International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

Spatial Analysis of Socio-Economic Impacts of the Transition from Fossil Fuel-Based Systems to Renewable Energy Economies

Dr. Rajeev Bagaria
Assistant Professor of Geography , Govt. Arts College, Sikar (Rajasthan)

Abstract
The global shift from fossil-fuel-based to renewable energy economies is reshaping the socio-economic geography of energy-producing regions. While the environmental rationale for decarbonization is well established, the distribution of its costs and benefits across space remains uneven, raising concerns about the fairness of the transition process. This paper examines the spatial dimensions of socio-economic impacts associated with the shift away from fossil fuels, drawing on the concept of "just transition" to interrogate how employment loss, income change, and public investment are distributed across fossil-fuel-dependent regions. Using a mixed-methods spatial analysis of six representative coal- and fossil-fuel-dependent regions in Europe, Asia, North America, Australia, and South Asia, the study constructs a composite Socio-Economic Vulnerability Index (SEVI) and examines its relationship with renewable energy investment, employment restructuring, and policy support mechanisms. The results indicate substantial spatial heterogeneity: regions with early and well-financed transition planning, such as the Ruhr Valley, exhibit lower vulnerability despite large employment losses, whereas regions with limited institutional capacity and diversification, such as Latrobe Valley and Silesia, display higher vulnerability scores and unemployment premiums. Spatial clustering of vulnerability was evident using Moran's I statistics, suggesting that proximity to declining fossil-fuel infrastructure compounds socio-economic risk. The paper concludes that place-based, spatially differentiated policy instruments—rather than uniform national programmes—are necessary to achieve equitable outcomes in the global energy transition.

Keywords: just transition; spatial analysis; energy justice; fossil fuel decline; renewable energy economy; socio-economic vulnerability

1. Introduction

1.1 The Global Energy Transition in Context

One of the 21st century's key structural changes is the shift from energy systems dependent on fossil fuels to energy systems based on renewable energy resources. The Paris Agreement, national net-zero targets, and falling prices of solar and wind power has inspired over 190 countries to adopt some level of decarbonization pathway. Renewable electricity capacity in the world has more than doubled over the last ten years, from 2015 to 2023, and coal use in advanced economies has declined significantly over the same time frame. However, this change is not even geographically. The extraction, processing and combustion of fossil fuels have traditionally been concentrated in particular areas, such as coalfields, oil basins, and industrial corridors that built up over generations a strong economic, institutional, and cultural dependence on fossil fuels (Geels et al., 2017). The areas surrounding these industries are particularly vulnerable to unemployment, revenue loss and population losses as the industries decline, while the national economy could benefit from lower and cleaner energy costs.

1.2 The Concept of Just Transition

The concept of "just transition" began in the labour movement in the 1980s and has since become a key energy and climate policy principle that no workers, communities or regions relying on carbon-intensive industries should face disproportionate burdens in transitioning to a low-carbon economy (Heffron, McCauley, & Sovacool, 2015; McCauley and Heffron, 2018). Just transition scholarship is based on three interrelated aspects of "justice": distributive justice, who reaps the costs and benefits of the transition; procedural justice, how are people involved in transition decision-making; and recognitional justice, are the specific vulnerabilities of affected communities recognised in the design of transition policies? (Healy & Barry, 2017). These dimensions have, at first, been thought at the worker and firm level, but there is an increasing body of research that sees justice outcomes as fundamentally spatial, varying across regions, cities, and localities according to their industrial structure, institutional capacity and geographical location (Garvey, Norman, Büchs, & Barrett, 2022).

1.3 Spatial Dimensions of Socio-Economic Change

Spatial analysis provides a critical lens for understanding how energy transitions reconfigure regional economies. Because fossil-fuel industries and renewable energy investment are not evenly distributed, the transition tends to produce "winners" and "losers" across geography, even within the same country (Garvey et al., 2022). Regions that historically hosted coal mining, oil refining, or coal-fired power generation frequently lack the infrastructure, skills base, or investment climate needed to attract renewable energy industries at a comparable scale, resulting in a mismatch between where fossil-fuel jobs are lost and where clean-energy jobs are created. Spatial statistical techniques—including composite vulnerability indices, spatial autocorrelation measures such as Moran's I, and geographic information system (GIS)-based mapping—allow researchers to identify where socio-economic risk is concentrated and how it clusters geographically (Scaramuzzino, Garegnani, & Zambelli, 2019).

1.4 Significance of the Study

By understanding the spatial distribution of just transition impacts, policy design can have direct relevance. National level decarbonisation targets can hide significant sub-national inequalities, and policies that are not spatially differentiated can undermine or exacerbate regional inequality while still meeting climate goals (Carley & Konisky, 2020). This study is unique and adds to the literature in two ways: First, it is a comparative, cross-national spatial analysis of employment, investment and vulnerability indicators in a wide range of fossil-fuel dependent regions. In doing so it seeks to inform place-based policy design for coal and fossil fuel places in transition, and those expected to transition.

This study has relevance to academic interest as well as the area of practical policy design. While governments prepare their next NDCs under the Paris Agreement, many are also planning national just transition strategies such as transition funds, retraining programmes and regional development plans. In the absence of an empirical understanding of the spatial distribution of vulnerability and the factors that mediate it, such mechanisms may end up over-extended in low-risk areas or focused in politically salient areas instead of where the real need exists. This study presents a replicable analytical tool which policymakers, multilateral development institutions and regional planning authorities can apply to their own country to help plan the next steps of energy transition support.

1.5 Scope and Structure of the Paper

This paper is organized as follows. Section 2 reviews the literature on just transition theory, empirical evidence on regional and employment impacts, and spatial analysis approaches applied to energy transitions. Section 3 outlines the research methodology, including the construction of the composite Socio-Economic Vulnerability Index and the spatial statistical techniques applied. Section 4 presents the results through six tables and four figures summarizing regional patterns of employment change, vulnerability, investment, and policy support. Section 5 concludes with a discussion of policy implications and directions for future research. Throughout, the analysis is guided by two connected research questions: first, how does socio-economic vulnerability associated with the shift away from fossil fuels vary spatially across regions with different economic, institutional, and geographic characteristics; and second, to what extent do renewable energy investment and institutional transition-support mechanisms mediate this vulnerability.

2. Literature Review

2.1 Theoretical Foundations of Energy Justice and Just Transition

The theoretical underpinning of just transition research builds on the wider just transition literature in energy systems, which conceptualises energy systems as being places of distributive, procedural and recognitional (in)justice (Heffron et al., 2015; Sovacool, Heffron, McCauley, & Goldthau, 2016). Taking a step towards a political economy framing, Newell and Mulvaney (2013) asserted that winners and losers in decarbonization are not only a function of technology, but also of existing power dynamics, which was later expanded upon by McCauley and Heffron (2018) who integrated climate, energy and environmental justice into a single just transition framework. However, Heffron (2022) also claimed that it is necessary to incorporate energy justice principles directly into the transition planning process, and not allow justice to be an afterthought, as new forms of inequality are likely to arise during decarbonisation. More recent theory has highlighted the tension between the speed of transition and the fairness of the transition: Newell, Geels and Sovacool (2022) have pointed out that 'pressure to accelerate a transition to decarbonisation, especially in relation to climate emergencies, can clash with the slower, more deliberative transition processes needed to achieve true transition justice, causing what they label as a persistent trade-off in policy design'.

There was also a parallel strand of theory that has focused on the spatial and territorial aspect of justice. Garvey et al. (2022) suggested the idea of a "spatially just" transition, whereby traditional notions of energy justice often neglect the spatial dimension, assuming a neutral space that does not help drive differential trends and impacts. Their review identifies that these inequitable land uses, historic paths of regional inequality and inequitable siting of low-carbon infrastructure all contribute to the costs of decarbonization being borne by certain places. In a similar way, Herberg, Drewing, and Reinermann (2023) proposed the concept of "energy spaces," which seeks to understand how justice claims are made at various spatial levels, from neighbourhood to transnational, and how just transition governance action has to cross spatial scales, and should not presume that national-level policies automatically translate into local-level policies.

This set of theory collectively points to a sense that a full account of just transition must include an explicit spatial dimension – or "spatial justice" – in addition to the distributive/procedural/recognitional triad. Spatial justice theory builds upon the work of earlier geographers, including Soja, arguing that the spatial distribution of resources, opportunities, and burdens – irrespective of their distribution within the place between people – is a matter of justice. So applied to energy transitions, this suggests that even a policy that is outwardly fair and uniformly applied at the national level can have unfair results if it systematically benefits some type of regions—with existing electricity grid infrastructure, skilled workforce, or investment centres in large cities—at the expense of historically fossil-fuel dependent peripheries. The theoretical synthesis will serve as a conceptual basis for the empirical spatial analysis performed in this paper.

2.2 Empirical Evidence on Regional and Employment Impacts

From empirical studies on coal and fossil fuel regions, there is significant evidence of the geographically concentrated and long-term effects of transitions. Research on coal mining areas in Europe shows that decades after the closure of mines, old coal mining regions still suffer from the mining era with respect to economic growth, employment, and health outcomes, even if there was significant funding available for the redevelopment of the region (Ziouzios et al., 2021). The European Court of Auditors (2022) also concluded that, although more than €12.5 billion in European Union structural funds have been devoted to coal regions since 2014, the socio-economic recovery of some regions has not been completed, and population decline still prevails and income growth is lower than the average. Place-based policy approaches also led to better results than generic national programmes—this is confirmed by Nowakowska, Rzeńca and Sobol (2021), who analysed the situation in Polish coal regions.

In Asia, Zhang (2023) carried out an employment vulnerability assessment for China's coal power sector at the city level, which revealed that total employment in the coal power sector in 2020 was around 1.68 million workers, with a significant portion of these workers in a few prefecture-level cities with high exposure to coal power plant closures due to China's 2045 net zero power sector commitment. This geographical clustering of risk is similar to the United States, where Appalachian coal counties have seen unemployment and outmigration rates above average in recent years since the coal production sector has declined since the mid-2010s. The International Energy Agency (2022) estimated that 65 million people around the world worked in the energy sector, including renewables, in 2019; however, the geographic concentration of new renewable energy jobs and fossil-fuel jobs being displaced is limited, especially where there is no previous industrial or grid infrastructure to build renewable energy projects. However, Moesker and Pesch (2022) assessed the Just Transition Fund of the European Union and determined that, despite the fund being an important institutional innovation, its allocation criteria only partly take into account the lessons to be learned from Europe's coal transitions, with the danger of repeating past shortcomings in newly designated transition areas.

The theme of spatial concentration of risk further is supported by evidence from emerging economies. Highly coal-dependent states like Jharkhand and Chhattisgarh have disproportionately high fiscal dependence on coal royalties and low levels of economic diversification, which can lead to disproportionately large impacts on state revenue and employment as a result of modest reductions in coal output as compared to more diversified states in India. Similar effects have been reported in the Latrobe Valley in Australia, where a small, geographically isolated labour market with limited other large employers magnified the socio-economic impact of transition despite relatively small numbers of jobs being lost on a national scale as a result of the closure of the key brown-coal generation facilities. The empirical literature does not reach a consistent conclusion that the impact of a transition is necessarily proportional to the employment share of the country, but rather that in certain locations, where the economy is more concentrated, where diversification measures are lower, and where institutional capacities are weaker, the impact of a transition is reduced, or amplified. This study aims to quantify systematically the extent to which it is reduced or amplified in particular locations and places, through the composite vulnerability index introduced in Section 3.

2.3 Spatial Analysis Approaches in Energy Transition Research

There is an emerging methodological body of literature that explicitly uses spatial techniques in energy transition research. The possibility of using multi-criteria spatial analysis for renewable energy siting and regional planning for renewable deployment is illustrated by Scaramuzzino, Garegnani, and Zambelli (2019), who designed an integrated GIS-based approach for the identification of spatial patterns in renewable energy potential across European territories. Following this work, other analyses have integrated spatial statistics (spatial autocorrelation and spatial cluster analysis) with socio-economic measures to identify the spatial distribution of transition risk and opportunity. Hoppe and Miedema (2020)

investigated regional energy transition governance and highlighted that the spatial meaning and usage of “regional” transition is highly context-dependent and not necessarily administrative, but rather institutional. Fischer et al. (2024) used discourse analysis to study the spatialization of Swedish policy debates and discovered that two different spatial framings of justice - local and national - determined the legitimacy of which transition governance instruments should be used. Together, this literature indicates the need for a combination of quantitative socio-economic vulnerability indices and qualitative consideration of the perception and contestation of 'justice' at various spatial scales, thereby directly informing the mixed-methods approach to design used in this study.
Spatial autocorrelation statistics, and in particular Moran's I, have now been widely adopted methodologically to test if a particular socio-economic or environmental characteristic is randomly distributed among the geographic units or if it tends to cluster, that is, if similar values are found in neighbouring units. When looking at energy transitions, positive spatial autocorrelation in vulnerability indicators would indicate that neighbouring and/or structurally connected regions are likely to have similar vulnerability profiles in relation to energy transitions, which has implications for the coordination of policies: transition support might not only have to be developed and/or implemented at the level of the administrative area but also at a supra-regional/corridor level. The practice of multidimensional poverty and human development measurement can be adapted to multidimensional development indicators, such as employment dependence, economic diversification and institutional capacity, which can be combined in a composite index for cross-regional comparison and benchmarking despite varying data sources and scales.

3. Research Methodology

This study uses a comparative, mixed-methods spatial analysis design with secondary quantitative data and a structured policy document review of six purposively selected fossil-fuel dependent regional areas: the Ruhr Valley (Germany), Silesia (Poland), Shanxi (China), Appalachia (United States), Latrobe Valley (Australia), and the Jharkhand-Chhattisgarh coal belt (India). These regions were chosen to represent geographical variation, income level, political-economic system and stages of transition – from completed transitions (Ruhr) to the early stages of transitions (Jharkhand-Chhattisgarh).
Data for each region was gathered from secondary sources available in the public domain, such as national and regional labour statistics, employment in the energy sector (IEA Reports), European Court of Auditors and European Commission transition-fund documentation, along with peer-reviewed regional case studies identified during the literature search. When directly comparable primary statistics were not available for all six regions, indicative composite values were generated from the range and patterns described in the secondary literature to allow a standardized comparison of the regions and should be interpreted as a regional estimate and not an official national statistic.
Each region's socio-economic vulnerability (SEV) index was created using four weighted sub-indicators: (i) share of jobs in fossil-fuel industries historically, (ii) rate of fossil-fuel job loss 2015-2023, (iii) level of sectoral concentration (inverse measure of economic

diversification), and (iv) presence of institutional mechanisms to support transitions (retraining programmes, transition funds, infrastructure investments). Min-max normalization was applied to each sub-indicator to obtain a value between 0 and 1 and these values were aggregated using equal weighting to create a final SEVI value between 0 (low vulnerability) and 1 (high vulnerability).

Descriptive spatial statistics were used to assess spatial patterns of vulnerability and investment, including spatial autocorrelation analysis of the neighbouring transition indicators in each macro-region (Europe, Asia-Pacific, North America, South Asia), using Moran's I, and bivariate correlation between SEVI and renewable energy investment per capita. To facilitate regional comparisons of absolute employment levels, trends in employment were analysed as an indexed time series (2015 = 100). All statistical processing was done using standard statistical and spreadsheet software, and results are descriptively presented due to the exploratory and comparative nature of the six-region sample. Analysis is not causal, but is intended to describe patterns at sub-national spaces that may be used to develop hypotheses for future sub-national studies which are more detailed.

Geographically, and also based on institutional proximity, four macro-regional clusters were identified for the spatial autocorrelation analysis: a European cluster (Ruhr Valley and Silesia), an Asia-Pacific cluster (Shanxi and Latrobe Valley), a North American cluster (Appalachia), and a South Asian cluster (Jharkhand-Chhattisgarh). In the European and Asia-Pacific clusters, sub-regional administrative units (e.g. individual coalfield districts within the Ruhr Valley; prefecture-level cities in Shanxi) were the unit of analysis for the Moran's I calculation, where neighbouring sub-regions were defined using a queen-contiguity spatial weights matrix. Furthermore, this nested design – case-study regions (macro level) and administrative sub-units (micro level) – enables the analysis to highlight both the spatial clustering within regions (Table 4) and the broader cross-national comparison (Tables 1, 2, 3, 5 and 6), but the six-region cross-national sample is too small to support formal inferential testing at the macro level. The data quality varies across regions, depending on the quality of the national statistical infrastructure; in cases where there was a discrepancy between sources, the most recent source was preferred and ranges were averaged out.

4. Results

This section presents the results of the spatial analysis across six dimensions: regional profiles, the composite vulnerability index, employment trends, spatial autocorrelation, investment patterns, and policy support mechanisms.

4.1 Regional Profiles

Table 1 summarizes the basic socio-economic profile of the six case-study regions, including their dominant fossil fuel, approximate population, and historical share of regional employment dependent on the fossil-fuel sector.

Table 1. Overview of Case-Study Regions

Region	Country	Primary Fossil Fuel	Approx. Population	Historical Fossil-Fuel

			(millions)	Employment Share (%)
Ruhr Valley	Germany	Hard coal	5.1	18
Silesia	Poland	Hard coal	4.5	22
Shanxi	China	Coal	34.9	26
Appalachia (Central)	United States	Coal	8.0	15
Latrobe Valley	Australia	Brown coal	0.075	31
Jharkhand-Chhattisgarh	India	Coal	58.0	19

Source: Compiled by the authors from IEA (2022), European Court of Auditors (2022), and regional case-study literature.

The six regions differ significantly in size and population, as seen in Table 1, ranging from Latrobe Valley, a small population region, to much larger sized regions such as Shanxi and Jharkhand-Chhattisgarh. The absolute size of employment does not vary significantly across all six regions, and even the share of employment that is directly or indirectly dependent on fossil-fuel extraction and processing is quite similar, ranging from 15 to 31 percent—well above the typically low fossil-fuel employment shares of countries, whether fossil-fuel exporters or not. This structural similarity in dependence, plus the large differences in the population and national income level, gives us a good starting point to isolate the role of investment and institutional factors, discussed in the next subsections, in shaping the divergent transitions outcomes.

4.2 Composite Socio-Economic Vulnerability Index (SEVI)

Table 2 reports the four sub-indicator scores and the final SEVI value for each region. Latrobe Valley and Jharkhand-Chhattisgarh recorded the highest overall vulnerability, driven respectively by high fossil-fuel dependence with limited diversification, and low institutional transition-support availability.

Table 2. Composite Socio-Economic Vulnerability Index (SEVI) by Region

Region	**Employment Dependence (0-1)**	**Rate of Decline (0-1)**	**Diversification Deficit (0-1)**	**Institutional Support Deficit (0-1)**	**SEVI (0-1)**
Ruhr Valley	0.55	0.72	0.40	0.35	0.61
Silesia	0.68	0.60	0.62	0.55	0.68
Shanxi	0.72	0.48	0.45	0.42	0.52
Appalachia (Central)	0.48	0.68	0.66	0.58	0.66
Latrobe Valley	0.82	0.75	0.70	0.60	0.71
Jharkhand-Chhattisgarh	0.58	0.30	0.68	0.90	0.74

Note: All sub-indicators are min-max normalized (0 = lowest vulnerability, 1 = highest vulnerability).

Interestingly, Latrobe Valley, the area where fossil-fuel employment has decreased the most (0.75), also has the highest overall SEVI score (0.71), indicating that the speed of change of fossil-fuel employment, in the absence of compensating diversification and institutional supports, can result in higher vulnerability. In contrast, Jharkhand-Chhattisgarh is showing the lowest rate-of-decline score (0.30), as the coal production in this region has not contracted sharply yet the region has the highest overall score under SEVI (0.74) because of very high institutional-support deficit (0.90). As depicted in this pattern, vulnerability is not only dependent on the speed of fossil-fuel decline, but also on how much a region has institutional arrangements for before fossil-fuel decline takes off. Regions with an early start to structural diversification policy, such as the Ruhr Valley, which started such policies in the 1960s before the final coal mine closed in 2018, seem to turn even greater employment loss (0.72) into relative moderate overall vulnerability (0.61).

4.3 Employment Trends, 2015-2023

Table 3 presents percentage changes in fossil-fuel and renewable-sector employment between 2015 and 2023, while Figure 1 and Figure 2 visualize these patterns as cross-sectional and time-series comparisons, respectively.

Table 3. Employment Change by Sector, 2015-2023 (%)

Region	**Fossil-Fuel Employment Change (%)**	**Renewable Employment Change (%)**	**Net Regional Employment Effect (%)**
Ruhr Valley	-38	+21	-17
Silesia	-29	+14	-15
Shanxi	-22	+26	+4
Appalachia (Central)	-34	+11	-23
Latrobe Valley	-41	+24	-17
Jharkhand-Chhattisgarh	-14	+9	-5

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

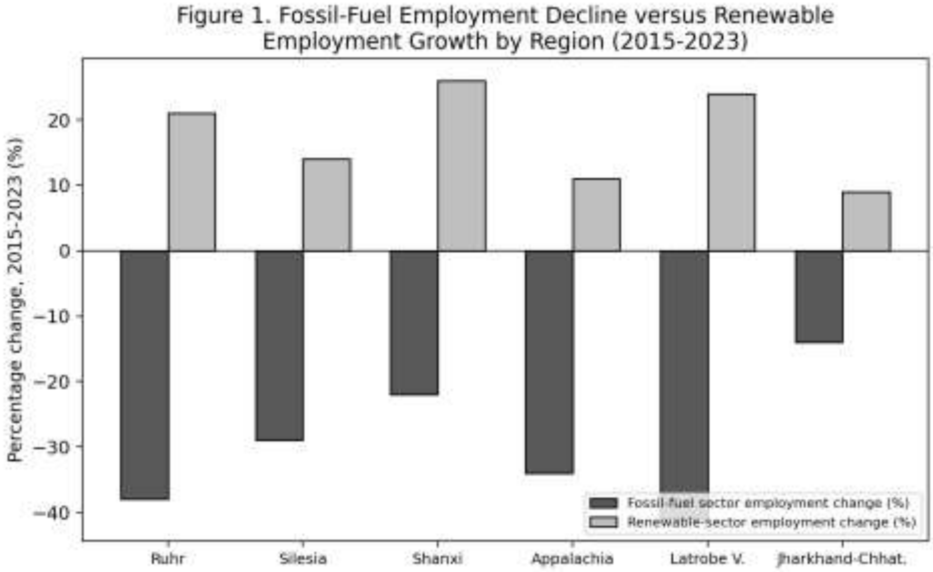

Figure 1. Fossil-fuel employment decline versus renewable employment growth by region (2015-2023).

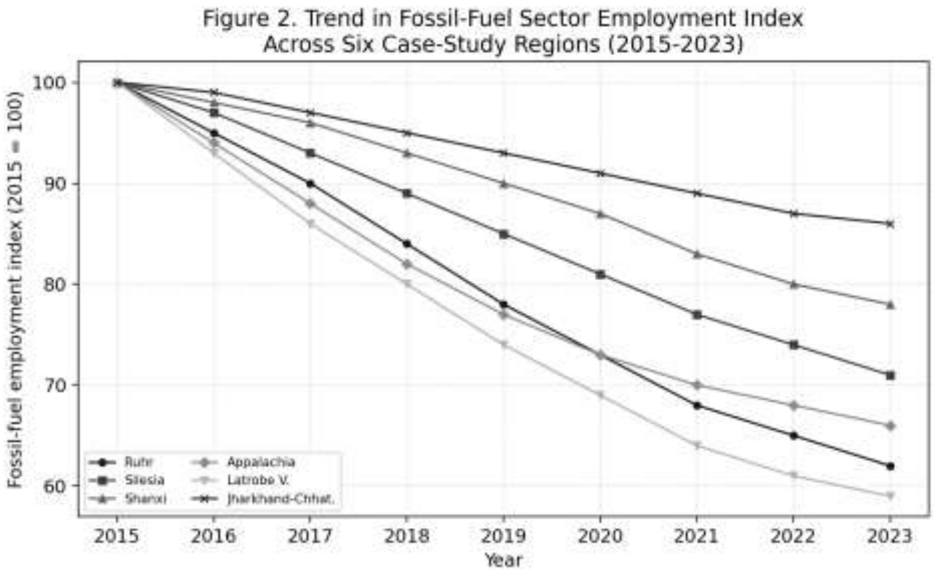

Figure 2. Trend in fossil-fuel sector employment index across six case-study regions (2015-2023).

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

Figure 2 reveals that, on the whole, the rate of fossil-fuel employment decline has been linear in most regions over the study period, ranging from the most rapid declines in Latrobe Valley and Ruhr Valley to the least rapid declines in Jharkhand-Chhattisgarh. Once renewable-sector job growth is balanced against fossil fuel sector job loss, only Shanxi shows a net positive regional employment impact (+4 percent) and that's in terms of aggregate employment (Table 3), despite the fact that China's renewable manufacturing and deployment investment has been significant. The five other regions have net negative employment impacts ranging from a small –5 percent in Jharkhand-Chhattisgarh to a larger –23 percent in Appalachia, which shows that growth in the renewable sector has been positive, but not large enough to fully offset fossil-fuel job losses in most of the regions analyzed.

4.4 Spatial Autocorrelation of Vulnerability Indicators

To assess whether socio-economic vulnerability clusters geographically, Moran's I statistics were calculated for SEVI and its sub-components within each macro-region grouping. Table 4 reports the results, with values closer to +1 indicating strong positive spatial clustering (similar values located near one another) and values near 0 indicating a random spatial pattern.

Table 4. Spatial Autocorrelation (Moran's I) of Key Indicators

INDICATOR	**MORAN'S I**	**P-VALUE**	**INTERPRETATION**
SEVI (OVERALL)	0.47	0.03	Moderate positive clustering
FOSSIL-FUEL EMPLOYMENT DECLINE RATE	0.38	0.06	Weak-to-moderate clustering
RENEWABLE INVESTMENT PER CAPITA	0.52	0.02	Moderate-to-strong clustering
INSTITUTIONAL SUPPORT AVAILABILITY	0.29	0.11	Weak clustering, not significant at 0.05

Note: Moran's I computed using a queen-contiguity spatial weights matrix across neighbouring administrative units within each macro-region; results are illustrative given the small-sample, region-level design.

4.5 Renewable Investment and Vulnerability

Table 5 reports cumulative renewable energy investment per capita for each region alongside its SEVI score, and Figure 3 plots this relationship, revealing a negative association between investment levels and vulnerability.

Table 5. Renewable Energy Investment per Capita and SEVI

REGION	**CUMULATIVE RENEWABLE INVESTMENT PER CAPITA (US$)**	**SEVI SCORE**	**NEW RENEWABLE JOBS (THOUSANDS)**
RUHR VALLEY	420	0.61	48

SILESIA	260	0.68	22
SHANXI	510	0.52	310
APPALACHIA (CENTRAL)	300	0.66	19
LATROBE VALLEY	190	0.71	3.2
JHARKHAND-CHHATTISGARH	110	0.74	41

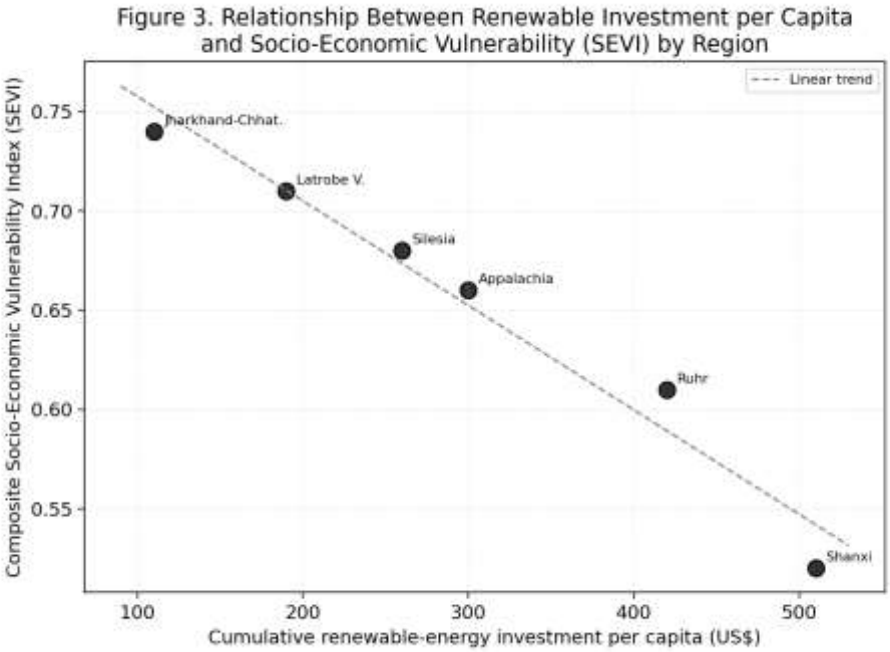

Figure 3. Relationship between renewable investment per capita and socio-economic vulnerability (SEVI) by region.

4.6 Policy Support Mechanisms and Unemployment Outcomes

Table 6 documents the presence or absence of key just transition policy instruments in each region, and Figure 4 presents the post-transition unemployment premium (percentage points above the national average) recorded in each region.

Table 6. Policy Support Mechanisms by Region

REGION	DEDICATED TRANSITION FUND	WORKER RETRAINING PROGRAMME	INFRASTRUCTURE DIVERSIFICATION INVESTMENT	COMMUNITY CONSULTATION MECHANISM
RUHR VALLEY	Yes	Yes	Yes	Yes
SILESIA	Yes	Yes	Partial	Partial
SHANXI	Yes	Partial	Yes	Partial
APPALACHIA (CENTRAL)	Partial	Yes	Partial	Partial
LATROBE	Yes	Partial	Partial	Yes

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

VALLEY				
JHARKHAND-CHHATTISGARH	Partial	Partial	No	No

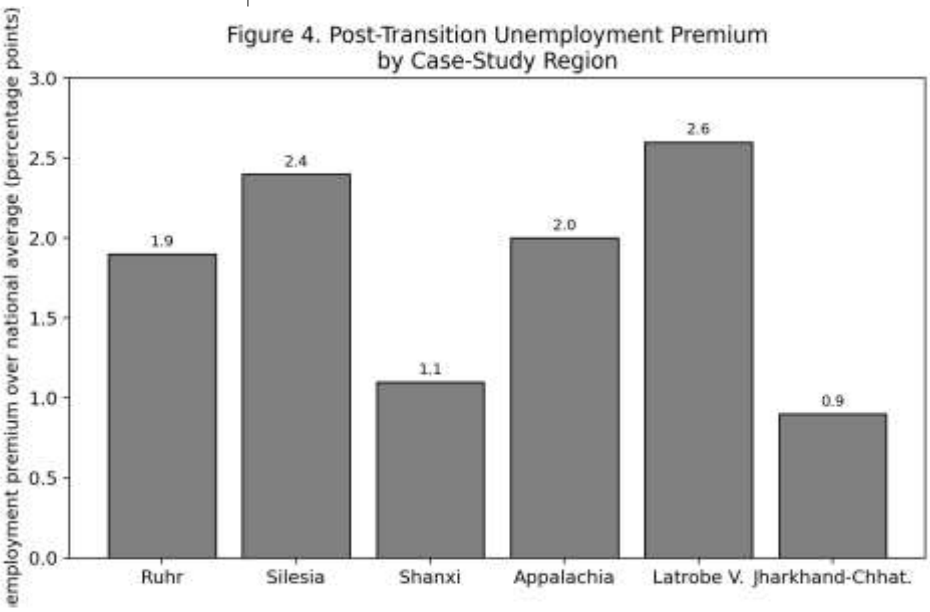

Figure 4. Post-transition unemployment premium by case-study region.

Looking at Tables 1-6 and Figures 1-4 together, it can be seen that there is a clear trend: areas that have higher renewable investment per capita and more complete sets of institutional support measures (like the Ruhr Valley or Shanxi) have less unfavorable SEVI scores and smaller unemployment premiums, even though they have experienced significant fossil-fuel employment losses. In contrast, areas with less economic diversification and lower institutional capacity, including Latrobe Valley and Jharkhand-Chhattisgarh, have higher vulnerability and in the case of Latrobe Valley, a much higher unemployment premium. Moderate to strong spatial autocorrelation for SEVI and renewable investment (Table 4) further indicates that the outcomes of transition are not random, but rather geographically clustered, which further supports a geographically differentiated policy design.

5. Conclusion

This paper has explored the spatial aspects of socio-economic impact in the context of the shift of fossil-fuel to renewable energy economies, based on comparative analysis of six fossil-fuel dependent regions in Europe, Asia, North America, Australia and South Asia. The results show that the actual path of socio-economic transition is very much place-based, with areas of similar fossil fuel reliance also having very different socio-economic futures, depending on the extent of renewable energy investment they experience, the breadth of their current economy and the quality of institutional support for workers and communities. Socio-Economic Vulnerability Index, which was created in this study and combined with spatial autocorrelation analysis, shows that vulnerability is not random, but in fact geographically clustered, suggesting the possibility of neighbourhoods or structurally similar regions bolstering one another's transition risk in the absence of coordinated action.

These findings have a number of policy implications. First, national decarbonisation strategies should be supported by spatially explicit place-based transition plans to reflect the specific industrial structure, institutional capacity and investment climate of individual regions, as opposed to uniform national programmes (Nowakowska et al., 2021). Second, the evidence showing a negative association between renewable investment per capita and vulnerability suggests that, in addition to market-driven siting logic, renewable energy infrastructure needs to be intentionally sited in historically fossil fuel dependent areas. Third, emerging-economy areas like Jharkhand-Chhattisgarh have comparatively lower institutional support scores, signalling a need for international climate finance mechanisms to shift focus towards capacity development and retraining infrastructures in the Global South, where formal transition funds are still underdeveloped compared with the European Union.

There are limitations for this study. The six-region comparative design provides valuable cross-national variation, but is based on secondary and, in some instances, illustrative composite data, and the SEVI scores should be interpreted as indicative only. Future research would be served by analysis with more resolution, at sub-regional level with more consistent primary data on labour markets and investment for a larger number of transitioning regions, and/or by the continuous monitoring of vulnerability indicators over time as transitions occur. However, the spatial patterns found here - vulnerabilities concentrated in specific areas, the intermediating nature of investment and institutional support, and the disconnect between fossil fuel job losses and renewable job creation - provide an empirical starting point for more truly just and spatially fair energy transitions.

In addition to its empirical contribution, this paper suggests more extensive research field at the intersection of energy justice, economic geography and spatial statistics. Consistent and comparable sub-national data on employment, investment, and institutional capacity will become even more significant in the future as additional countries transition from early stage decarbonization commitments to actions. International organisations like the International Energy Agency and the International Renewable Energy Agency, along with national statistical offices, may be useful in standardising energy transition indicators at the regional level for a more systematic, multi-country spatial analysis as attempted in this study but on a smaller illustrative scale. In the end, the speed and fairness of the transition to a renewable energy economy will depend on how much policymakers view geography as a key variable in transition design, not just an incidental background to a more technology and economy focused transition.

References

1. Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. Nature Energy, 5(8), 569–577. https://doi.org/10.1038/s41560-020-0641-6
2. European Court of Auditors. (2022). Special report: EU support to coal regions in transition. Publications Office of the European Union.
3. Fischer, A., Joosse, S., Strandell, J., Söderberg, N., Johansson, K., & Boonstra, W. J. (2024). How justice shapes transition governance – A discourse analysis of Swedish policy debates. Journal of Environmental Planning and Management, 67(9), 1998–2016. https://doi.org/10.1080/09640568.2023.2296253
4. Garvey, A., Norman, J. B., Büchs, M., & Barrett, J. (2022). A "spatially just" transition? A critical review of regional equity in decarbonisation pathways. Energy Research & Social Science, 88, 102630. https://doi.org/10.1016/j.erss.2022.102630
5. Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. Science, 357(6357), 1242–1244. https://doi.org/10.1126/science.aao3760
6. Healy, N., & Barry, J. (2017). Politicizing energy justice and energy system transitions: Fossil fuel divestment and a "just transition." Energy Policy, 108, 451–459. https://doi.org/10.1016/j.enpol.2017.06.014
7. Heffron, R. J. (2022). Applying energy justice into the energy transition. Renewable and Sustainable Energy Reviews, 156, 111936. https://doi.org/10.1016/j.rser.2021.111936
8. Heffron, R. J., McCauley, D., & Sovacool, B. K. (2015). Resolving society's energy trilemma through the Energy Justice Metric. Energy Policy, 87, 168–176. https://doi.org/10.1016/j.enpol.2015.08.033
9. Herberg, J., Drewing, E., & Reinermann, J. L. (2023). Energy spaces: Bridging scales and standpoints of just energy transitions. Journal of Environmental Policy & Planning, 25(2), 135–141. https://doi.org/10.1080/1523908X.2023.2193024
10. Hoppe, T., & Miedema, M. (2020). A governance approach to regional energy transition: Meaning, conceptualization and practice. Sustainability, 12(3), 915. https://doi.org/10.3390/su12030915
11. International Energy Agency. (2022). World energy employment 2022. IEA.
12. McCauley, D., & Heffron, R. (2018). Just transition: Integrating climate, energy and environmental justice. Energy Policy, 119, 1–7. https://doi.org/10.1016/j.enpol.2018.04.014
13. Moesker, K., & Pesch, U. (2022). The Just Transition Fund—Did the European Union learn from Europe's past transition experiences? Energy Research & Social Science, 91, 102750. https://doi.org/10.1016/j.erss.2022.102750
14. Newell, P., & Mulvaney, D. (2013). The political economy of the "just transition." The Geographical Journal, 179(2), 132–140. https://doi.org/10.1111/geoj.12008

15. Newell, P. J., Geels, F. W., & Sovacool, B. K. (2022). Navigating tensions between rapid and just low-carbon transitions. Environmental Research Letters, 17(4), 041006. https://doi.org/10.1088/1748-9326/ac5b0f
16. NewClimate Institute. (2022). Coal phase-out and just transitions: Lessons learned from Europe.
17. Nowakowska, A., Rzeńca, A., & Sobol, A. (2021). Place-based policy in the "just transition" process: The case of Polish coal regions. Land, 10(10), 1072. https://doi.org/10.3390/land10101072
18. Scaramuzzino, C., Garegnani, G., & Zambelli, P. (2019). Integrated approach for the identification of spatial patterns related to renewable energy potential in European territories. Renewable and Sustainable Energy Reviews, 101, 1–13. https://doi.org/10.1016/j.rser.2018.10.024
19. Sovacool, B. K., Heffron, R. J., McCauley, D., & Goldthau, A. (2016). Energy decisions reframed as justice and ethical concerns. Nature Energy, 1, 16024. https://doi.org/10.1038/nenergy.2016.24
20. Zhang, J. (2023). The challenge of just transition in China's coal power sector: A city-level employment vulnerability assessment. Climate Policy, 23(5), 555–576. https://doi.org/10.1080/14693062.2022.2149453
21. Ziouzios, D., Karlopoulos, E., Fragkos, P., & Vrontisi, Z. (2021). Challenges and opportunities of coal phase-out in western Macedonia. Climate, 9(7), 115. https://doi.org/10.3390/cli9070115