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Putting off the coal in Europe: Socio-economic trade-offs across the European regions

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ABSTRACT

This study quantifies the socioeconomic and environmental repercussions of complete substitution of coal and lignite in the EU27 providing insights for policymakers. The analysis is conducted at the NUTS-2 level, using the EUREGIO-2017 multiregional input-output table, and considers the substitution of coal and lignite for electricity generation and household heating. The results reveal winners and losers at the regional level, with job losses in coal-reliant regions but gains in areas with alternative energy sectors. A pronounced reduction in CO2 emissions emerges as a key positive outcome, with significant abatements concentrated in Central-Eastern European regions where coal and lignite were historically more intensively utilized. This study emphasizes the importance of adopting balanced policies that strike an equilibrium between environmental goals and mitigating adverse socioeconomic effects, including at the subnational level. Policymakers are strongly encouraged to conduct comprehensive analyses, considering direct and indirect impacts on variables such as value-added, employment, and CO2 emissions. Moreover, compensatory measures, such as the Just Transition Mechanism, should be tailored to provide targeted support to the most affected regions, fostering fair and equitable social change.

List of abbreviations

Abbreviation	Definition
CGE	Computable General Equilibrium
CO2	Carbon dioxide
EFTA	European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland)
EMP	Employment
EU	European Union
EU27	European Union – Not including UK
EU28	European Union – Including UK
FIGARO	Full International and Global Accounts for Research Input Output Analysis
FTE	Full-time equivalent (for employment)
GEM	Global Extraction Method
GHG	Greenhouse Gas (emissions)
GW	Gigawatt
HEM	Hypothetical Extraction Method
ILO	International Labour Organisation
IO	Input-Output
kWh	Kilowatt-hour
NUTS-2	Nomenclature of Territorial Units for Statistics – level 2
MRIO	Multiregional Input-output
OECD	Organisation for Economic Co-operation and Development
PM2.5	Particulate Matter
SDA	Structural Decomposition Analysis
SI	Supplementary Information
SOx	Sulphur oxides
SUTs	Supply and Use Tables
UK	United Kingdom
US	United States
VA	Value-Added
WIOD	World Input-Output Database

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1. Introduction

Historically, coal has played a pivotal role in the energy landscape of numerous EU member states, contributing significantly to power generation and industrial processes. However, the combustion of coal is a major contributor to air pollution and greenhouse gas emissions, posing risks to public health and exacerbating climate change. Therefore, this historical reliance on coal has, raised concerns about environmental sustainability, air quality, and greenhouse gas emissions. Recognizing the urgency to transition to cleaner and more sustainable energy sources, the EU has outlined ambitious decarbonization goals, prominently featured in initiatives such as the European Green Deal (European Commission, 2019).

Furthermore, the socio-economic conditions in the EU-27 also play a crucial role in shaping the discourse on coal use and phase-out. Various regions within the EU have distinct economic structures, with some heavily dependent on coal-related industries (Widuto, 2019). The socio-economic impact of phasing out coal involves considerations of employment, economic diversification, and regional development (Böhringer and Rosendahl, 2022).

In the contemporary landscape, where more than 75% of the EU's greenhouse gas (GHG) emissions emanate from the production and utilization of energy across diverse economic sectors (Alves Dias et al., 2018, 2021), the imperative is clear. Prioritizing energy efficiency becomes paramount, necessitating the development of a new power sector predominantly based on renewable sources (Solomon and Krishna, 2011). Simultaneously, ensuring the security and affordability of the EU's energy supply for consumers and businesses requires a fully integrated and interconnected European energy market (Gielen et al., 2019).

In alignment with the vision for a sustainable and decarbonized future, the European Green Deal stands as the EU's comprehensive strategy to achieve zero net GHG emissions by 2050 (European Commission, 2019). This initiative aims to foster a fair and prosperous society with a resource-efficient and competitive economy, placing a particular emphasis on clean, affordable, and secure energy. However, achieving decarbonization involves a crucial step—transitioning away from coal for electricity and heating.

Despite significant strides towards a greener future, it is noteworthy that some European economies still heavily depend on coal. As reported by Widuto (2019) in 2015, there were approximately 128 coal mines in 12 Member States, distributed across 41 regions at the NUTS-2 level. Additionally, there were 207 coal power plants in 21 Member States, spanning 103 NUTS-2 regions. Poland hosts the largest number of coal mines, while Germany leads as the largest European coal producer, contributing 184 million tons annually. Poland follows closely with 135 million tons, along with Greece and Czechia at 46 million tons each. The concentration of coal power plants is notably high in Germany (53), Poland (37), and Spain (16). The European coal sector currently sustains employment for almost half a million people, although this varies significantly between regions and countries, with the highest employment observed in Poland.

Extensive research has explored the socio-economic and environmental impacts of coal phase-out with different geographical scope. With a multiregional country-level perspective (Chen et al., 2019), at the regional level in China (Wang et al., 2020; Yan et al., 2022), and in specific countries such as India (Roy and Schaffartzik, 2021), Colombia (Oei and Mendelevitch, 2019), and Germany (Hansen et al., 2019; Oei, 2019). In Europe, studies have focused on various aspects such as the impact of decarbonization targets on investment decisions (Gerbaulet et al., 2019; Löffler et al., 2019), the projection of GHG emissions (Giannakis and Zittis, 2021), and the environmental impacts of EU enlargement (Duarte and Serrano, 2021). Additionally, research has examined the economic and environmental impacts of coal phase-out scenarios (Böhringer and Rosendahl, 2022), the role of solar photovoltaic electricity (Bódis et al., 2019), and employment effects from removing coal and lignite (Alves Dias et al., 2021; Mandras and Salotti, 2021).

While these studies provide valuable insights, there is a need for a more granular analysis of the socioeconomic and environmental impacts of coal substitution across Europe. In light of this context, this study aims to explore a pivotal question regarding the socio-economic and environmental consequences of coal substitution. The specific focus is on European regions at the NUTS-2 level, considering both regional and sectoral interdependencies. Then, this study complements these previous works by utilizing a multiregional input-output (MRIO) table, specifically the EUREGIO-2017 (Almazán-Gómez et al., 2023; ESPON, 2022), and employing the Global Extraction Method (GEM) (Dietzenbacher et al., 2019) to estimate the direct plus indirect impact of coal substitution on value-added, employment, and CO2 emissions at the NUTS-2 level. This regional-level perspective identifies regions most affected and allows to assess potential mitigation strategies.

The GEM is applied at the sectoral level for two alternative scenarios: both considers the substitution of intermediate inputs provided by the coal and lignite mining sector to produce electric power in the EU27; in addition, the second one also considers the substitution of mining to the heating of households. The substitution of this input is obtained by raising the production of the alternative sources.

Each scenario is divided into 3 subscenarios. These subscenarios identify which regions or countries increase their production to replace the drop in energy production generated by the disappearance of coal. The first subscenario implies that all countries in the world can supply each region; This is the least realistic and least restrictive of the scenarios; It is calculated, and the results are offered in the supplementary information (SI). The second subscenario is the most restrictive and assumes that the substitution will be carried out by the same country; The results of this scenario are also provided in the SI. The third subscenario implies coupled markets and assumes that the replacement of energy not produced via coal in each European region must be produced in the same country or in contiguous countries. This is, from the authors opinion, the most realistic scenario within the European energy market. The results presented in this work emanate from this third scenario, serving as the focal point for the ensuing discussions and forming the basis for our conclusive analyses. Then, this work is considering the net effects on socioeconomic and environmental variables of the substitution of coal by other sources in the power generation sector and for heating systems.

The results suggest that the substitution of coal and lignite will have both the negative and positive effects in terms of value-added and employment. The regions suffering the largest negative impacts are the Eastern regions specialized in coal and lignite, while the positive effects appear in a larger number of regions where the alternative energy sectors are present within the own country and the adjacent ones. The total effects in terms of employment are reasonable aligned with the ones of value-added. The CO2 estimation reflects a strong and generalized reduction in the emissions across all regions in Europe. The largest CO2 abatements are obtained in the Central-Eastern European regions, where coal and lignite were more intensively used.

This work provides policymakers with a tool to analyse the socio-economic and environmental trade-offs involved in the energy transition. By identifying both the winners and losers at the regional level, this study offers insights into the necessary compensatory measures and targeted support programs, such as the Just Transition Mechanism, to ensure a balanced and equitable transition (European Commission, 2020a). This is particularly important in light of the European Green Deal's objectives, which aim to achieve a fair and prosperous society with a competitive economy and zero net GHG emissions by 2050.

The rest of the paper is structured as follows: Section 2 revises the literature on the computation of current GHG emissions and its potential reduction in Europe and other relevant regions in the World. Following that, Section 3 describes the methodology and scenarios description; Section 4 reports the results obtained for the two alternative scenarios considered. Section 5 is dedicated to the Discussion. Section 6, is dedicated to the Conclusions and Policy Implication, providing insights into the practical implications of the findings.

2. Literature review

The existing body of research on greenhouse gas (GHG) emissions measurement, decarbonization, and the transition from coal to alternative energy sources spans global and regional perspectives, highlighting both challenges and opportunities.

With global perspectives, Chen et al. (2019), utilized the world input-output database (WIOD) to map energy use, identifying regions with significant energy imbalances. Yan et al. (2022) and Wang et al. (2020) using MRIO models and Structural Decomposition Analysis (SDA) to reveal regional energy use patterns and emission intensities. Their findings emphasized the varying carbon emission performances across different regions within China.

Challenges in phasing out coal are well-documented by Zhao and Alexandroff (2019) who pointed out the high costs of renewable energy and the vested interests in the coal industry. Conversely, opportunities were noted in the development of new renewable technologies and the growing demand for clean energy. Figueiredo et al. (2019) explored the potential of photovoltaic alternatives in Portugal, underscoring the broader relevance of integrating such technologies into national energy systems.

In the European context, Gerbaulet et al. (2019) offer a valuable contribution. analyzed the impact of decarbonization targets on investment decisions in the electricity sector, using the dynELMOD model to highlight the need for clear policy signals. Löffler et al. (2019) stressed similar needs in their exploration of the European energy system's future trajectories, identifying risks associated with shortsighted planning. Heinrichs et al. (2017) and Hansen et al. (2019) provided detailed assessments of Germany's transition from coal, focusing on the socio-economic and environmental implications and the pathways to achieving a fully renewable energy system by 2050.

Country-specific studies, such as those by Spencer et al. (2018) and Roy and Schaffartzik (2021) examined the broader challenges of transitioning away from coal in developing economies like India. These studies highlighted the tension between increasing energy demands and the need for clean energy, illustrating the complex dynamics of energy transitions. Oei and Mendelevitch (2019) provided insights into the Colombian context, emphasizing the need to reassess coal mining sustainability amid changing global demand.

Further research by Giannakis and Zittis (2021), utilized an environmentally extended input–output model to project significant GHG emissions increases in the EU by 2030 without additional mitigation measures. Duarte and Serrano (2021) examined the effects of EU enlargement on Central and Eastern Europe, finding that economic integration could offset environmental pressures through technological and structural changes.

The phase-out of coal in Europe has been extensively studied, with Böhringer and Rosendahl (2022) quantifying the economic and environmental impacts of various scenarios using a CGE model. Oei et al. (2020a, 2020b) explored the socio-economic effects of coal phase-out in Germany, underscoring the importance of supportive policies for a successful transition. Bódis et al. (2019) emphasized the role of solar photovoltaic electricity in aiding the transition of European coal regions.

Technological improvements in energy efficiency were highlighted by Duarte et al. (2018), who demonstrated positive environmental outcomes. Alves Dias et al. (2021) estimated significant job losses in coal-in tensive regions due to decarbonization, while Mandras and Salotti (2021) provided a comprehensive analysis of the direct and indirect employment effects of removing coal and lignite in Europe.

Despite the breadth of these studies, a gap remains in the regional analysis of coal substitution impacts across Europe at the NUTS-2 level. Then, the present work addresses this gap by employing a NUTS-2 level MRIO framework to estimate impacts on value-added, employment, and CO2 emissions.

3. Methodology

The MRIO table used is the EUREGIO-2017 (Almazán-Gómez et al., 2023; ESPON, 2022), encompassing 297 regions at the NUTS-2 level and 64 sectors. This MRIO table is rooted in the FIGARO table for 2017 (Remond-Tiendrez and Rueda-Cantuche, 2019). The EUREGIO-2017 surpasses its predecessor, the EUREGIO-2013 (Thissen et al., 2019), by extending the FIGARO multi-country framework to the NUTS-2 level, capturing region-to-region flows for all EU27 countries, the UK, Norway, Iceland, Switzerland, and Liechtenstein. This multiregional and multisectoral framework stands as the most complete and updated inter-sectoral inter-regional framework currently available in Europe.

Let's represent $\mathbf{Z}$ as a block matrix with $\mathbf{Z}^{rs}$ matrices that capture the inter-industry relations between regions *r* and *s*. Each submatrix $\mathbf{Z}^{rs}$ is a n-by-n matrix where n is the number of sectors considered. The on-diagonal matrices ($\mathbf{Z}^{rr}$) capture the domestic intermediate flows (intra-regional intermediate flows). In contrast, all off-diagonal matrices ($\mathbf{Z}^{rs}\ \forall\ r \neq s$) contain the inter-industry interregional flows, where Z_{ij}^{rs} is the value of the production generated by sector *i* in region *r* that is being used as an intermediate input by sector *j* in region *s* (interregional inter-industry flow). The gross output of each industry is depicted by a column vector $\mathbf{x}$. Then, by dividing each element of the intermediate inputs matrix (Z_{ij}^{rs}) by the gross output of the sector *j* in region *s* (x_j^s) we obtain the matrix of technical coefficients, denoted as $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$. Each element of this matrix (A_{ij}^{rs}) inform us about the requirements that the industry *j* of region *s* has from the industry *i* from region *r* to produce an output of 1 monetary unit (one million Euros in our case). Let's denote the matrix of value-added generated as $\mathbf{M}$, where each component M_{cj}^{s} represents the component *c* of value-added (gross operating surplus, compensation of employees, taxes, etc.) associated with industry *j* from region *s*. For the shake of simplicity let's assume there are no other components on the supply side, and to aggregate the matrix $\mathbf{M}$ to obtain a row vector called $\mathbf{m}\ \left(m_j^s = \sum_c M_{cj}^s\right)$. Then, by dividing the $\mathbf{m}$ vector element to element by the gross output, we obtain, for each sector of each region the share of value-added over the total output, let's call this vector as $\mathbf{v}$. Note that this vector ($\mathbf{v}$) is a vector of value-added requirement per unit of output. Finally, the final demand matrix, usually called $\mathbf{Y}$, is also a block matrix of matrices $\mathbf{Y}^{rs}$ where each component Y_{id}^{rs} represent the final demand that the agent *d* (households, government, NPISHs, etc.) of region *s* makes from industry *i* of region *r*. Let's also aggregate all columns in the final demand matrix to obtain a column vector ($\sum_{sd} Y_{id}^{rs} = y_i^r \rightarrow \mathbf{y}$). Then, the main equations are as follows:

$$\mathbf{x} = \mathrm{A}\mathrm{x} + \mathbf{y} \quad \leftrightarrow \quad \mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{1}$$

$$\mathbf{m} = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{2}$$

Equation (1) depicts the output needed to satisfy the final demand, while equation (2) shows the associated value-added. Note that the Leontief model[1] is linear, meaning that percentage changes in output reflect the same percentage changes in value-added at the sector-region level ($\frac{x_i^{r*} - x_i^r}{x_i^r} = \frac{m_i^{r*} - m_i^r}{m_i^r}$), as well as in employment and CO2 emissions. Therefore, by utilizing an alternative vector (employment requirement per unit of output or CO2 emissions per unit of output) in equation (2) instead of the one for value-added, it is possible to calculate the employment and CO2 emissions associated with each scenario.

The scenarios, described below, imply changes in certain values of the intermediate inputs matrix ($\mathbf{Z}$), and consequently in the technical coefficients matrix ($\mathbf{A}$). Additionally, type B scenarios involve changes in

[1] This work employs an input-output model, a general equilibrium model in practice. This model is value-based (price multiplied by quantity) and does not incorporate price mechanisms or elasticities. This limitation is recognised and is expected to be addressed in future research.

the final demand vector (**y**). Subsequently, the effect of each scenario on each sector in each region is calculated by applying equation (2) and comparing the results with the status quo. This method, known in the input-output framework as the "Global Extraction Method – GEM" (Dietzenbacher et al., 2019), is an alternative approach for multiregional input-output models to the "Hypothetical Extraction Method – HEM" (Miller and Blair, 2009), which should only be used in single-region frameworks.

3.1. Scenarios description

As mentioned, the IO framework we use encompasses 64 sectors across the 297 NUTS-2 European regions (rev. 2016). The specific sectors can be found in the Annex. Here, our focus centres on the following three sectors, encompassing all the assumptions.

- B - Mining and quarrying
- C19 - Manufacture of coke and refined petroleum products
- D - Electricity, gas, steam, and air conditioning supply

The scenarios are divided into two groups. Scenarios type A (Fig. 1 exclusively target the electricity generation sector, while scenarios type B (Fig. 2) introduce the prohibition of coal in the final demand (assuming that the use of coal for heating is prohibited). Thus, all scenarios assume the disappearance of coal as an input for energy production in the EU27, requiring an increase in the use of oil (Sector C19) or other sources (Sector D) to compensate for the decline in energy production in each region. Scenarios "type B″ also imply that coal cannot be used by households. Consequently, to fulfil their heating needs, sectors C19 and D are utilized. These extractions adhere to the GEM (Dietzenbacher et al., 2019). Both type A and type B scenarios are further divided into three sub-scenarios, each subject to three hypotheses regarding the origin of the inputs required to substitute the unused coal.

In this scenario, the focus is on substituting intermediate inputs from the coal and lignite mining sector for electricity production in the EU27. This reduction is counterbalanced by an equivalent increase in inputs from all other alternative energy sources (oil, wind, thermal, nuclear, etc.). It's important to note that this scenario doesn't involve eliminating the use of coal in household heating, confining the shock to intermediate demand rather than final demand.

3.1.1. Scenarios type A - decarbonization of energy production

In more technical terms, we assume a reduction in all Z_{ij}^{rs} where the demanding sector *j* is "D - Electricity, gas, steam, and air conditioning supply", the demandant region *s* belongs to EU27, the supplying sector *i* is "B - Mining and quarrying", and the supplying region belong to the EU27. The reduction applied to the Z_{ij}^{rs} is related to the portion of "coal and lignite" within the entire "Mining and Quarrying" sector in each region. These values, denoted as c_i^r, have been calculated based on EUROSTAT data and are detailed in Table A3 in the annex. The equations expressing this reduction are as follows:

$$\dot{Z}_{ij}^{rs} = \left(1 - c_i^r\right) Z_{ij}^{rs} \quad \forall\,(j = D \text{ and } s \in EU27 \text{ and } i = B \text{ and } r \in EU27)$$

$$\dot{Z}_{ij}^{rs} = Z_{ij}^{rs} \quad \forall\,(j \neq D \text{ or } s \notin EU27 \text{ or } \ i \neq B \text{ or } s \notin EU27)$$

Furthermore, we assume that the total intermediate inputs required by sectors remain constant $\left(\sum_{ri} Z_{ij}^{rs} = \sum_{ri} \dot{Z}_{ij}^{rs}\right)$, prompting the need to establish criteria to compensate for declines in the energy supply sector of the EU27 regions. As mentioned earlier, we estimate three sub-scenarios corresponding to three alternative assumptions.

S_A1: The overall reduction $(\sum_{ri} z_{ij}^{rs} - \sum_{ri} \dot{z}_{ij}^{rs})$ is offset by a proportional increase in the input vectors generated by sectors "C19″ and "D" across all regions, with an equal distribution. It is crucial to emphasize that the declines are specifically concentrated in the input flows from "B" to "D" in EU27 regions (where *j* = "D" and *s* ∈ EU27). In this scenario, the augmented inputs "C19″ and "D" (subscript *i*) compensating for the absence of coal can originate from any region *r* and are adjusted to maintain the same quantity of intermediate inputs as before, ensuring that $\sum_{ri} Z_{ij}^{rs} - \sum_{ri} \dot{Z}_{ij}^{rs} = 0$. In this scenario, there are no restrictions on the source regions of the compensating products. This scenario, along with the subsequent ones, adheres to the ad-hoc GEM approach (Dietzenbacher et al., 2019). Implicit in this scenario is the assumption that the reduction of the input provided by coal mining in the whole EU27 is compensated with the increase of "C19" and "D" sectors inputs using the effective structure of flows already included in the EUREGIO-2017 table, without imposing any restrictions on the geographical origin of the new inputs substituting the ones eliminated from mining.

S_A2: The overall reduction is compensated by the "C19" and "D" sectors of the regions in the producing countries, with an equitable distribution. In this case, the inputs "C19" and "D" must come from regions within the same country. These inputs are rescaled to maintain the same value of intermediate inputs as before, ensuring that $\sum_{ri} z_{ij}^{rs} - \sum_{ri} \dot{z}_{ij}^{rs} = 0$. Implicit in this second sub-scenario is the assumption that the reduction of the input provided by coal mining in the entire EU27 is compensated with the increase of "C19" and "D" sectors inputs produced within the same country where the mining sector was eliminated. This

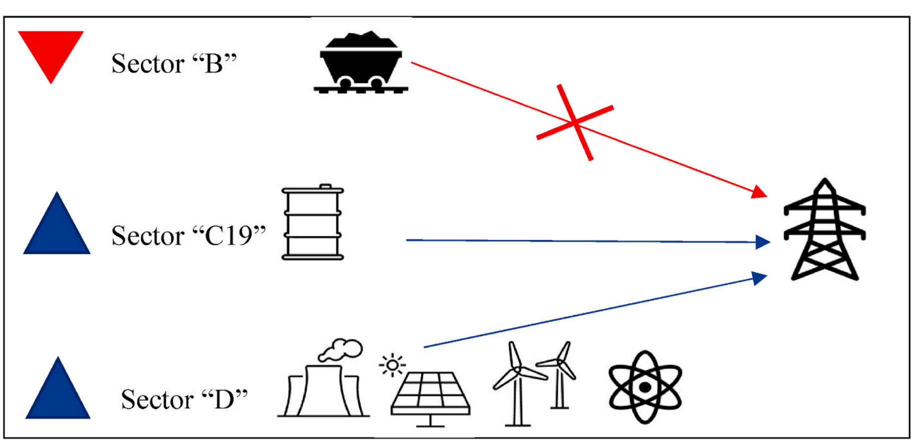

Fig. 1. Scheme summarizing Scenarios type A: intermediate demand.

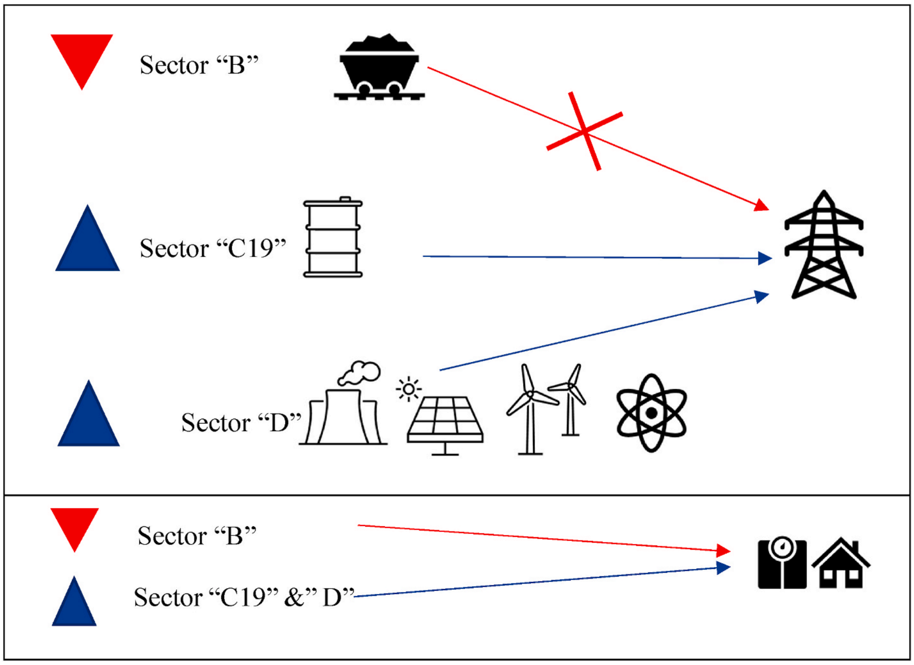

Fig. 2. Scheme for scenario B: intermediate demand + final demand substitution.

scenario enforces a "within-country" substitution of energy input, potentially influencing the positive/negative spillovers of electricity decarbonization between countries.

S_A3: The overall reduction is compensated by the "C19" and "D" sectors of the producer country regions and the contiguous countries, with an equal distribution. Here, the inputs ("i") "C19" and "D" that come from regions of the same country and contiguous countries are rescaled to maintain the same value of intermediate inputs as before, ensuring that $\sum_{ri} z_{ij}^{rs} - \sum_{ri} \dot{z}_{ij}^{rs} = 0$. The contiguity matrix used is restricted to EU27 and can be found in the annex Table A4. Implicit in this third scenario is the assumption of a coupled market, wherein the reduction of the input provided by coal mining in the entire EU27 is compensated with the increase of "C19" and "D" sectors inputs produced within the same country or in neighbouring ones. This setup is designed to facilitate potential adjustments in the net requirements of energetic inputs, given the easier integration of the electric networks of the contiguous countries.

3.1.2. *Scenarios type B - decarbonization of energy production and the cessation of coal heating*

Scenarios Type B involve the substitution of intermediate inputs from the coal and lignite mining sector for electricity production (Scenarios Type A), previously considered, plus the replacement of mining (sector B) for household heating in the EU27. Thus, the shock extends from intermediate demand to final demand, anticipating a larger effect. Here, the hypothesis is complete decarbonization in the EU27. Regions that still produce carbon must reduce the output of sector "B" by the proportion in which sector "B" is composed of carbon (see Table A3). Let x_i^r be the output of sector *i* of region *r*. Then, the output of sector "B" of EU27 regions must be reduced:

$$\dot{x}_i^r = \left(1 - c_i^r\right) x_i^r \; \forall \; (i = B \text{ and } r \in EU27)$$

Note that the multiregional IO framework represented by EUREGIO-2017 corresponds to a closed economy (the whole world). When the total output of any sector falls, this sector must reduce demand. We then estimate the fall in final demand as follows (with *d* subscript indicating the component of final demand):

$$\dot{x}_i^r - \sum_{sj} \dot{z}_{ij}^{rs} = \sum_{sd} \dot{y}_{id}^{rs}$$

In this manner, we obtain a column vector indicating a provisional new total final demand. To appropriately compensate for the declines in the "B" sectors, we allocate the decreases to the household's final demand in EU27 regions. Then, following the same approach as before, we consider three sub-scenarios with hypotheses regarding the geographical origin of the new inputs required.

- In **S_B1**, it is assumed that the compensation can come from sectors "C19" and "D" from any region (the whole world), with full respect to the effective trade structure of such inputs considered in the EUREGIO-2017 for each region.
- In **S_B2**, it is assumed that the compensation will come from the "C19" and "D" sector produced within the same country where the "B" is reduced.
- Finally, **S_B3** compensates the falls with an increase in "C19" and "D" households' final demand, as well as intermediate inputs from the same country and contiguous countries.

3.2. *Socioeconomic and environmental extension of the model*

In addition to the EUREGIO-2017 table, it is essential to construct two additional vectors at the regional-sectoral level that are compatible with the EUREGIO-2017, capable of translating any impact in Value Added (VA) and Output into the number of employees and CO2 emissions. To develop the employment (EMP) and carbon dioxide (CO2) vectors, we utilize the Environmental extended EXIOBASE database (Stadler et al., 2018). The scope of the socioeconomic and environmental satellite accounts in the latest release of EXIOBASE covers the period from 1995 to 2020 and contains the values of 1113 stressors (satellite accounts) for each of the 163 sectors accounted for in 44 countries.

Initially, we define the following approaches: Value-Added (VA) is the sum of stressors 3 to 9. Employment (EMP) is the sum of stressors 10 to 15, and CO2 emissions are the sum of stressors 24, 93, 94, 428, 438, and 439 (see Table A4 in the Appendix). Then, we aggregate the 163 industries available to the 64 considered in EUREGIO-2017. Details about these 163 industries and the matching can be found in Table A5 in the Appendix. Subsequently, we divide employment and CO2 by the value added. These two vectors establish the relationship between these variables (CO2 and EMP) with VA, now for the 64 sectors considered in EUREGIO-2017 and the countries considered in EXIOBASE. The countries included in EUREGIO-2017 but not in EXIOBASE are Iceland, Liechtenstein, and Argentina. For these three economies, we use, as proxies, the coefficients from the most closely related countries available in EXIOBASE, namely Finland, Switzerland, and Brazil, respectively.

Next, we calculate the sectoral CO2 and EMP implicit values in the EUREGIO-2017 table at the NUTS-2 level. Finally, the resultant vectors have been adjusted (re-scaled) to align with the official values provided by EUROSTAT, OECD, and ILO (see Table A7 in the Annex).

Note that an additional vector of CO2 emissions is needed, where the emissions of sector "D" represent the emissions caused by electricity production, but in this case, considering that the energy mix does not include coal. To develop a CO2 emissions vector coherent with the general assumptions we first assume a fix coefficient of 800 g of CO2 per kWh, which has been computed as a conservative average from several sources (Understanding CO2 Emissions from the Global Energy Sector (Foster and Bedrosyan, 2014), Carbon Dioxide Emissions from Electricity (World Nuclear Association, 2022), Specific Carbon Dioxide Emissions of Various Fuels (Volker Quaschning, 2022)). Then, we subtract those emissions and calculate new coefficients for each country. Table A8 show the adjustment in the CO2 coefficient of energy supply sector.

4. Results

In this section, we present the main results, focusing on scenarios **S_A3** and **S_B3** due to their complexity. These scenarios involve only the same country and neighbouring countries supplying the inputs needed to compensate for the declines in coal and lignite. Results for the other scenarios are available in the Supplementary Information (SI). Note also that the results from scenarios type A can be associated with decarbonization effects from the supply-side, meanwhile scenarios type B can be associated with supply plus demand side effects.

4.1. Results of S_A3 scenario

The main results obtained for **S_A3** are summarized in Fig. 3, divided into three panels presenting the outcomes in terms of Value Added (panel a), Employment (panel b), and CO2 emissions (panel c). It is important to note that this scenario is the least invasive, as it assumes that the substitution of coal & lignite only affects the intermediate input for producing electric power, without involving final demand. The substitution of this input affects other sectors within each country and neighbouring ones. Results for the alternative scenarios **S_A1** and **S_A2** are reported in the SI.

4.1.1. Value added and employment: winners and losers

In terms of value added (VA) and employment, the results depict a mix of negative and positive effects, reflecting the dynamics of winners and losers caused by the substitution in the energy mix advocated by the European Green Deal. Regions heavily specialized in coal and lignite mining experience substantial negative impacts. Conversely, regions with a strong presence in alternative energy sectors (C19 and D) observe positive effects as they provide the necessary input to replace coal and lignite. The negative shock is pronounced in certain regions, exceeding 1% in terms of Value Added and surpassing 0.5% in terms of Employment (EMP). The positive effects are moderate and more evenly distributed, with peaks of 0.23% in terms of VA and 0.06% in terms of EMP in some regions.

4.1.2. CO2 emission reductions

The estimation of CO2 emissions reflects a substantial and widespread reduction across all European regions. The most significant CO2 reductions occur in Eastern European regions, as well as in Spain, Italy, and the southern part of France. It's worth noting that, in this scenario, increases in CO2 emissions (primarily in Germany and Switzerland) are consistently lower than 0.32%.

4.1.3. Spatial distribution

Since the substitution is confined to the alternative energy sources available within each country and its neighbouring ones, the negative and positive effects are spatially concentrated. This clustering provides insight into how the positive and negative effects in terms of production and employment will be grouped in "clubs" of neighbouring countries. This spatial concentration helps counterbalance the negative and positive spillovers of the mining and alternative energy sectors within these regional groups.

In general terms, the detailed results for each European NUTS-2 region are provided in the Supplementary Information (SI), covering scenario types 1 and 2. In summary, the decarbonization of the energy production process does not lead to significant alterations in the overall value added (VA) generated across Europe, with a minimal variation of −0.001% in total Europe's VA. However, there is a shift in the regional distribution of VA, identifying winners and losers (Fig. 3, panel a). Parallel findings and identical spatial distribution patterns are observed in terms of employment (Fig. 3, panel b). In terms of CO2 emissions, the **S_A3** scenario indicates a notable reduction of nearly 7.6% in CO2 emissions within the EU27. It is noteworthy that these reductions exhibit spatial unevenness (Fig. 3, panel c).

4.2. Results of S_B3 scenario

Let the focus be on the results of **S_B3**, summarized in Fig. 4, which is also divided into three panels, considering the results in terms of Value Added (panel a), Employment (panel b) and CO2 emission (panel c). This scenario is the most extensive and aggressive as it assumes the substitution of both the intermediate input for electricity production and the elimination of heating based on coal & lignite. Similar to other scenarios, this substitution involves increasing the production of alternative sources in the same country (other regions) and neighbouring ones.

4.2.1. Value added and employment: winners and losers

In terms of Value Added (VA) and employment, regions specializing in coal and lignite mining, especially in Eastern regions, experience the most significant negative impacts. Conversely, positive effects are observed in numerous regions where alternative energy sectors (C19 and D) are present within the country and adjacent ones. The negative shock is notable in some regions, with VA losses exceeding 3% and employment losses exceeding 2%. Positive effects are more widely distributed among regions.

4.2.2. CO2 emission reductions

Regarding CO2 emissions, it is important to note that the data only reflect CO2 emissions caused by each productive sector, excluding household emission. Therefore, the results indicate percentage variations in emissions required for production. The reduction in CO2 emissions due to not using coal for heating is not considered in Fig. 4 panel c). However, the actual reduction in CO2 emissions is expected to be greater than shown. Taking this into account, the results demonstrate a substantial and widespread reduction in emissions across most European regions. Exceptions, where emissions increase, are concentrated in Germany, Switzerland, Poland, and the Baltic republics. These increases are lower than 6% in all cases. The rise in emissions in these regions is attributed to their already decarbonized or mostly decarbonized electricity generation sectors, leaving limited room for improvement. Thus,

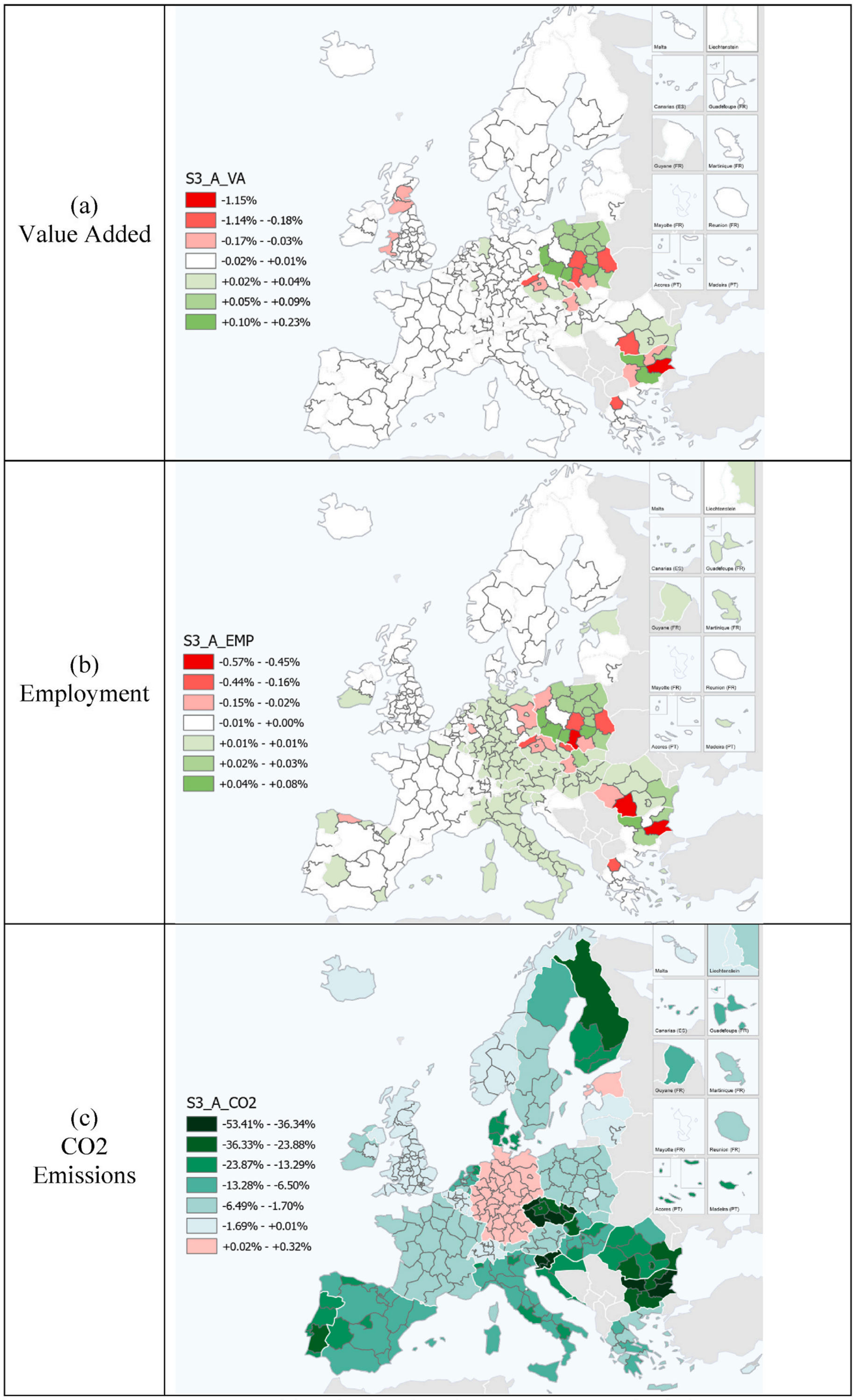

Fig. 3. Scenario A3. Total effects: VA, employment, and CO2 emissions.

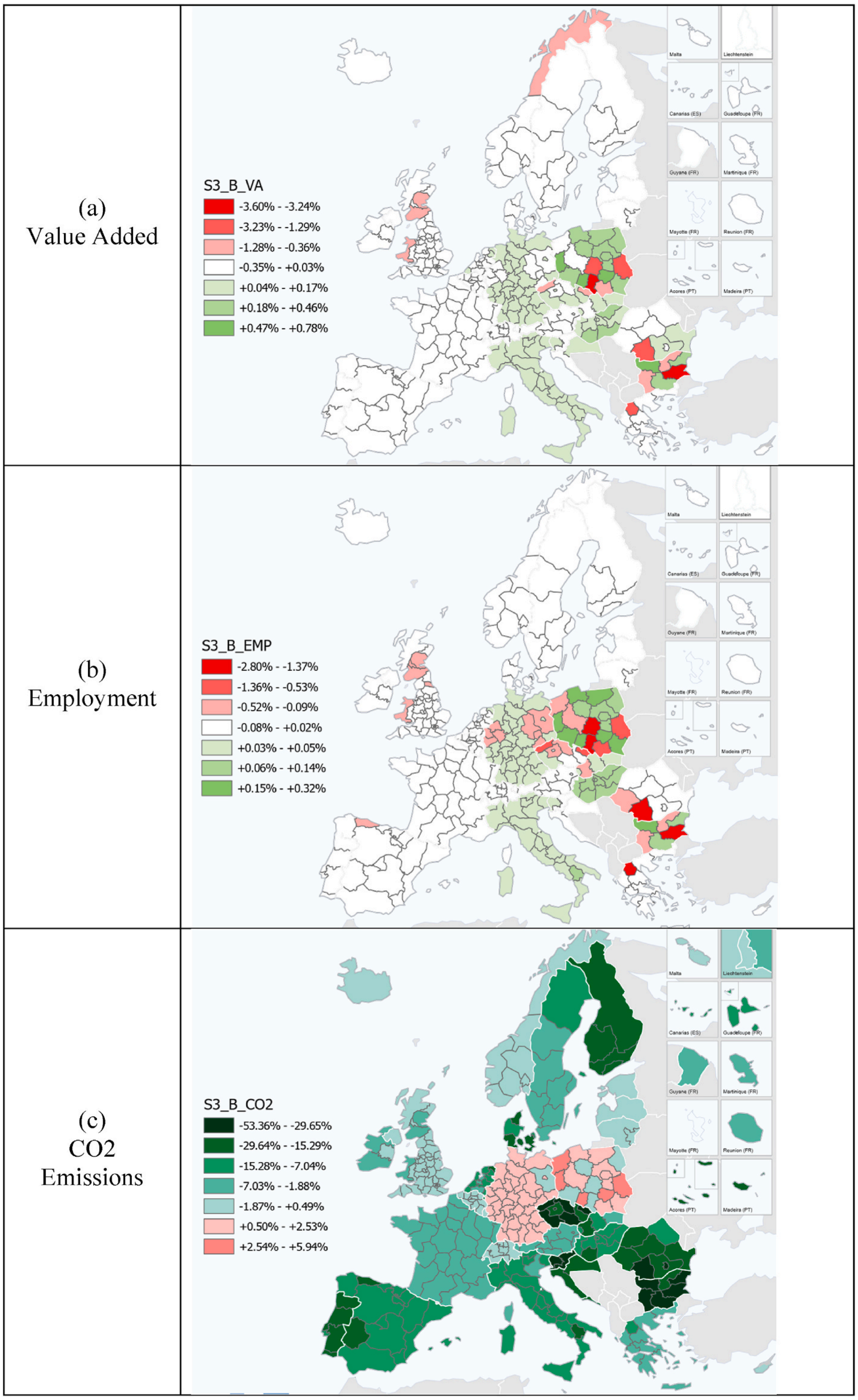

Fig. 4. Scenario B3. Total effects: VA, employment, and CO2 emissions.

increased electricity production in these regions inevitably leads to higher CO2 emissions.

4.2.3. Spatial distribution

Given the assumption that substitution occurs within each country reducing mining and its neighbouring countries, the negative and positive effects are observed within groups of countries. It's essential to note that this representation is constructed and may not precisely correspond to reality. However, it illustrates the negative and positive spillovers can be observed, considering that neighbouring economies are usually more closely interconnected by inter-regional and inter-sectoral relations. Notably, the negative effects on socioeconomic variables observed in regions like Poland, Bulgaria, or Romania generate positive effects in those countries, as well as in Germany, Slovenia, Austria, and Italy. This result supports the idea that countries suffering the most from the CO2 emissions of neighbouring coal & lignite use are the ones reaping potential benefits from their substitution.

Overall, this scenario entails the complete substitution of 'coal & lignite' across the EU27. Similar to the previous scenario, the overall impacts (across the entire Europe) on VA and employment are practically zero (refer to results in the SI). However, there is a shift in the regional distribution of VA and employment, leading to the identification of winners and losers (Fig. 4, panels a) and b In terms of CO2 emissions (required for production, excluding household direct emissions), the **S_B3** scenario indicates a notable reduction of nearly 6.9% in CO2 emissions within the EU27. It's important to note that, as mentioned earlier, this reduction in CO2 emissions is underestimated as household direct emissions are not considered.

4.3. Key findings

The analysis of the socio-economic and environmental impacts of coal and lignite substitution in the EU27, using the EUREGIO-2017 multiregional input-output table, reveals a complex set of trade-offs at the regional level. The substitution of coal and lignite in both electricity generation and household heating generates significant variability in outcomes across different regions.

One of the key findings is the identification of regions that experience both positive and negative economic impacts as a result of the transition. Regions that are heavily dependent on coal and lignite, particularly in Central-Eastern Europe, are the most negatively affected, with substantial declines in value-added and employment. Conversely, regions with established alternative energy sectors see positive economic effects, as the demand for these alternative sources increases.

The environmental outcomes are unequivocally positive, with a pronounced reduction in CO2 emissions across all European regions. The most significant reductions are observed in regions where coal and lignite were historically the dominant sources of energy, further underscoring the environmental benefits of the transition.

5. Discussion

The European Green Deal represents a unified and ambitious strategy within the EU27 aimed at combatting global warming (European Commission, 2019). Beyond environmental concerns, the initiative seeks to safeguard the EU's natural capital, ensuring the well-being of its citizens by addressing environment-related risks and impacts. It also emphasizes the principles of justice and inclusivity in the transition process (European Commission, 2020b).

A pivotal component of this overarching framework is the imperative to decarbonize the energy sector and eliminate coal usage in heating systems (European Commission, 2020c). While this endeavour promises significant positive outcomes, particularly in reducing greenhouse gas emissions, it simultaneously poses undeniable challenges, notably in regions traditionally dependent on coal mining, leading to pronounced negative socioeconomic impacts (Alves Dias et al., 2018). The trade-offs inherent in these environmental and socioeconomic variables necessitate a nuanced analysis that considers not only the direct impacts but also the intricate web of indirect effects, collectively representing the total repercussions (Mandras and Salotti, 2021).

The findings of this study align with other works focussed on Europe (Alves Dias et al., 2018, 2021; Mandras et al., 2019a; Mandras and Salotti, 2021) This work adds to the existing literature a comprehensive Pan-European quantitative analysis focuses on the socioeconomic and environmental repercussions associated with the complete substitution of coal and lignite.

The results obtained suggests that, in the most restrictive scenario proposed (**S_B3**), the EU27 could achieve a reduction of approximately 160 thousand tons of CO2 emissions. However, this reduction comes at a total net cost of approximately 425 million in value-added and a reduction of 95,000 employment opportunities. These results complement findings obtained through alternative methodologies, such as the RHOMOLO-IO model (Mandras et al., 2019b; Mandras and Salotti, 2021). This alternative approach not only estimates employment losses but also considers the broader impact on value-added and the positive gains associated with CO2 emissions reduction.

In concert, these diverse insights contribute to a better understanding of the trade-offs between environmental objectives and the socio-economic consequences inherent in the European Green Deal. This nuanced understanding positions our approach as a fundamental tool for policymaking, offering policymakers a comprehensive view of the multifaceted implications associated with the pursuit of environmental goals, thereby facilitating more informed and balanced decision-making processes.

6. Conclusion and policy implications

The present work contributes to enrich the debate about the need of compensatory programs such as the Just Transition Mechanism adopted by the EU (European Commission, 2020a). This instrument is under the umbrella of the European Green Deal and provides targeted support to help mobilise at least €150 billion over the period 2021–2027 to support the most affected regions involved in coal, peat, and oil shale activities. As the European Green Deal progresses, it becomes evident that the transition away from coal and lignite is not a one-size-fits-all solution. Regional disparities, technological nuances, and the evolving geopolitical landscape demand an adaptive policy framework. The analysis provided here is expected to assist policymakers in making informed decisions by considering the total net trade-offs at both national and sub-national levels.

This study aimed to quantify the socio-economic and environmental impacts of transitioning away from coal and lignite in the EU. Using the EUREGIO-2017 MRIO table and the GEM, two scenarios (S_A3 and S_B3) were analyzed, focusing on value-added, employment, and CO2 emissions across European regions. The results indicated a mix of negative and positive effects, with significant reductions in CO2 emissions but varying socio-economic impacts across different regions.

This work employs an input-output (IO) model, one of the most widely used frameworks for economic and environmental analysis (Rose, 1995; Timilsina, 2022). IO models and Computable General Equilibrium (CGE) models are both powerful tools, each with their own strengths and limitations. While both approaches can account for demand- and supply-side effects, CGE models are typically more flexible for long-term analysis due to their ability to model agent behaviour and substitutions between factors and inputs. By contrast, IO models, such as the one used in this study, rely on fixed coefficients (Leontief production functions) and do not allow for substitution possibilities or reflect price changes. This fixed nature limits their ability to model supply constraints and dynamic market adjustment s (Rose, 1995; Timilsina, 2022).

Despite these limitations, the IO approach provides a more disaggregated analysis than a standard CGE model, particularly useful for regional-level studies such as ours, which focuses on the NUTS-2 level. Additionally, comparisons with works such as those by Mandras and Salotti (2021), which use a more CGE-oriented framework, highlight the different analytical capabilities between the two approaches. While a CGE model might offer greater flexibility in accounting for elasticities and substitution effects, the linear relationships assumed in an IO model allow for more detailed sectoral and regional insights, even if these relationships are more static.

Our analysis includes two types of scenarios that reflect both supply-side and demand-side considerations. The Type A scenarios focus solely on the disappearance of coal as an input for electricity production, representing the supply-side effect. On the other hand, the Type B scenarios assume a complete decarbonization, eliminating coal not only as an input but also from final demand (households, institutions, exports). By comparing these two types of scenarios, the demand-side impact can be inferred, though it is not the primary focus of the study. The interaction between supply- and demand-side dimensions could lead to more complex effects, but such interactions are beyond the scope of this work and would require more flexible approaches that consider substitution elasticities and dynamic market adjustments.

The findings of this study have significant policy implications for the ongoing efforts to align with the European Green Deal's objectives and address the challenges associated with the decarbonization of the energy sector. This analysis underscores the need for policymakers to adopt approaches considering the balance between environmental sustainability and socioeconomic impacts. The following policy recommendations emerge from our study.

- Balanced Policies: Policymakers must strike a delicate balance between achieving environmental goals, such as reducing greenhouse gas emissions through the elimination of coal in the energy sector and mitigating the adverse socioeconomic effects on regions dependent on coal mining.
- Comprehensive Analysis: When formulating and evaluating decarbonization policies, it is imperative to conduct a comprehensive analysis that goes beyond direct effects. Considering both direct and indirect impacts on variables such as value added, employment, and CO_2 emissions provides a better understanding of the trade-offs involved.
- Compensatory Measures: Compensatory programs, such as the Just Transition Mechanism, should be designed to provide targeted support to the most affected regions, ensuring fair and equitable social change.
- Sub-national Dimension: Understanding the trade-offs at sub-national levels is crucial for tailoring interventions to the specific needs and challenges of most affected regions.
- Adaptability to External Factors: Recognizing the impact of external events, such as geopolitical shifts, policymakers should be adaptable in their approach. The recent Russian invasion of Ukraine and ensuing economic sanctions serve as a reminder that unforeseen events can reshape the energy landscape, necessitating a flexible policy framework (Almazán-Gómez et al., 2024).
- Addressing Research Gaps: Policymakers should acknowledge the limitations highlighted in this study and support further research to address gaps, including the technical aspects of energy substitution, variations in total energy supply, investment requirements for plant transformations, and potential modifications in technology and production capacity.

Overall, this research provides an analysis of the socio-economic and environmental trade-offs involved in the transition away from coal and lignite in the EU. The identified trade-offs and policy implications offer valuable insights, but they must be considered within the context of an ever-changing global and regional landscape. Ensuring a resilient and equitable energy transition across the European Union requires a commitment to environmental sustainability, socio-economic justice, and adaptable policy formulations.

While this research makes significant contributions, it is not without limitations. The approach does not address price elasticity and factors such as the technical substitution relationships between fossil and alternative energy sources, potential variations in total energy amounts, and the investment needed for plant transformation. Additionally, it does not explicitly consider modifications in technology within each alternative energy source, production capacity constraints, or external factors like sanctions and geopolitical events (Almazán-Gómez et al., 2024; Chepeliev et al., 2022; Estrada and Koutronas, 2022). Future research should delve deeper into the technical and economic intricacies of energy substitution, evaluate potential shifts in overall energy demand, and consider the dynamic nature of technological advancements. Additionally, the impact of geopolitical events on energy policies requires ongoing evaluation to ensure that strategies remain resilient and adaptable to changing circumstances.

CRediT authorship contribution statement

MiguelÁngel Almazán-Gómez: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carlos Llano:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Julián Pérez:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2024.114360.

8. Annex

Table A.1
Countries and sectors included in FIGARO IO table.

BE	Belgium	S_64	CH	Switzerland	S_30
BG	Bulgaria	S_64	NO	Norway	S_30
CZ	Czechia	S_64	RU	Russian Federation	S_30
DK	Denmark	S_64	TR	Turkey	S_30
DE	Germany	S_64	CA	Canada	S_30
EE	Estonia	S_64	MX	Mexico	S_30
IE	Ireland	S_64	AR	Argentina	S_30
EL	Greece	S_64	BR	Brazil	S_30
ES	Spain	S_64	ZA	South Africa	S_30
FR	France	S_64	AU	Australia	S_30
HR	Croatia	S_64	SA	Saudi Arabia	S_30
IT	Italy	S_64	ID	Indonesia	S_30
CY	Cyprus	S_64	CN	China	S_30
LV	Latvia	S_64	IN	India	S_30
LT	Lithuania	S_64	JP	Japan	S_30
LU	Luxembourg	S_64	KR	Korea (Republic of)	S_30
HU	Hungary	S_64	WRL_REST	Rest of the World	S_30
MT	Malta	S_64			
NL	Netherlands	S_64			
AT	Austria	S_64			
PL	Poland	S_64			
PT	Portugal	S_64			
RO	Romania	S_64			
SI	Slovenia	S_64			
SK	Slovakia	S_64			
FI	Finland	S_64			
SE	Sweden	S_64			
UK	United Kingdom	S_64			
US	United States of America	S_64			

Source: EUROSTAT. Note: Switzerland and Norway economies in the EUREGIO-2017 are composed by 64 sectors.

Table A.2
Sectors in FIGARO tables

A	A01	Crop and animal production, hunting and related service activities
	A02	Forestry and logging
	A03	Fishing and aquaculture
B	B	Mining and quarrying
C10-12	C10-12	Manufacture of food products; beverages and tobacco products
C13-15	C13-15	Manufacture of textiles, wearing apparel, leather and related products
C16-18	C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	C17	Manufacture of paper and paper products
	C18	Printing and reproduction of recorded media
C19	C19	Manufacture of coke and refined petroleum products
C20_21	C20	Manufacture of chemicals and chemical products
	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22_23	C22	Manufacture of rubber and plastic products
	C23	Manufacture of other non-metallic mineral products
C24_25	C24	Manufacture of basic metals
	C25	Manufacture of fabricated metal products, except machinery and equipment
C26	C26	Manufacture of computer, electronic and optical products
C27	C27	Manufacture of electrical equipment
C28	C28	Manufacture of machinery and equipment n.e.c.
C29_30	C29	Manufacture of motor vehicles, trailers and semi-trailers
	C30	Manufacture of other transport equipment
C31-33	C31_32	Manufacture of furniture; other manufacturing
	C33	Repair and installation of machinery and equipment
D_E	D	Electricity, gas, steam and air conditioning supply
	E36	Water collection, treatment and supply
	E37-39	Sewerage, waste management, remediation activities
F	F	Construction
G	G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
	G46	Wholesale trade, except of motor vehicles and motorcycles
	G47	Retail trade, except of motor vehicles and motorcycles
H	H49	Land transport and transport via pipelines
	H50	Water transport
	H51	Air transport
	H52	Warehousing and support activities for transportation
	H53	Postal and courier activities
I	I	Accommodation and food service activities
J58-60	J58	Publishing activities
	J59_60	Motion picture, video, television programme production; programming and broadcasting activities
J61	J61	Telecommunications
J62_63	J62_63	Computer programming, consultancy, and information service activities
K	K64	Financial service activities, except insurance and pension funding
	K65	Insurance, reinsurance and pension funding, except compulsory social security
	K66	Activities auxiliary to financial services and insurance activities
L68	L68	Real estate activities
M_N	M69_70	Legal and accounting activities; activities of head offices; management consultancy activities
	M71	Architectural and engineering activities; technical testing and analysis
	M72	Scientific research and development
	M73	Advertising and market research
	M74_75	Other professional, scientific and technical activities; veterinary activities
	N77	Rental and leasing activities
	N78	Employment activities
	N79	Travel agency, tour operator reservation service and related activities
	N80-82	Security and investigation, service and landscape, office administrative and support activities
O84	O84	Public administration and defence; compulsory social security
P85	P85	Education
Q	Q86	Human health activities
	Q87_88	Residential care activities and social work activities without accommodation
R_S	R90-92	Creative, arts and entertainment activities; libraries, archives, museums, and other cultural activities; gambling and betting activities
	R93	Sports activities and amusement and recreation activities
	S94	Activities of membership organisations
	S95	Repair of computers and personal and household goods
	S96	Other personal service activities
T_U	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
	U	Activities of extraterritorial organisations and bodies

Source: FIGARO Project / EUREGIO-2017

Table A.3
Weight of Carbon over all mining sector

NUTS2	Name	B5/B
BE10	Région de Bruxelles-Capitale / Bruss	0.00%
BE21	Prov. Antwerpen	0.00%
BE22	Prov. Limburg (BE)	0.00%
BE23	Prov. Oost-Vlaanderen	0.00%
BE24	Prov. Vlaams-Brabant	0.00%
BE25	Prov. West-Vlaanderen	0.00%
BE31	Prov. Brabant wallon	0.00%
BE32	Prov. Hainaut	0.00%
BE33	Prov. Liège	0.00%
BE34	Prov. Luxembourg (BE)	0.00%
BE35	Prov. Namur	0.00%
BG31	Severozapaden	0.00%
BG32	Severentsentralen	76.00%
BG33	Severoiztochen	0.00%
BG34	Yugoiztochen	76.00%
BG41	Yugozapaden	45.70%
BG42	Yuzhentsentralen	0.00%
CZ01	Praha	0.00%
CZ02	Stredni Cechy	69.90%
CZ03	Jihozápad	0.00%
CZ04	Severozápad	87.30%
CZ05	Severovýchod	35.80%
CZ06	Jihovýchod	0.00%
CZ07	Strední Morava	0.00%
CZ08	Moravskoslezsko	77.50%
DK01	Hovedstaden	0.00%
DK02	Sjælland	0.00%
DK03	Syddanmark	0.00%
DK04	Midtjylland	0.00%
DK05	Nordjylland	0.00%
DE11	Stuttgart	0.00%
DE12	Karlsruhe	0.00%
DE13	Freiburg	0.00%
DE14	Tübingen	0.00%
DE21	Oberbayern	0.00%
DE22	Niederbayern	0.00%
DE23	Oberpfalz	0.00%
DE24	Oberfranken	0.00%
DE25	Mittelfranken	0.00%
DE26	Unterfranken	0.00%
DE27	Schwaben	0.00%
DE30	Berlin	0.00%
DE40	Brandenburg	82.50%
DE50	Bremen	0.00%
DE60	Hamburg	0.00%
DE71	Darmstadt	0.00%
DE72	Gießen	0.00%
DE73	Kassel	0.00%
DE80	Mecklenburg-Vorpommern	0.00%
DE91	Braunschweig	0.00%
DE92	Hannover	0.00%
DE93	Lüneburg	0.00%
DE94	Weser-Ems	0.00%
DEA1	Düsseldorf	74.40%
DEA2	Köln	74.40%
DEA3	Münster	74.40%
DEA4	Detmold	0.00%
DEA5	Arnsberg	74.40%
DEB1	Koblenz	0.00%
DEB2	Trier	0.00%
DEB3	Rheinhessen-Pfalz	0.00%
DEC0	Saarland	0.00%
DED2	Dresden	0.00%
DED4	Chemnitz	75.60%
DED5	Leipzig	75.60%
DEE0	Sachsen-Anhalt	49.70%
DEF0	Schleswig-Holstein	0.00%
DEG0	Thüringen	0.00%
EE00	Eesti	0.00%
IE04	Northern and Western	8.00%
IE05	Southern	0.00%
IE06	Eastern and Midland	10.70%
EL30	Attiki	0.00%
EL41	Voreio Aigaio	0.00%
EL42	Notio Aigaio	0.00%
EL43	Kriti	0.00%
EL51	Anatoliki Makedonia, Th	0.00%
EL52	Kentriki Makedonia	0.00%
EL53	Dytiki Makedonia	49.10%
EL54	Ipeiros	0.00%
EL61	Thessalia	0.00%
EL62	Ionia Nisia	0.00%
EL63	Dytiki Ellada	0.00%
EL64	Sterea Ellada	0.00%
EL65	Peloponnisos	0.00%
ES11	Galicia	0.00%
ES12	Principado de Asturias	63.90%
ES13	Cantabria	0.00%
ES21	País Vasco	13.40%
ES22	Comunidad Foral de Nav	0.00%
ES23	La Rioja	0.00%
ES24	Aragón	12.90%
ES30	Comunidad de Madrid	7.20%
ES41	Castilla y León	7.80%
ES42	Castilla-la Mancha	3.00%
ES43	Extremadura	0.00%
ES51	Cataluña	0.10%
ES52	Comunidad Valenciana	0.00%
ES53	Illes Balears	0.00%
ES61	Andalucía	0.20%
ES62	Región de Murcia	0.00%
ES63	Ciudad Autónoma de Ce	0.00%
ES64	Ciudad Autónoma de Me	0.00%
ES70	Canarias (ES)	0.00%
FR10	Île de France	0.00%
FRB0	Centre - Val de Loire	0.00%
FRC1	Bourgogne	0.00%
FRC2	Franche-Comté	0.00%
FRD1	Basse-Normandie	0.00%
FRD2	Haute-Normandie	0.00%
FRE1	Nord-Pas-de-Calais	0.00%
FRE2	Picardie	0.00%
FRF1	Alsace	0.00%
FRF2	Champagne-Ardenne	0.00%
FRF3	Lorraine	0.00%
FRG0	Pays-de-la-Loire	0.00%
FRH0	Bretagne	0.00%
FRI1	Aquitaine	0.00%
FRI2	Limousin	0.00%
FRI3	Poitou-Charentes	0.00%
FRJ1	Languedoc-Roussillon	0.00%
FRJ2	Midi-Pyrénées	0.00%
FRK1	Auvergne	0.00%
FRK2	Rhône-Alpes	0.00%
FRL0	Provence-Alpes-Côte d'	0.00%
FRM0	Corse	0.00%
FRY1	Guadeloupe	0.00%
FRY2	Martinique	0.00%
FRY3	Guyane	0.00%
FRY4	La Réunion	0.00%
FRY5	Mayotte	0.00%
HR03	Jadranska Hrvatska	0.00%
HR04	Kontinentalna Hrvatska	0.00%
ITC1	Piemonte	0.00%
ITC2	Valle d'Aosta/Vallée d'A	0.00%
ITC3	Liguria	0.00%
ITC4	Lombardia	0.00%
ITF1	Abruzzo	0.00%
ITF2	Molise	0.00%
ITF3	Campania	0.00%
ITF4	Puglia	0.00%
ITF5	Basilicata	0.00%
ITF6	Calabria	0.00%
ITG1	Sicilia	0.00%
ITG2	Sardegna	0.00%
ITH1	Provincia Autonoma di B	0.00%
ITH2	Provincia Autonoma di T	0.00%
ITH3	Veneto	0.00%
ITH4	Friuli-Venezia Giulia	0.00%
ITH5	Emilia-Romagna	0.00%
ITI1	Toscana	0.00%
ITI2	Umbria	0.00%
ITI3	Marche	0.00%
ITI4	Lazio	0.00%
CY00	Kypros	0.00%
LV00	Latvija	0.00%
LT01	Sostinesregionas	0.00%
LT02	Vidurio ir vakaru Lietuvo	0.00%
LU00	Luxembourg	0.00%

NUTS2	Name	B5/B
HU11	Budapest	2.70%
HU12	Pest	0.00%
HU21	Közép-Dunántúl	3.10%
HU22	Nyugat-Dunántúl	0.00%
HU23	Dél-Dunántúl	17.00%
HU31	Észak-Magyarország	4.00%
HU32	Észak-Alföld	0.00%
HU33	Dél-Alföld	0.00%
MT00	Malta	0.00%
NL11	Groningen	0.00%
NL12	Friesland (NL)	0.00%
NL13	Drenthe	0.00%
NL21	Overijssel	0.00%
NL22	Gelderland	0.00%
NL23	Flevoland	0.00%
NL31	Utrecht	0.00%
NL32	Noord-Holland	0.00%
NL33	Zuid-Holland	0.00%
NL34	Zeeland	0.00%
NL41	Noord-Brabant	0.00%
NL42	Limburg (NL)	0.00%
AT11	Burgenland (AT)	0.00%
AT12	Niederösterreich	0.00%
AT13	Wien	0.00%
AT21	Kärnten	0.00%
AT22	Steiermark	0.00%
AT31	Oberösterreich	0.00%
AT32	Salzburg	0.00%
AT33	Tirol	0.00%
AT34	Vorarlberg	0.00%
PL21	Malopolskie	59.00%
PL22	Slaskie	96.40%
PL41	Wielkopolskie	29.50%
PL42	Zachodniopomorskie	54.30%
PL43	Lubuskie	6.80%
PL51	Dolnoslaskie	1.10%
PL52	Opolskie	0.00%
PL61	Kujawsko-Pomorskie	0.00%
PL62	Warminsko-Mazurskie	0.00%
PL63	Pomorskie	0.00%
PL71	Lódzkie	85.10%
PL72	Swietokrzyskie	0.00%
PL81	Lubelskie	98.90%
PL82	Podkarpackie	0.00%
PL84	Podlaskie	0.00%

NUTS2	Name	B5/B
PL91	Warszawski stoleczny	8.40%
PL92	Mazowiecki regionalny	0.00%
PT11	Norte	0.00%
PT15	Algarve	0.00%
PT16	Centro (PT)	0.00%
PT17	Área Metropolitana de Li	0.00%
PT18	Alentejo	0.00%
PT20	Região Autónoma dos Aç	0.00%
PT30	Região Autónoma da Ma	0.00%
RO11	Nord-Vest	0.60%
RO12	Centru	0.00%
RO21	Nord-Est	0.00%
RO22	Sud-Est	0.00%
RO31	Sud - Muntenia	0.20%
RO32	Bucuresti - Ilfov	0.20%
RO41	Sud-Vest Oltenia	78.00%
RO42	Vest	40.10%
SI03	Vzhodna Slovenija	8.60%
SI04	Zahodna Slovenija	0.00%
SK01	Bratislavský kraj	0.00%
SK02	Západné Slovensko	34.00%
SK03	Stredné Slovensko	0.00%
SK04	Východné Slovensko	0.00%
FI19	Länsi-Suomi	0.00%
FI1B	Helsinki-Uusimaa	0.00%
FI1C	Etelä-Suomi	0.00%
FI1D	Pohjois- ja Itä-Suomi	0.00%
FI20	Åland	0.00%
SE11	Stockholm	0.00%
SE12	Östra Mellansverige	0.00%
SE21	Småland med öarna	0.00%
SE22	Sydsverige	0.00%
SE23	Västsverige	0.00%
SE31	Norra Mellansverige	0.00%
SE32	Mellersta Norrland	0.00%
SE33	Övre Norrland	0.00%
UKC1	Tees Valley and Durham	15.60%
UKC2	Northumberland and Tyr	0.00%
UKD1	Cumbria	0.00%
UKD3	Greater Manchester	0.00%
UKD4	Lancashire	0.00%
UKD6	Cheshire	0.00%
UKD7	Merseyside	0.00%
UKE1	East Yorkshire and North	0.00%
UKE2	North Yorkshire	0.00%
UKE3	South Yorkshire	0.00%
UKE4	West Yorkshire	0.00%
UKF1	Derbyshire and Nottingh	1.40%
UKF2	Leicestershire, Rutland a	0.00%
UKF3	Lincolnshire	0.00%
UKG1	Herefordshire, Worceste	6.90%
UKG2	Shropshire and Stafford	0.00%
UKG3	West Midlands	0.00%

NUTS2	Name	B5/B
UKH1	East Anglia	0.00%
UKH2	Bedfordshire and Hertfordshire	0.00%
UKH3	Essex	0.00%
UKI3	Inner London - West	0.00%
UKI4	Inner London - East	0.00%
UKI5	Outer London - East and North East	0.00%
UKI6	Outer London - South	0.00%
UKI7	Outer London - West and North West	0.00%
UKJ1	Berkshire, Buckinghamshire and Oxf	0.00%
UKJ2	Surrey, East and West Sussex	0.00%
UKJ3	Hampshire and Isle of Wight	0.00%
UKJ4	Kent	0.00%
UKK1	Gloucestershire, Wiltshire and Bristo	0.00%
UKK2	Dorset and Somerset	0.00%
UKK3	Cornwall and Isles of Scilly	0.00%
UKK4	Devon	0.00%
UKL1	West Wales and The Valleys	33.70%
UKL2	East Wales	0.00%
UKM5	North Eastern Scotland	0.00%
UKM6	Highlands and Islands	0.00%
UKM7	Eastern Scotland	29.40%
UKM8	West Central Scotland	0.00%
UKM9	Southern Scotland	29.20%
UKN0	Northern Ireland (UK)	0.00%
IS00	Ísland	0.00%
LI00	Liechtenstein	0.00%
NO01	Oslo og Akershus	0.00%
NO02	Hedmark og Oppland	0.00%
NO03	Sør-Østlandet	0.00%
NO04	Agder og Rogaland	0.00%
NO05	Vestlandet	0.00%
NO06	Trøndelag	0.00%
NO07	Nord-Norge	6.60%
CH01	Région lémanique	0.00%
CH02	Espace Mittelland	0.00%
CH03	Nordwestschweiz	0.00%
CH04	Zürich	0.00%
CH05	Ostschweiz	0.00%
CH06	Zentralschweiz	0.00%
CH07	Ticino	0.00%

The data on mining and more specifically the share of the B5 division in the B section have been estimated on the basis of data contained in EUROSTAT's Structural Business Statistics tables for economic entities in the NACE nomenclature. The calculation took into account the number of employees and the number of entities in both division B5 – Mining of coal and lignite and the corresponding proportion of division B9 - Mining support service activities.

Table A.4
EU27 contiguity matrix at the country level

	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE
BE	1				1					1						1			1								
BG		1						1															1				
CZ			1		1															1	1				1		
DK				1	1																						
DE	1		1	1	1					1						1			1	1	1						
EE						1								1													
IE							1																				
EL		1						1																			
ES									1	1												1					
FR	1				1				1	1		1				1											
HR											1						1							1			
IT										1		1								1				1			
CY													1														
LV						1								1	1												
LT														1	1						1						
LU	1				1					1						1											
HU											1						1			1			1	1	1		
MT																		1									
NL	1				1														1								
AT			1		1							1					1			1				1	1		
PL			1		1										1						1				1		
PT									1													1					
RO		1															1						1				
SI											1	1					1			1				1			
SK			1														1			1	1				1		
FI																										1	1
SE																										1	1

Source: Own elaboration

Table A.5
Stressors used.

variable	code	description
Value Added	str0003	Compensation of employees; wages, salaries, & employers' social contributions: Low-skilled
	str0004	Compensation of employees; wages, salaries, & employers' social contributions: Medium-skilled
	str0005	Compensation of employees; wages, salaries, & employers' social contributions: High-skilled
	str0006	Operating surplus: Consumption of fixed capital
	str0007	Operating surplus: Rents on land
	str0008	Operating surplus: Royalties on resources
	str0009	Operating surplus: Remaining net operating surplus
Employment	str0010	Employment: Low-skilled male
	str0011	Employment: Low-skilled female
	str0012	Employment: Medium-skilled male
	str0013	Employment: Medium-skilled female
	str0014	Employment: High-skilled male
	str0015	Employment: High-skilled female
CO2	str0024	CO2 - combustion - air
	str0093	CO2 - non-combustion - Cement production - air
	str0094	CO2 - non-combustion - Lime production - air
	str0428	CO2 - agriculture - peat decay - air
	str0438	CO2 - waste - biogenic - air
	str0439	CO2 - waste - fossil - air

Source: Own elaboration based on EXIOBASE.

Table A.6
Sectoral matching

A01	s001	Cultivation of paddy rice
A01	s002	Cultivation of wheat
A01	s003	Cultivation of cereal grains nec
A01	s004	Cultivation of vegetables, fruit, nuts
A01	s005	Cultivation of oil seeds
A01	s006	Cultivation of sugar cane, sugar beet
A01	s007	Cultivation of plant-based fibers
A01	s008	Cultivation of crops nec
A01	s009	Cattle farming
A01	s010	Pigs farming
A01	s011	Poultry farming
A01	s012	Meat animals nec
A01	s013	Animal products nec
A01	s014	Raw milk
A01	s015	Wool, silk-worm cocoons
A01	s016	Manure treatment (conventional), storage and land application
A01	s017	Manure treatment (biogas), storage and land application
A02	s018	Forestry, logging and related service activities (02)
A03	s019	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)
B	s020	Mining of coal and lignite; extraction of peat (10)
B	s021	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
B	s022	Extraction of natural gas and services related to natural gas extraction, excluding surveying
B	s023	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
B	s024	Mining of uranium and thorium ores (12)
B	s025	Mining of iron ores
B	s026	Mining of copper ores and concentrates
B	s027	Mining of nickel ores and concentrates
B	s028	Mining of aluminium ores and concentrates
B	s029	Mining of precious metal ores and concentrates
B	s030	Mining of lead, zinc and tin ores and concentrates
B	s031	Mining of other non-ferrous metal ores and concentrates
B	s032	Quarrying of stone
B	s033	Quarrying of sand and clay
B	s034	Mining of chemical and fertiliser minerals, production of salt, other mining and quarrying n.e.c.
C10-12	s035	Processing of meat cattle
C10-12	s036	Processing of meat pigs
C10-12	s037	Processing of meat poultry
C10-12	s038	Production of meat products nec
C10-12	s039	Processing vegetable oils and fats
C10-12	s040	Processing of dairy products
C10-12	s041	Processed rice
C10-12	s042	Sugar refining
C10-12	s043	Processing of Food products nec
C10-12	s044	Manufacture of beverages
C10-12	s045	Manufacture of fish products
C10-12	s046	Manufacture of tobacco products (16)
C13-15	s047	Manufacture of textiles (17)
C13-15	s048	Manufacture of wearing apparel; dressing and dyeing of fur (18)
C13-15	s049	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)
C16	s050	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)
C16	s051	Re-processing of secondary wood material into new wood material
C17	s052	Pulp
C17	s053	Re-processing of secondary paper into new pulp
C17	s054	Paper
C18	s055	Publishing, printing and reproduction of recorded media (22)
J58	s055	Publishing, printing and reproduction of recorded media (22)
J59_60	s055	Publishing, printing and reproduction of recorded media (22)
C19	s056	Manufacture of coke oven products
C19	s057	Petroleum Refinery
C24	s058	Processing of nuclear fuel
C20	s059	Plastics, basic
C20	s060	Re-processing of secondary plastic into new plastic
C20	s061	N-fertiliser
C20	s062	P- and other fertiliser
C20	s063	Chemicals nec
C21	s063	Chemicals nec
C22	s064	Manufacture of rubber and plastic products (25)
C23	s065	Manufacture of glass and glass products
E37-39	s066	Re-processing of secondary glass into new glass
C23	s067	Manufacture of ceramic goods
C23	s068	Manufacture of bricks, tiles and construction products, in baked clay
C23	s069	Manufacture of cement, lime and plaster
C33	s070	Re-processing of ash into clinker
C23	s071	Manufacture of other non-metallic mineral products n.e.c.
C24	s072	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
C24	s073	Re-processing of secondary steel into new steel

(*continued on next page*)

Table A.6 (*continued*)

C24	s074	Precious metals production
C24	s075	Re-processing of secondary precious metals into new precious metals
C24	s076	Aluminium production
C24	s077	Re-processing of secondary aluminium into new aluminium
C24	s078	Lead, zinc and tin production
C24	s079	Re-processing of secondary lead into new lead, zinc and tin
C24	s080	Copper production
C24	s081	Re-processing of secondary copper into new copper
C24	s082	Other non-ferrous metal production
C24	s083	Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
C24	s084	Casting of metals
C25	s085	Manufacture of fabricated metal products, except machinery and equipment (28)
C33	s085	Manufacture of fabricated metal products, except machinery and equipment (28)
C25	s086	Manufacture of machinery and equipment n.e.c. (29)
C27	s086	Manufacture of machinery and equipment n.e.c. (29)
C28	s086	Manufacture of machinery and equipment n.e.c. (29)
C33	s086	Manufacture of machinery and equipment n.e.c. (29)
S95	s086	Manufacture of machinery and equipment n.e.c. (29)
C26	s087	Manufacture of office machinery and computers (30)
C28	s087	Manufacture of office machinery and computers (30)
C33	s087	Manufacture of office machinery and computers (30)
C26	s088	Manufacture of electrical machinery and apparatus n.e.c. (31)
C27	s088	Manufacture of electrical machinery and apparatus n.e.c. (31)
C28	s088	Manufacture of electrical machinery and apparatus n.e.c. (31)
C29	s088	Manufacture of electrical machinery and apparatus n.e.c. (31)
C33	s088	Manufacture of electrical machinery and apparatus n.e.c. (31)
C26	s089	Manufacture of radio, television and communication equipment and apparatus (32)
C27	s089	Manufacture of radio, television and communication equipment and apparatus (32)
C28	s089	Manufacture of radio, television and communication equipment and apparatus (32)
C33	s089	Manufacture of radio, television and communication equipment and apparatus (32)
S95	s089	Manufacture of radio, television and communication equipment and apparatus (32)
C26	s090	Manufacture of medical, precision and optical instruments, watches and clocks (33)
C28	s090	Manufacture of medical, precision and optical instruments, watches and clocks (33)
C31_32	s090	Manufacture of medical, precision and optical instruments, watches and clocks (33)
C33	s090	Manufacture of medical, precision and optical instruments, watches and clocks (33)
C29	s091	Manufacture of motor vehicles, trailers and semi-trailers (34)
C30	s091	Manufacture of motor vehicles, trailers and semi-trailers (34)
C28	s092	Manufacture of other transport equipment (35)
C30	s092	Manufacture of other transport equipment (35)
C33	s092	Manufacture of other transport equipment (35)
C26	s093	Manufacture of furniture; manufacturing n.e.c. (36)
C31_32	s093	Manufacture of furniture; manufacturing n.e.c. (36)
C33	s093	Manufacture of furniture; manufacturing n.e.c. (36)
S95	s093	Manufacture of furniture; manufacturing n.e.c. (36)
E37-39	s094	Recycling of waste and scrap
E37-39	s095	Recycling of bottles by direct reuse
D	s096	Production of electricity by coal
D	s097	Production of electricity by gas
D	s098	Production of electricity by nuclear
D	s099	Production of electricity by hydro
D	s100	Production of electricity by wind
D	s101	Production of electricity by petroleum and other oil derivatives
D	s102	Production of electricity by biomass and waste
D	s103	Production of electricity by solar photovoltaic
D	s104	Production of electricity by solar thermal
D	s105	Production of electricity by tide, wave, ocean
D	s106	Production of electricity by Geothermal
D	s107	Production of electricity nec
D	s108	Transmission of electricity
D	s109	Distribution and trade of electricity
D	s110	Manufacture of gas; distribution of gaseous fuels through mains
D	s111	Steam and hot water supply
E36	s112	Collection, purification and distribution of water (41)
F	s113	Construction (45)
F	s114	Re-processing of secondary construction material into aggregates
G45	s115	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
G45	s116	Retail sale of automotive fuel
G46	s117	Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)
G47	s118	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)
S95	s118	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)
I	s119	Hotels and restaurants (55)
H49	s120	Transport via railways
H49	s121	Other land transport
H49	s122	Transport via pipelines
H50	s123	Sea and coastal water transport
H50	s124	Inland water transport
H51	s125	Air transport (62)

(*continued on next page*)

Table A.6 (*continued*)

H52	s126	Supporting and auxiliary transport activities; activities of travel agencies (63)
N79	s126	Supporting and auxiliary transport activities; activities of travel agencies (63)
H53	s127	Post and telecommunications (64)
J61	s127	Post and telecommunications (64)
K64	s128	Financial intermediation, except insurance and pension funding (65)
K65	s129	Insurance and pension funding, except compulsory social security (66)
K66	s130	Activities auxiliary to financial intermediation (67)
L68	s131	Real estate activities (70)
N77	s132	Renting of machinery and equipment without operator and of personal and household goods (71)
J58	s133	Computer and related activities (72)
J62_63	s133	Computer and related activities (72)
S95	s133	Computer and related activities (72)
M72	s134	Research and development (73)
J62_63	s135	Other business activities (74)
K64	s135	Other business activities (74)
M69_70	s135	Other business activities (74)
M71	s135	Other business activities (74)
M73	s135	Other business activities (74)
M74_75	s135	Other business activities (74)
N77	s135	Other business activities (74)
N78	s135	Other business activities (74)
N80-82	s135	Other business activities (74)
P85	s135	Other business activities (74)
O84	s136	Public administration and defence; compulsory social security (75)
P85	s137	Education (80)
M74_75	s138	Health and social work (85)
Q86	s138	Health and social work (85)
Q87_88	s138	Health and social work (85)
E37-39	s139	Incineration of waste: Food
E37-39	s140	Incineration of waste: Paper
E37-39	s141	Incineration of waste: Plastic
E37-39	s142	Incineration of waste: Metals and Inert materials
E37-39	s143	Incineration of waste: Textiles
E37-39	s144	Incineration of waste: Wood
E37-39	s145	Incineration of waste: Oil/Hazardous waste
E37-39	s146	Bio gasification of food waste, incl. land application
E37-39	s147	Bio gasification of paper, incl. land application
E37-39	s148	Bio gasification of sewage sludge, incl. land application
E37-39	s149	Composting of food waste, incl. land application
E37-39	s150	Composting of paper and wood, incl. land application
E37-39	s151	Wastewater treatment, food
E37-39	s152	Wastewater treatment, other
E37-39	s153	Landfill of waste: Food
E37-39	s154	Landfill of waste: Paper
E37-39	s155	Landfill of waste: Plastic
E37-39	s156	Landfill of waste: Inert/metal/hazardous
E37-39	s157	Landfill of waste: Textiles
E37-39	s158	Landfill of waste: Wood
S94	s159	Activities of membership organisation n.e.c. (91)
J59_60	s160	Recreational, cultural, and sporting activities (92)
J62_63	s160	Recreational, cultural, and sporting activities (92)
N79	s160	Recreational, cultural, and sporting activities (92)
R90-92	s160	Recreational, cultural, and sporting activities (92)
R93	s160	Recreational, cultural, and sporting activities (92)
R93	s161	Other service activities (93)
S96	s161	Other service activities (93)
T	s162	Private households with employed persons (95)
U	s163	Extra-territorial organisations and bodies

Source: Own elaboration.

Table A.7
CO2 emissions and employment at the country level

Country	CO2 (thousand tons)	Jobs (thousand people)
AU	414,598	12,252
AT	69,599	4260
BE	99,448	4638
CA	569,360	18,416
CZ	107,613	5222
DK	36,235	2789
EE	18,788	659
FI	44,652	2473
FR	353,367	26,803
DE	785,883	41,664
EL	74,855	3753

(*continued on next page*)

Table A.7 (*continued*)

Country	CO2 (thousand tons)	Jobs (thousand people)
HU	49,452	4421
IS	3605	194
IE	39,133	2194
IT	352,850	23,023
JP	1,188,123	64,815
KR	650,156	26,868
LV	7215	895
LT	13,572	1355
LU	9261	272
MX	487,667*	229
NL	162,610	8605
NO	43,631	2644
PL	337,683	16,423
PT	55,231	4757
SK	36,031	2531
SI	14,592	959
ES	274,642	18,825
SE	42,594	5022
CH	38,183	4637
TR	425,329	28,197
UK	388,283	31,965
US	5,207,751	153,337
AR	121,932*	11,568
BR	474,097*	89,808
BG	47,582	3150
CN	6,233,500*	776,400
HR	18,718	1625
CY	7523	380
IN	982,728*	360,574
ID	381,061*	122,781
LI	155	19
MT	1559	221
RO	77,203	8671
RU	1,646,457	2795
ZA	273,170*	16,364

Source: EUROSTAT, OECD and ILO. *Data from a different year.

Table A.8
CO2 coefficient (adjustment factor for European Green Deal scenarios)

BE	Belgium	0.9965
BG	Bulgaria	0.4211
CZ	Czechia	0.3645
DK	Denmark	0.1317
DE	Germany	1.0000
EE	Estonia	1.0000
IE	Ireland	0.9060
EL	Greece	0.8937
ES	Spain	0.7009
FR	France	0.8144
HR	Croatia	0.3853
IT	Italy	0.7583
CY	Cyprus	1.0000
LV	Latvia	0.9998
LT	Lithuania	1.0000
LU	Luxembourg	1.0000
HU	Hungary	0.6254
MT	Malta	1.0000
NL	Netherlands	0.7392
AT	Austria	0.8108
PL	Poland	0.9323
PT	Portugal	0.6016
RO	Romania	0.5055
SI	Slovenia	0.0840
SK	Slovakia	0.3835
FI	Finland	0.4157
SE	Sweden	0.8526

Source: Own work.

8.1. Appendices (supplementary material to be published online)

Results: further details.

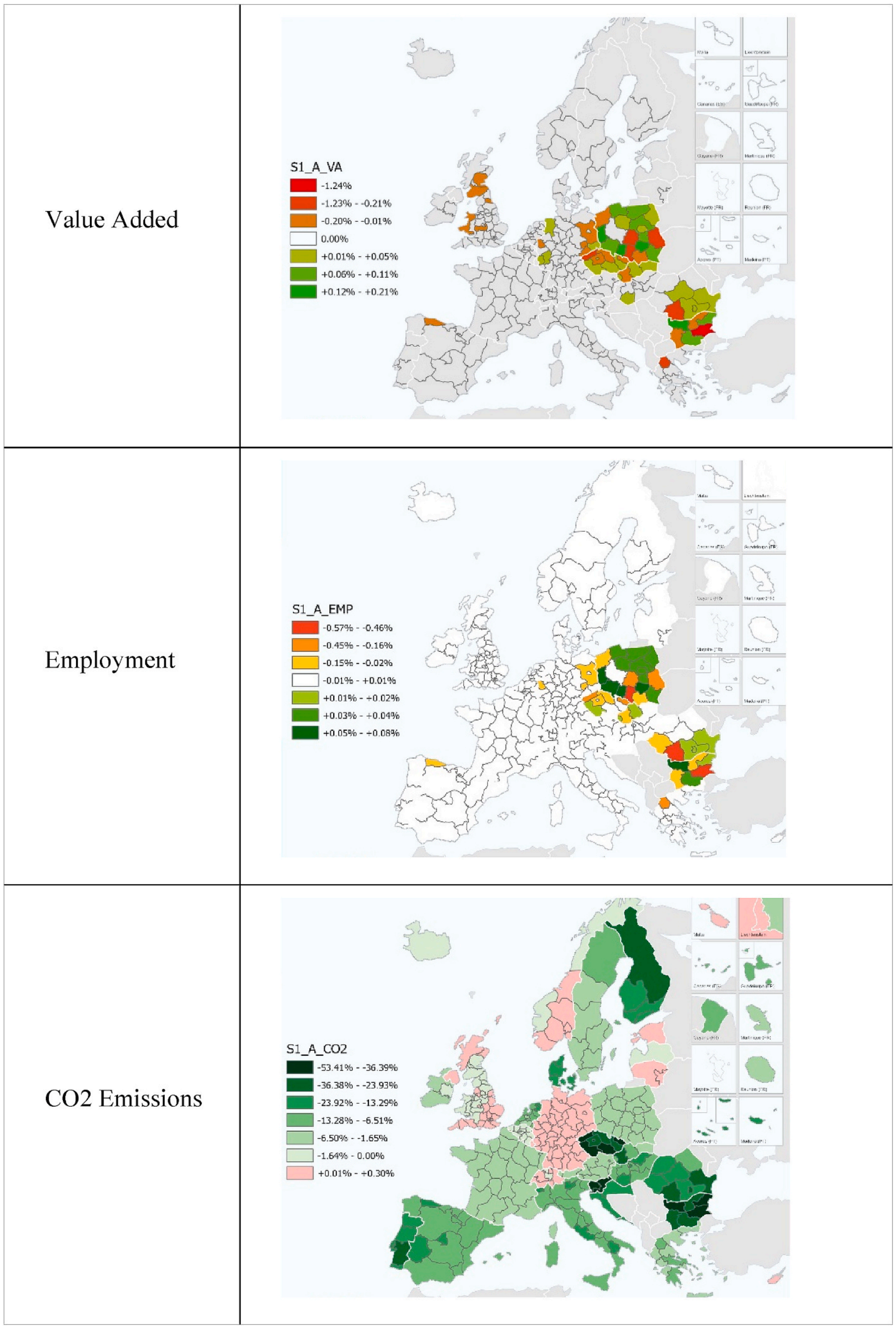
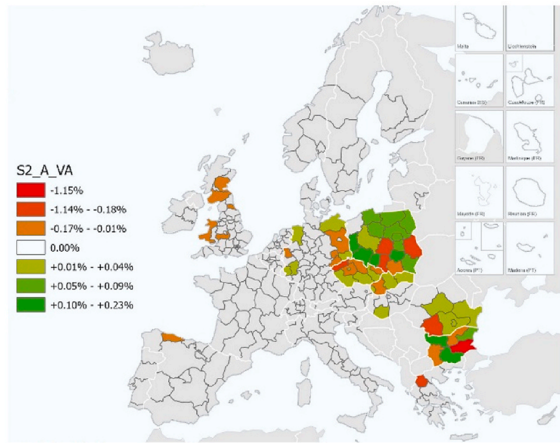
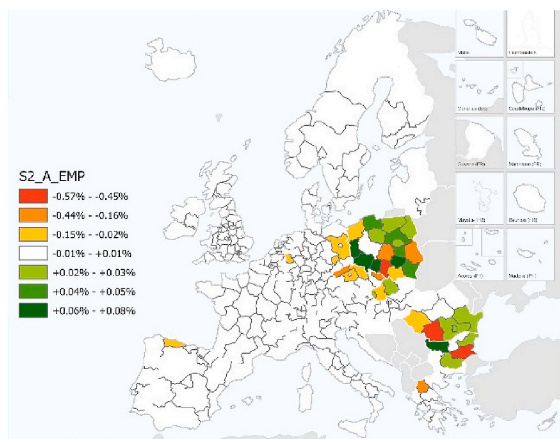


Fig. A.6. Scenario A.1. Total effects: VA, employment, and CO2 emissions.

Value Added



Employment



CO2 Emissions

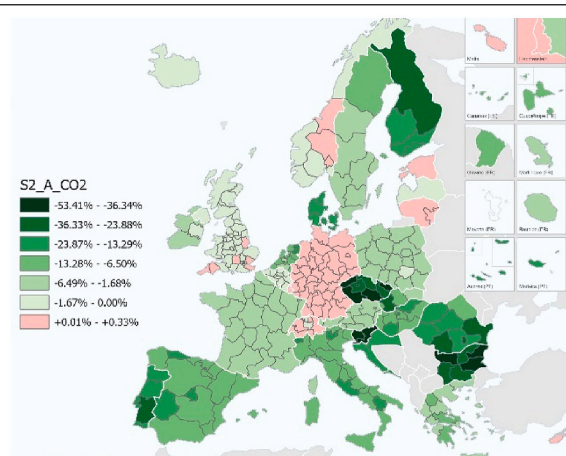


Fig. A.7. Scenario A.2. Total effects: VA, employment, and CO2 emissions.

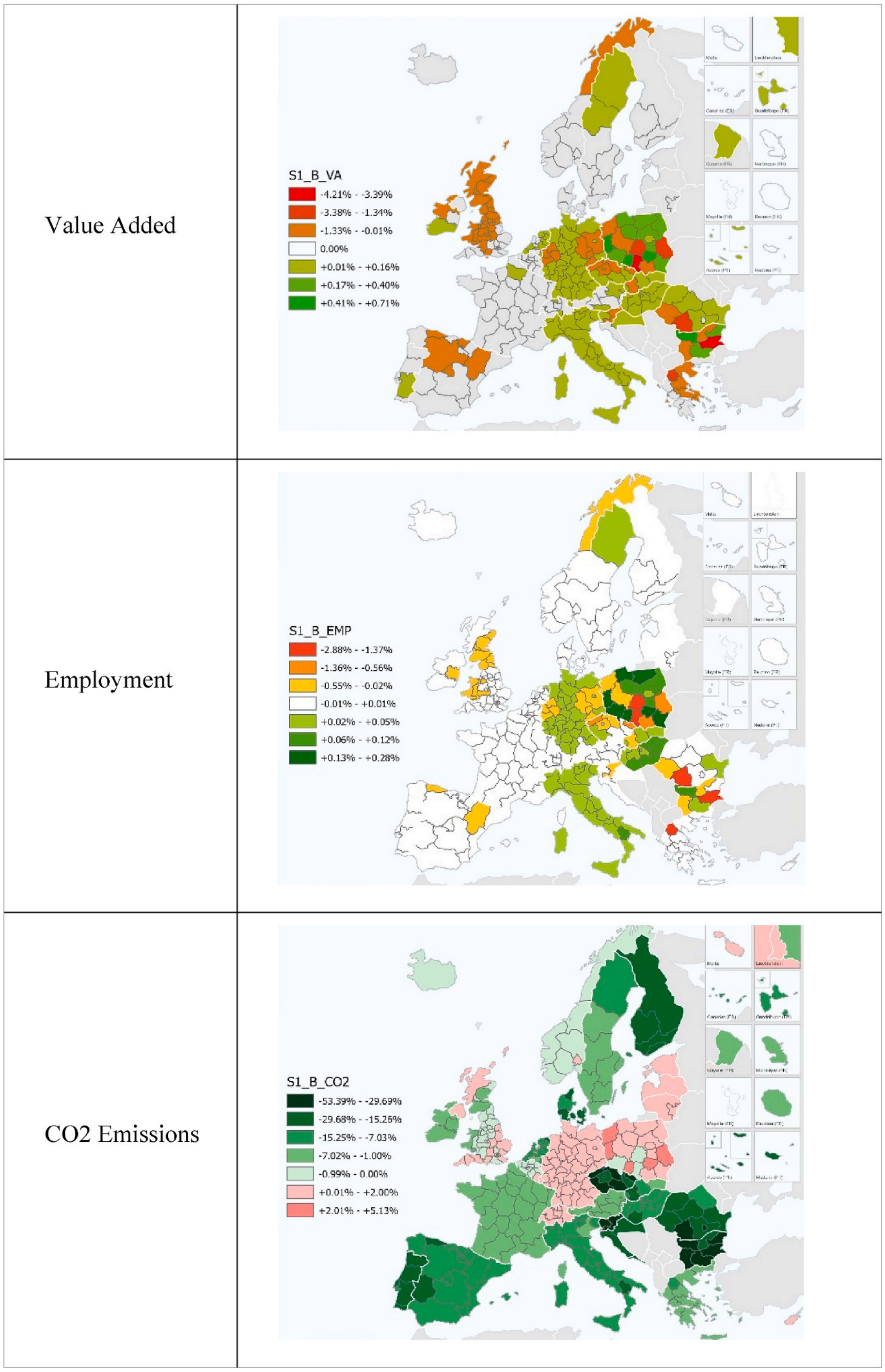


Fig. A.8. Scenario B.1. Total effects: VA, employment, and CO2 emissions.

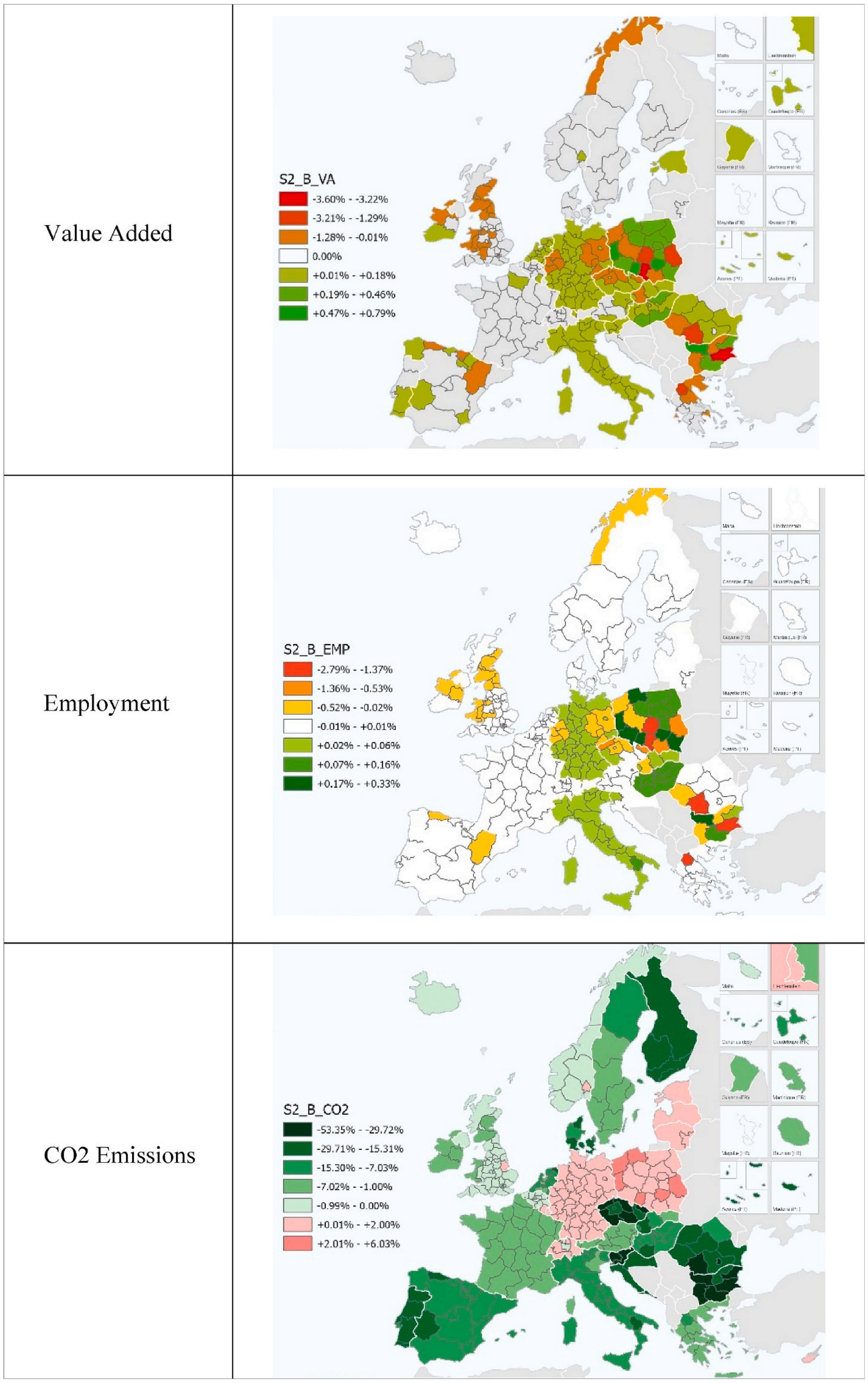


Fig. A.9. Scenario B.2. Total effects: VA, employment, and CO2 emissions.

References

Almazán-Gómez, M.Á., Llano, C., Pérez, J., Mandras, G., 2023. The European regions in the global value chains: new results with new data. Pap. Reg. Sci. 102, 1097–1126. https://doi.org/10.1111/pirs.12760.

Almazán-Gómez, M.Á., Llano, C., Pérez, J., Rauhut, D., 2024. Socioeconomic impacts of Russian invasion of Ukraine: a multiregional assessment for Europe. J. Reg. Sci. 64, 333–354. https://doi.org/10.1111/jors.12676.

Alves Dias, P., Conte, A., Kanellopoulos, K., Kapetaki, Z., Mandras, G., Medarac, H., Nijs, W., Ruiz-Castello, P., Somers, J., Tarvydas, D., 2021. Recent Trends in EU Coal, Peat and Oil Shale Regions. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/510714.

Alves Dias, P., Kanellopoulos, K., Medarac, H., Kapetaki, Z., Miranda-Barbosa, E., Shortall, R., Czako, V., Telsnig, T., Vazquez Hernandez, C., Lacal Arántegui, R., Nijs, W., Gonzalez Aparicio, I., Trombetti, M., Mandras, G., Peteves, E., Tzimas, E., 2018. EU Coal Regions: Opportunities and Challenges Ahead, JRC Science for Policy

Report - JRC112593. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/668092.
Bódis, K., Kougias, I., Taylor, N., Jäger-Waldau, A., 2019. Solar photovoltaic electricity generation: a lifeline for the European coal regions in transition. Sustainability 11, 3703. https://doi.org/10.3390/su11133703.
Böhringer, C., Rosendahl, K.E., 2022. Europe beyond coal – an economic and climate impact assessment. J. Environ. Econ. Manag. 113, 102658. https://doi.org/10.1016/j.jeem.2022.102658.
Chen, G.Q., Wu, X.D., Guo, J., Meng, J., Li, C., 2019. Global overview for energy use of the world economy: household-consumption-based accounting based on the world input-output database (WIOD). Energy Econ. 81, 835–847. https://doi.org/10.1016/j.eneco.2019.05.019.
Chepeliev, M., Hertel, T.W., van der Mensbrugghe, D., 2022. Cutting Russia's fossil fuel exports: short-term pain for long-term gain. SSRN Electron. J. https://doi.org/10.2139/ssrn.4081300.
Dietzenbacher, E., van Burken, B., Kondo, Y., 2019. Hypothetical extractions from a global perspective. Econ. Syst. Res. 31, 505–519. https://doi.org/10.1080/09535314.2018.1564135.
Duarte, R., Sánchez-Chóliz, J., Sarasa, C., 2018. Consumer-side actions in a low-carbon economy: a dynamic CGE analysis for Spain. Energy Pol. 118, 199–210. https://doi.org/10.1016/j.enpol.2018.03.065.
Duarte, R., Serrano, A., 2021. Environmental analysis of structural and technological change in a context of trade expansion: lessons from the EU enlargement. Energy Pol. 150, 112142. https://doi.org/10.1016/j.enpol.2021.112142.
ESPON, 2022. Dataset for Interregional Relations in Europe. Applied research project [WWW Document]. https://www.espon.eu/interregional-relations-europe-new-project-espon, 3.3.22.
Estrada, M.A.R., Koutronas, E., 2022. The impact of the Russian aggression against Ukraine on the Russia-EU trade. J. Pol. Model. 44, 599–616. https://doi.org/10.1016/j.jpolmod.2022.06.004.
European Commission, 2020a. The Just Transition Mechanism: Making Sure No One Is Left behind.
European Commission, 2020b. Circular Economy Action Plan, vol. 28. European Commission. https://doi.org/10.2775/855540.
European Commission, 2020c. A new Industrial Strategy for a globally competitive. Green and Digital Europe, A European Industrial Strategy. Luxembourg.
European Commission, 2019. The European green deal. Communication from the European Commission. COM(2019) 640 Final, Communication from the Commission to the European Parliament, the Eruopean Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM, 2019) 640 final.
Figueiredo, R., Nunes, P., Meireles, M., Madaleno, M., Brito, M.C., 2019. Replacing coal-fired power plants by photovoltaics in the Portuguese electricity system. J. Clean. Prod. 222, 129–142. https://doi.org/10.1016/j.jclepro.2019.02.217.
Foster, V., Bedrosyan, Daron, 2014. Understanding CO2 Emissions from the Global Energy Sector, Live Wire Knowledge Note Series ; No. 2014/5. Washington DC.
Gerbaulet, C., von Hirschhausen, C., Kemfert, C., Lorenz, C., Oei, P.-Y., 2019. European electricity sector decarbonization under different levels of foresight. Renew. Energy 141, 973–987. https://doi.org/10.1016/j.renene.2019.02.099.
Giannakis, E., Zittis, G., 2021. Assessing the economic structure, climate change and decarbonisation in Europe. Earth Systems and Environment 5, 621–633. https://doi.org/10.1007/s41748-021-00232-7.
Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R., 2019. The role of renewable energy in the global energy transformation. Energy Strategy Rev. 24, 38–50. https://doi.org/10.1016/j.esr.2019.01.006.
Hansen, K., Mathiesen, B.V., Skov, I.R., 2019. Full energy system transition towards 100% renewable energy in Germany in 2050. Renew. Sustain. Energy Rev. 102, 1–13. https://doi.org/10.1016/j.rser.2018.11.038.
Löffler, K., Burandt, T., Hainsch, K., Oei, P.-Y., 2019. Modeling the low-carbon transition of the European energy system - a quantitative assessment of the stranded assets problem. Energy Strategy Rev. 26, 100422. https://doi.org/10.1016/j.esr.2019.100422.
Mandras, G., Conte, A., Salotti, S., 2019a. Coal regions in transition: the RHOMOLO-IO indirect jobs estimates. Territorial Development Insights Series, JRC118641.
Mandras, G., Conte, A., Salotti, S., 2019b. The RHOMOLO-IO modelling framework: a flexible Input-Output tool for policy analysis (No. 06/2019-JRC117725). JRC Working Papers on Territorial Modelling and Analysis. Seville.
Mandras, G., Salotti, S., 2021. Indirect Jobs in Activities Related to Coal, Peat and Oil Shale: a RHOMOLO-IO Analysis on the EU Regions. Joint Research Centre (Seville site).
Oei, P.-Y., 2019. Greenhouse gas emission reductions and the phasing-out of coal in Germany. In: von Hirschhausen, C., Gerbaulet, C., Kemfert, C., Lorenz, C., Oei, P.-Y. (Eds.), Energiewende "Made in Germany": Low Carbon Electricity Sector Reform in the European Context. Springer, Cham, pp. 45–48. https://doi.org/10.1007/978-3-319-95126-3.
Oei, P.-Y., Brauers, H., Herpich, P., 2020a. Lessons from Germany's hard coal mining phase-out: policies and transition from 1950 to 2018. Clim. Pol. 20, 963–979. https://doi.org/10.1080/14693062.2019.1688636.
Oei, P.-Y., Hermann, H., Herpich, P., Holtemöller, O., Lünenbürger, B., Schult, C., 2020b. Coal phase-out in Germany – implications and policies for affected regions. Energy 196, 117004. https://doi.org/10.1016/j.energy.2020.117004.
Oei, P.-Y., Mendelevitch, R., 2019. Prospects for steam coal exporters in the era of climate policies: a case study of Colombia. Clim. Pol. 19, 73–91. https://doi.org/10.1080/14693062.2018.1449094.
Remond-Tiendrez, I., Rueda-Cantuche, J.M., 2019. EU inter-country supply, use and input-output tables — full international and global accounts for research in input-output analysis (FIGARO). Statistical Working Papers (EUROSTAT). Luxembourg.
Rose, A., 1995. Input-output economics and computable general equilibrium models. Struct. Change Econ. Dynam. 6. https://doi.org/10.1016/0954-349X(95)00018-I.
Roy, B., Schaffartzik, A., 2021. Talk renewables, walk coal: the paradox of India's energy transition. Ecol. Econ. 180, 106871. https://doi.org/10.1016/j.ecolecon.2020.106871.
Solomon, B.D., Krishna, K., 2011. The coming sustainable energy transition: history, strategies, and outlook. Energy Pol. 39, 7422–7431. https://doi.org/10.1016/j.enpol.2011.09.009.
Spencer, T., Colombier, M., Sartor, O., Garg, A., Tiwari, V., Burton, J., Caetano, T., Green, F., Teng, F., Wiseman, J., 2018. The 1.5°C target and coal sector transition: at the limits of societal feasibility. Clim. Pol. 18, 335–351. https://doi.org/10.1080/14693062.2017.1386540.
Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J.H., Theurl, M.C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.-H., de Koning, A., Tukker, A., 2018. Exiobase 3: developing a time series of detailed environmentally extended multi-regional input-output tables. J. Ind. Ecol. 22, 502–515. https://doi.org/10.1111/jiec.12715.
Thissen, M., Ivanova, O., Mandras, G., Husby, T., 2019. European NUTS 2 Regions: Construction of Interregional Trade-Linked Supply and Use Tables with Consistent Transport Flows (No. JRC115439). Seville.
Timilsina, G.R., 2022. Carbon taxes. J. Econ. Lit. 60, 1456–1502. https://doi.org/10.1257/jel.20211560.
Volker Quaschning, 2022. Statistics: specific carbon dioxide emissions of various Fuels [WWW Document]. Erneuerbare-Energien-und-Kilimaschutz.de. URL. https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php.
Wang, Z., Su, B., Xie, R., Long, H., 2020. China's aggregate embodied CO2 emission intensity from 2007 to 2012: a multi-region multiplicative structural decomposition analysis. Energy Econ. 85, 104568. https://doi.org/10.1016/j.eneco.2019.104568.
Widuto, A., 2019. EU Support for Coal Regions.
World Nuclear Association, 2022. Carbon dioxide emissions from electricity [WWW Document]. Energy and the Environment. URL. https://www.world-nuclear.org/information-library/energy-and-the-environment/carbon-dioxide-emissions-from-electricity.aspx.
Yan, J., Li, Y., Su, B., Ng, T.S., 2022. Contributors and drivers of Chinese energy use and intensity from regional and demand perspectives, 2012-2015-2017. Energy Econ. 115, 106357. https://doi.org/10.1016/j.eneco.2022.106357.
Zhao, S., Alexandroff, A., 2019. Current and future struggles to eliminate coal. Energy Pol. 129, 511–520. https://doi.org/10.1016/j.enpol.2019.02.031.