causes the suspension of fine particulate matter in the air, the pollution of waterways, and the use of land. Additionally, it directly effects the status of waterways. Ground depressions effects the ground water level, and the quality of the ground water, e.g. due to sulphate and chloride. Wastewater from lignite mining usually contains iron and can lead to ochre in surface waters, which affects aquatic life. Besides that, the relocation of villages destroys valuable ecosystems, cultural assets and changes rural environments permanently [26,27].

Germany's own CO₂ reduction goals cannot be achieved without a rapid phase-out of coal, which is responsible for over 70% of the electricity sectors' CO₂ emissions. Nevertheless, by the end of 2019,

there have been no specific policy measures implemented. The European Emissions Trading System (ETS), which is always emphasised as the key for reaching the climate targets [28], is a barrier to coal phase-out in its current form [17,29]. The initial free allocations and mechanisms (cf. "Joint Implementation" and "Clean Development Mechanism") that created additional allowances have led to too low auctioning prices and hence a failure of the trading system to reduce coal-based electricity production. Free allocation (and windfall profits) for new coal power plants and political support for new coal power plants have been additional reasons for a lack of progress in cutting down emissions from coal, as Pahle [30] argues; there was a dash for coal in Germany from 2009 to 2013, where around 13.8 GW of new power plants were (planned to be) established, of which 80% were based on hard coal or lignite – which now can be considered stranded.

At the same time, climate policy became steadily more important in Germany, as well as throughout Europe. However, the urgency of phasing out coal was more or less ignored for many years. For quite some time, the political rhetoric was rather vague or even in favour of coal. Practical decision-making was also in favour of coal. In 2007, the federal government's so-called *Integrated Energy and Climate Programme (Integrierte Energie- und Klimaprogramm)* was an important milestone in climate policy in Germany, because it set the goal to reduce emissions by 40% in 2020. At the same time, it saw a long-term perspective for coal in combination with carbon capture and storage (CCS) [31,32] – despite contrary research [33,34]. The same is true for the 2010 *Energy Concept (Energiekonzept)*, which plans new carbon neutral coal-fired power plants with CCS by around 2050 [35]. New flexible fossil power plants (including coal) were seen as a backup for fluctuating wind and solar energy. It is remarkable that structural change and potential job losses in German coal regions were not part of any debate in either 2007 or 2010. The coalition treaty in 2013 [36] has brought only a gradual change, because it mentions the lignite industry as a relevant regional economic factor for eastern Germany. However, the so-called *Climate Action Programme 2020*

(*Aktionsprogramm Klimaschutz 2020*), approved by the German government in 2014, says almost nothing about emission reduction in the power sector. It only consists of a reduction target of 22 mill. tons CO₂ for the year 2020 [37]. A few months later in 2015, the German Government suggested a supporting instrument, the so-called *Climate Contribution (Klimabeitrag)* that was intended to limit the electricity generation of old coal-fired power plants, but was not implemented [38]. Instead a stand-by reserve was realised that paid old power plants to guarantee capacities although some of the power plants would have been decommissioned anyways [39]. By the end of 2019, none of the stand-by power plants has been needed [40].

The current ruling parties of conservatives (CDU) and social democrats (SPD) agreed in 2018 in their coalition contract [41] to make more of an effort in addition to the *Climate Protection Plan 2050 (Klimaschutzplan 2050)* [28] and the *Action Programme Climate Protection 2020 (Aktionsprogramm Klimaschutz 2020)* to close the emissions gap for 2020. Complementary to phasing out coal, the coalition contract promises support for regional structural transition.

As the development in the German energy system has shown, it is not sufficient to support RES to achieve national decarbonisation targets. Incentives to reduce fossil fuel are also important [42]. Turnheim and Geels [43] have suggested the end of subsidies to reduce fossil fuel use, as a lesson from the analysis of the British coal sector. In Germany, the subsidies for domestic hard coal production ended in 2018, which was a crucial step, but its effects on the energy sector and CO₂ emissions were limited as the hard coal demand is now entirely covered via imports [8].

Further measures are therefore necessary to limit the consumption of coal, as proposed by Brauers et al. [44]. Effective measures to achieve emission targets are likely to produce winners and losers. The reallocation of production factors from established industries to new innovative industries leads to the spread of new technologies, also known as creative destruction (cf [45]). The transformation process is likely to lead to social friction due to job losses, which have a severe impact on regional economic development (cf [46]). Incumbent players obstruct this transformation and maintain their influence by forming networks with politicians and unions. Especially in the phase-out of hard coal production in Germany, this has led to a conservation of this industry beyond economic and ecological reason [47]. Unruh [48] and Walker [49] name the close relationships of the industry with politics as one of the key aspects for this lock-in. Hospers [50] gives additional types of lock-ins exemplary for the Ruhr area, while Campbell and Coenen [51] provide examples for Europe's old industrial regions.

In Germany, starting in the 1960s, approximately 600,000 jobs were affected by the coal phase-out and there was an additional high motivation to slow the pace of the decline to reduce the social impact in the affected regions.

The underlying narrative is the shift in the public perception of coal from being the former backbone of Germany's economy towards resembling the Achilles' heel of its energy transition. As a consequence, due to rising pressure from civil society as well as from the coal regions demanding financial support, the government, in accordance with its coalition treaty, started tackling the coal issue by introducing a "Commission on Growth, Structural Change and Employment" – often also referred to as the "coal commission". The commission consisted of four chairs and 24 representatives from industry, unions, environmental NGOs, the regions and selected scientists [44]. It recommended a coal phase-out by 2035 or, at the latest, 2038 [52].

Gerbaulet et al. [53] included different levels of foresight in their modelling and showed that reduced foresight would lead to stranded investments in the fossil fuel industry. It is an important

step, not only for Germany, to announce the phase-out date as soon as possible. This could reduce potential stranded assets for the coal industry [54]. One can conclude that it was a cumbersome political process in Germany until the phase-out decision was possible, and it remains to be seen if the recommendations of the coal commissions will be fully implemented by the government.

Recent results from energy modelling show that the decarbonisation and transformation into a 100% renewable based system is technically and economically feasible by 2050 (see Refs. [55–57] for global scale [58]; for Germany). As social and economic changes accompany this transformation, it is obligatory to include these in the assessment.

Recent studies have examined the loss of jobs in the lignite sector itself and related jobs [17,29,59] and its associated social costs (for employees in power plants only cf [60]) through bottom-up approaches. To calculate the effects outside the lignite sector, several studies have examined the economic effects of the coal sector in Germany with input-output models (IOM) (cf [61–63]) and computable general equilibrium (CGE) models (e.g. Ref. [64]). To estimate the effects of a coal phase-out, integrated assessment models (IAM) are helpful because they can link energy modelling and economic modelling together (cf [65,66]).

Hansen et al. [67] collected over 180 studies covering the energy transition towards a 100% renewable energy system that were published in the previous decade. Most of these studies concentrated on the techno-economic consequences of the transition (power plant capacities or resulting electricity price changes), neglecting the associated direct and indirect loss of jobs in some regions – one of the key barriers in the political and public debate. In this study, we therefore examine the effect of various coal phase-out pathways in Germany in line with the coal commission's recommendations. We applied a model linking an energy system model with two different economic models, which will be introduced in section 2, followed by section 3 describing the relevant data from the lignite areas. Section 4 describes the phase-out scenarios and section 5 presents the modelling results. The paper concludes with section 6 and a discussion of policy implications.

This work originates from an interdisciplinary research project from 2016 to 2019, see Oei et al. [68]. It also profited from direct feedback of local representatives within the coal regions to test the validity of the results. The novelty of our approach – in addition to the model linkage – is the comparison of a static input-output model with a dynamic regional macroeconomic model, which also provides region-specific effects. Therefore, the study can add to the existing literature on the economic effects of different coal phase-out pathways in Germany by quantifying regional macroeconomic effects considering adjustment processes. These findings can also support international research on enabling a just and timely transition from fossil to renewable resources.

2. Methodology

In the present study, we examine the (socio-) economic effects of an accelerated coal phase-out in Germany, especially in the lignite regions. The considered lignite regions in this paper consist of the lignite mining region containing a lignite-fired power plant or mine as well as the surrounding area with high commuter flows. On the one hand, we analyse the implications for the energy system (closure of lignite power plants), which are national and supranational in reach, and on the other hand, we consider the consequences of the reduced value added in the lignite coal regions. Due to the coupling of power plants and open pit mines, the local employment effects are concentrated in lignite regions. The phase-out affects social, economic and technical aspects at the local, regional, national and, to a lesser extent, European level. We

therefore soft link¹ the energy system model *PowerFlex* (cf. e.g. Refs. [70–72]) with two economic models, an input-output model [68] and a regional macroeconomic model [73] (cf. Table 1).

2.1. Energy system model *PowerFlex*

The results of the energy system are based on calculations made with the model *PowerFlex*. The scenarios and the key assumptions such as energy prices are documented in Ref. [72]. *PowerFlex* is a linear, cost-minimising dispatch model implemented in GAMS and solved with the cplex-Solver (simplex algorithm). It covers the German energy sector (electricity and heating) in high detail, as well as the other countries of the ENTSO-E² network (except Iceland and Cyprus), which are each represented as one node in aggregated form, with the underlying “copperplate” assumption. The model calculates the optimal dispatch of thermal power plants, renewable energy technologies and flexibility options at an hourly resolution, as well as the energy production of the power plants, the primary energy demand (especially from lignite) and the CO₂-emissions in five-year steps. The exogenously decided installed capacity and phase-out of lignite and hard coal power plants in Germany was based on explicit phase-out criteria discussed in section 4. Other calculations of *PowerFlex* with fixed costs of power plants and lignite mines have been done in Ref. [70].

The objective function (equation (1)) of the model minimizes the total variable costs C^{tot} which consist of the sum of the costs for each period t . C^{tot} splits up into the marginal costs for the electricity generation by the conventional power plants C_{pp}^{mar} and the renewable energies C_{ren}^{mar} multiplied with the power of each technology ($P_{pp,t}^{elec}$, $P_{ren,t}^{elec}$). On top of that, the variable costs for heating C^{boil} multiplied with thermal power $P_{pp,t}^{boil}$ and the costs for the flexibility options $flex$ are added.

$$C^{tot} = \sum_t \left(\sum_{pp} C_{pp}^{mar} * P_{pp,t}^{elec} + \sum_{ren} C_{ren}^{mar} * P_{ren,t}^{elec} + \sum_{pp} C^{boil} * P_{pp,t}^{boil} + \sum_{flex} C_{flex}^{var} * P_{flex,t}^{charge} \right) \quad (1)$$

Furthermore, the model is constraint by the need to meet the demand in each period t consisting of the energy from conventional and renewable sources ($P_{pp,t}^{elec}$, $P_{ren,t}$), the difference from the flexibility options ($P_{flex,t}^{discharge}$, $P_{flex,t}^{charge}$) (cf. equation (2)).

$$Load = \sum_{pp} P_{pp,t}^{elec} + \sum_{ren} P_{ren,t} + \sum_{flex} P_{flex,t}^{discharge} - \sum_{flex} P_{flex,t}^{charge} \quad (2)$$

A second constraint is the demand for heat: $Load_{pp,t}^{dh}$ is the demand for district heating and industrial consumers served by CHP plants that needs to be covered by a combination of CHP power plants $P_{pp,t}^{th}$, boilers $P_{pp,t}^{boil}$, heating rods $P_{pp,t}^{heat\ rod}$, as well as heat storages (cf. equation (3)).

$$Load_{pp,t}^{dh} = P_{pp,t}^{th} + P_{pp,t}^{boil} + P_{pp,t}^{heat\ rod} + storage_{pp,t-1}^{heat} * \eta_{heat} - storage_{pp,t}^{heat} \quad (3)$$

The model takes into account the regulations such as the nuclear phase-out by 2022 and the deployment of renewable energies. The

model uses exogenous data for wind (off- and on-shore), PV and run-of-river. The load curve is derived from ENTSO-E, with 2011 as base year, including an evenly spread industrial electricity demand.

2.2. Input-Output Model³

Input-output models (IOM) link the sectors i, j production $\mathbf{x} = [x_1, \dots, x_n]'$ of an economy via intermediate inputs z_{ij} . Under the usual assumption of constant input to output ratios we compute technical coefficients $a_{ij} = \frac{z_{ij}}{x_j}$. Final demand $\mathbf{f} = [f_1, \dots, f_n]'$ is exogenous and equals output less intermediate inputs

$$\mathbf{f} = (\mathbf{I} - \mathbf{A})\mathbf{x}, \text{ where } \mathbf{I} = \begin{pmatrix} 1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1 \end{pmatrix}, \mathbf{A} = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \dots & a_{nn} \end{bmatrix} \quad (4)$$

We use the inverse Leontief $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ to compute the effect of reducing total output in the lignite coal sector to other upstream sectors in the German economy. We apply an open static IOM (prices and wages are fixed), which is based on data from the national accounts of Germany [74]. The data are only available on the country level, not for individual regions. We derive the reduction in lignite production from the *PowerFlex* model. Changes in the lignite sector affect up- and down-stream sectors, as well as the income of employees and capital owners. Down-stream sectors are affected through income effects in the IOM. The direct and indirect employment effects will reduce labour income. Part of the labour income is spend by households to consume consumption goods $\mathbf{c} = [c_1, \dots, c_n]'$. We assume that households maintain their consumption behaviour according to the Input-Output table and reduce sectoral consumption expenditures accordingly. We compute the income-induced effect on the German economy by multiplying the change in household consumption with the inverse Leontief [75].

We report the total employment effect of the coal phase-out for the respective year keeping the technical coefficients for the industrial relations constant. The technical coefficients for employment to output follow a time trend according to the Input-Output tables of the years 2010–2014. The modification of the technical coefficients for employment implies a time-varying income-induced multiplier.

A major drawback of a static input-output model is the rigidity of its structure which neglects economic adjustment processes. In particular, the model is not able to cover the growth or establishment of activities that are triggered by an up-coming coal phase-out.

2.3. Regional Macroeconomic Model⁴

The regional macroeconomic model (RMM) is a dynamic general equilibrium model (wages and prices adjust over time) and is described in detail in Ref. [73]. Both economic models, the IOM and RMM, have different strengths and weaknesses and can therefore complement each other. The RMM is especially useful to study regional adjustment processes, which are very important for the discussion of structural change [77]. In comparison to the IOM, the sectoral composition of the economy in the RMM is highly aggregated. The regional perspective of the RMM adds to the literature investigating the potential consequences of the transition process towards a low carbon intensive economy using dynamic general

¹ For different degrees of model linkages see Ref. [69].

² European Network of Transmission System Operators for Electricity (ENTSO-E).

³ We use in this section the mathematical notation from Ref. [74].

⁴ This section uses the mathematical notation of [76].

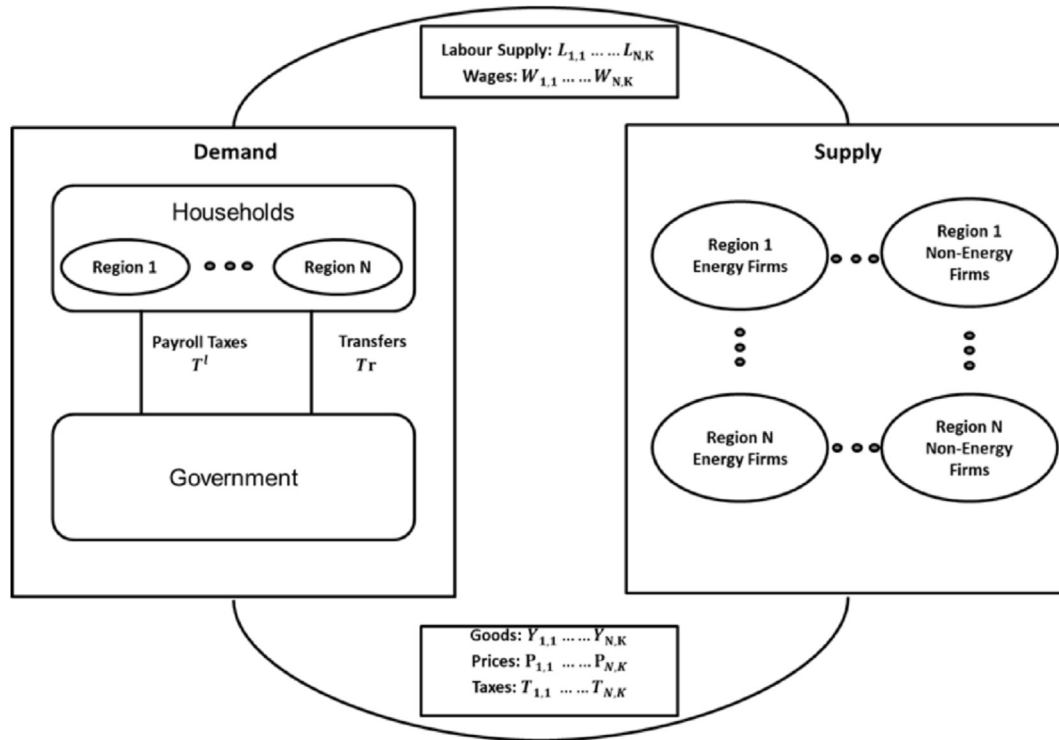


Fig. 2. Overview of the RMM

equilibrium models [78,79]. The RMM uses as input the reduction of electricity generation by lignite.

Besides economic effects, the RMM depicts intra-regional migration flows depending on regional job opportunities. In each period, some people decide to move to other regions. We consider four distinct regions, namely the lignite regions of Lusatia, Central Germany and Rhineland, as well as the rest of Germany.

The model contains as actors the government, firms and households. The latter are homogenous within each region. The households maximise their utility with respect to consumption and labour. The dis-utility of labour is sector and region specific.

The firms maximise profits. They are differentiated between energy and non-energy intermediate goods producers. Firms

selling final consumer goods act in perfect competition.

The government demands goods and imposes taxes. Furthermore, the government grants lump-sum transfers and unemployment payments to households. Fig. 2 gives an overview of the model.

One can cast the model into a vector of endogenous variables $y_t = [y_{t1}, \dots, y_{tn}]'$, exogenous variables $x = [x_{t1}, \dots, x_{tm}]'$ and parameters $\theta = [\theta_1, \dots, \theta_p]'$. Endogenous variables encompass employment, gross value added, wages, prices and population shares. Labour productivity and living preferences are exogenous variables. The dynamic system is described by n equations with forward and backward looking variables:

Table 1 Comparison of the IOM and RMM models.

Characteristics	Input-output model (IOM)	Regional macroeconomic model (RMM)
Regions	Germany	3 lignite coal regions and rest of Germany
Literature	Brautzsch et al. [75]	Schult et al. [73]
Measurement unit for production	Gross output	Real gross value added
Sectors	72 product categories	Energy and non-energy sector
Results for employment	Direct, indirect, induced	Direct, indirect, induced
Primary data source	Input-output-tables	Regional economic accounts
Secondary data source	PowerFlex Model	PowerFlex Model
Expectation formation	Static	Dynamic (perfect foresight)
Macroeconomic feedback effects		
Goods market	No price adjustment	Endogenous price adjustment
Labour market	No wage adjustment	Endogenous wage adjustment
Lignite coal in the model		
Directly affected sectors	Lignite coal mining	Lignite coal mining and power generation
Directly affected sectors in the official statistics	Coal (product group 4)	Lignite coal mining economic sector B Lignite coal power generation economic sector C
Sectors affected by lower input demand of the lignite coal industry	All	No input-output linkages modelled
Electricity price effects	Not included	Included

$$f_t(z_t, x_t, \theta) = \begin{cases} g_1(y_{t-r}, \dots, y_t, \dots, y_{t+s}, x_t, \theta) & 0 \\ \vdots & = \vdots t = 1, \dots, T, \text{ where } z_t = [y_{t-r}, \dots, y_t, \dots, y_{t+s}]' \\ g_n(y_{t-r}, \dots, y_t, \dots, y_{t+s}, x_t, \theta) & 0 \end{cases} \quad (5)$$

The maximum number of lags and leads is denoted by r and s , respectively. For the simulation of the model, we need to specify initial and terminal conditions. Our initial conditions are the steady state values of the endogenous variables of the system such that regional and sectoral population, employment, gross value added and wage bill shares are identical to the shares for the German economy in the year 2014. The terminal condition is the steady state of the model, such that lignite coal production is approximately zero. The dynamic system of equations is recursively solved using a Newton method.

3. Description of lignite regions in Germany

The spatial definition of lignite mining areas in Germany is

based on all administrative districts with a lignite mine or power plant. They are complemented by those regions with high commuter flows within a maximum of 45 (in rare cases 60 min) forming a larger lignite region (see Fig. 3).

In Germany, total lignite production declined from 411 million t in 1989 to 166 million t in 2018 [80]. Since the mid-1990s, the Rhineland replaced Lusatia as the largest lignite area in Germany. The Rhineland's installed capacity of 9.1 GW is the highest, followed by Lusatia with 5.9 GW and 2.9 GW in Central Germany (status 2018) [17]. The Rhineland produces the largest amount of electricity with 79 TWh_{el}, followed by Lusatia with 49 TWh_{el} and the Central German region with 17 TWh_{el} (as at end of 2017; cf. Table 2).

The population density varies between the regions. The Rhineland is by far the most densely populated region, with the lowest share of people over 50. This share corresponds to the federal

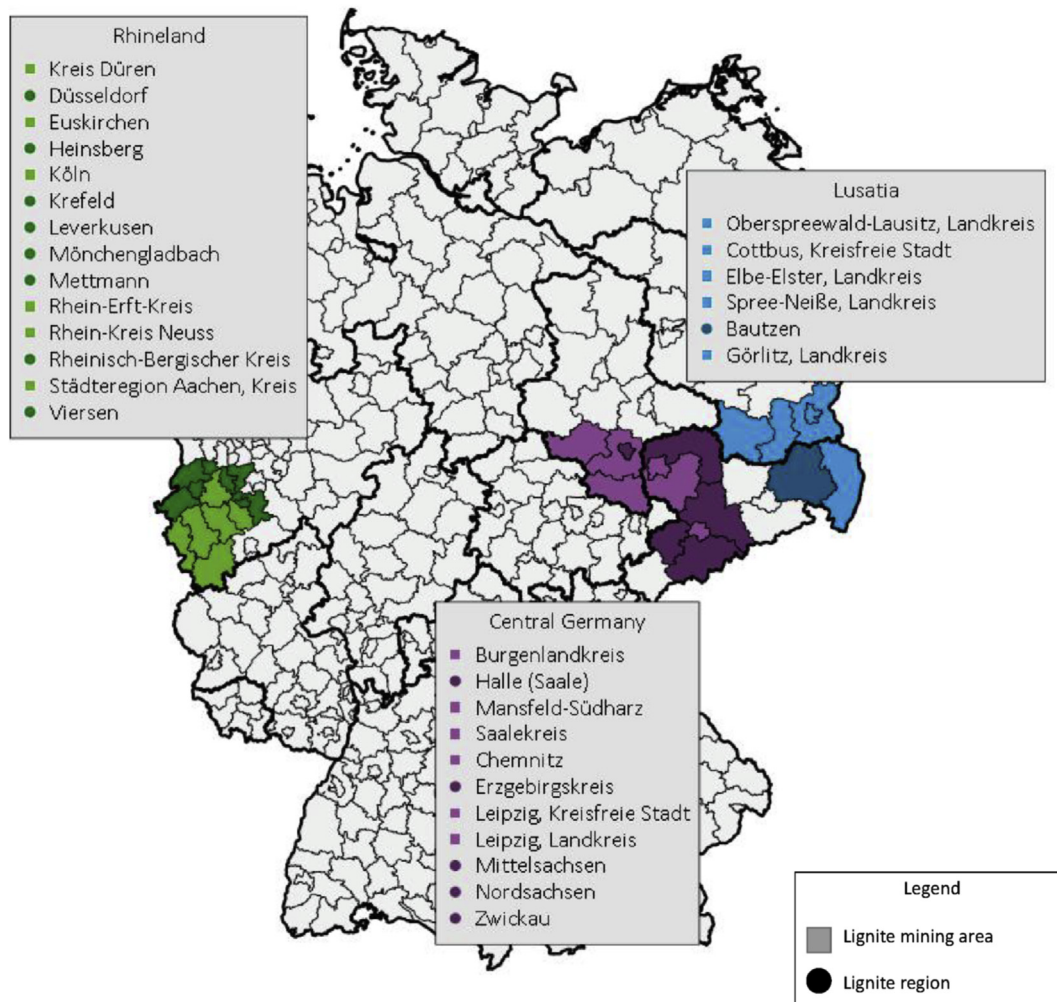


Fig. 3. Lignite mining areas and lignite regions. Source: own exhibition.

Table 2

Key figures for the lignite regions (base year 2014, unless stated otherwise).

	Rhineland	Lusatia	Central Germany	Germany
Labour force [persons]	3,261,791	518,072	1,602,561	4,560,388
Share of people over age of 50	43%	55%	48%	43%
Population density [persons/km ²]*	700	106	222	230
Unemployment rate	7.3%	11.0%	9.2%	5.7%
Gross value added [mill. €]	204,602	22,606	71,090	2,624,437
Share mining, energy, water supply***	4%	13%	5%	3%
Share production industry	24%	38%	33%	31%
Share services	76%	62%	67%	69%
Employees in lignite **	8873	7763	1895	18,531
Installed lignite capacity [MW] **	10,370	7000	3330	21,000
Lignite production [mill. t] **	91	61	19	171
Electricity by lignite (gross) [TWh _{el}]**	79	49	17	150
Lignite reserves [mill. t] **	2479	1291	395	4165
CO ₂ -emissions by lignite [Mill. t] **	95.2	56.7	18.7	170.6

Note: * The cities Chemnitz und Halle in Central Germany and Görlitz and Cottbus in Lusatia are responsible for a higher density; ** Status at the end of 2017; *** Mining, energy and water supply are part of production industry.

Sources [29,59,81,83–86]: and own calculations.

average [81]. It is the largest mining area in terms of employment and production, closely followed by Lusatia⁵. Lusatia is the region with the highest share of people above 50 and also the one with the lowest population density. For this region, mining activities play the most important role for the economy among the regions.

The employment figures in Table 2 for the lignite sector include employees in lignite mines and power plants. This figure has decreased since 2002 from 26,827 to 18,531 in 2017 – that is, around 30%. From a country-wide perspective, the lignite sector plays only a minor role as an employer.

4. Coal phase-out scenarios for the German electricity sector

The analysed scenarios are based on discussions surrounding the German coal commission. In its final report, the coal commission suggested a coal phase-out lasting until 2038 with a potential earlier phase-out by 2035 [87]. Coal capacities are to be reduced gradually. For the first closures a financial compensation is planned. The amount of compensation decreases over time. Intermediate targets for power plant capacities have been defined. By the beginning of the year 2030 the capacity of lignite fired power plants in operation is to be reduced to 9 GW and the capacity of hard coal fired power plants is to be reduced to 8 GW.

Prior to the coal commission report a set of studies analysed different instruments to phase out coal [56,57]. Theoretically, the pricing of carbon leads to a cost efficient solution. However [57], found that distributional effects of carbon pricing are quite high. Especially power plant owners are better off, when capacities are closed down and when they are compensated. From an environmental perspective the closure of power plants is attractive, because this gives certainty, that emission abatement happens.

It is now the government's turn to decide on the precise pathway for phasing out lignite power plants and lignite mines. By the end of 2019, no final decision has been made regarding the expected phase-out corridor in Germany. To analyse the effect of the coal phase-out additional research with respect to different scenarios is therefore useful.

A total of four phase-out pathways have been elaborated in this paper, as well as a "Reference" pathway. There are basically two

possible options for deriving a decommissioning order (cf [88]):

1. Decommissioning according to a certain criterion (e.g. age or specific emissions) that affects all fuels equally; or
2. Proportional contributions: In the lignite sector, a possible outcome could be – similar to the stand-by reserve – that the decommissioning in each lignite area corresponds to its share of the total lignite capacity.

The "Reference" pathway describes the development of the installed capacity of power plants under consideration of the climate protection measures adopted until 2017 [88].

In the first phase-out pathway (pathway "Fast"), the coal-fired power plants (hard coal and lignite) will be decommissioned according to their specific emissions by 2035; this will especially affect older lignite power plants.

In the moderate pathway (pathway "Moderate"), in line with a coal phase-out by 2038, plant age serves as the decommissioning criterion affecting both lignite and hard coal power plants. The pathway "Moderate" splits into two variants, A and B, of which A is the strict version that leads to stronger emissions reduction in the Rhineland due to the older power plant fleet in that area. Variant B considers that fact and distributes the plant closures more evenly among the mining regions.

In the pathway "Flex", the emissions start to decline from 2020 on due to a reduction of full load hours (flh). The flh's of all coal-fired power plants above the age of 20 will be limited to 4000.

Table 3

Overview of installed capacity of lignite- and hard coal-fired power plants in reference and phase-out pathways in GW in Germany.

Path	Type	2015	2020	2025	2030	2035
Reference	Total	48	40	38	36	29
	Lignite	21	18	17	16	11
	Hard coal	27	22	21	20	18
Fast	Total	48	40	29	22	15
	Lignite	21	18	9	5	0
	Hard Coal	27	22	20	17	15
Moderate	Total	48	40	27	19	9
	Lignite	21	18	13	9	5
	Hard Coal	27	22	14	10	6
Flex	Total	48	40	33	19	5
	Lignite	21	18	14	9	0
	Hard Coal	27	22	17	10	5

Source: Own calculation based on [88].

⁵ The employment figures are based on own calculations by Öko-Institut and derived from Refs. [59,82]. Employees in power plants in stand-by reserve or the association for renaturation of former lignite mines (LMBV) as well as employees from Romonta (producer of lignite wax) are not included.

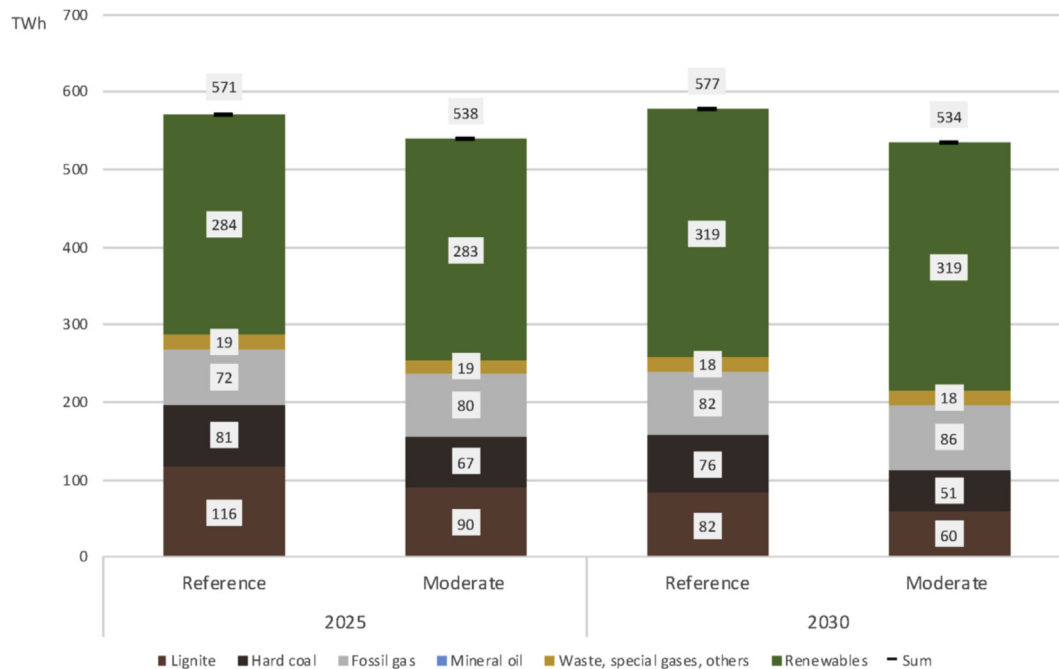


Fig. 4. Electricity generation in selected scenarios in Germany.

Restricting flh allows for emission reduction while still keeping coal capacities online and preserving employment and higher energy security [20]. From 2025 on, this will be enhanced by closures of plants which exceed the age of 40 (in 2025).

Table 3 displays the development of the installed capacity based on previous calculations done in Ref. [88]. An additional reduction until the year 2020 to meet the respective climate targets is only achieved following the pathway “Flex”.

The amount of renewable generation is similar in the “Reference” pathway and in the pathways with a reduction of coal-fired generation. It increases from about 284 TWh to 319 TWh in 2030. Fig. 4 shows the change in production for the “Reference” pathway and the “Moderate” pathway. The coal-fired generation is reduced from 197 TWh (Reference 2025) to 111 TWh (Moderate 2030). This is replaced by a minor increase in gas-fired generation. Also, Germany net exports approximately half of the electricity in the “Moderate” pathway scenarios compared to the “Reference” pathway (Reference: ca. 80 TWh) in 2025 and 2030. Regardless of the scenarios, Germany stays a net exporter. Several model sensitivity runs show that the changes in the electricity mix will lead to only a minor increase in prices – for the pathways “Moderate” this will be around 2€/MWh in 2030 compared to “Reference” [88].

5. Economic effects of the lignite coal phase-out

The lignite phase-out will have a negative impact on production and consumption and lead to an adjustment process. We assume that the long-run structural unemployment rate in the coal regions does not increase due to growth policies and federal transfers (cf. section 6). This assumption is based on previous comparable cases, such as the structural change in the Ruhr area. Studies have shown that regional migration is an important mechanism to respond to regional specific shocks [77,89]. We simulate the effects of the coal phase-out in terms of employment, production and gross value added with the IOM and RMM. The reduction of hard coal is not considered in the economic calculations for the lignite regions.

5.1. Results of the IOM

In 2014, 16,500 persons were employed by opencast lignite coal mines in Germany. Already the demographic decline in the German population will reduce the employment in the lignite industry until 2040 to 15,100 persons. Furthermore, even without a politically induced coal phase-out employment in the coal industry will decrease to 9100 persons due to technical progress. This development forms the basis of our simulations as benchmark.

The IOM calculates the additional effects caused by the policy-induced reduction of lignite extraction (direct effects) as well as the supply-chain effects due to a lower demand for intermediate inputs in the lignite production (indirect effects). Additionally, effects caused by the change in income are also reported (induced effects).

Effects in the production phase are significantly greater than the income-induced effects. About 80% of total gross output effects and 75% of total gross value added and employment effects originate from the production phase and the associated input purchases.

The results of the IOM show a decrease in employment by 12,500 in 2025 and by 14,600 in 2030 (cf. Fig. 5) for the pathway “Fast” compared to the “Reference” path, when assuming that productivity follows its long-run trend. About one-third of this decline are direct employment effects. The remaining exit scenarios have lower initial negative employment effects, but in 2040, they are all identical because in each of them the coal phase-out has been completed.

Comparing the resulting multiplier – that is, the factor of additional jobs lost besides the direct employees in the lignite sector – we see that, the one in the income phase is 1.5 and smaller compared to the production phase multiplier with 2.0. This means that final consumption goods produced for households influence the production level less than the input purchases from coal production. Similarly, the value added and employment multipliers are smaller.

The multipliers of the IOM are comparable to other previous input-output studies. Potential employment effects of a total

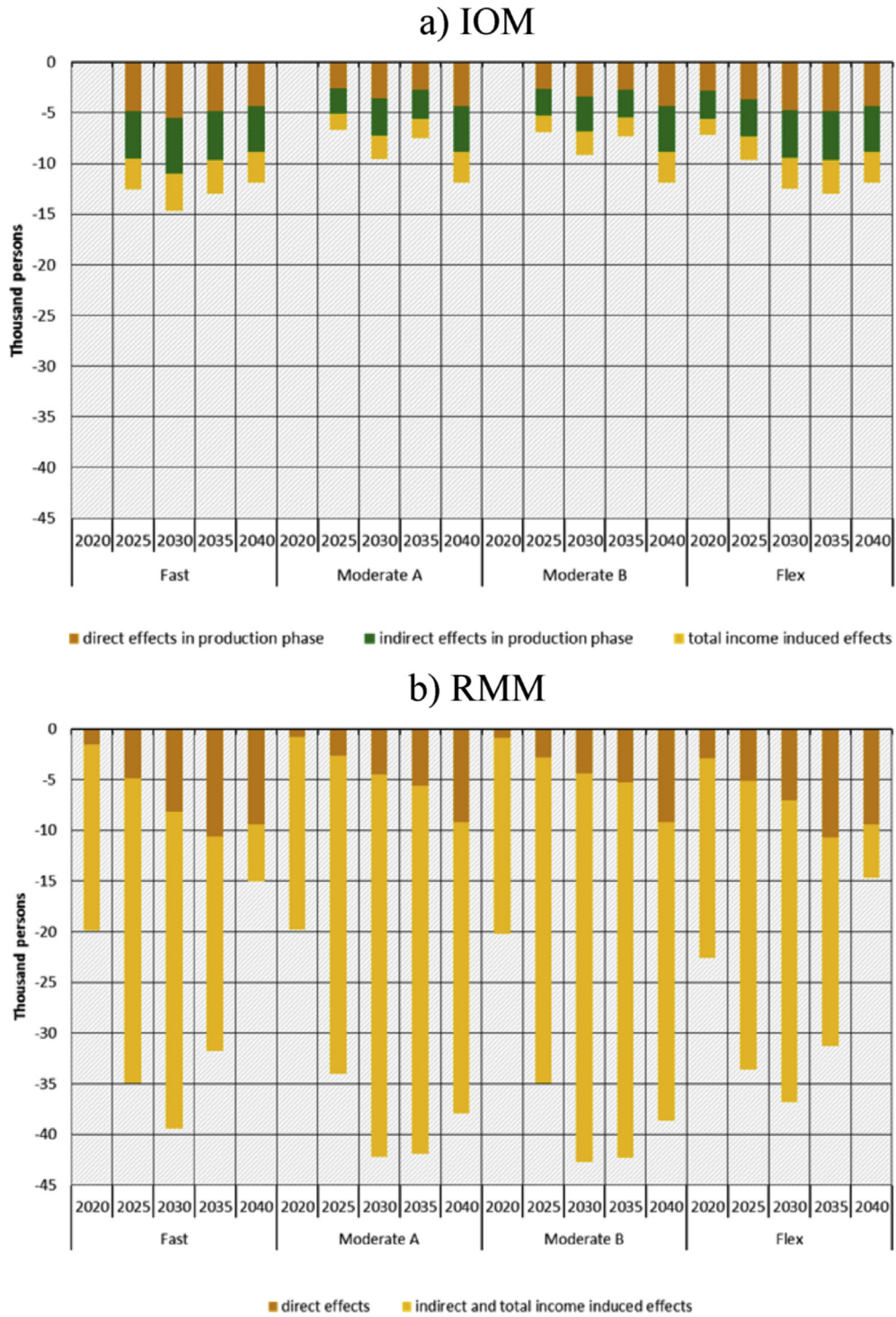


Fig. 5. Direct, indirect and income-induced employment effects in Germany due to coal phase-out calculated with the input-output model and regional macroeconomic model. Sources [90]: and own calculations, [68].

phase-out of the lignite industry (mining, power plants, etc.) for the year 2009 are reported in Ref. [62]. The employment multiplier for mining, excluding investments, is 2.1. In a study by RWI [61], employment multipliers for mining and electricity generation are 2.8 for the year 2016. Without investments, the multiplier is 2.4 and close to the one reported in this study.

The use of intermediate inputs by the lignite coal industry

employs the same number of persons as the coal industry itself. It is therefore important to consider the producers of intermediate inputs as well as the lignite coal industry itself when organising the upcoming coal phase-out. As different studies using IOM show, the loss of one job in the lignite coal industry leads to a decrease of one to two jobs in other sectors in the German economy.

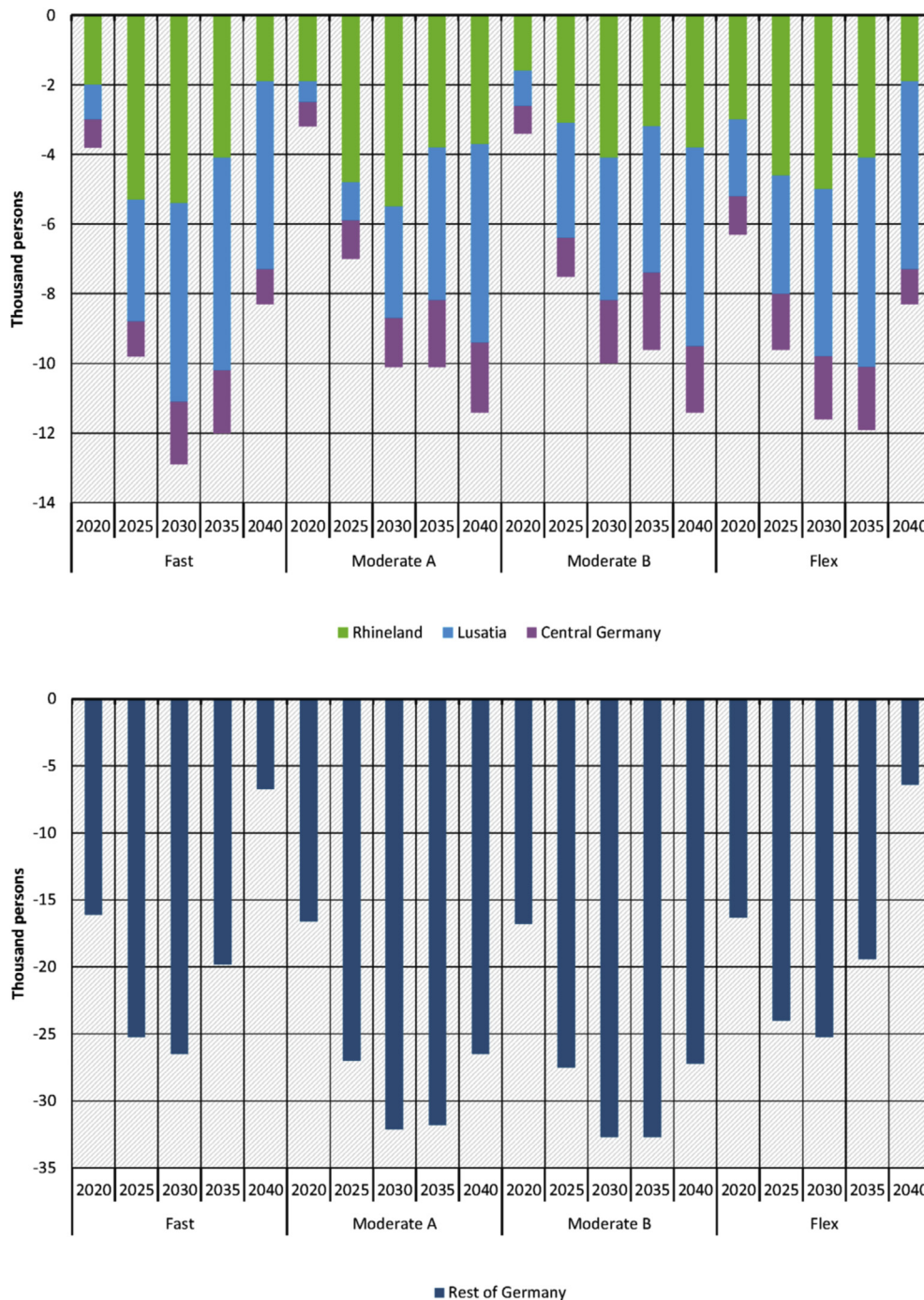


Fig. 6. Direct, indirect and induced employment effects in Germany due to coal phase-out calculated with the regional macroeconomic model. Sources [68,85]; and own calculations.

5.2. Results of the regional macroeconomic model

The results of the RMM show that actions to reduce electricity generation by lignite will lead to 9000 fewer employees even in the “Reference” path. This consists of a direct employment effect equal to 3200 persons and 4800 fewer persons employed by suppliers of the lignite industry. The residual employment effect of 1300 is induced by higher energy prices. Additional policies that reduce coal consumption faster would lead to a drop in employment compared to the “Reference” pathway of 37,000 to 43,000 persons

(cf. Fig. 6). This reduction includes direct, indirect and income-induced effects. Most of the employment effects are located outside of the lignite regions, due to, for example, energy price effects. One can use the multiplier from the IOM analysis, 2.5, to compute the total employment effects for the suppliers of the lignite industry Fig. 7.

Effects on payrolls and gross value added are also higher in the RMM compared to the IOM because of the inclusion of the electricity market. For Germany, the effect on payrolls is, with a deviation of –€4 billion compared to the “Reference” pathway, which is

four times larger in the RMM than in the IOM. Lusatia exhibits the largest effects, with around €1700 per person, whereas for the Rhineland and Central Germany the effect is only at around €400–€500 and €100 for the rest of Germany.

The gross value added effects in the IOM are more than two times smaller than in the RMM (million €1000–€1200 vs. €1200–€2700). The RMM, on the other hand, shows significant recovery in the pathways “Fast” and “Flex” from 2030 to 2040. In this period, the negative deviation of value added compared to “Reference” pathway drops to half.

The wage sum declines more than the gross value added. Other employment opportunities outside the lignite industry pay lower wages on average. Further, the increase in the number of unemployed depresses wage growth. A slower phase-out would postpone the negative effects into the future. The pathway “Flex” has the greatest effects in the next five years but has a faster recovery process. This result is associated with the assumption that intra-German migration decisions are independent of the coal phase-out timing and that higher energy prices will trigger a faster expansion of other energy carriers. National employment rates recover faster in the pathways “Flex” and “Fast” compared to the pathways “Moderate A” and “Moderate B”. If intra-German migration flows were dependent on the coal phase-out timing, employment effects in the “Moderate” pathways would be lower. Individuals would postpone migration from lignite regions to other regions in Germany until new employment opportunities in those regions become available. Housing prices and mark-ups charged by firms in other regions therefore would not rise as fast as in the “Fast” scenario.

The analysis of the RMM shows that most of the employment effects are not located in the lignite regions, because they result from price effects. Among the lignite regions, Lusatia suffers the most significant increase in unemployment rate and the highest drop in gross value added per capita. Real wages fall, especially in the lignite coal regions, because former high-wage jobs in the lignite industry disappear.

Migration reduces the labour force in the Rhineland and Lusatia if no new jobs are created in those regions. Compared to the reduction in the labour force in the lignite regions caused by demographic changes (3.6 million fewer employees in Germany until 2040; own calculations based on [91]), migration induced by the lignite phase-out, however, is rather small. Additional tables (Tables 4–12) and figures (Figs 7–10) for both economic models can be found in Appendix.

6. Conclusion and policy recommendations

The energy system model illustrates the effects of different phase-out pathways for power plants and opencast lignite mines. Based on the results of the electricity market model, the socio-economic effects of a lignite phase-out are quantified both in the lignite regions and in the rest of Germany.

Compared to the negative effects of demographic change on the labour force, the drop in the number of employees caused by the lignite phase-out is rather small. The results of the RMM show that most of the absolute employment effects of a lignite coal phase-out do not occur in the lignite regions themselves. Among the lignite regions, Lusatia is the region most affected by a lignite phase-out in terms of unemployment rate and gross value added per employee. The Rhineland is less affected in terms of unemployment rate and gross value added. The labour force in both lignite regions will decrease due to migration outflows to other regions in Germany. Central Germany is the lignite region with the lowest economic effects and its labour force is almost not affected.

Our calculations show that the negative effects of structural

change become apparent earlier in the event of an early phase-out. In this case, however, a quicker recovery can counteract the negative effects in following periods.

Targeted labour market and social policy can at least partially compensate for the direct negative effects on employment and income. In addition, measures such as retraining or further training increase the probability of finding a new job and exploiting economic opportunities – as also recommended by the German coal commission.

An additional assessment of the strengths and possibilities of the lignite regions shows significant employment potential in various fields, including renewable energies and building refurbishment. Oei et al. [68] analyse potential jobs stemming from building refurbishment within the lignite regions. In a case study, they identify more than 25,000 additional jobs in the Rhineland and more than 5,000 additional jobs each in Lusatia and Central Germany (decade 2020 to 2030). Other economic opportunities may come from touristic and other uses of former lignite mining areas, an improved public transport infrastructure, a new digital economy, and opportunities resulting from stronger science and innovative businesses.

In Lusatia, a quality offensive should be promoted in the vocational schools to counteract the high rate of dropouts. New know-how should also be transferred to the region through technical competence centres and – as a consequence – investors can be attracted to the region.

Better conditions have already been created in the Rhineland region, but there is a lack of an overarching, moderating management that actively initiates the connecting of actors. The expertise of universities and non-university research institutions, particularly in new forms of energy, should be used to attract and keep companies and people in the region. This requires not only good equipment at universities, but also regional incentives to implement innovations. This could be done, for example, by designating former mining areas for precisely these forms of energy.

In the Central German region, the backlog of building renovation projects is comparatively high and could be addressed by appropriate measures at the state level. This would not only support climate protection goals but could also lead to more employment in the construction sector. In the context of refurbishment and energy efficiency, network and cluster activities should also be supported. Especially, for Saxony-Anhalt, land use planning could be reconsidered, and areas formerly planned as open-cast mines as well as redeveloped open-cast mining areas could be developed not only for tourism but also for renewable energies.

Federal financial support is likely since the coal commission suggested around €40 billion for cohesion policies within the next 20 years. Interpreting the upcoming coal phase-out within the next 20 years not as a hurdle but as a window of opportunity (due to the immense political and financial support) to transform the regions according to a more sustainable vision is the main task for all involved actors. Linking quantitative model applications can help to estimate the effects of different pathways and should be fostered in further research.

Acknowledgements

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Appendix

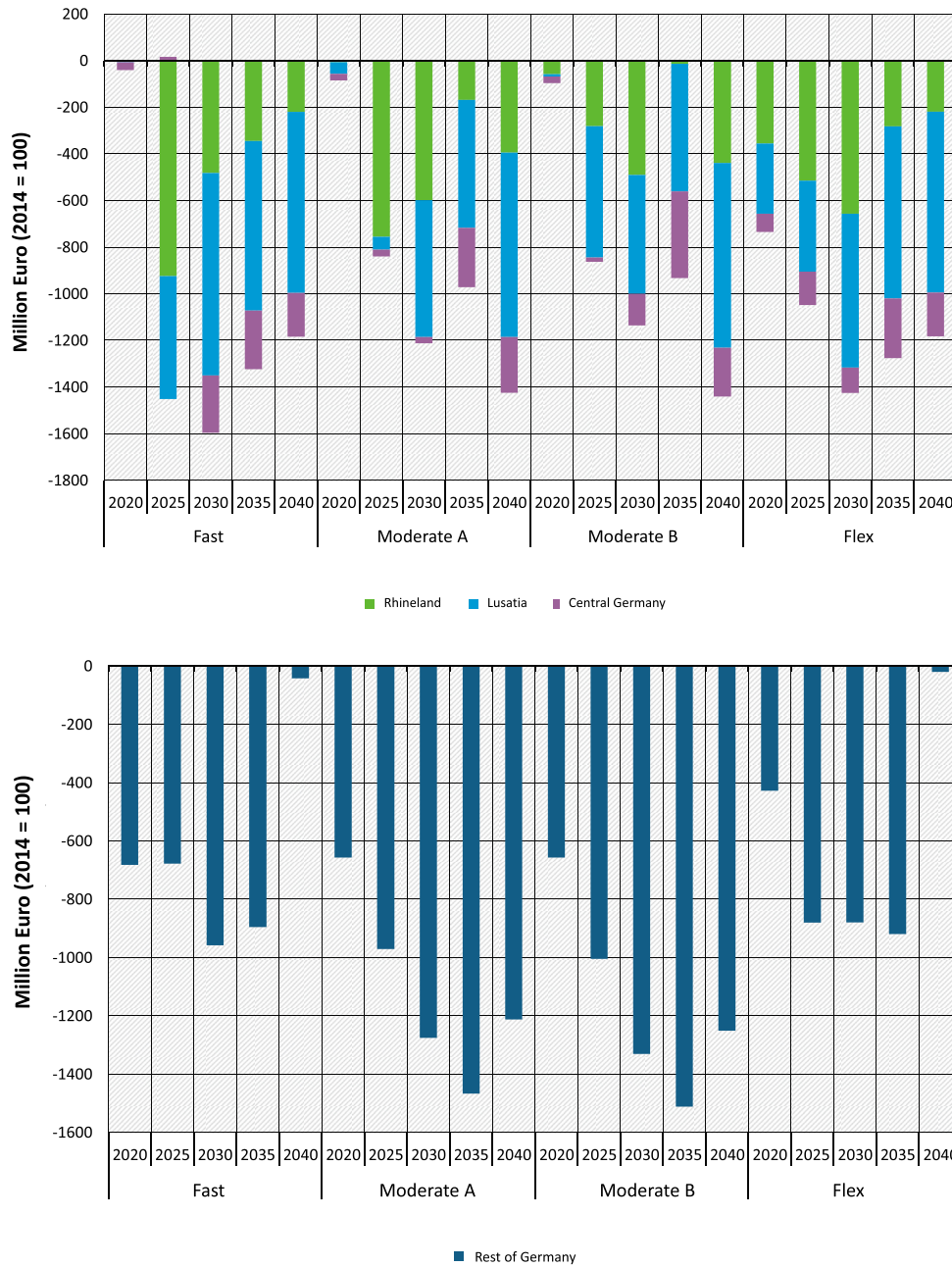


Fig. 7. Regional total real gross value added effects across all phases in comparison to “Reference” pathway in RMM. Note: Difference of value added to “Reference” pathway. Sources [85]; and own calculations. Source [92,93]; and Unternehmensregister. Source [92,93]; and Unternehmensregister. Source [59,85]; and own calculations. Source [59]; and own calculations. Source [92]; a down calculations. Source [59,85]; and own calculations.

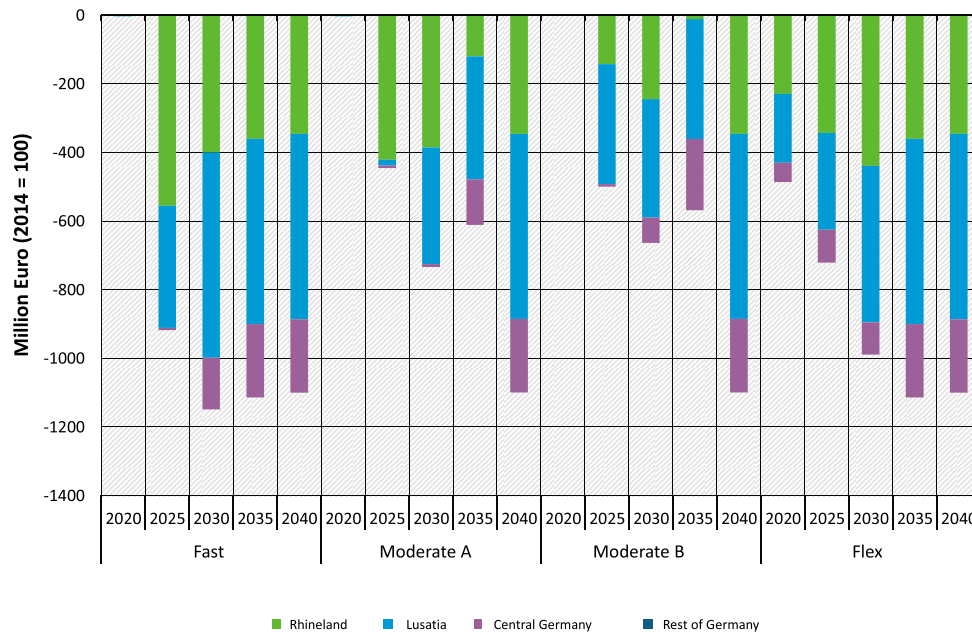


Fig. 8. Regional direct real gross value added in lignite sector in comparison to "Reference" pathway. Note: Difference of value added to "Reference" pathway. Source [85]; and own calculations.

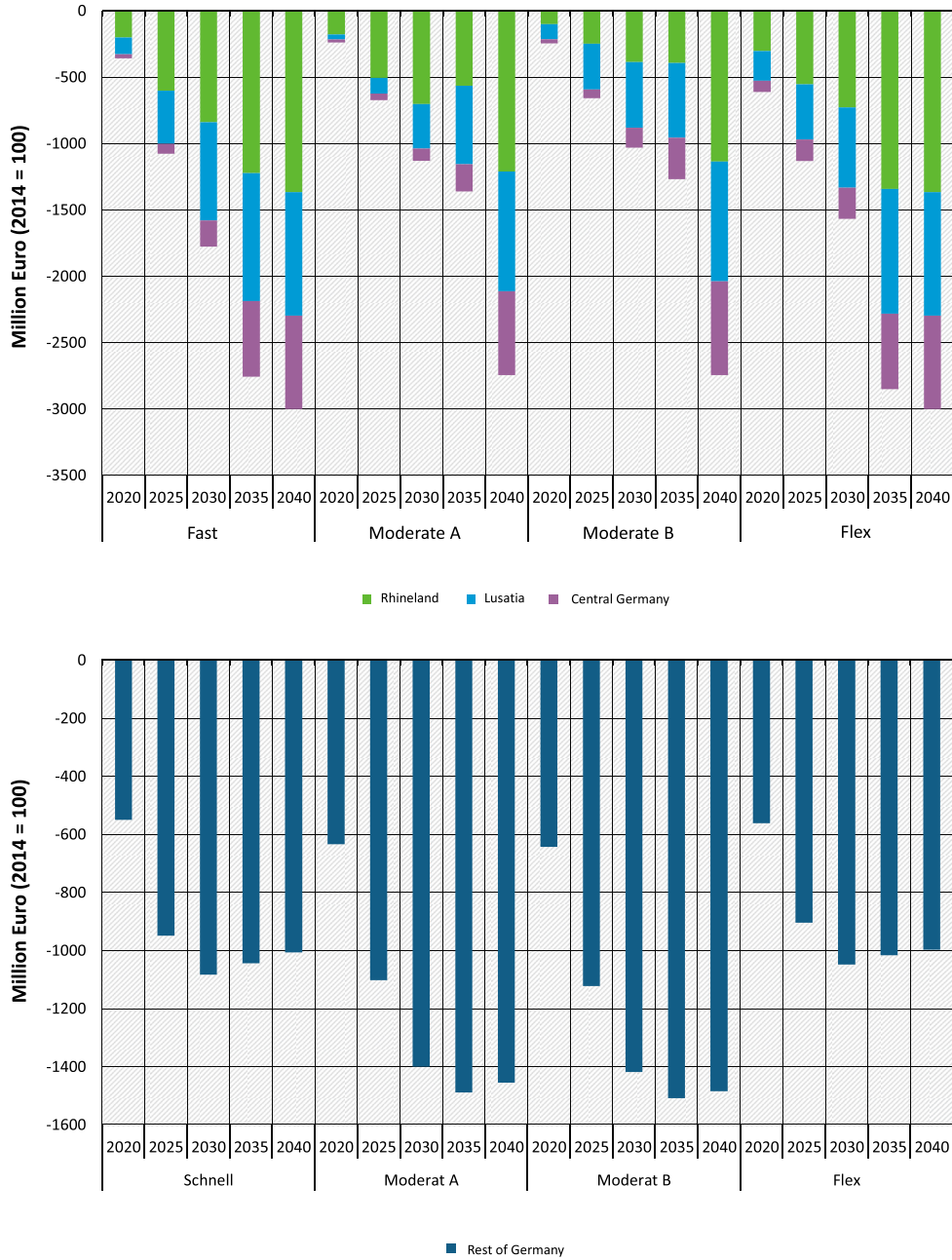


Fig. 9. Regional total effects on payrolls across all phases in comparison to "Reference" pathway in RMM. Note: Difference of wage sums to "Reference" pathway. Source [92,93]; and own calculations.

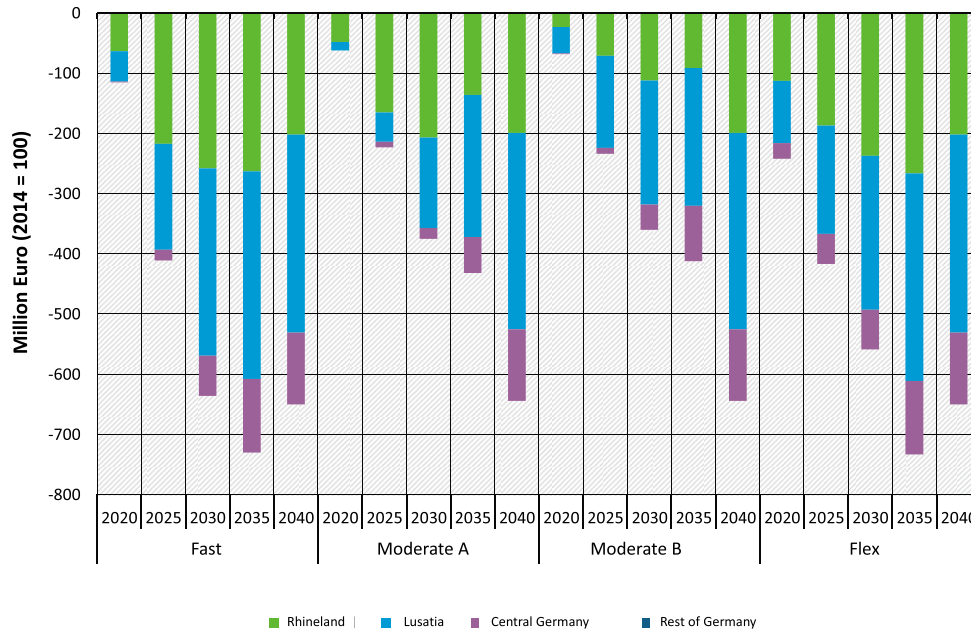


Fig. 10. Regional direct effects on payrolls in lignite sector in comparison to “Reference” pathway in RMM. Note: Difference of wage sums to “Reference” pathway. Source [92,93]; and own calculations.

Table 4

Difference of total effects of lignite production of scenarios in comparison to “Reference” pathway in IOM (productivity assumption: forward projection)

	2014	2020	2025	2030	2035	2040
Production effect in million Euro						
Fast	0	0	-2167	-2768	-2678	-2680
Moderate A	0	0	-1154	-1813	-1547	-2680
Moderate B	0	0	-1197	-1725	-1510	-2680
Flex	0	-1131	-1673	-2361	-2678	-2680
Gross value added effect in million Euro						
Fast	0	0	-885	-1130	-1094	-1095
Moderate A	0	0	-471	-740	-632	-1095
Moderate B	0	0	-489	-704	-617	-1095
Flex	0	-460	-683	-964	-1094	-1095
Employment effect in thousand people						
Fast	0.0	0.0	-12.5	-14.6	-13.0	-11.9
Moderate A	0.0	0.0	-6.7	-9.6	-7.5	-11.9
Moderate B	0.0	0.0	-6.9	-9.1	-7.3	-11.9
Flex	0.0	-7.2	-9.7	-12.5	-13.0	-11.9
Payroll effect in million Euro						
Fast	0	0	-815	-1040	-1007	-1010
Moderate A	0	0	-434	-681	-582	-1010
Moderate B	0	0	-450	-648	-568	-1010
Flex	0	-400	-629	-887	-1007	-1010

Table 5

Difference of total effects of lignite production in scenarios in comparison to “Reference” pathway in IOM (productivity assumption: constant)

	2014	2020	2025	2030	2035	2040
Production effect in million Euro						
Fast	0	0	-2231	-2897	-2856	-2917
Moderate A	0	0	-1188	-1897	-1649	-2917
Moderate B	0	0	-1232	-1805	-1610	-2917
Flex	0	-1164	-1722	-2471	-2856	-2917
Gross value added effect in million Euro						
Fast	0	0	-918	-1197	-1185	-1217
Moderate A	0	0	-489	-784	-684	-1217
Moderate B	0	0	-507	-746	-668	-1217
Flex	0	-477	-708	-1021	-1185	-1217
Employment effect in thousand people						
Fast	0.0	0.0	-14.1	-17.5	-16.5	-16.2
Moderate A	0.0	0.0	-7.5	-11.5	-9.5	-16.2
Moderate B	0.0	0.0	-7.8	-10.9	-9.3	-16.2
Flex	0.0	-7.7	-10.9	-14.9	-16.5	-16.2
Payroll effect in million Euro						
Fast	0	0	-937	-1289	-1349	-1466
Moderate A	0	0	-499	-844	-779	-1466
Moderate B	0	0	-518	-893	-760	-1466
Flex	0	-464	-724	-1099	-1349	-1466

Table 6
Results of simulation for real gross value added in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Fast					
2014	0.00	0.00	0.00	0.00	0.00
2020	-720.00	-682.00	-33.00	-7.00	2.00
2025	-2114.00	-678.00	16.00	-528.00	-924.00
2030	-2554.00	-958.00	-245.00	-870.00	-481.00
2035	-2218.00	-895.00	-251.00	-727.00	-345.00
2040	-1226.00	-42.00	-187.00	-777.00	-220.00
Moderate A					
2014	0.00	0.00	0.00	0.00	0.00
2020	-742.00	-657.00	-29.00	-49.00	-7.00
2025	-1811.00	-971.00	-30.00	-55.00	-755.00
2030	-2487.00	-1275.00	-26.00	-588.00	-598.00
2035	-2439.00	-1467.00	-255.00	-549.00	-168.00
2040	-2636.00	-1212.00	-238.00	-792.00	-394.00
Moderate B					
2014	0.00	0.00	0.00	0.00	0.00
2020	-753.00	-657.00	-28.00	-10.00	-58.00
2025	-1867.00	-1004.00	-19.00	-563.00	-281.00
2030	-2467.00	-1331.00	-136.00	-510.00	-490.00
2035	-2445.00	-1512.00	-372.00	-548.00	-13.00
2040	-2692.00	-1251.00	-209.00	-793.00	-439.00
Flex					
2014	0.00	0.00	0.00	0.00	0.00
2020	-1162.00	-427.00	-79.00	-301.00	-355.00
2025	-1928.00	-880.00	-143.00	-390.00	-515.00
2030	-2304.00	-879.00	-108.00	-660.00	-657.00
2035	-2195.00	-919.00	-256.00	-738.00	-282.00
2040	-1202.00	-20.00	-187.00	-776.00	-219.00

Note: Real gross value added in million Euro.

Table 8
Results of simulation of payrolls per work force in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Fast					
2014	0.00	0.00	0.00	0.00	0.00
2020	-19.00	-14.00	-17.00	-185.00	-57.00
2025	-44.00	-25.00	-46.00	-687.00	-182.00
2030	-65.00	-30.00	-125.00	-1368.00	-263.00
2035	-89.00	-31.00	-380.00	-1842.00	-396.00
2040	-95.00	-31.00	-476.00	-1782.00	-450.00
Moderate A					
2014	0.00	0.00	0.00	0.00	0.00
2020	-19.00	-16.00	-14.00	-20.00	-51.00
2025	-39.00	-29.00	-29.00	-142.00	-153.00
2030	-58.00	-39.00	-56.00	-552.00	-219.00
2035	-67.00	-43.00	-135.00	-1067.00	-179.00
2040	-99.00	-43.00	-427.00	-1716.00	-398.00
Moderate B					
2014	0.00	0.00	0.00	0.00	0.00
2020	-19.00	-16.00	-16.00	-158.00	-28.00
2025	-40.00	-30.00	-40.00	-582.00	-73.00
2030	-55.00	-39.00	-93.00	-872.00	-118.00
2035	-65.00	-44.00	-207.00	-1015.00	-122.00
2040	-100.00	-44.00	-479.00	-1713.00	-372.00
Flex					
2014	0.00	0.00	0.00	0.00	0.00
2020	-25.00	-14.00	-50.00	-372.00	-88.00
2025	-45.00	-24.00	-100.00	-719.00	-167.00
2030	-59.00	-29.00	-149.00	-1094.00	-227.00
2035	-91.00	-31.00	-377.00	-1798.00	-435.00
2040	-95.00	-31.00	-476.00	-1782.00	-449.00

Note: Real payroll bills in million Euro.

Table 7
Results of simulation of wage sums in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Fast					
2014	0.00	0.00	0.00	0.00	0.00
2020	-908.00	-550.00	-31.00	-126.00	-201.00
2025	-2026.00	-949.00	-75.00	-400.00	-602.00
2030	-2860.00	-1083.00	-197.00	-740.00	-840.00
2035	-3803.00	-1044.00	-572.00	-963.00	-1224.00
2040	-4009.00	-1006.00	-705.00	-932.00	-1366.00
Moderate A					
2014	0.00	0.00	0.00	0.00	0.00
2020	-873.00	-634.00	-23.00	-38.00	-178.00
2025	-1775.00	-1102.00	-49.00	-118.00	-506.00
2030	-2530.00	-1400.00	-92.00	-335.00	-703.00
2035	-2851.00	-1489.00	-206.00	-591.00	-565.00
2040	-4202.00	-1455.00	-633.00	-903.00	-1211.00
Moderate B					
2014	0.00	0.00	0.00	0.00	0.00
2020	-888.00	-643.00	-31.00	-113.00	-101.00
2025	-1781.00	-1123.00	-65.00	-345.00	-248.00
2030	-2450.00	-1419.00	-150.00	-495.00	-386.00
2035	-2778.00	-1509.00	-313.00	-564.00	-392.00
2040	-4232.00	-1485.00	-709.00	-901.00	-1137.00
Flex					
2014	0.00	0.00	0.00	0.00	0.00
2020	-1173.00	-561.00	-84.00	-226.00	-302.00
2025	-2035.00	-904.00	-161.00	-416.00	-554.00
2030	-2616.00	-1048.00	-234.00	-606.00	-728.00
2035	-3868.00	-1016.00	-568.00	-941.00	-1343.00
2040	-4000.00	-997.00	-705.00	-932.00	-1366.00

Note: Real payroll bills in million Euro.

Table 9
Results of simulations for “Reference” pathway in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Work force in thousand people					
2014	0.00	0.00	0.00	0.00	0.00
2020	0.00	2.08	0.00	-0.78	-1.30
2025	0.00	3.46	0.00	-1.30	-2.17
2030	0.00	4.52	0.00	-1.69	-2.83
2035	0.00	5.38	0.00	-2.01	-3.37
2040	0.00	6.14	0.00	-2.30	-3.84
Employees in lignite sector in thousand people					
2014	0.00	0.00	0.00	0.00	0.00
2020	-3.20	0.00	-0.30	-1.20	-1.70
2025	-4.70	0.00	-0.50	-1.60	-2.60
2030	-6.00	0.00	-0.50	-1.80	-3.70
2035	-8.30	0.00	-0.50	-2.40	-5.40
2040	-9.50	0.00	-0.60	-2.70	-6.20
Employees in thousand people					
2014	0.00	0.00	0.00	0.00	0.00
2020	-9.30	-3.90	-0.50	-2.00	-2.90
2025	-11.70	-4.60	-0.80	-2.40	-3.90
2030	-11.90	-3.60	-0.70	-2.50	-5.10
2035	-12.80	-1.40	-0.70	-3.50	-7.20
2040	-8.90	3.00	-0.50	-3.80	-7.60
Real gross value added by lignite in million Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-644.00	0.00	-70.00	-235.00	-339.00
2025	-651.00	0.00	-76.00	-211.00	-364.00
2030	-903.00	0.00	-86.00	-240.00	-577.00
2035	-1492.00	0.00	-108.00	-410.00	-974.00
2040	-1564.00	0.00	-115.00	-431.00	-1018.00
Real gross value added in million Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-632.00	261.00	-67.00	-324.00	-502.00
2025	-643.00	217.00	-78.00	-273.00	-509.00
2030	-700.00	519.00	-72.00	-316.00	-831.00
2035	-1022.00	1018.00	-69.00	-561.00	-1410.00
2040	-753.00	1276.00	-79.00	-576.00	-1374.00
Real payroll bills in lignite sector in million Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-291.00	0.00	-28.00	-104.00	-159.00
2025	-420.00	0.00	-44.00	-136.00	-240.00
2030	-552.00	0.00	-47.00	-158.00	-347.00
2035	-783.00	0.00	-51.00	-221.00	-511.00
2040	-904.00	0.00	-60.00	-253.00	-591.00
Real payroll bills in million Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-716.00	-81.00	-64.00	-212.00	-359.00
2025	-1062.00	-105.00	-99.00	-291.00	-567.00
2030	-1358.00	-107.00	-110.00	-334.00	-807.00
2035	-1886.00	-66.00	-128.00	-456.00	-1236.00
2040	-2128.00	31.00	-136.00	-534.00	-1489.00

Note: Difference of considered variable for “Reference” pathway in comparison to “Null-Scenario”.⁶

Table 10
Results of simulations for “Reference” pathway per work force in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Changes in unemployment rate					
2014	0.00%	0.00%	0.00%	0.00%	0.00%
2020	0.02%	0.02%	0.04%	0.25%	0.05%
2025	0.03%	0.02%	0.05%	0.23%	0.06%
2030	0.03%	0.02%	0.05%	0.20%	0.08%
2035	0.03%	0.02%	0.04%	0.34%	0.13%
2040	0.02%	0.01%	0.04%	0.36%	0.13%
Real gross value added per work force in Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-13.00	3.00	-41.00	-543.00	-124.00
2025	-14.00	0.00	-49.00	-408.00	-111.00
2030	-16.00	6.00	-47.00	-467.00	-202.00
2035	-25.00	17.00	-46.00	-947.00	-383.00
2040	-18.00	23.00	-54.00	-957.00	-362.00
Payroll bill per work force in Euro					
2014	0.00	0.00	0.00	0.00	0.00
2020	-15.00	-4.00	-40.00	-365.00	-93.00
2025	-23.00	-6.00	-61.00	-496.00	-147.00
2030	-31.00	-7.00	-72.00	-579.00	-221.00
2035	-44.00	-7.00	-85.00	-824.00	-360.00
2040	-51.00	-6.00	-92.00	-985.00	-441.00
Available income					
2014	0.00%	0.00%	0.00%	0.00%	0.00%
2020	-0.06%	-0.05%	-0.10%	-0.58%	-0.15%
2025	-0.08%	-0.08%	-0.14%	-0.52%	-0.18%
2030	-0.10%	-0.09%	-0.16%	-0.61%	-0.23%
2035	-0.10%	-0.10%	-0.19%	-1.00%	-0.18%
2040	-0.07%	-0.07%	-0.18%	-1.01%	-0.14%

Note: Difference of considered variable for “Reference” pathway in comparison to Null-Scenario.

Table 11
Results of simulations for work force in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Fast					
2014	0.0	0.0	0.0	0.0	0.0
2020	-19.9	-16.1	-0.8	-1.0	-2.0
2025	-35.0	-25.2	-1.0	-3.5	-5.3
2030	-39.4	-26.5	-1.8	-5.7	-5.4
2035	-31.8	-19.8	-1.8	-6.1	-4.1
2040	-15.0	-6.7	-1.0	-5.4	-1.9
Moderate A					
2014	0.0	0.0	0.0	0.0	0.0
2020	-19.8	-16.6	-0.7	-0.6	-1.9
2025	-34.0	-27.0	-1.1	-1.1	-4.8
2030	-42.2	-32.1	-1.4	-3.2	-5.5
2035	-41.9	-31.8	-1.9	-4.4	-3.8
2040	-37.9	-26.5	-2.0	-5.7	-3.7
Moderate B					
2014	0.0	0.0	0.0	0.0	0.0
2020	-20.2	-16.8	-0.8	-1.0	-1.6
2025	-35.0	-27.5	-1.1	-3.3	-3.1
2030	-42.7	-32.7	-1.8	-4.1	-4.1
2035	-42.3	-32.7	-2.2	-4.2	-3.2
2040	-38.6	-27.2	-1.9	-5.7	-3.8
Flex					
2014	0.0	0.0	0.0	0.0	0.0
2020	-22.6	-16.3	-1.1	-2.2	-3.0
2025	-33.6	-24.0	-1.6	-3.4	-4.6
2030	-36.8	-25.2	-1.8	-4.8	-5.0
2035	-31.3	-19.4	-1.8	-6.0	-4.1
2040	-14.7	-6.4	-1.0	-5.4	-1.9

Note: Change in work force in the scenario pathways in comparison to “Reference” pathway.

⁶ In the “Null-Scenario”, only demographic change is considered to calculate a pathway as basis for the “Reference” scenario.

Table 12
Results of simulations for work force in lignite sector in RMM

Year	Germany	Rest of Germany	Central Germany	Lusatia	Rhineland
Fast					
2014	0.0	0.0	0.0	0.0	0.0
2020	-1.5	0.0	0.0	-0.7	-0.8
2025	-4.9	0.0	-0.2	-2.2	-2.5
2030	-8.1	0.0	-0.8	-4.1	-3.2
2035	-10.6	0.0	-1.7	-5.0	-3.9
2040	-9.4	0.0	-1.6	-4.7	-3.1
Moderate A					
2014	0.0	0.0	0.0	0.0	0.0
2020	-0.8	0.0	0.0	-0.2	-0.6
2025	-2.6	0.0	-0.1	-0.6	-1.9
2030	-4.5	0.0	-0.2	-1.8	-2.5
2035	-5.6	0.0	-0.7	-3.1	-1.8
2040	-9.2	0.0	-1.6	-4.6	-3.0
Moderate B					
2014	0.0	0.0	0.0	0.0	0.0
2020	-0.9	0.0	0.0	-0.6	-0.3
2025	-2.8	0.0	-0.1	-1.9	-0.8
2030	-4.4	0.0	-0.5	-2.6	-1.3
2035	-5.3	0.0	-1.1	-3.0	-1.2
2040	-9.2	0.0	-1.6	-4.6	-3.0
Flex					
2014	0.0	0.0	0.0	0.0	0.0
2020	-2.9	0.0	-0.3	-1.3	-1.3
2025	-5.1	0.0	-0.6	-2.3	-2.2
2030	-7.0	0.0	-0.8	-3.3	-2.9
2035	-10.7	0.0	-1.7	-5.0	-4.0
2040	-9.4	0.0	-1.6	-4.7	-3.1

Note: Change in work force in the scenario pathways in comparison to "Reference" pathway (in 1000 people).

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