Renewable and Sustainable Energy Transition 6 (2025) 100088

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Transition

journal homepage: www.journals.elsevier.com/renewable-and-sustainable-energy-transition

Full-length article

Industrial European regions at risk within the Fit for 55: How far implementing CBAM can mitigate?

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ARTICLE INFO

Keywords:
European Union
Carbon border adjustment
Computable general equilibrium model
Jobs
Energy intensive industries
Employment impacts
Regional vulnerability

ABSTRACT

The transition to a low-carbon economy can create new job opportunities but may cause job displacement in some sectors that heavily rely on fossil fuels. In order to gain a balanced appraisal in understanding the broader consequences of climate policies, this paper analyses the impact of the EU Fit for 55 with carbon border adjustment on EU employment at the regional level. Research findings prove that certain regions are disproportionately affected by job losses, indicating that the acceptability of these targeted policies should address these potential inequalities. The most exposed are regions with vast energy mining industries, however implementing CBAM reduces the exposure of regions with energy-intensive industries. Some regions in Greece, Spain and Italy are still very vulnerable post-CBAM implementation, suggesting high sensitivity of job losses and low capability of these regions to deal with energy transition. Accordingly, ensuring effective support for these vulnerable regions is critical to enhancing public acceptance and further cooperation for the EU climate commitment and a more well-managed transition to a low-carbon economy.

1. Introduction

The EU's climate neutrality target requires substantial changes in the energy system and toward the transition to deep decarbonisation. The introduction of the Carbon Border Adjustment Mechanism (CBAM) aims to support this transition by putting a fair price on the carbon emitted energy-intensive goods imported to the EU. As a part of the Fit for 55 package, CBAM is a central anti-leakage policy, expected to improve European industries' competitiveness and to support the revision of the EU's Emissions Trading System (ETS) market in phasing out free emissions allowances [1]. Switching from free allowance to a full auction emission trading scheme is very crucial in transitioning to a climate neutral industry [2].

The conventional narrative of CBAM focuses mainly around this competitiveness issue [3], in addition to the welfare and leakage analysis. Since the introduction of the EU CBAM, which aims to alleviate concerns of unfair competitive disadvantage, vis-à-vis foreign firms [4], the rising dissent among contending industries within the EU is about the passing out of free allowances [5]. Switching to a full auction certainly results in higher production costs, especially for the Energy Intensive Industries (EII) that currently receive free emissions allowances under the ETS [6]. Further, such analysis on the competitiveness of EU industries is relevant for the political acceptability of the EU new climate target Fit for 55 and its complementary policy, CBAM.

On the other hand, competitiveness is not the only indicator to evaluate the political acceptability of a new climate policy. The effects on workers are equally substantial [7], and the design of a complementary policy [8,9], i.e. CBAM, appears to be the key to improve political acceptability of the EU Fit for 55 [10]. This impact on employment, however, remains underrepresented in recent quantitative analyses. This is the issue that this paper aims to address through quantitatively analysing the impact of phasing out the free allowances under the EU Fit for 55 and replacing it with CBAM, focusing on the impacts on employment at regional levels of the EU.

There are at least three considerations that substantiate the importance to analyse the impact of the EU Fit for 55 and CBAM on regional employment. First, despite the competitiveness issue being central in the analytical study of CBAM, its contribution toward analysing the impact on employment has been minimal. Among 97 recent studies dealing with CBAM, only three include the keyword "employment" [11]. These studies primarily specify fossil fuel energy [12] and renewable energy resources [13]. While CBAM will affect most EII [14], expanding the analysis to this sector is critical in order to comprehensively understand this new policy instrument's effectiveness.

Second, there is a broad consensus that policies in general impacts differently between sectors [15], groups [16], and geographical regions [17]. Admittedly, the political resistance to climate policy tends

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https://doi.org/10.1016/j.rset.2024.100088
Received 22 November 2023; Received in revised form 31 May 2024; Accepted 4 June 2024
Available online 15 June 2024

Nomenclature

Abbreviation

CBAM	Carbon Border Adjustment Mechanism
CGE	Computable General Equilibrium
EII	Energy Intensive Industries
ETS	Emissions Trading System
ESR	Effort Sharing Regulation
ESIF	European Structural and Investment Fund
ESPON	European Spatial Planning Observation Network
EU	The European Union
FTE	Full Time Employment
MS	Member States
NUTS	Nomenclature of Territorial Unit of Statistic
RES	Renewable Energy Resources
UK	The United Kingdom

to be more pronounced in countries that heavily depend on fossil fuel exports and have a carbon-intensive energy systems [18], or countries with ETS sectors that constitute a larger part of their economy [19]. As increasing regional inequality can intensify opposition against European policies and EU construction, the focus of CBAM analysis should be redirected from the EU aggregated [20,21] or the Member States (MS) level [22], to the regional scope to capture differences in labour markets [23], dependency on high-carbon industries [24] and social group elements [25].

Third, understanding how each MS will be affected differently at their regional level is critical to improving political acceptability of CBAM [26]. The most negatively impacted sectors are fossil energy and energy intensive, while the potential effect of a lack of employment opportunities and industrial decline because of deep decarbonisation targets, could have been fundamental drivers of the anti-EU vote [24]. The influence of certain types of local economic decline may be greater than individual social economic conditions [27].

Consequentially, analysing how Fit for 55 affects labour employment in the EU and how effectively CBAM minimises the adverse impacts is vital and relevant to support the EU policy sequencing strategy [28]. The analysis in this paper will focus on this aspect, simulating EU Fit for 55 with several CBAM scenarios. For capturing the impacts at the regional level, the current methodology of the general equilibrium analysis with the GEMINI-E3 model is expanded to the EU regional level to evaluate the employment loss impact of Fit for 55 policy and how far CBAM could minimise it. Simulations will be further directed through regional exposure and employment vulnerability analysis. Following the parliament's recent approval of the EU's Fit for 55 package,[1] a comprehensive analysis and the results provided in this paper can contribute to a balanced appraisal, feedback and measures to equip subsequent EU policy initiatives.

For the purpose of comprehensively narrating and evaluating this issue, the paper is organised as follows: the subsequent Section 2 reviews literature on CBAM, tracing and discussing how far employment impact has been identified and analysed in current studies. Section 3 elaborates the methodological approach of integrating the general equilibrium model used with regional data, confirms the scenario development for simulations, and defines assessment indicators for the evaluation of the EU decarbonisation policy Fit for 55 and CBAM's impact on the regional employment. The numerical results will be examined in Section 4, followed by synthesising the analysis in Section 5.

2. Decarbonisation, CBAM and employment: literature review

2.1. CBAM supports decarbonisation, employment impacts and regional perspectives

Recent literature on CBAM generally focuses on conceptualisation [29], feasibility studies for concrete implementation [21,30] and policy design [31,32] of this policy instrument. These include quantitative studies to measure the direct or indirect impacts of CBAM through various scenario development [14,22], narrative analysis on legal aspects and potential design [33–35], and the environmental and economic impact of CBAM measures [36]. The quantitative studies, in particular, mostly cover the direct impact of CBAM on leakage and improving EU competitiveness post-CBAM implementation.

While studies on CBAM are ubiquitous, particular analyses on the employment are few. The most common analytical directives are the expansion of renewable energy sources (RES) and phasing out fossil power plants with varying degrees of impacts on employment. Studies estimating the impact of RES expansion, such as Dell'Anna [13],Fragkos and Paroussos [37] and Sasse and Trutnevyte [38], conclude positive employment impacts and new job creations from low-carbon technologies. Expansion to renewables, especially wind and solar, captures technological learning with positive trade effects [39], followed by investment [40] that generates substantial new employment. General conclusion of current literature suggests that decarbonising power generation is likely to have a net positive effect on employment overall. Several studies estimate that under ambitious climate scenarios, the growth in renewable energy, energy efficiency, and other low-carbon sectors would create enough new jobs to offset losses in fossil fuel industries [41,42].

The employment impacts, however, may vary across regions and skill levels, with the lowest-skilled workers potentially facing more varied gains and losses [41,43]. Decarbonisation through regulated phasing out of fossil fuel power plant could have negatively impacted employment [12]. The effects are reflected in the CO_2 price, which reduces power generation capacity and affects demand for labour, including for downstream industries resulting in a net loss of labour force [44].

Conceivably, the impacts of EU decarbonisation will not be the same for all regions. A recent study by McDowall et al. [25] proves that some regions gain the benefit of low-carbon industrial activities while others may experience economic loss. The study finds that vulnerability for low carbon transition is regionally concentrated; all depending on high carbon activities, employment structures, and other social aspects. Regionally concentrated impacts of decarbonisation imply that employment analysis should be narrowed down to a regional scale from the MS level. McDowall's study used a Eurostat source to provide industry-by-industry data on employment at the NUTS (Nomenclature of Territorial Unit of Statistic) 2 level of spatial disaggregation of direct jobs of the energy sectors.

As the EU transition to a net-zero economy requires significant changes in economic structures, production patterns, and employment, which can have uneven impacts across regions and populations, the proactive policy interventions are crucial to manage these labour market implications and ensure an equitable distribution of the benefits of decarbonisation. The EU has established the Just Transition Fund to provide financial support to regions and sectors most impacted by the transition, helping them to mitigate social and economic costs [45]. The fund aims to enable a fair and inclusive transition by supporting economic diversification, job creation, and upskilling of workers [46]. Careful policy design and implementation, with input from affected stakeholders, is essential to deliver a just and equitable transition.

[1] As the backbone of the flagship climate policy package, the legislation approval puts the EU's commitment to achieving a more substantial climate target one step closer to the council's ratification before it can come into force.

2.2. Importance of energy intensive industries in CBAM analysis

Employment change due to decarbonisation underlines the significance of energy sectors [41]. However, to assess the effectiveness of CBAM in achieving EU decarbonisation targets, the employment analysis should be extended to include the EII. This is significant as CBAM initial targets apply to imports of certain goods and selected precursors with carbon intensive production and are at most risk of carbon leakage. The EII possesses a higher employment rate than the energy sectors, and covers electricity (generation, transmission and distribution) and energy-intensive goods, namely cement, iron and steel, aluminium, and fertilisers. This implies that evaluating the employment impact due to the EU decarbonisation efforts, focusing only on energy industries will lead to underestimated results.

The energy sector employed around 7.6 million people in the EU-27 with the production and distribution of electricity accounting for the largest share of employment (around 4.6 million people). Since the renewable energy sector also played a important role in employment with around 1.6 million people, the share of those who are employed in fossil energy will not be that significant. Employment levels for this sector are highly dependent on factors of government policy, disruptive technologies and changes in energy demand.

The EU EII, on the other hand, employed around 8.6 million people in 2019 or approximately 4% of the total employment in the EU. The largest sub-sector is basic metal with 2.2 million people, but employment levels in EII can be affected by a variety of factors, including changes in energy prices, technological advancements, and global competition.

The importance to assess CBAM at the regional level arises as the EII are highly dependent on a reliable and affordable supply of energy to maintain their operations. Regions that are rich in energy resources, such as coal, oil, or natural gas, may have a comparative advantage as they can produce energy more cheaply than other regions. The EII may be concentrated in these regions to take advantage of the lower energy costs. The availability of cheap energy is not the only factor that determines the location of EII. Other factors, such as access to raw materials, transportation infrastructure, and labour, also play a role. The recent trend of decentralisation and localisation of energy production, with a greater focus on renewable energy sources such as wind and solar power, may also have an impact on the location of EII.

3. Model and scenario design

3.1. Modelling approach

The economic model of computable general equilibrium (CGE) uses actual economic data and extensively applied to analyse how an economy might react to changes in policy, technology or other external factors. The granularity of the model captures the complex interactions between different sectors and markets, enabling to assess the impacts of trade policies, environmental regulations, and other economic policies, providing policymakers with quantitative estimates of the potential effects. Yet the analysis is carried out mostly at country levels, since the model's run is based on statistical regional input–output tables that are only available at a high level of aggregation [47]. Among a few that detailed to regional level, the RHOMOLO model [48] has been used to evaluate the performance of EU policies such as R&D and innovation policies or the European Cohesion Policy [49]. The model allows the analysis of EU policies at the regional NUTS2 level, but its constraints are the limited number of sectors. The other is the sub-national CGE Model for the European Mediterranean Countries [50], which includes more detail about the sectors. The model structure is based on the ICES model [51] and has been used to analyse the impacts of climate change at the regional level [52]. Yet shortcomings of this model are the limited number of EU countries.

While other regional studies limited their focus to within a specific country (eg. Scotland [53] and Finland [54]), we focus on coupling national models with a regional information system as the methodological approach for this research. A similar approach has been conducted by Joshi et al. [55] to analyse the economic impact of sea level rise, Karttunen et al. [56] in studying the Finnish forest potential, and McDowall et al. [25] in mapping employment regional vulnerability in Europe's energy transition. This coupling method, at least addresses the limitation of the availability of regional Input–Output Tables.

3.2. Coupling the GEMINI-E3 model with employment NUTS2 regional data

GEMINI-E3 is a recursive computable general equilibrium model [57] that has been already used to analyse several dimensions of the European climate policies, such as discussed in Babonneau et al. [58], Vielle [59], and Li et al. [19].[2] The European version of this model is built on the GTAP 9 data base [60], with 2011 as the reference year. The 27 EU member states and the United Kingdom are individually represented, along with China and the rest of the world. The model is developed based on the assumption of total flexibility in all markets, whereas sectors are aggregated to 11 by taking into consideration sectors participating in the ETS market and other sectors.

The analysis only considers CO_2 emissions from energy combustion, while the non-CO_2 emissions such as methane, nitrous oxide, and fluorinated gases are not covered. Calculation of emission contents for the analysis of CBAM policy follows Cosbey et al. [3] with three possible scopes, i.e direct emissions from fuel combustion within the sector boundary (scope 1), direct emissions plus the CO_2 content of electricity consumed by the sector or indirect emissions associated with energy use (scope 2), or direct emissions and any indirect production-related emissions including all the CO_2 content of intermediate consumption by the sector (scope 3). Methodologies for calculating these emission contents are detailed in Perdana and Vielle [21].

As a first step GEMINI-E3 is linked with regional employment data, focusing on the energy and the EII. The energy industries covering coal mining, crude oil, and natural gas extraction and the manufacture of refined petroleum products are linked to a sector detailed by GEMINI-E3 with the preliminary work done by McCollum et al. [61] which provides data for the year 2016. The employment of seven sectors (C17, C20, C21, C22, C23, C24, and C25) from the Eurostat 2018 database was aggregated to represent the EII sector.[3] All of the selected sectors and their mapping to the GEMINI-E3 model are listed in Table 1. The regional employment in 2030 (L^{2030}_{region}) will be estimated based on the results of each scenario on national employment computed by GEMINI-E3 ($L^{2030}_{country}$) using Eq. (1).

$$L^{2030,\ scenario\ i}_{region} = L^{reference\ year}_{region} \cdot \frac{L^{2030,\ scenario\ i}_{country}}{L^{reference\ year}_{country}}$$
$$\text{with region} \in \text{country} \quad \text{reference year} \in [2016, 2018] \quad \text{and scenario} \in [\text{reference, fit for 55, CBAM}] \tag{1}$$

Total labour supply is exogenous and calibrated from the working age population given by European Commission [62]. The GEMINI-E3 model assumes perfect labour flexibility within sectors at the national level, without considering any migration between regions. Analysing

[2] GEMINI-E3 is comparable to other models of this class such as EPPA, OECD-Env-Linkage, etc. Model's description is detailed in a supplementary material.

[3] To address the unavailability of data for certain regions, an estimation is performed based on a protocol, detailed in a supplementary material.

Table 1
Mapping between the GEMINI-E3 Sector and General Classification of Economic Activities (NOGA).

GEMINI-E3 sector	Noga code	Noga Definition	Source	Year
Energy	C17	Manufacture of paper and paper products	Eurostat	2018
Intensive	C20	Manufacture of chemicals and chemical products	Eurostat	2018
Industries	C21	Manufacture of basic pharmaceutical products	Eurostat	2018
		and pharmaceutical preparations	Eurostat	2018
	C22	Manufacture of rubber and plastic products	Eurostat	2018
	C23	Manufacture of other non-metallic mineral products	Eurostat	2018
	C24	Manufacture of basic metals	Eurostat	2018
	C25	Manufacture of fabricated metal products,		
		except machinery and equipment	Eurostat	2018
Coal	B05	Mining of coal and lignite	McCollum et al. [61]	2016
Crude oil Natural gas	B06	Extraction of crude petroleum and natural gas	McCollum et al. [61]	2016
Refined oil products	C192	Manufacture of refined petroleum products	McCollum et al. [61]	2016

the implications of these assumptions on the outcomes proves challenging. On one hand, presuming full flexibility nationally likely overestimates labour mobility within regions, given the higher degree of industrial specialisation at the regional level. Conversely, disregarding inter-regional labour migration likely underestimates labour flexibility between regions. Research on regional migration patterns in Europe indicates relatively limited labour market dynamics compared to countries like the USA [63,64]. Furthermore, migration between regions of different countries is constrained, primarily due to cultural and language barriers [65], thereby supporting the GEMINI-E3 model's assumption of negligible labour flexibility between European nations.

3.3. Measuring regions' exposure and vulnerability risk

Following the impact of EU employment as the cornerstone of this paper's analyses, the concept to measure economic dependence on certain industries needs to be expanded from the single dimensional method, which is commonly used in the current literature. Therefore, the concept of the regional exposure and vulnerability risk is revisited, and re-calibrated from the significance and openness in national/regional economic perspectives to the likelihood of job losses and regional capacity to adapt it.

The study by McDowall et al. [25] is used for developing this measurement concept, in which the exposure is related to projected declines of employment in the related sectors as a consequence of the decarbonisation policy. However, different to Mcdowall's postulate that defined exposure as an outcome of the technology pathway to deep decarbonisation, the definition is then expanded to include specific instruments i.e. CBAM. Decline in regional employment is translated as job loss, estimated by the new coupled GEMINI-E3 model.[4] Regional exposure is then calculated as the percentage of this employment loss relative to total employment in the year 2030. The effectiveness of CBAM in minimising the impact of deep decarbonisation of the EU Fit for 55 could be evaluated by comparing different regional exposures resulting from different scenarios.

Nonetheless, vulnerability risk has a broader definition. It includes not only a region's exposure indicator (I_e), but also the sensitivity of that particular region to the disruption (I_u) and its adaptive capacity to respond and to recover (I_a). The regional sensitivity is measured by total employment per labour force, while the adaptive capability is estimated by using the European Innovation Scoreboard (RIS) as the proxy [66]. As these two are exogenous longer-term estimated indicators, implementation of CBAM will have no effects. Consequently, regional vulnerability prior to and post CBAM implementation become less comparable, but regional vulnerability indexes post CBAM implementation are still the right indicators to assess the regional risk on the employment.

In estimating the vulnerability index, these three indicators are normalised on a comparable scale (Eq. (2)), and weighted to indicate the most important factors that affect regions' vulnerability risk (Eq. (3)). As the weighted factors of α_i is exogenously chosen, sensitivity analysis will be conducted to ensure the robustness of simulation results. Fig. 1 summarises the methodological approach, detailing the various steps and how the different statistical sources and the GEMINI-E3 model are combined to derive indicators used in this article.

$$I_x = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (2)$$

$$Vulnerability = I_e^{\alpha_e} \cdot I_u^{\alpha_u} \cdot (1 - I_a)^{\alpha_a} \quad (3)$$

For further investigation into the political acceptability of the CBAM, it is important to examine how vulnerability indexes interrelate with the structural characteristics inherent to each region, encompassing aspects such as political dispersion and tendencies towards accepting EU policies. This paper will also incorporate statistical analyses to further elucidate these dynamics and their implications.

3.4. Simulations and scenarios development

3.4.1. Reference scenario

The GEMINI-E3 reference scenario is built on the period 2011–2030 with yearly time steps. The reference scenario covers all policies implemented since 2015, emphasising those related to energy and climate fields. Population, GDP, and international energy prices post 2016 are exogenous and follow the assumptions used by the European Commission in the EU reference scenario 2016 [62]. It is predicted that European GDP will grow by 1.5% annually between 2015–2040, while the projection for each MS are in line with DG ECFIN [67]. Energy consumption and CO_2 emissions after 2015 in this reference scenario however, are slightly different from the EU scenario of 2016, following our assumption of no additional climate abatements in the EU-ETS and new climate and energy policies.

3.4.2. The fit for 55 scenarios

In capturing the integration of the new EU Fit for 55 targets with CBAM, the EU ETS sectors are participating in a CO_2 tradable market with full auctioned emission allowances. While the non-ETS sectors are represented by a uniform tax implemented in each MS that equalise

[4] In line with the general equilibrium concept, the coupled model assumes that one individual holds a full time job. The model calculates labour demand, while employment in each sector will be endogenously determined by equalising demand with exogenous labour supply. The difference in employment levels between scenarios describes job losses.

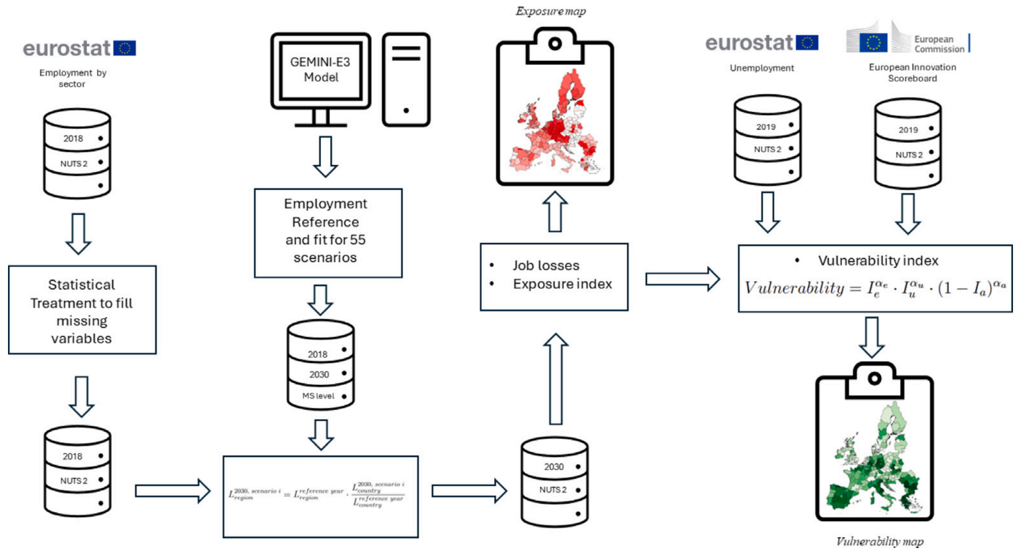

Fig. 1. Methodological overview.

their marginal abatement costs.[5] It follows that domestic CO_2 taxes are implemented in the non-ETS sectors based on the Effort Sharing Regulation (ESR) targets presented in a supplementary material in Table 1. Firms included in the ESR emissions and households pay a domestic CO_2 tax on their fossil energy consumption. The CO_2 tax revenue is redistributed to households through a lump-sum transfer.

This scenario is then developed by introducing CBAM, applied as an import tariff. Its implementation covers all three possible methods to calculate emissions contents, including its possibility to be complemented with an export subsidy. Results are studied and compared relative to a reference scenario.

4. Numerical result and discussion

4.1. Overview of the results

Table 2 synthesises the main results of the Fit for 55 scenarios with different potential CBAM implementation. In the absence of CBAM, the EU Fit for 55 target results in a significant welfare cost, estimated at 1.9% of GDP loss. The EU EII production decreases by 9.3%, resulting in 491,000 job loss in 2030. The leakage rate is 20.8%, which is slightly lower than the estimated rate by Mörsdorf [20] and considered significant (upper range) relative to the rate compiled by Branger and Quirion [68]. The ETS price is equal to 98 € per ton of CO_2 equivalent. Countries experience a decrease in the production of energy intensive goods, ranging from 1.1% to 22.2%, except Lithuania which has a production increase due to the reallocation of intra-European Union trade. All MS face a decline in GDP, ranging from 0.23% to 3.27% relative to the reference scenario.[6]

On the other hand, implementing CBAM reduces the loss of competitiveness. Loss of production for EII caused by higher abatement targets dwindles by increasing the implementation scope,[7] despite the range of losses between countries still being positive. Scope 3 is the most effective measure with the production loss reduced by half from 9.3% to 4.6%, and the leakage rate reduced to 12.5%. This scope also maximises the employment saved.

4.2. Impact on regional employment

According to Eurostat figures, the EII represents around one third of employment in the European manufacturing sector for the year 2018. Around 9.3 million people are employed at the EU level or 10.1 million if the UK is included. This level significantly exceeds the fossil fuel industries, which is estimated to 370,000 people at the EU27 level for same year. Using Eq. (1), the employment in 2030 is calculated based on GEMINI-E3 reference scenario. In the reference scenario, the EU27 employment of EII decreases by 22.9%, with unemployment reaches 7.2 million in 2030. GEMINI-E3 indicates that a third of this decline comes from a reduction in the level of production in the EU, and the other two thirds is linked to labour productivity improvement (i.e. a labour productivity improvement equal to 1.4% annually). Implementing the Fit for 55 policy results in 491,000 jobs lost in 2030 or 6.8% lower than the reference case (see Table 2). Employment decreases by 157,000 jobs in the fossil energy industries.

4.2.1. Regional exposure: prior to CBAM implementation

Scrutinisation at the regional scale reveals that implementing CBAM reduces job loss. Yet, job losses are concentrated in a limited number of regions. Fig. 2 shows the trend of cumulative job loss when regions are ordinarily ordered based on the number of jobs lost. In the Fit for 55 scenario without CBAM, the top 10 regions account for 24% of job losses, top 25 for 43% and top 50 for 60%. Clearly indicating that implementing CBAM reduces this cumulative job loss, however impacts for each region (that define this ranking composition) need to be further investigated.

Table 3 lists the top 50 most exposed regions in the EU Fit for 55 scenario in the absence of CBAM. There are five countries that represent 47 of these 50 regions. More than half of regions are in Germany (28 regions), followed by Austria with 5 regions, and Bulgaria, Belgium and the UK with 3 regions each. Among the top five, the most impacted area is Dytiki Makedonia, which is also known as the "Balkan Ruhr", the energy heart of Greece. The city of Kozani in this area has been the major centre of coal and lignite production for more than 50 years. This region has already been impacted by the coal phasing-out policy in Greece, and it is predicted to lose 90% of its employment by 2030. Our finding is consistent with a previous study of Dias et al. [69], which identifies the highest social impact if an additional 3.5% of the active population becomes unemployed due to the decommissioning of power plants and mines.

The second most exposed region is Silesia (Slaskie), the most densely populated region in Poland. As one of the most carbon-intensive regions

[5] Diverse set of economic instruments for non-ETS sectors that vary between MS are impossible to represent within a CGE model. Representing them by a domestic carbon tax is the best approach with little impact on the sectors belonging to the ETS and in particular to EII.

[6] Results per MS are detailed in a supplementary material in Table 2.

[7] See Figure 1 in the supplementary material.

Table 2
Fit for 55 scenarios impact on EU27 aggregates w.r.t to reference scenario in % - year 2030.

	Without CBAM	Scope 1	Scope 1 +sub export	Scope 2	Scope 3
GDP	−1.89%	−1.85%	−1.90%	−1.82%	−1.80%
ETS price[a]	98	101	102	104	106
Leakage rate	20.8%	18.7%	19.0%	16.7%	12.5%
EII production	−9.3%	−7.7%	−5.9%	−5.9%	−4.6%
Employment (job FTE)					
EII	−491,689	−362,878	−220,773	−225,793	−117,683
Fossil industries	−156,874	−155,994	−193,153	−155,131	−153,401

[a] In €$_{2022}$ per ton of CO_2 equivalent.

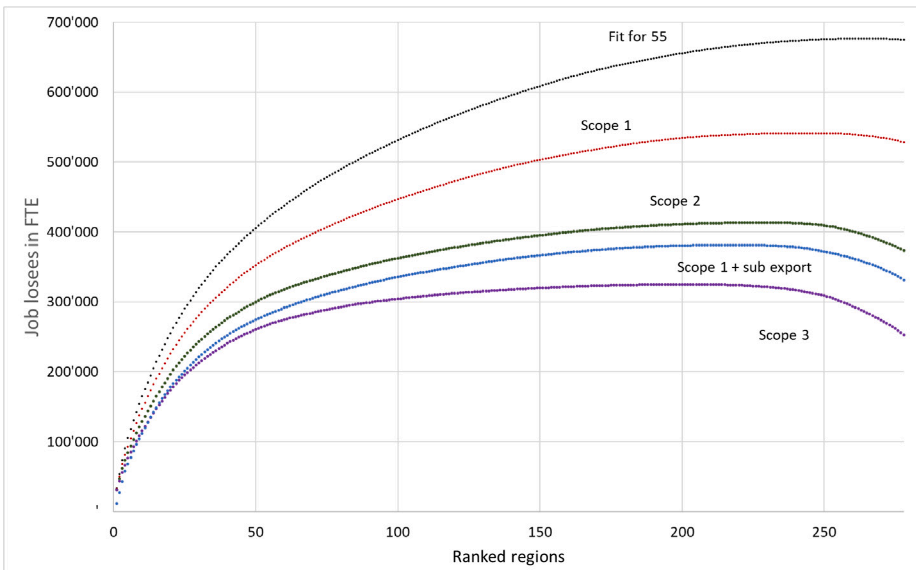

Fig. 2. Cumulative job loss per region in 2030 - number of jobs lost - EU27+UK.

of Europe [70,71], its economy is characterised by labour and energy-intensive traditional raw material industries including coal mining, and metallurgic and chemical sectors. Similar with Żuk et al. [72], it is confirmed that energy transition poses a great risk to Silesia.

The third in our list is Yugoiztochen, the second richest Bulgarian region. The Stara Zagora District in this region is the energy heart of Bulgaria, where industry and energy are the leading sectors. Around 30% of job losses are located in the fossil energies industries, and without a proper strategy, the energy transition can increase the unemployment rate close to the maximal [69]. The next on the list are two German regions with significant activity in the basic metal and fabricated metal industries, and Rheinhessen-Pfalz; Europe's leading chemical cluster where the world's largest chemical company, BASF, is located.

4.2.2. Regional exposure: post CBAM implementation

Complementing the Fit for 55 policy with CBAM implementation does not significantly change the top 50 exposed regions. Here the focus is on implementation using scope 2, based on the latest discussion among the European Parliament.[8] As CBAM is imposed on EII, this measure has no direct impact to fossil industry employment. This implies that a change in position on the exposure rank, should relate to EII due to CBAM. While there is no change in our top 3 regions, others are significantly affected by CBAM implementation (Table 4).

Two Czech regions are positively impacted by CBAM implementation, namely Severozápad (−11) and Moravskoslezsko (−11). The region Severozápad is where Karlovy Vary is located. Here basic metals are refined and automotive and power industries (mostly with renewables) are located. The EU CBAM definitely supports industries' production as well as the intensification of renewable energies in this region. The same can be seen in Moravskoslezsko, which became the heart of the steel industry of the country. Other beneficiaries include two regions in Austria: Vorarlberg (−9) and Oberösterreich (−8).

Four regions enter into the top 50 i.e: Leipzig (+9), Malta (+9) Braunschweig (+8) and Lüneburg (+6). Regions of North Eastern Scotland of the UK and Sud-Vest Oltenia of Romania are now in the top 5. The higher ranking for North Eastern Scotland is on account of its major oil and gas resources that are linked to the North Sea. This sector will be particularly affected by the Fit for 55 climate policy, and have less counter-balance effects from implementing CBAM. This is also the case for Sud-vest Oltenia region with 95% Romanian proven reserves of lignite. Its economy is mainly based on two sectors; agriculture and industry, which rely on the intensive use of existing natural resources inherited from the communist period [73]. More than 80% of resources are surface mined in this region. All regions' exposure indexes after implementing CBAM with scope 2 are illustrated in Fig. 3.

4.3. Regional vulnerability analysis

4.3.1. Top 50 most vulnerable regions

Table 5 presents the top 50 vulnerable regions in the scenario Fit for 55 with CBAM scope 2. Compared to the regional exposure analysis under the same scenario, it can be seen that the vulnerability risk

[8] The initial public consultation by the European Commission, considered computing the carbon content using scope 1, but the EU parliament tended towards scope 2. The final details of the CBAM are still under negotiation.

Table 3
Top 50 exposed regions - scenario: Fit for 55 - Year 2030.

NUTS	Country	Regions	Expos.	♯	NUTS	Country	Regions	Expos.	♯
EL53		Dytiki Makedonia	3.92%	1	EE00		Eesti	0.78%	26
PL22		Slaskie	1.96%	2	BE31		Brabant Wallon	0.77%	27
BG34		Yugoiztochen	1.56%	3	DE40		Brandenburg	0.76%	28
DEA5		Arnsberg	1.20%	4	DE23		Oberpfalz	0.76%	29
DEB3		Rheinhessen-Pfalz	1.06%	5	DE12		Karlsruhe	0.72%	30
UKM5		North East. Scotland	1.02%	6	DEA4		Detmold	0.71%	31
DEA3		Münster	1.02%	7	DEA2		Köln	0.71%	32
DE13		Freiburg	1.01%	8	DE94		Weser-Ems	0.69%	33
RO41		Sud-Vest Oltenia	1.00%	9	DEB2		Trier	0.66%	34
DEG0		Thüringen	1.00%	10	DE26		Unterfranken	0.63%	35
DE24		Oberfranken	0.98%	11	DE25		Mittelfranken	0.61%	36
DEE0		Sachsen-Anhalt	0.97%	12	BE22		Limburg	0.59%	37
DEB1		Koblenz	0.97%	13	BG32		Severen tsentralen	0.59%	38
CZ04		Severozápad	0.95%	14	DE11		Stuttgart	0.58%	39
AT34		Vorarlberg	0.94%	15	AT12		Niederösterreich	0.57%	40
DED4		Chemnitz	0.92%	16	AT22		Steiermark	0.57%	41
CZ08		Moravskoslezsko	0.92%	17	DE92		Hannover	0.56%	42
DE14		Tübingen	0.89%	18	RO42		Vest	0.56%	43
DEC0		Saarland	0.87%	19	SE31		Norra Mellansverige	0.54%	44
DE22		Niederbayern	0.84%	20	UKD1		Cumbria	0.54%	45
DE72		Gießen	0.84%	21	BE21		Antwerpen	0.53%	46
DED2		Dresden	0.82%	22	UKE1		East Yorkshire, North. Lincolnshire	0.50%	47
DEA1		Düsseldorf	0.82%	23	BG42		Yuzhen tsentralen	0.49%	48
DE27		Schwaben	0.80%	24	DE71		Darmstadt	0.49%	49
AT31		Oberösterreich	0.78%	25	AT33		Tirol	0.49%	50

Table 4
Top 50 exposed regions - scenario: fit for 55 with CBAM scope 2 - Year 2030.

NUTS	Country	Regions	Expos.	♯	Δ♯	NUTS	Country	Regions	Expos.	♯	Δ♯
EL53		Dytiki Makedonia	3.97%	1	-	DE23		Oberpfalz	0.57%	26	+3
PL22		Slaskie	1.77%	2	-	DEA2		Köln	0.57%	27	+5
BG34		Yugoiztochen	1.44%	3	-	CZ08		Moravskoslezsko	0.56%	28	-11
UKM5		North East. Scotland	0.95%	4	+2	BE31		Brabant Wallon	0.55%	29	-2
RO41		Sud-Vest Oltenia	0.92%	5	+4	DE12		Karlsruhe	0.55%	30	-
DEA5		Arnsberg	0.91%	6	-2	DEA4		Detmold	0.54%	31	-
DEA3		Münster	0.88%	7	-	DE94		Weser-Ems	0.53%	32	+1
DEB3		Rheinhessen-Pfalz	0.81%	8	-3	AT31		Oberösterreich	0.50%	33	-8
DE13		Freiburg	0.77%	9	-1	DEB2		Trier	0.50%	34	-
DEE0		Sachsen-Anhalt	0.76%	10	+2	DE26		Unterfranken	0.48%	35	-
DEG0		Thüringen	0.76%	11	+7	DE25		Mittelfranken	0.46%	36	-
DE24		Oberfranken	0.74%	12	-1	DE11		Stuttgart	0.44%	37	+2
DEB1		Koblenz	0.73%	13	-	DE92		Hannover	0.43%	38	+4
DED4		Chemnitz	0.69%	14	+2	RO42		Vest	0.43%	39	+4
DED2		Dresden	0.68%	15	+7	BE22		Limburg	0.42%	40	-3
DE14		Tübingen	0.68%	16	+2	BE21		Antwerpen	0.41%	41	+5
DEC0		Saarland	0.67%	17	+2	BG32		Severen tsentralen	0.40%	42	-4
DE22		Niederbayern	0.64%	18	+2	DED5		Leipzig	0.39%	43	+9
DEA1		Düsseldorf	0.64%	19	+4	MT00		Malta	0.38%	44	+9
DE72		Gießen	0.64%	20	+1	AT12		Niederösterreich	0.38%	45	-5
DE40		Brandenburg	0.64%	21	+7	DE71		Darmstadt	0.37%	46	+3
EE00		Eesti	0.63%	22	+4	AT22		Steiermark	0.36%	47	-6
DE27		Schwaben	0.61%	23	+1	DE91		Braunschweig	0.35%	48	+8
AT34		Vorarlberg	0.60%	24	-9	DE93		Lüneburg	0.34%	49	+6
CZ04		Severozápad	0.60%	25	-11	BG42		Yuzhen tsentralen	0.33%	50	-2

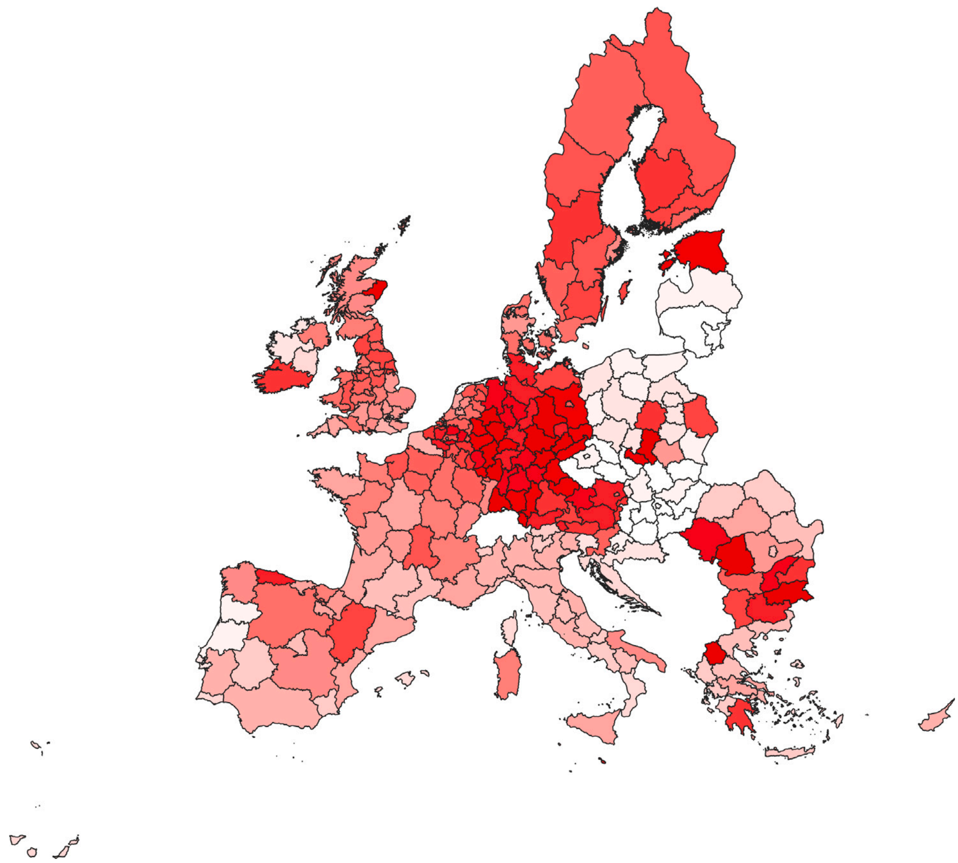

Fig. 3. Exposure - scenario: fit for 55 with CBAM scope 2 - Year 2030.

leads to very different regional coverage. Among the top 50, regions in Greece dominate with a total of 12 regions, while there are only 10 German regions. Fig. 4 also shows that Southern European countries (Greece, Spain and Italy) are over represented, with 9 regions in Spain and 7 in Italy amongst the top 50. Several Eastern European countries (such as regions in Bulgaria, Romania and Czechia) still make significant contributions.

The dominance of regions in the Southern European countries indicates that these regions have a higher sensitivity and lower adaptive capacity to deal with energy transition. Likewise, fewer regions in Germany suggest lower sensitivity and higher adaptive capacity despite high exposure in implementing Fit for 55 and CBAM. The absence of France, the United Kingdom, the Scandinavian and Baltic countries in this list also supports this.

The region of Peloponnisos in Greece enters the top 5. Its economy is mainly based on tourism and agriculture, but this region includes the Megalopoli mine, which is a large lignite and coal open-pit. This region also has a high unemployment rate and a low rate of adaptability, same as the other Greece regions in this list. Some Spanish regions also enter into the top 10. The Principado de Asturias has several heavy industries (steel, zinc, aluminium) that were built in association with mining industries, especially coal mines located in the central coal Basin of Asturias [74]. While the presence of the cities Melilla and Ceuta is more related to a statistical artifact for their few industrial jobs (less than 250 employees in EII). Meanwhile, a very low adaptive capacity is the main factor provoking a high vulnerability risk for the two Bulgarian regions of Severozapaden and Severen Tsentralen. These two regions are among the poorest in the European Union.

4.3.2. Regions' vulnerability and structural characteristics

Besides industrial characteristics, each region's position at the national scope may affect its vulnerability index. To understand this potential correlation, the distribution of the top 50 vulnerable regions is evaluated relative to their national context. For this, we follow the regional classification of European Spatial Planning Observation Network (ESPON) and analyse their distribution based on the results of the vulnerability risk analysis.[9] Fig. 5 compares this distribution with the one computed at EU28. Our top 50 samples include more regions categorised as left behind regions, i.e. regions with low levels of income and low-medium income growth. More than 70% of the top 15 most vulnerable regions are classified as left behind and none from the front runner. This distribution may suggest that the Fit for 55 will increase regional fragmentation.

Second, the correlation between vulnerability indicator and the distribution of European structural and investment funds (ESIF) by regions is analysed. The ESIF is one of the main fiscal instruments to achieve economic and social convergence across regions [75] by supporting the low-carbon economy, and a sustainable management of natural resources. This investment variable is represented by the cumulative R&D fund in € per capita from 2014 to 2020 by regions from the Territorial Economic Data viewer [76] for the EU27. The correlation coefficient between our vulnerability index and the ESIF variable for the 278 regions is weak and negative (−0.1), suggesting the current distribution of ESIF is not entirely reaching regions with a high vulnerability energy transition risk. Detailed allocation of this fund is illustrated in Figure 2 in the supplementary material.

[9] ESPON classifies regions as left behind: low income — low medium income growth, losing pace: medium income — low income growth, catching up: low medium income — high income growth, median profile: medium income and income growth, and front runners: high income — medium high income growth. For more details refer to: https://www.espon.eu/tools-maps/espon-database.

Table 5
Top 50 Vulnerable regions - scenario: fit for 55 with CBAM scope 2 - Year 2030.

NUTS	Country	Regions	Vuln.	♯	NUTS	Country	Regions	Vuln.	♯
EL53		Dytiki Makedonia	0.916	1	DEG0		Thüringen	0.221	26
BG34		Yugoiztochen	0.370	2	CZ04		Severozápad	0.220	27
RO41		Sud-Vest Oltenia	0.337	3	ES43		Extremadura	0.218	28
EL65		Peloponnisos	0.278	4	ES70		Canarias	0.217	29
PL22		Slaskie	0.277	5	DEC0		Saarland	0.217	30
DEE0		Sachsen-Anhalt	0.261	6	ITH4		Friuli-Venezia Giulia	0.217	31
ES12		Principado de Asturias	0.259	7	DE40		Brandenburg	0.215	32
BG31		Severozapaden	0.257	8	ES42		Castilla-la Mancha	0.214	33
ES64		Ciudad de Melilla	0.253	9	CZ08		Moravskoslezsko	0.214	34
BG32		Severen tsentralen	0.253	10	BE31		Brabant Wallon	0.213	35
ES63		Ciudad de Ceuta	0.248	11	DEA1		Düsseldorf	0.212	36
EL63		Dytiki Ellada	0.245	12	ES61		Andalucía	0.211	37
DEA5		Arnsberg	0.243	13	BE32		Hainaut	0.210	38
EL64		Sterea Ellada	0.243	14	BG42		Yuzhen tsentralen	0.201	39
EL51		Anatoliki Makedonia, Thraki	0.235	15	ITI4		Lazio	0.201	40
EL61		Thessalia	0.234	16	ITH3		Veneto	0.201	41
EL52		Kentriki Makedonia	0.231	17	DED2		Dresden	0.201	42
EL54		Ipeiros	0.230	18	ES41		Castilla y León	0.199	43
EL41		Voreio Aigaio	0.229	19	DE24		Oberfranken	0.199	44
DEA3		Münster	0.229	20	ES24		Aragón	0.199	45
DED4		Chemnitz	0.227	21	RO42		Vest	0.198	46
ITI3		Marche	0.227	22	EL62		Ionia Nisia	0.198	47
EL30		Attiki	0.226	23	ITH5		Emilia-Romagna	0.198	48
ITI2		Umbria	0.224	24	ITG2		Sardegna	0.196	49
BG33		Severoiztochen	0.223	25	EL42		Notio Aigaio	0.196	50

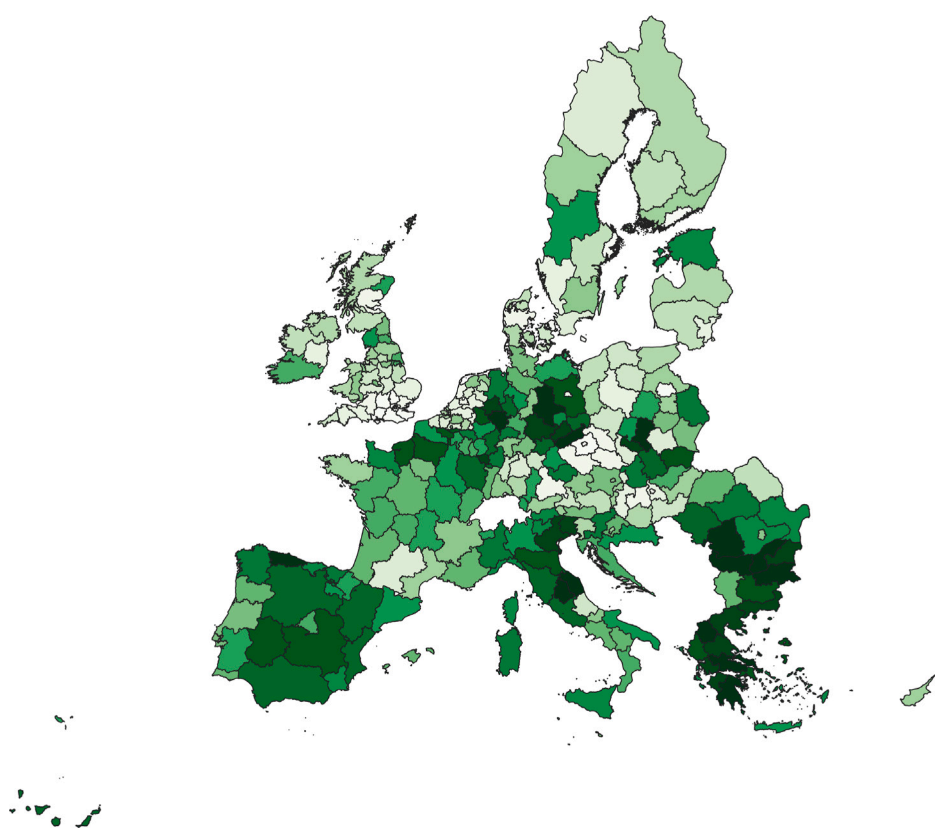

Fig. 4. Vulnerability index - scenario: Fit for 55 with CBAM scope 2 - Year 2030.

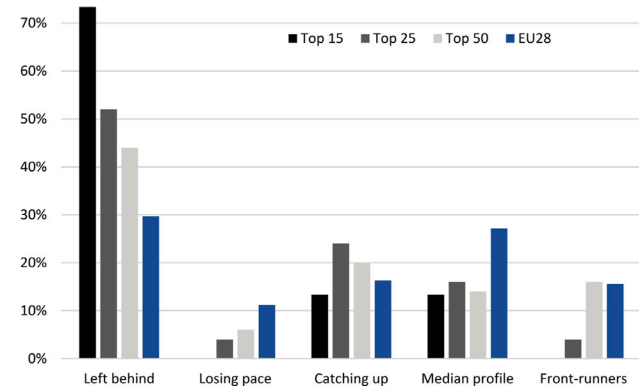

Fig. 5. Distribution of top 50 vulnerable regions.

Furthermore, a correlation analysis between the regional vulnerability and the European electoral geography is then performed, to gain a deeper understanding of the political acceptability of the EU Fit for 55 and CBAM with their consequences of energy transition. For this analysis, the dataset by Schraff et al. [77] of the percentage deviation of regional vote share to the country average over the period 1990–2020 is used. Schraff's study merged NUTS-Level Election Database and Populist datasets of Rooduijn et al. [78] to calculate deviation, and for the analysis, eurosceptism (anti-EU), populist (anti-establishment) and far-right (extreme right wing) indexes are the point of interest. Table 6 reveals these correlations, summarised at the aggregated EU level. The correlation between political opposition and the regional vulnerability index is positive and significant for some EU MS, such as Belgium, France and Spain, suggesting that the political resistance against the EU decarbonisation effort is more likely arises from vulnerable regions from these countries. Positive correlation are less pronounced to regions of countries that recently joined the Union. Table 3 in the supplementary material presents the 95% confidence intervals for each correlation. The intervals are relatively wide for individual countries but become narrower at the aggregated level. Although the limited number of regions at the NUTS 2 level reduces the degrees of freedom, grouping these regions by accession time robustly demonstrates that political resistance to EU policy is generally stronger in the founding member states of the EU.

4.3.3. Regional vulnerability: sensitivity analysis

Following the weighted factor (α parameters) that is exogenous in calculating the vulnerability index that may cause a measurement bias within the analysis, a sensitivity analysis is performed to ensure the robustness of our estimations and mitigate such bias. For this analysis, The value of these weighted factors is varied (Table 7) and followed by running an additional 15 scenarios.

Fig. 6 presents the vulnerability indexes for a total of 278 regions under various scenarios. From this figure, there is a presence of outliers, which occur in a few regions with relatively high vulnerability indexes. These outliers, resulting from variability in measurement, indicate a higher level of uncertainty in these regions compared to those with lower vulnerability indexes. This heightened uncertainty may suggest a greater sensitivity to specific indicators related to the structural characteristics of these particular regions. While a detailed analysis of these specific regions would be an interesting direction for further research, it lies beyond the scope of the current study.

Presenting the top 50 vulnerable regions using the median of these additional scenarios and comparing against our previously discussed results in Table 5, the 47 regions in the top 50 are consistent (Table 8). The Top 4 are the same regions across the two rankings lists and 7 regions are common in the top 10, ensuring the robustness results obtained in our analysis.

5. Limitations of the study and conclusion

5.1. Limitations of the study

The current study has at least three significant limitations that should be acknowledged. First, the assumption of full flexibility at the national level likely overestimates labour mobility within regions due to the greater industrial specialisation at the regional level. Conversely, ignoring inter-regional labour migration likely underestimates labour flexibility between regions. These effects may compromise the predictability in assessing labour mobility across the nation and could potentially introduce compounded biases, affecting regional exposure and vulnerability risks. However, given that inter-regional migration within Europe is relatively limited, as previously elaborated, concerns about its significant impact on the study's outcomes are alleviated.

Second, this version of GEMINI-E3 only includes CO_2 emissions from fuel combustion, and does not account for nitrous oxide emissions from the production of nitric acid, adipic acid, and glyoxylic acid, nor for perfluorocarbons emissions from aluminium production, all of which are covered by the ETS market. Additionally, it overlooks CO_2 emissions from clinker production in the cement industry. Including these emissions would likely increase the perceived negative impact of the fit-for-55 package, especially in regions with substantial cement industry activity. The last limitation lies in the relevant information at the EU national level.

The final limitation pertains to the availability of relevant information at the EU regional level. The scarcity of such data restricts a more comprehensive explanation of regional heterogeneity. Identifying the drivers of regional exposure to EU climate policy and linking our exposure and vulnerability indicators to quantitative variables, such as trade exposure and carbon intensity—as demonstrated in the work by Graham and Knittel [79]—is of significant scientific relevance and clearly a matter of future work.

5.2. Conclusion

Analysing the political acceptability of the EU Fit for 55 policy with its energy and economy transitions, substantiates the importance to move beyond the analysis competitiveness issue of the EU energy industry. For a more holistic approach, this paper provides the analysis of such an impact, focusing on European employment related to the fossil energy sectors and energy intensive industries. These two sectors represent a substantial number of employments, and are likely to be heavily impacted by the new mitigation targets. Our analysis results are synthesised as follows.

First, the negative distortion on EU industries' competitiveness by implementing Fit for 55 sequentially causes a number of job losses in both fossil energy and energy intensive sectors. It is estimated that by 2030, around 675,000 employed positions will be lost, however complementing the policy with CBAM will reduce this figure by 300,000. Therefore, CBAM is an effective economic tool based on its ability to improve competitiveness and reduce employment loss in both sectors.

Second, our analysis confirms that a policy will have varying degrees of impact across geographical regions. Employment loss tends to be concentrated in a number of regions, indicating that a particular regional analysis should be taken into account when discussing political acceptability for EU Fit for 55 and its complementary CBAM policy instrument. The most exposed regions are the coal mining basins, which historically have seen the development of heavy mining industries such as Dytiki Makedonia, Slaskie and Yugoiztochen. Regions that have specialised in energy intensive industries are also impacted, but the implementation of CBAM likely reduces their exposures. Our analysis reveals that the German regions are highly exposed to negative distortion in an endeavour to reach the EU climate target.

Third, the social impact of these job losses must, however, take into account factors of the local labour market and the region's capacity to

Table 6
Correlation between vulnerability index and extreme votes.

No	Countries	Vulnerabilities & Eurosceptism	Vulnerabilities & Populist	Vulnerabilities & Far Right	Accession Year
1	Belgium	0.84	0.90	0.90	1952
2	France	0.60	0.60	0.66	1952
3	Germany	0.40	0.40	0.42	1952
4	Italy	-0.06	-0.20	0.30	1952
5	Netherlands	0.07	0.19	0.00	1952
	All Regions of Group 1 - Fondation EC (1950s)*	**0.30**	**0.21**	**0.28**	
1	Denmark	0.34	0.82	0.82	1973
2	United Kingdom	0.21	0.39	0.39	1973
3	Greece	-0.21	-0.10	0.07	1981
4	Spain	0.49	0.49	0.49	1986
5	Portugal	-0.06	--	--	1986
	All Regions of Group 2 - First Expansion (1970-80s)**	**0.01**	**0.08**	**0.09**	
1	Austria	-0.22	-0.22	-0.22	1995
2	Finland	-0.15	-0.15	-0.15	1995
3	Sweden	0.67	0.61	0.61	1995
	All Regions of Group 3 - Second Expansion (1990s)	**0.10**	**0.16**	**0.16**	
1	Czechia	0.82	0.83	0.76	2004
2	Hungary	0.18	0.18	0.18	2004
3	Slovakia	-0.10	0.97	0.76	2004
4	Poland	0.22	0.22	0.22	2004
5	Bulgaria	0.17	0.08	0.17	2007
	All Regions of Group 4 - Third Expansion (2000s)****	**0.15**	**0.21**	**0.12**	
All Regions of EU 27 (Excluding UK)		**0.12**	**0.12**	**0.13**	

*Belgium, France, Germany, Italy, Netherland and Luxembourg
**Denmark, UK, Greece, Spain, Portugal and Ireland
***Czechia, Hungary, Slovakia, Poland, Bulgaria + Cyprus, Malta, Balkan & Baltic Countries

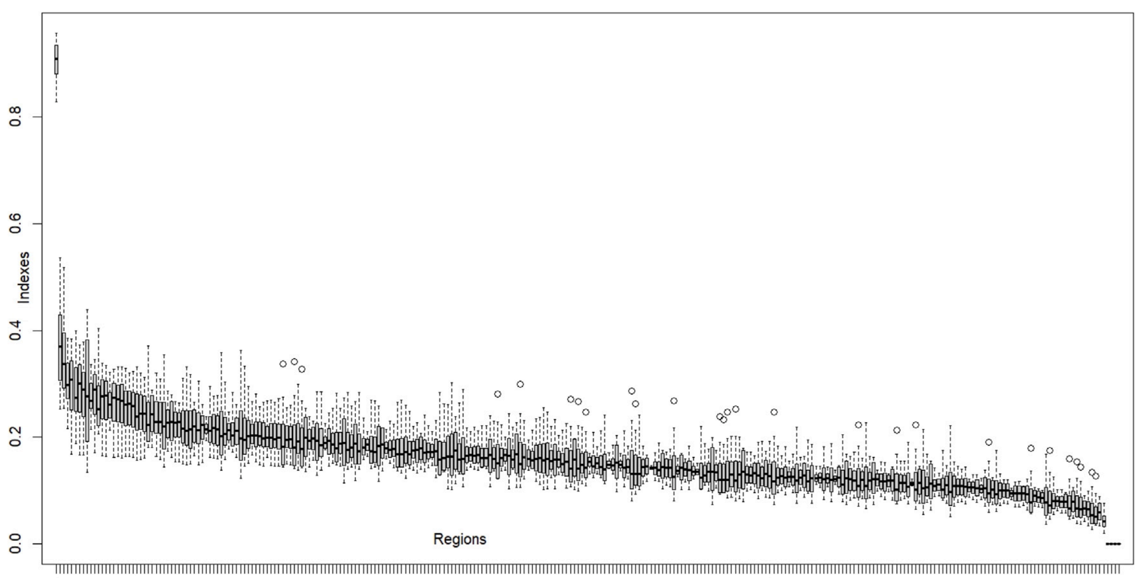

Fig. 6. Vulnerability indexes - Box-and-Whisker plot of the 15 scenarios.

Table 7
Parameters Used for the sensitivity analysis — inside the table α_e.

	α_u				
α_a	0.5	0.4	0.3	0.2	0.1
0.5					0.4
0.4				0.4	0.5
0.3			0.4	0.5	0.6
0.2		0.4	0.5	0.6	0.7
0.1	0.4	0.5	0.6	0.7	0.8

adapt to this energy and industrial transition. By taking these factors into account and estimating the vulnerability risk of each of the regions, our analysis reveals a different picture. Most regions in Germany that are highly exposed were also found to be less vulnerable, suggesting low sensitivity and high adaptive capability of these regions to deal with energy transition. The Southern European regions of Greece, Spain and Italy, and central European regions in Bulgaria, Romania, and Czechia are much more vulnerable.

The follow up analysis also confirms that most vulnerable regions have low-medium income growth, yet have not been the main target of investment using the European structural fund. Further analysis also found strong positive correlation between political opposition and the regional vulnerability index, proving that the political resistance against the EU decarbonisation effort potentially arises from vulnerable regions, even post CBAM implementation.

The final remark should be that the foreseen challenge for the EU will be to effectively support these vulnerable regions. This should be a main consideration and set as the objective of the "Just Transition

Table 8
Sensibility analysis - Top 50 vulnerable regions using the median - scenario: Fit for 55 with CBAM scope 2.

NUTS	Country	Regions	Med.	♯	NUTS	Country	Regions	Med.	♯
EL53		Dytiki Makedonia	1	1	ES42		Castilla-la Mancha	28	26
BG34		Yugoiztochen	2	2	CZ04		Severozápad	29	27
RO41		Sud-Vest Oltenia	3	3	BG33		Severoiztochen	30	28
EL65		Peloponnisos	6	4	ITH4		Friuli-Venezia Giulia	30	29
ES64		Ciudad de Melilla	6	5	DED4		Chemnitz	32	30
ES63		Ciudad de Ceuta	8	6	EL62		Ionia Nisia	32	31
EL64		Sterea Ellada	9	7	FRM0		Corse	34	32
BG31		Severozapaden	10	8	CZ08		Moravskoslezsko	35	33
BG32		Severen tsentralen	11	9	DEA3		Münster	36	34
EL63		Dytiki Ellada	11	10	BE32		Hainaut	38	35
PL22		Slaskie	12	11	ITI4		Lazio	38	36
EL61		Thessalia	14	12	BG42		Yuzhen tsentralen	39	37
ES12		Principado de Asturias	15	13	ES41		Castilla y León	39	38
EL51		Anatoliki Makedonia, Thraki	15	14	ITH3		Veneto	41	39
DEE0		Sachsen-Anhalt	17	15	EL42		Notio Aigaio	42	40
EL52		Kentriki Makedonia	17	16	DEC0		Saarland	43	41
EL54		Ipeiros	18	17	ITG2		Sardegna	44	42
EL41		Voreio Aigaio	19	18	DE40		Brandenburg	45	43
EL30		Attiki	20	19	DEG0		Thüringen	46	44
ITI3		Marche	22	20	ES24		Aragón	46	45
ES70		Canarias	22	21	RO42		Vest	46	46
ES43		Extremadura	23	22	ITH5		Emilia-Romagna	48	47
ITI2		Umbria	24	23	ITG1		Sicilia	49	48
ES61		Andalucía	26	24	BE31		Brabant Wallon	51	49
DEA5		Arnsberg	27	25	FRD2		Haute-Normandie	53	50

Fund": a new instrument of the European Cohesion Policy of the European Green Deal [80] aiming to support the territories most affected by the transition towards climate neutrality to avoid regional inequalities. Since the actual distribution of funding to individual member states is still in the process of being finalised, the financial support must be redirected from compensating mechanisms that have failed in the past to overcome the territorial inequality [27,81], to concentrate on building adaptive capacity for minimising social impact [45] and reducing political resistance [80] against the EU climate policy in the future.

CRediT authorship contribution statement

Sigit Perdana: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Marc Vielle:** Writing – review & editing, Validation, Supervision, Software, Resources, Formal analysis, 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.

Acknowledgements

This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) Project No. SERFRI 22.00361 as part of the Horizon Europe European Commission Project "DIAMOND" under Grant Agreement No. 101081179. The content of this paper does not necessarily reflect the opinions of the European Commission or the Swiss Confederation and the responsibility for it lies solely with its authors. We warmly thank Will McDowall for complementing the employment database, Dominik Schraff, Ionannis Vergioglou for sharing their results of regional electoral deviation. We thank Margarita Agriantoni for her infinite knowledge of the Greek economy, and Adam Swietek for his advice on GIS software. Lastly, we extend our sincere gratitude to the anonymous reviewers of this paper for their insightful comments and constructive feedback.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rset.2024.100088.

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