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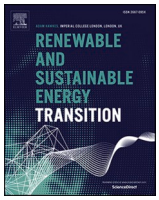

Full-length article

Just energy transition in coal regions: Innovative framework for assessing territorial just transition plans

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ABSTRACT

Coal regions are particularly vulnerable to the plans to reduce regional pollution and move towards a climate-neutral economy. The European Union therefore supports the transition away from coal in those regions that are socio-economically most affected to reduce negative impacts for communities. Coal regions have developed their Territorial Just Transition Plans (TJTPs); however, it is unclear which impacts the plans should address to ensure a just transition and to what degree. To address this gap, the following research aims to develop an indicator and impact matrix to assess the extent to which TJTPs address key impacts related to just transitions and how are these quantified. Key just transition impacts were investigated quantitatively and qualitatively in six coal regions. The results indicate that the expected transition impacts on communities in coal regions are mainly negative. Furthermore, it was also found that TJTPs predominantly address the impacts on employment and the environment, whereas social and demographic impacts are less comprehensively considered. These deficiencies should be addressed in each region in order to define tailored policies and investments that can assist in minimising negative impacts and capitalising on positive benefits for communities. The proposed approach can facilitate a more precise definition and assessment of regional impacts of transition towards climate neutrality, thereby aiding the identification of policy areas and measures that will enable the implementation of a truly just transition.

1. Introduction

The European Union (EU) must phase out the production and use of coal to achieve its goal of becoming climate-neutral by 2050 [1]. This involves not only an international effort but also regional, as the transition process should be planned and accompanied from the local perspective which is most concerned by the economic consequences [2]. Across Europe, regions continue to rely on coal extraction and coal power generation, which provide employment, income, and a sense of identity and belonging [3]. Additionally, the distribution of natural resources deemed crucial to the energy transition is not uniform across regions, placing certain regions at a disadvantage [4].

The EU has only applied a loose "definition" of what constitutes a just transition, calling for the transition to be conducted in a fair and inclusive manner in order to ensure that no person or region is left behind [1]. García-García et al. [5] define a just energy transition as a "long-term technological and socio-economic process of structural change that affects the generation, distribution, storage and use of energy, […] while also ensuring that the desired socioeconomic functions can be accomplished through decarbonised and renewable means of energy production and consumption, safeguarding social justice, equity and welfare" (p. 5). This understanding emphasises the holistic nature of transition processes, extending beyond the sole consideration of energy infrastructure [6].

Just transitions can be considered as enablers of transformative change in coal regions, sustained by different governance capacities [7]. In this context, the transition to green energies is understood as a multilevel, multi-domain and long-term process which will involve impacts stemming from economic, environmental and social dimensions [8,9]. Arora and Schroeder [10] highlight that while the victims of the

Abbreviations: JTF, Just Transition Fund; TJTP, Territorial Just Transition Plan; EC, European Commission, EU, European Union; GDP, Gross Domestic Product; NUTS, Nomenclature of Territorial Units for Statistics.

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transition (individuals, communities, and industry) are often financially cushioned, there is a lack of a broad coalition to foster the transition process. This relates to the concept of procedural justice, which essentially calls for a meaningful and continuous engagement of affected parties [11]. On the other hand, valuing and representing affected citizens by ensuring that their political rights are expressed can be understood as recognitional justice [11]. A third concept of energy justice is distributive justice, which can be understood as ensuring an equal and fair distribution of both the benefits and costs associated with the transition [11].

Analyses conducted at the national level and traditional just transition policy approaches frequently fail to capture the specific characteristics of coal regions. This limits the analysis to a single impact, failing to consider the various socioeconomic aspects and consequences of transitions [12,13]. A notable absence in the literature is the quantitative analyses of just transitions at the regional level. This is however of great importance in order to guide the delineation of regional policies [12,14]. More practical applications are found in grey literature, such as the "Just Transition Readiness Evaluation Tool" (JT:READY), which employs a whole-systems approach and showcases qualitatively how sub-national policies can support just transitions (developed as part of the "CINTRAN" project) [15]. Other projects that focused on more social factors, such as psychological, cultural, and political were also found, but again limited to a qualitative analysis [16–18]. These more practical contributions confirm what is widely acknowledged within the academic literature, and that is that traditional policy measures, which focus on specific sectors addressing solely economic aspects, are insufficient to optimally advance the just transition [19].

Achieving a just transition throughout Europe will require significant investments. In particular, the Just Transition Fund (JTF) has been established with a budget of €8.4 billion to provide financial assistance to EU territories over the period 2021–2027 (with an additional €10.8 billion to come from the NextGenerationEU) [20]. The JTF is part of the Just Transition Mechanism, a key instrument within the European Green Deal. To receive a portion of the JTF, each Member State is required to prepare its Territorial Just Transition Plan (TJTP) and associated cohesion policy programmes, for territories that are expected to be the most negatively impacted by the transition towards climate-neutrality. These plans must provide a description of the transition process at national level towards a climate-neutral economy, including a timeline for key transition steps towards the 2030 and 2050 targets, and demonstrate the impact of the transition process at the territorial level in the near future [21].

The development of a practical approach, which would enable policymakers and regional authorities to perform both qualitative and quantitative analyses, in order to improve the delineation of optimal regional transition plans, was identified as a knowledge gap. In fact, to date, there is no systematic framework that can be applied to assess how TJTPs consider all the impacts of just transitions, both qualitatively and quantitatively. The only similar framework found is the one developed by the WWF, that assesses qualitatively the envisioned effectiveness of the TJTPs [22]. Nonetheless, this is necessary to ensure that the regions are transitioning in a socially fair and equitable way. In fact, a comprehensive framework is required that not only lists the impacts that have to be addressed by TJTPs, but also a quantification method to understand the magnitude of each impact and to identify those that warrant greater attention contingent upon the specific characteristics of the territory under analysis.

The main objective of this research is to identify the multifaceted impacts of just transitions in (rural) coal regions, which present some of the most challenging contexts for just transitions to climate neutrality. This paper presents two main research questions: *i) what are the main impacts resulting from the implementation of just transitions in coal regions? ii) what is the status quo of the found impacts in coal regions and how are these addressed in the TJTPs?* In order to answer these questions, this research employs a quantitative and qualitative analysis of the TJTPs and their impacts. The analysis will notably be applied to six coal regions, namely: Stara Zagora (Bulgaria), Istria (Croatia), Western Macedonia (Greece), the Silesian Voivodeship (Poland), Hunedoara (Romania), and Asturias (Spain). In the next sections of this paper, the methodology employed will be explained, followed by a review of the found impacts of just transitions and related indicators to measure the latter, followed by a discussion and conclusion.

2. Case studies and methods

2.1. Case study selection

Vrontisi et al. [23] developed a socioeconomic risk indicator to delineate the EU regions most at risk of being negatively affected by the transition. It was found that 6 % of all EU regions were classified as being at high risk. In fact, regions that are highly economically dependent on fossil fuels will bear a greater share of the burdens associated with the transition [23]. The Greek region of Western Macedonia was found to be the most exposed and vulnerable region to the transition in the EU according to all three sub-indicators considered in the research, followed by the Polish region of Silesia. Greece produces only lignite, and 80 % of the national lignite production is in Western Macedonia [24]. Similarly, The Upper Silesian Coal Basin is home to all operating coal mines in Poland except for one (i.e., Bogdanka); accounting for about 80 % of hard coal domestic resources [25]. Southeastern Bulgaria was found to be the fourth most vulnerable region in the EU, due to low Gross Domestic Product (GDP) and income per capita [23]. Western Romania was another EU region found to be highly vulnerable, partly due to the low efficiency of power plants [26]. Interestingly, the majority of vulnerable coal regions are located in Central-Eastern Europe, including Adriatic Croatia which was found to be one of the ten most vulnerable coal regions in Europe, despite having closed its last coal mine in 1999. Nonetheless, a coal fired power plant remains, namely TPP Plomin Units 1 and 2, located in Istria. Lastly, although only 3 % of the EU hard coal is produced in Spain, low national economic growth and low levels of regional population density characterise Spanish coal regions as vulnerable [26]. Due to the vulnerabilities of the outlined coal regions, namely Stara Zagora (Bulgaria), Istria (Croatia), Western Macedonia (Greece), the Silesian Voivodeship (Poland), Hunedoara (Romania), and Asturias (Spain); these were chosen as case studies to investigate the multiple impacts of just transitions.

2.2. Methodology

The research follows three main steps: i) reviewing multiple impacts of just transitions and how these impacts can be quantitatively measured through the use of indicators; ii) developing an impact and indicator matrix; and iii) performing a quantitative ex-ante data analysis of the selected indicators and assessing the TJTPs as to see if the areas of concern found quantitatively were addressed in the TJTPs.

First, a review was conducted to identify the most important impacts related to the implementation of a just transition in coal regions, along with a review of the indicators available for quantifying the identified impacts. The review included both academic literature and policy documents. The Scopus search engine was used to find relevant academic papers and to review academic articles from 2018 to 2024. This timeline was chosen as to keep the references fairly recent, considering also that the JTF regulation came into force in 2021 [3]. Two different searches were performed within the TITLE-ABSTRACT-KEYWORDS search engine; the first was: (("impact" OR "assessment") AND "just transition") AND ("factors" OR "indicators"), which yielded 99 results; and the second was: "just transition" AND "factors", which gave 54 results. Furthermore, other sources of information such as Google Scholar and general grey literature (e.g., official websites of EU institutions) were also included during the literature review (applying the same timeline). These references were considered when selecting the different impacts and

indicators, further illustrated in Section 3. In fact, it was decided to select the impacts listed by the European Commission (EC) as a starting point [3], and thereafter to verify these in the literature, and add or remove impacts. Such approach was employed as this research addresses TJTPs, which are plans intended to be approved by EU institutions, hence following EU guidelines. Essentially, the proposed impacts by the EC were corroborated by academic and/or more technical references.

Second, based on the identified impact dimensions and concrete indicators, the indicator and impact matrices were developed. The impact matrix aims to provide an overview of the key impacts that need to be considered when analysing the multiple regional impacts of a just energy transition. On the other hand, the indicator matrix aims to provide an ex-ante analysis of all the considered indicators. Hence, the indicator matrix will provide an overview of the status quo and past trends for each indicator. This allows to indicate the vulnerability of different regions to different impacts and, when used in tandem with the impact matrix, to assess whether the impacts showing greater vulnerability have been considered in the TJTPs and to what degree.

As mentioned, the matrix considers a multitude of impacts, rather than focusing on an individual one, inspired by other similar research approaches [13,23,27,28]. Yanguas Parra [13] outlined the COTRAVI indicator, which considers regions where >70 % of national coal production is focused; whereas Vrontisi et al. [23] outlined a socioeconomic risk indicator as to delineate the most vulnerable regions to the transition. Similarly, Chlechowitz et al. [27] developed a multi-criteria indicator consisting of 13 criteria to capture the different impacts related to the application of the Energy Efficiency First Principle; whereas Reuter et al. [28] outlined a composite indicator to measure the multiple benefits of energy efficiency consisting of 20 different indicators. In this case, a non-weighted multi-criteria analysis (MCA) will be performed to achieve two performance matrices without scoring and weighing, setting the grounds for a full-fletched MCA [29]. The purpose of such matrices is to present the decision-maker with a comprehensive overview of the situation and leave the ranking and decision-making up to the individual policy maker depending on the specific policy process [29].

The scope of the study is limited to the indicators available in the Eurostat data repository [30]. The choice to limit the considered data to the Eurostat repository is threefold: Firstly, to ensure that the matrix is applicable throughout all European regions. Secondly, to maintain the cohesiveness of both the matrix and data, as the Eurostat data gets updated regularly for all EU27 members. Thirdly, to ensure the replicability of the impact and indicator matrix. The level of geographic granularity for each indicator is also specified, differentiating between national, NUTS2 (roughly corresponding to regional), and NUTS3 (roughly corresponding to local) level data. The Nomenclature of Territorial Units for Statistics (NUTS) is a nomenclature of the EC used by Eurostat. The latter divides countries in regions (NUTS2) and regional units (NUTS3) [31]. Of the six regions considered, three were NUTS3 and three were NUTS2 level (Table 1).

Following the indicator analysis, it was investigated whether these were mentioned in the TJTP and, if so, what the expected impact would be. The indicator matrix was applied to the six coal regions to perform an ex-ante analysis and individuate areas of vulnerability. Thereafter, the impact matrix was applied to assess (1) whether and how the current TJTPs of the chosen coal regions address multiple, positive or negative, impacts of the transition process (including the found areas of vulnerability), and (2) how the socio-economic situation has changed and is expected to change. The TJTPs of six coal regions were analysed (Table 2).

A traffic light system was used to indicate whether a specific impact was mentioned and whether it was expected to be positive (green), negative (red), mixed (yellow) or undefined (blue). In case one impact was not mentioned at all in the TJTP, this would correspond to the grey colour. In general, positive impacts were underlined by specific actions, but the level of detail varied between plans. It is important to mention that given the different terminologies used across the TJTPs, such as “intended” actions, or “expected results”, the analysis is subject to interpretation. In fact, most plans fail to quantify impacts, but rather only describe these qualitatively. Since the majority of plans outline intended measures rather than actual detailed action plans, whether positive or negative results will be obtained will depend on how these will be implemented. Hence, it was chosen to analyse what type of consequences are expected by the impacts rather than if specific actions are planned or not. Finally, the analysis was performed by two researchers independently from each other, to increase the validity. The two independent analyses were thereafter merged and in case of differing opinions on specific impacts per TJTP, these were discussed, and a final assessment was chosen after consultation.

To summarise, the indicator matrix quantifies the different impacts, highlighting the regional status quo and areas of major concern where policy interventions should be directed; whereas the impact matrix assesses if and the degree to which the current TJTPs of the six considered coal regions address the found areas of concern and the multiple impacts resulting from a just transition in general, and in what manner has the regional socio-economic situation changed and/or is expected to change. The two matrices are intended to be used in tandem.

3. Results

3.1. Definition and delineation of multiple impacts and related indicators of just transitions

A review of just transition impacts and indicators was performed in order to quantify these. This was done per impact dimension, categorised between social, economic, demographic, and environmental. These dimensions were defined by the EC when considering just transitions [3], in addition to having been extensively used in the literature (with the exception of the demographic one) [8,38–40]. All impacts and

Table 1
Corresponding NUTS level units per coal region.

Region	NUTS2 level	NUTS3 level
Stara Zagora (BG)	Southeastern Bulgaria (BG34)	Stara Zagora Province (BG344)
Istria (HR)	Adriatic Croatia (HR03)	County of Istria (HR036)
Western Macedonia (EL)	Western Macedonia (EL53)	
The Silesian Voivodeship (PL)	Silesia (PL22)	
Hunedoara (RO)	Macro Region 4 West (RO42)	Hunedoara County (RO423)
Asturias (ES)	Principality of Asturias (ES12)	

Table 2
Analysed TJTPs.

Region	Reference of the TJTP
Stara Zagora (BG)	Ministry of Energy of the Republic of Bulgaria, 2023, Territorial plan for a just transition of Stara Zagora region. [32]
Istria (HR)	Republika Hrvatska, 2022, Teritorijailni Plan za Pravednu Tranziciju. [33]
Western Macedonia (EL)	Government Committee SDAM, 2021, Εδαφικό σχέδιο δίκαιης και αναπτυξιακής μετάβασης Δυτικής Μακεδονίας. [34]
Silesian Voivodeship (PL)	Województwo Śląskie, 2022, Terytorialny Plan Sprawiedliwej Transformacji Województwa Śląskiego 2030. [35]
Hunedoara (RO)	Ministerul Investițiilor și Proiectelor Europene, 2022, Tranzitie Justa, Version 1.2. [36]
Asturias (ES)	Gobierno de Espana and Instituto para la transicion justa, 2021, Plan Territorial de Transición Justa de España 2021–2027, Version 1.2. [37]

indicators were chosen based on their accuracy and relevance.

The selected impacts and indicators respectively delineate the impact (Table 3) and indicator matrix (Table 4). In Table 3, a brief explanation summarising why the impact was chosen was added, with the related reference. In Table 4, the related impact for each indicator, the reference and the available data granularity level was added. All in all, different sources focused on different impacts depending on the source's focus and objective. Majority of the references tackled just transitions from a qualitative perspective, hence sources for indicators were more difficult to find. Additionally, considering the innovative specificity of this study, the impacts and indicators were taken from a multitude of references and when not available, indicators were selected by the authors from the Eurostat repository. Nonetheless, no disagreements among references concerning the impacts or indicators to measure these were found. Lastly, all impacts and indicators were given the same importance, as the goal was to produce a non-weighted MCA, as mentioned in Section 2.2. The impact matrix and indicator matrix will be employed in the following subsections to assess the TJTPs of the selected case studies qualitatively and thereafter to perform a quantitative analysis of the status quo in the regions related to the multiple impacts of just transitions.

Table 3
Impact matrix for Just Energy Transitions. The impacts noted with an asterisk will be considered only qualitatively due to data availability and relevancy.

Impact	Impact description	Literature reference
Social Dimension		
Reskilling/upskilling of workers	Workers currently employed in coal activities will have to be retrained and upskilled	[39,41]
Access to public infrastructure and services*	Provide access to public services and ensuring accommodation in case workers are displaced	[42,43]
Gender implications	Coal regions often present a gender mismatch when analysing the workforce	[44]
Community cohesiveness*	Cultural norms often dictate societal roles in communities from mining-regions	[45,46]
Socio-cultural identity*	With a major involvement of women in the job market, community activities might see a decrease in coal regions	[45,46]
Energy poverty	Energy poverty is delineated by the EC as one impact concerning just transitions	[3]
Living conditions	Rural areas present different socioeconomic characteristics related to living conditions compared to urban areas	[47]
Economic Dimension		
Unemployment	Central issue in regional just transitions	[39,44]
Closure of mines and extraction sites	In the EU, 208,000 people are directly employed in coal activities, with 76 % being employed in the mining sector	[48]
Decommissioning of fossil fuel-fired powerplants*	Decommissioning of fossil fuel-fired powerplants will have huge economic impacts	[48]
Structural changes in related industries*	Between half and two-thirds of the present coal-fired power capacity is expected to be retired by 2030	[47]
Demographic Dimension		
Migration of (young) people	Outmigration of (young) people from coal regions is strongly linked to unemployment	[49]
Attractiveness to live and work in the region*	Decline in employment in coal regions is linked to a decline in the attractiveness of the region as a place to live and work for young people	[3]
Environmental Dimension		
Greenhouse gas emissions	Environmental pollution and related health risks are mentioned as a key environmental impact of the industry today	[50]
Health, including pollution*	Environmental pollution and related health risks are mentioned as a key environmental impact of the industry today	[50]
Nature restauration/ revitalisation*	The just transition concept is in itself rooted in environmental justice	[51]

3.2. Application of the indicator matrix to assess the status of coal regions

The developed indicator matrix was employed to evaluate the status quo and past trends of the different indicators quantifying the impacts within the six coal regions. The analysis of the 12 indicators shows that regions are differently impacted by the transition process (Table 5). The goal of this tool is to provide the user with a complete understanding of the background and improvement opportunities of each region, but also with a quantitative backing of possible proposed policies to be implemented as part of the TJTPs. To allow for a comparison of the values obtained for each indicator per region, and to illustrate the intended application of the developed indicator matrix, it was decided to consider one year and to analyse how the different regions differed when applying the indicator matrix. It was chosen to consider the year 2019, as to have fairly recent data but at the same time try to avoid as much as possible nuances in the data caused by the COVID-19 pandemic and the succeeding energy crisis of 2022.

Table 5 summarises the results obtained when applying the indicator matrix to the six coal regions considering data from 2019. The analysis shows that Western Macedonia is much more affected by unemployment than the other regions. Energy poverty is specifically an issue in Stara Zagora and Western Macedonia. Hunedoara, Western Macedonia, Stara Zagora and, to some extent, Silesia, are affected by a population decline among young people due to outmigration from the region. Furthermore, Stara Zagora shows the highest energy intensity of the regions, whereas Silesia lacks behind with renewable energy generation. It must be noted that for every region, the highest degree of data granularity was chosen. However, this did not impact the results, as of the 12 indicators considered, only one was available at NUTS3 level granularity from the Eurostat repository as illustrated in Table 4.

To have a more detailed understanding of the regional status quo concerning the different indicators, it was decided to compare the regional averages with the national averages. This was preferred to comparing regional averages to European averages, as if the whole country is lagging behind the EU for one given indicator, then the region would be presented as lagging behind even though it might be better off compared to other regions within the country or the national average. Hence, indicators available only at national level were not considered. Essentially, the values for each indicator in 2019 at regional level were subtracted by the values at national level, illustrating the gap between the two. A higher gap will reflect a higher need to address one given impact in the region compared to the rest of the country. N.B., when considering demographic indicators, a higher negative gap will reflect a higher need to address one impact. Table 6 illustrates the comparisons between regional and national level.

Western Macedonia classifies as the most vulnerable region to the energy transition. Western Macedonia presents both the general *unemployment rate* (EI1) and the *female unemployment rate* (SI3) higher than the national averages. Very interestingly, it is the only analysed region illustrating such a situation. Indeed, for 2019 specifically, it seems that coal regions had lower unemployment levels compared to the national averages. Additionally, when considering only unemployment, the gender sphere would not seem to be an issue with the exception of Western Macedonia (and Istria, but however only by less than half percentage point and thus neglectable). Figs. 1 and 2 illustrate the evolution of the general unemployment rate and female unemployment rate respectively in Western Macedonia and Greece. As can be seen, in

Table 4
Indicator matrix for Just Energy Transitions.

Indicator	Related impact	Literature reference	Data granularity available	Metric
Social Dimension				
People living in households with very low work intensity	Reskilling/upskilling of workers	[52]	NUTS2 level	% working equal or <20 % of their work-time potential
Female unemployment rate	Gender implications	[45]	NUTS2 level	% of female labour force
Inability to keep the home adequately warm	Energy poverty	[53]	National level	% of people who cannot afford suitable home temperature
Arrears on utility bills		[53]	National level	% of houses in arrears in last 12 months
Type of dwelling in cities or rural areas	Living conditions	Eurostat repository	National level	% by degree of urbanisation
Economic Dimension				
Unemployment rate	Unemployment	Eurostat repository	NUTS2 level	% of total labour force
Severe material and social deprivation rate	Closure of mines and extraction sites	[54]	NUTS2 level	% of people who cannot afford 7/13 deprivation items
Risk of poverty and social exclusion rate		[55]	NUTS2 level	% of people at risk of either or both
Demographic Dimension				
Net change in the population under 30	Migration of (young) people	[47]	NUTS3 level	% population change people under 30
Environmental Dimension				
Energy intensity of GDP	Greenhouse gas emissions	[53]	National level	Kg of oil equivalent per €1000 of GDP
Share of energy from renewable sources		[53]	National level	% energy from renewable energy sources
Use of renewables and biofuels for heating and cooling		Eurostat repository	National level	1000 Kg of oil equivalent

both cases the unemployment rate has been higher in the Greek coal region compared to the national average, signalling a historical and recurring phenomenon that still needs to be tackled. Similarly, the female unemployment rate has been historically and consistently higher compared to the general unemployment rate, highlighting the importance of the gender implications in Western Macedonia.

Stara Zagora presents high gaps when compared to national averages both in terms of the *severe material and social deprivation rate* (EI2a) and the *risk of poverty and social exclusion rate* (EI2b). For the former specifically, it is the only region presenting a "positive" gap (i.e., higher levels of material and social deprivation in the region compared to national averages). It is however not surprising that Stara Zagora presents the highest values for both indicators, as the two are correlated, since the *risk of poverty and social exclusion rate* includes the *severe material and social deprivation rate* [40]. Additionally, the two indicators have historically been higher in Stara Zagora than at national level, illustrating once again a chronic and recurring phenomenon that still needs to be tackled. Western Macedonia presents the highest gap in terms of outmigration of young people (DI1) (Table 6). In fact, the net change of the population under 30 is lower in Western Macedonia compared to the Greek national average (regional average (−2.4 %) – national average (3.3 %) = −5.7 %). This signals a high outmigration of young people in Western Macedonia, which should thus be an area of priority for local policy makers, as it has been a historic and recurring problem. Interestingly, Istria is the only analysed region presenting a higher net change of population when compared to the national level (Table 6).

3.3. Application of the impact matrix to assess TJTPs of coal regions

Given the analysis of indicators, six TJTP were investigated to see whether identified vulnerabilities have been reflected and if so to what extent. The analysis indicates that all TJTPs have gaps in defining transition impacts. Most plans do not specifically address the "impacts" of the transition but rather outline needs, define "intended" actions, and provide "expected results". This might be the case because the status quo of certain transition issues is not well known. Furthermore, most plans lack to quantify impacts; instead, they are mainly qualitatively described. For example, the TJTP of Stara Zagora highlights the need to close knowledge gaps in term of reskilling needs[32]. Furthermore, the analysis found that there are positive and negative impacts to be expected in all the coal regions analysed. A pressing indicator in the indicator matrix was unemployment, which was given a lot of space in the TJTPs. Energy poverty (measured with the severe material and social deprivation rate in the indicator matrix) was addressed in most TJTPs. On the other hand, gender impacts were mainly not sufficiently addressed. Fig. 3 summarises the expected impacts of just transitions in the territories based on the authors' assessment of the TJTP. Following, a general overview of how the impacts were tackled in the TJTPs per dimension will be given, focusing mainly on the impacts found to be most pressing in the quantitative analysis.

3.3.1. Social impacts

In order to minimise the negative effects on employment, all TJTPs include a component which addresses the issue of **reskilling and retraining** [SIm1] of workers. Stara Zagora's TJTP notes that the region has a highly educated workforce, which is a significant advantage in light of the national shortage of skilled labour. The number of workers who will require retraining remains uncertain, as the TJTPs do not make any assumptions about this, or if they do, only for specific processes. Some of the plans explicitly state that socially vulnerable or disadvantaged individuals, youth groups (Asturias, Stara Zagora, Hunedoara) and women (Hunedoara) should benefit from retraining and upgrading programmes. On the other hand, Western Macedonia's TJTP states the reskilling of workers could result in some workers leaving the region once being reskilled, hence mixed impacts are expected. **Gender aspects** [SIm3] are hardly addressed, or the impact is not clearly defined. The exception is Asturias, which places a strong emphasis on the necessity of implementing training, qualification, and employment support initiatives with the goal of integrating women into the labour market. The TJTP of Hunedoara mentions the promotion of

Table 5
Application of the indicator matrix in the six coal regions considering data from 2019. For each indicator, when the regional value is higher than the EU value, it is highlighted in orange. In case no EU value is provided, the highest regional value is highlighted in orange.

Impact dimension	Indicator	Stara Zagora (BG)	Istria (HR)	Western Macedonia (EL)	Silesian Voivodeship (PL)	Hunedoara (RO)	Asturias (ES)	European Union (EU27)
Social	People living in households with very low work intensity (SI1)	7.50%	7.20%	16.10%	4%	7.60%	15.10%	N.A.
	Female unemployment rate (SI3)	3.40%	7.60%	32.90%	2.90%	2.40%	15.20%	7.00%
	Inability to keep the home adequately warm (SI6a)	30.10%	6.60%	17.90%	4.20%	9.30%	7.50%	6.90%
	Arrears on utility bills (SI6b)	27.60%	14.80%	32.50%	5.80%	13.70%	6.50%	6.20%
	Type of dwelling in cities or rural areas (rurality %) (SI7)	31.80%	37.60%	31.90%	41.20%	43.90%	26.10%	28.30%
Economic	Unemployment rate (EI1)	4.00%	6.40%	24.60%	2.40%	3.40%	14.20%	6.70%
	Severe material and social deprivation rate (EI2a)	28.30%	4.10%	15.20%	3.50%	12.90%	5.40%	N.A.
	Risk of poverty and social exclusion rate (EI2b)	37.90%	19.40%	33.60%	13%	24%	25%	N.A.
Demographic	Net change in the population under 30 (DI1)	-1.80%	8.40%	-2.40%	-0.50%	-2.50%	4.30%	N.A.
Environmental	Energy intensity of GDP (Kg oeq/1000€) (Env1a)	408.96	170.49	136.79	212.05	184.30	112.97	107.12
	Share of energy from renewable sources (Env1b)	21.55%	28.47%	19.64%	15.38%	24.29%	17.85%	19.89%
	Use of renewables and biofuels for heating and cooling (1000 kilos of oeq) (Env1c)	1404.394	1175.295	1520.575	8611.071	3495.856	5078.663	104143.112

entrepreneurial initiative, including female entrepreneurship. The TJTPs of Silesia, Stara Zagora and Istria do not address gender aspects at all.

The analysis of the indicators showed that the regions will be challenged by energy poverty (measured with the severe material and social deprivation rate). Indeed, **energy poverty** [SIm6] is identified as an impact of the transition in all plans except Istria. Hunedoara, Stara Zagora and Western Macedonia, see the transition plans as an opportunity to combat energy poverty by promoting renewable energy, self-consumption, energy storage and renewable hydrogen. The Silesian TJTP also includes the objective of developing social housing. Impacts on social infrastructure and energy poverty were also linked to impacts on overall **living conditions** [SIm7] (for Istria, Silesia, Western Macedonia). The main challenges to citizens' living conditions are the age of buildings, low energy efficiency standards and old heating systems (Silesia, Western Macedonia). In particular, it is mentioned that the region of Western Macedonia is characterised by the highest heating demand among the other Greek regions. However, just transitions can also promote better living conditions if measures are taken to improve the existing building stock.

3.3.2. *Economic impacts*

The primary focus of the TJTPs is on the impact of the transition processes on employment. This is in line with our analysis of indicators, where unemployment was seen as a priority indicator. The coal regions studied have already been affected by **unemployment** [EIm1] in various ways. It is also important to note that individuals employed in ancillary or indirect roles may be more susceptible to unemployment than those affected by mine closures. Consequently, regions such as Silesia are implementing redundancy procedures by devising and assisting redundant employees in mining and mining-related businesses. Nevertheless, the transition processes themselves are also anticipated to

Table 6
Gap between the regional and national level transition indicators in 2019.

Impact dimension	Indicator	Stara Zagora (BG)	Istria (HR)	Western Macedonia (EL)	Silesian Voivodeship (PL)	Hunedoara (RO)	Asturias (ES)
Social	People living in households with very low work intensity (SI1)	-1.70%	-0.30%	3.40%	-1%	3.10%	4.2%
	Female unemployment rate (SI3)	-0.50%	0.40%	11.40%	-0.70%	-1%	-0.80%
Economic	Unemployment rate (EI1)	-0.20%	-0.20%	7.30%	-0.90%	-0.50%	0.10%
	Severe material and social deprivation rate (EI2a)	6.20%	-0.50%	-0.60%	0%	-11.60%	-2.30%
	Risk of poverty and social exclusion rate (EI2b)	4.70%	-1.40%	4.60%	-4.90%	-12.10%	-1.20%
Demographic	Net change in the population under 30 (DI1)	-1.50%	9%	-5.70%	-1%	-1.20%	-5.30%

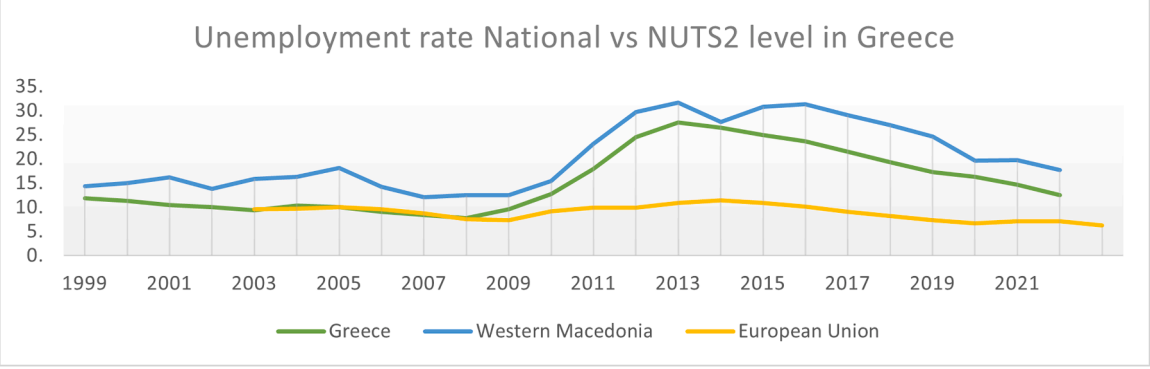

Fig. 1. Unemployment rate (in percentage) evolution in Greece, Western Macedonia and the EU.

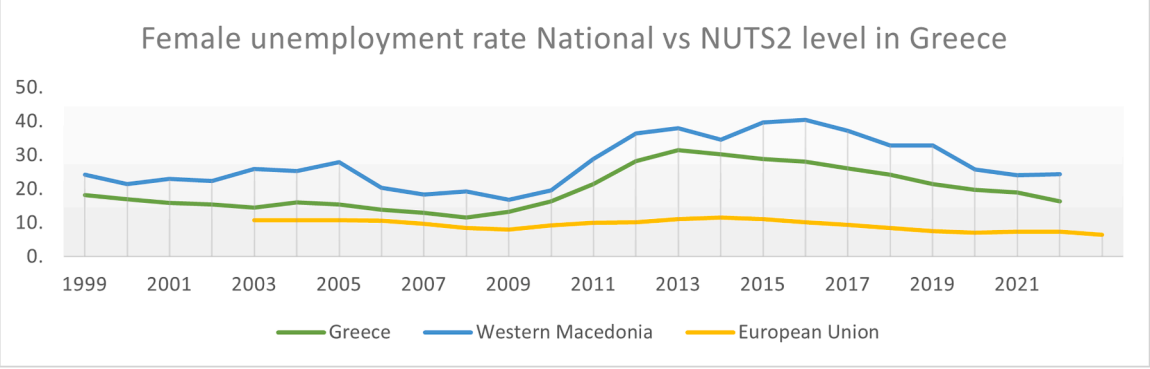

Fig. 2. Female unemployment rate (in percentage) evolution in Greece, Western Macedonia, and the EU.

Impact dimension	Impact categories	Expected impacts on the just transition territories					
		Stara Zagora (BG)	Istria (HR)	Western Macedonia (EL)	Silesian Voivodeship (PL)	Hunedoara (RO)	Asturias (ES)
Social impacts	Reskilling/upskilling of workers	Highly educated labour force; but reskilling and upscaling needed	Retraining of working via dedicated programmes	Risk outflow of skilled labour; reskilling need of workforce mentioned	Retraining need of thousands of workers	Investments in upskilling and/or retraining of jobseekers	Training and requalification of people is critical
	Access to public infrastructure and services	Developed educational and transport infrastructure	Reference only to education	Lack of adequate social infrastructure; objective to develop and improve social and health infrastructure, and access to services	Objective to improve education and quality of the environment, access to social services	Support rural communities without access or with limited access to social services, pre-hospital medical infrastructure and health units	Objective to promote social infrastructure
	Gender implications					Promotion of the principles regarding non-discrimination, equal opportunities, and gender; support female and youth entrepreneurship and enterprise development	Consideration of women in (re)training, along young people, and people over 55 years
	Community cohesiveness, social inclusion/exclusion	Disadvantaged and youth groups to be considered in upskilling and reskilling measures	Planned retraining and education programmes also for socially vulnerable and disadvantaged groups	Population movement expected to increase demographic problems and lead o disruption of social cohesion; measure mentioned for active inclusion of jobseekers	Objective to increase territorial cohesion (no details provided)	Consideration of disadvantaged workers and disabled workers to contribute to cohesion between people	"Social piece" at risk
	Socio-cultural identity	Contribution to the preservation of the region's energy profile	Reference only to cultural heritage and mining and industrial heritage in relation to products and services to be offered	Maintenance of the energy identity	Challenge of preserving identify; thus, plans to increase the level of social activity, particularly in the aspect, incl. social activation programmes		Reference only to promotion of historical and cultural heritage
	Energy poverty	Measures planned to with focus on energy poor and vulnerable consumers to addressing energy poverty		Objective to tackle energy poverty (no details on status quo and how)		High energy poverty; measures planned to combat energy poverty	Only mentioned energy poverty must be considered in context of renewable energy and self-consumption
	Living conditions		Objective to provide better living conditions	Objective to improve living conditions	Challenge and objective to increase quality of life of residents	Measure planned to retrain quality of life; greening and conversion of buildings	
Economic impacts	Unemployment	Up to 80% of the jobs in coal-based mining and energy production facilities could be affected; shift to new employment in industry-based jobs	Reduction of workforce in business that are closed; creation of new jobs in new businesses	Risk of increased unemployed; possibly new jobs in energy, industry and agricultural production	Reduction of employment; absorption of workers in the industries, incl. transport, logistics and construction	Unemployment of young workers; support service and active employment measures planned	Jobs will be affected; but potential to create more jobs than lost
	Closure of mines and extraction site	Pre-mine-closure planning (no details)	Planned investments in mining heritage and related tourism and products and services	Negative impacts on GDP, but positive ones on natural and ecological environment	Decrease in electricity production; decrease in incomes of municipalities		
	Decommissioning of fossil fuel-fired power plants	Planned substitution of coal-based power generation with renewable energy and other industrial activities		Reduction in activity, and this impacts on unemployment	Decommissioned enterprises negatively affect the economic and living attractiveness		
	Structural changes in related industries	Promising region for R&D and innovation in the field of new clean technologies	Plans to diversify the economy in agricultural, ICT, gaming, tourism; entrepreneurship support			Plans for sustainable economic diversification, incl. automotive, food, tourism, health, CT	Carbon-intensive industry needs to transform; opportunity for regional diversification
Demographic impacts	Migration of (young) people			Population movement, intra-regional transfer of businesses and workers of the regions	Objective to prevent or at least minimise outflow		
	Attractiveness to live and work in the region		Objective to increase attractiveness		Abandoned industrial activities (brownfields) reduce their attractiveness both in economic and residential terms		
Environmental impacts	Greenhouse gas emissions	Objective to transition to a carbon neutral industrial centre					Decarbonisation as opportunity for economic development
	Health, including pollution			Positive impacts on health due to emission reductions, but lack of social infrastructure expected to bring negative impacts	Improved air quality due to radical elimination of primary sources of air pollution		
	Nature restauration/ revitalisation, renaturation	Rehabilitation measures	Reduction of air, soil and water pollution	Promotion of natural wealth	Restoration of post-industrial land		Recovery of land

Fig. 3. Summary of the expected impacts of just transition in the regions based on the analysis of the TJTP. Traffic light: green = overall positive impact expected; yellow = mixed impacts – both positive and negative one; red = overall negative impact expected; blue = impact unclear; grey = not mentioned.

have a positive impact on employment, primarily due to the expansion of the renewable energy and rehabilitation and reconstruction sectors. For instance, the TJTP of Asturias posits that the energy transition could potentially generate up to 6300 jobs, in contrast to the 1316 direct jobs that will be affected [37].

The **closure of mines and extraction sites** [EIm2] is expected to have an impact on the regions, including on economic activity, employment and energy supply in the areas affected by the transition. Some plans include clear deadlines for the closure of (some) mines. For example, Western Macedonia plans to close most of its lignite plants by 2023. However, in the Greek National Energy and Climate Plan (NECP) preliminary draft from October 2023, the lignite phase-out was postponed to 2028 [56]. Other plans (e.g., Silesia) foresee a "gradual closure" of coal-fired power plants. As a result, the TJTPs identify economic diversification as a key measure to address mine closures.

3.3.3. *Demographic impacts*

Coal regions have already perceived an **emigration of people** [DIm1] from the region. This has also led to a decline in the work force. The migration of young people is not dealt with in depth in none of the TJTPs, even though it affects most regions. This phenomenon is due to the fact that lignite power stations are being closed down and many people working in the energy sector are losing their jobs. As a result, young people in particular are leaving these areas in search of a better and more sustainable future.

3.3.4. *Environmental impacts*

The just transition processes are expected to have a positive impact on **emission levels** [EnvIm1] and on the restoration and revitalisation of nature. In Silesia, the planned reduction in coal-fired power generation translates into a 62.1 % reduction in CO_2 emissions [35]. Economic transformation will be key to reducing emissions in carbon-intensive industries.

While the elimination of primary sources of air pollution will have a positive impact on **people's health** [EnvIm2], the health infrastructure in some regions (Western Macedonia, Hunedoara) is considered to be critically weak.

4. Discussion

The developed matrix tools allow the user to successfully deliver an initial ex-ante quantitative analysis of the status quo of transition impacts within the regions and to assess whether and how these impacts have been tackled in the TJTPs. Relating to the research questions, it was found that there are 16 main impacts resulting from the implementation of just transitions in coal regions, based on which the impact matrix was developed. However, not all of the found impacts were addressed in the TJTPs of the six considered coal regions. Additionally, a better quantification of the impacts is needed through the use of indicators, in order to better understand the status quo and individuate areas of intervention to prioritise. The two non-weighted matrices provide an innovative way of tackling this issue by performing a MCA, highlighting the most challenging impacts, and verifying whether these have been considered in the TJTPs and if so, how.

The developed matrices relate differently to the various definitions and interpretations of the concept of justice and just transition which are present in the literature. As mentioned in Section 1, hereby the definition of García-García et al. [5] was employed as it provides a rather holistic approach to the transition to more sustainable forms of energy systems. Nonetheless, the term originated within the labour movement and originally encompassed different social measures focusing on the workers' lives and rights [57]. By considering four different dimensions relating to justice and transitions, the developed matrices encompass different definitions of justice without discriminating or focusing on one specific aspect. In fact, if one were to consider a more social definition of just transition for example, the matrices could still be employed just by focusing on the social dimension. Additionally, no weighting of impacts and/or indicators was performed in this case, as mentioned in Section

2.2. Whereas this was done to have a non-weighted MCA, other such multidimensional analyses found in the literature did assign different weights to different impacts [13,23]. Once again, if one were to apply specific weights to the impacts and/or indicators depending on the focus of the definition and analysis being performed, this could always be done when employing the matrices. Hence, the developed methodology is fairly adaptable to different interpretations and analyses of just transitions.

The ex-ante quantitative analysis showed that Western Macedonia is the most negatively affected region among the six considered regions (for 4/12 indicators (Table 5)), confirming the results obtained by Vrontisi et al. [23]. However, the present matrix includes indicators that consider data obtained at the national level. While these indicators serve to give a complete picture of the regional status quo, they do not provide an optimal means of comparison between regions. For example, the three environmental indicators are only available at national level, and two of three are only available in absolute terms. The share of households living in a rural environment was also only available at national level. Romania has the highest level of rurality (Table 5); however, considering also that the share of rurality in Romania in 2019 is only 2.7 percentage points higher than in Poland, it is not safe to assume that Hunedoara has more households living in a rural setting than Silesia. Nevertheless, by focusing only on the indicators available at regional level, and comparing these with the national averages (Table 6), more precise results were obtained, confirming Western Macedonia as the most vulnerable region, once again confirming the results obtained by Vrontisi et al. [23].

The analysis of the TJTPs revealed important gaps in the quantification of transition impacts. In terms of qualitative socio-economic impacts, all TJTPs had a strong focus on employment. In contrast, less quantifiable impacts, (e.g., socio-cultural identity) were often neglected in the plans. The gaps in the qualification and quantification of the impacts show that further work is needed to better understand the impacts and define appropriate measures to minimise negative social, economic and demographic impacts. Additionally, none of the analysed TJTPs considered all 16 impacts. For example, while all plans consider employment and reskilling, three of the six analysed regions did not even address the gender implications in their TJTPs. This finding is in line with a recent study by CBE Bankwatch Europe [58], which shows that most of the money of the JTF goes to economic and environmental policy measures, while social policies are underrepresented.

4.1. Limitations and further research

The approach outlined in this report can help to better define and assess the regional impacts of the transition to climate neutrality and support the development of policies that minimise negative impacts and enable a truly just transition. However, there are some limitations.

The Eurostat repository was used as the sole source of data for the quantitative assessment. While it provides data for six different regions hence allowing for great breadth of research, it does not provide regional data for all the indicators considered. In fact, only for 1/12 indicators was NUTS3 level data available. Similarly, only 6 indicators were available at NUTS2 level (including those available at NUTS3 level) (Table 4). Additionally, the 3 environmental indicators were exclusively available at national level. This inevitably reduces the precision of the indicator matrix and shows the great lack of regional data to assess just transitions at least at a European level. National statistical institutions might provide such indicators at national level, but verification of such repositories was out of the scope of the present research. This is an important issue, as the lack of data availability hinders the delineation of quantitatively robust policies backed by precise modelling activities and does not allow to scientifically verify proposed policies. The strength of the choice of Eurostat data is nevertheless that the just transition approach developed here can be extended to a much larger set of regions in Europe. Additionally, only half of the impacts could be quantified. Hence, a more comprehensive quantification of the found impacts is also needed.

This study highlights three important points for further research. Firstly, in order to achieve greater precision, each region should be analysed using only regional data (as opposed to national data). Therefore, future research should use data not available in the Eurostat repository. Secondly, the comparison of different regions should be done at a lower geographical level, not considering regions from the whole continent, but perhaps only at the national level or European regional level (e.g., Southeastern Europe). This would also allow for a more accurate comparison, avoiding differences due to geographical or cultural reasons. Finally, the quantitative tool developed could potentially be extended to model future developments of each indicator resulting from the implementation of proposed policies. In essence, the current tool could be upgraded to become a modelling tool to simulate the effects of implementing different territorial just transition policies.

5. Conclusion

This research carried out a qualitative assessment of the TJTPs in six European coal regions and analysed the status quo of impact indicators for each region. It was shown that transitions away from coal have multiple impacts on societies and economies. Among the social, economic, demographic and environmental impacts, all TJTPs show a greater emphasis on the impact of employment and the measures to combat it, mainly through the retraining, upgrading and reintegration of workers negatively affected by the transition. A major blind spot is the impact of transition processes on the social and demographic fabric of society, including socio-cultural identity, where negative effects are expected to be high. Additionally, many impacts are not quantified in the TJTPs, which is also linked to the lack of regional data. However, quantification is crucial to better tailor regional interventions; for example, to know what role women can play in filling the employment gaps. The main objective of the indicator matrix is to provide the user with a clear overview of the regional status quo and to highlight the impacts of concern that should be given greater attention. The indicator matrix is not intended to be used on its own, but rather in conjunction with the impact matrix, to verify that the impacts of greatest concern have indeed been addressed in the TJTP. In conclusion, the approach outlined in this report can help to better define and assess the regional impacts of the transition to climate neutrality and support the development of policies that minimise negative impacts and thus enable a truly just transition.

CRediT authorship contribution statement

M. Peretto: Writing – original draft, Validation, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **W. Eichhammer:** Writing – review & editing, Supervision. **D. Süsser:** Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, 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.

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Data availability

All the data utilised is available on the Eurostat repository. All links to other type of data have been provided as references.

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