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The Green Reallocation Insurance Hypothesis: Carbon Exposure, Renewable Capacity and Macroeconomic Resilience

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ABSTRACT

Climate policy creates a structural-reallocation problem. Carbon-intensive economies must redirect capital, technology and labor toward lower-emission activities, yet the same policy shock may generate very different outcomes across countries and regions. This paper develops the **Green Reallocation Insurance** (GRI) framework, which treats renewable capacity and adjacent productive capabilities as an endogenous form of transition insurance. The framework predicts that carbon exposure raises adjustment pressure, while renewable capacity and related capabilities can reduce the social cost of reallocation. Using 2000–2024 World Bank country data for up to 260 countries and territories, the paper builds a lagged panel with carbon emissions per capita, renewable electricity output, unemployment, GDP per capita and GDP per person employed. Because the renewable-electricity series is complete only through 2021 in the acquired release, the principal lagged regressions cover 2001–2021. Two-way fixed-effects models with country-clustered standard errors find no statistically significant association of lagged carbon exposure, renewable electricity or their interaction with unemployment or labor productivity. The interaction is positive and statistically significant in the GDP model, with a coefficient of 0.000940 and a p-value of 0.007, although this association is not causal and may reflect selection into productive, energy-intensive economies. The results reject the idea that renewable capacity automatically operates as labor-market insurance. They instead support a more disciplined policy principle: transition insurance requires renewable capacity to be combined with worker mobility, training, fiscal capacity and related industrial capabilities. The paper contributes a mechanism-based framework, a reproducible global baseline and a clear agenda for regional and firm-level identification.

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Introduction

The low-carbon transition is frequently described as a technological substitution from fossil fuels to renewable energy. Economically, it is more accurately understood as a reallocation problem. Capital must move across sectors, workers must change occupations or locations and governments must manage distributional consequences. Carbon pricing, emissions standards, green industrial policy and public investment can accelerate the transition, but they can also impose short-run costs on carbon-intensive firms, communities and workers. The political durability of climate policy therefore depends on whether affected economies can convert pressure into new productive opportunities.

The literature has made progress on the environmental effectiveness of carbon pricing and the innovation response to energy prices. Environmental policy can induce directed technological change toward cleaner technologies [1-3]. Carbon pricing can reduce emissions while creating incentives for clean innovation, although distributional and political-economy concerns remain [4,5]. Firm-level evidence from the European Union Emissions Trading System suggests that pricing carbon can reduce emissions without necessarily destroying output, but the effects depend on firm characteristics and policy design [6]. Yet the employment and development consequences remain uneven. A carbon-intensive region with diversified skills, renewable potential and related technologies may adapt more quickly than a region with narrow capabilities and weak fiscal capacity.

This paper develops the Green Reallocation Insurance framework, abbreviated GRI. The central idea is that renewable capacity is not merely an environmental input. When paired with related productive capabilities, it can insure an economy against the adjustment costs generated by carbon exposure. The insurance is endogenous because it depends on prior choices in infrastructure, technology, skills, institutions and industrial diversification. It is also conditional because renewable electricity alone may not create jobs for displaced workers or generate local value added.

The framework integrates three literatures. The first is directed technical change, which explains how prices and policy can shift innovation toward clean technologies [1,2]. The second is economic complexity and relatedness, which argues that development paths depend on the proximity between existing capabilities and new activities [7-9]. The third is regional economic resilience and just-transition research, which emphasizes that shocks affect places differently depending on labor mobility, institutional capacity and industrial structure [10-12]. GRI connects these literatures through a testable interaction: the effect of carbon exposure should depend on renewable capacity and the economy's ability to absorb related green activities.

The empirical design uses publicly acquired World Bank data for 260 countries and territories from 2000 to 2024. The main variables are carbon dioxide emissions excluding LULUCF per capita, renewable electricity output as a percentage of total electricity output, unemployment, GDP per capita and GDP per person employed. Carbon exposure and renewable capacity are lagged by one year. Country and year fixed effects are included and standard errors are clustered by country. Because renewable-electricity observations in the downloaded release end in 2021, the lagged specifications effectively cover 2001–2021. This limitation is important and is not hidden.

The results are mixed. In unemployment and labor-productivity models, neither lagged carbon exposure, lagged renewable electricity nor their interaction is statistically significant. The interaction is positive in the GDP model, with a coefficient of 0.000940 and a p-value of 0.007. This result is consistent with a growth complementarity interpretation, but it does not demonstrate causal insurance. Higher-income and more productive economies may both emit more and invest more in renewables. Country fixed effects reduce but do not eliminate this concern.

The paper makes four contributions. First, it introduces GRI as a mechanism-based framework for distinguishing environmental capacity from labor-market resilience. Second, it tests whether renewable capacity moderates carbon exposure in a global panel rather than assuming that all green investment is automatically protective. Third, it reports statistically insignificant labor-market results as substantive evidence rather than as a failure to find a positive story.

Fourth, it supplies a research design for the next stage: combine regional emissions exposure with patent relatedness, occupational mobility, training and transition-fund allocations.

Literature Review and Theoretical Framework

Carbon Policy and Directed Innovation

The theory of directed technical change shows that environmental policy can change the direction of innovation, not only the level of innovation. When clean technologies become more profitable relative to dirty technologies, firms have incentives to innovate in the clean direction [1]. Energy prices can induce innovation and patenting, but the response is heterogeneous across industries and depends on the technological opportunity set [2-13]. The effectiveness of policy therefore depends on whether clean alternatives are available, scalable and economically related to existing capabilities.

Carbon pricing is a central instrument because it internalizes part of the environmental cost. Its political economy is more complex than a simple Pigouvian correction. Carbon prices can be regressive if low-income households spend a larger share of income on energy. They can also impose concentrated losses on carbon-intensive workers and regions. Complementary instruments such as transfers, green industrial policy, public infrastructure and labor-market programs can improve both distributional outcomes and political support [4-14]. Recent work identifies nonlinear or tipping-point dynamics in which carbon pricing and redistribution jointly accelerate the transition to green growth [15].

The paper does not assume that carbon prices alone produce resilience. The GRI framework instead treats policy pressure as a stressor whose consequences depend on local capacity. A carbon-intensive economy may become more resilient when it has access to renewable generation, grid infrastructure, skills and related industries. Without those complements, carbon pricing may generate adjustment without a credible replacement pathway.

Economic Complexity, Relatedness and Green Capabilities

Economic complexity research argues that productive capabilities are embedded in networks of products, technologies, skills and organizations. Countries with more complex economic structures can diversify into activities that are related to their existing capabilities [7]. The product space formalizes this idea by showing that new export activities tend to emerge near existing capabilities [8]. The principle of relatedness applies the same logic to regions and industries: diversification is more likely when the new activity is cognitively, technologically or organizationally proximate to current activity [9].

The green economy creates both constraints and opportunities for this process. Mealy and Teytelboym construct a green-product space and show path dependence in countries' ability to export complex green products [16]. Higher green complexity is associated with environmental patenting, lower emissions and more stringent environmental policy, even after controlling for GDP per capita [16]. The implication for transition policy is that the same carbon price may have different outcomes in economies with different green capability portfolios.

GRI extends this literature by treating related green capability as an insurance stock. It is not insurance in the actuarial sense. It is a productive buffer that reduces the expected output and employment cost of transition pressure by making new activities easier to discover, finance and staff. The framework predicts that a raw count of green patents or renewable capacity is insufficient. What matters is the relationship between new green activities and existing local capabilities.

Regional Resilience and the Just Transition

Economic resilience concerns how places absorb, recover from and transform aftershocks. The regional-resilience literature emphasizes adaptation, path dependence, institutional agency and the possibility of divergent outcomes [10]. Climate change and decarbonization add a distributional dimension because carbon-intensive sectors are geographically concentrated. Workers may face occupational mismatch, relocation costs and losses of community-specific human capital. The European Commission's analysis of the green transition emphasizes that aggregate employment effects can mask substantial shifts across sectors, occupations and regions [11]. The wider complexity literature shows why these shifts are path dependent. Balland and co-authors describe economic complexity as a framework for studying growth, innovation, inequality, spatial disparities and resilience [18]. Neffke, Henning and Boschma show that regions diversify through related industries rather than arbitrary jumps [19]. Evidence from Spain similarly links related variety to regional growth, while Frenken, Van Oort and Verburg distinguish related from unrelated variety in explaining regional economic performance [20,21]. Hidalgo and Hausmann formalize productive capabilities as hidden building blocks of observed output [22]. Mealy and Teytelboym's green-industrialization work applies this logic directly to green products and export pathways [23]. The task-based automation literature is also relevant because decarbonization reallocates tasks and occupations rather than merely replacing sectors [24]. Research on green skills finds that environmental regulation changes workforce composition and raises demand for particular competencies [25]. Green employment is multidimensional and "greening" can alter occupations without creating a simple new category of jobs [26]. These findings imply that regional transition insurance must connect physical energy capacity to related skills, firms and institutions.

The just-transition literature therefore focuses on labor reallocation, skills and policy design. OECD research finds significant cross-country variation in green-skill supply and in the potential to reallocate workers from brown jobs to green jobs [12]. IMF analysis argues that environmental policies can green the labor market but work better when reallocation incentives are not blunted [17]. These findings suggest that renewable capacity should be studied jointly with labor-market institutions, training and mobility.

The Green Reallocation Insurance Framework

Let C represent carbon exposure, measured here by lagged emissions per capita. Let R represent renewable electricity capacity, measured by renewable electricity output as a percentage of total output. Let K represent related green capabilities, such as environmental patents, green exports, adjacent industries and transferable skills. Let A represent adaptive capacity, including worker mobility, training and fiscal support. The GRI relationship is:

Resilience = f(C, R, K, A, C×R, C×K, C×A) + fixed effects + error.

The first-stage empirical proxy uses C, R and C×R because the acquired global data do not yet contain comparable country-year measures of green relatedness or training. This is a deliberately incomplete test. The full framework predicts that the interaction between carbon exposure and renewable capacity should be associated with stronger growth or smaller labor-market losses only where renewable capacity is economically connected to local capabilities.

The hypotheses are as follows. H1: higher lagged carbon exposure is associated with greater adjustment pressure. H2: higher lagged renewable capacity is associated with better medium-run macroeconomic outcomes. H3: the carbon-exposure effect is moderated by renewable capacity. H4: the moderation is stronger for GDP and productivity than for unemployment when green investment is capital-intensive. H5: the interaction will be weaker when renewable capacity is disconnected from local skills and industrial capabilities.

Materials and Methods

Data Sources and Coverage

The primary source is the World Bank World Development Indicators [28]. The broader development literature emphasizes that financial systems and recovery capacity shape the distribution of environmental and macroeconomic shocks [27]. The downloaded release covers 2000–2024 for the selected variables and includes up to 260 countries and territories. The proposed regional extension will use OECD Regional Statistics, Eurostat's regional database and NUTS classification and European Environment Agency emissions-trading data [29-31]. ILOSTAT will supply harmonized employment, productivity and labor-market transition measures when the regional design is implemented [32]. Carbon exposure is measured using the current World Bank series for carbon dioxide emissions excluding LULUCF per capita. Renewable capacity is proxied by renewable electricity output as a percentage of total electricity output. The renewable series has non-missing observations through 2021 in the acquired release but no non-missing observations in 2022–2024. The analysis therefore reports the coverage limitation and uses the latest valid year for the cross-sectional figure.

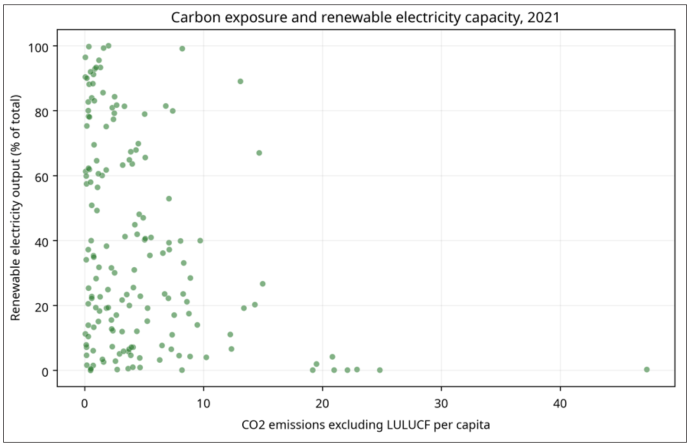

Figure 1: Carbon Exposure and Renewable Electricity Capacity, 2021

Outcomes are unemployment, GDP per capita and GDP per person employed. GDP per capita and GDP per person employed are log transformed. Carbon exposure and renewable electricity are lagged one year. The panel contains country and year fixed effects. The country fixed effects absorb time-invariant differences such as geography, historical institutions and long-run resource endowment. Year fixed effects absorb global shocks and common trends. Standard errors are clustered by country.

Estimation Models

The Main Panel Model is

Y_{ct} = beta1 C_{c,t-1} + beta2 R_{c,t-1} + beta3 C_{c,t-1}×R_{c,t-1} + gamma X_{ct} + alpha_c + delta_t + epsilon_{ct}

where Y is unemployment, log labor productivity or log GDP per capita. X includes log GDP per capita and log population where appropriate. The coefficient of interest is beta3. A positive interaction in the GDP model would be consistent with the hypothesis that renewable capacity is associated with greater growth in carbon-exposed economies. A negative interaction in the unemployment model would be consistent with labor-market insurance.

The fixed-effects estimates are associational. Carbon exposure is endogenous to income, industrial structure, energy demand and resource endowment. Renewable investment is endogenous to policy, geography and expected growth. The data do not provide a credible instrument or policy discontinuity in the current version. The paper therefore does not describe the estimates as causal effects of carbon pricing or renewable energy.

Reproducibility and Data Limitations

The main acquisition script is scripts/download_wdi.py. The empirical script is scripts/analyze_papers.py. It produces analysis/key coefficients.csv, analysis/model_summaries.txt, analysis/paper2_descriptives.csv and figures/paper2_carbon_renewable.png. The carbon-series code was updated after the legacy World Bank indicator EN.ATM.CO2E.PC was confirmed as archived. The current carbon measure is documented in the script and should be frozen with the replication package at submission.

No data were simulated. Missing values are not imputed. The renewable-electricity truncation after 2021 is retained as a formal limitation. The next version should add national energy accounts, EU ETS exposure, emissions by sector, green patents and regional labor-force data.

Results and Observations

Descriptive Evidence

The acquired global panel contains 6,600 country-year rows for 260 countries and territories between 2000 and 2024. Carbon emissions per capita have a mean of 4.72 metric tons and a median of 2.52 in the pooled observations. The 25th and 75th percentiles are 0.66 and 6.11. Renewable electricity output has a pooled mean of 29.53% and a median of 20.09%, with a 25th percentile of 4.18% and a 75th percentile of 49.16%. The dispersion is substantial, which supports studying heterogeneity rather than imposing a uniform transition path.

Table 1: Descriptive Variables and Source Coverage

Variable	Operational definition	Source	Main coverage
Carbon exposure	CO2 emissions excluding LULUCF per capita	World Bank WDI	2000–2024, 250 non-missing countries per year in the acquired panel
Renewable capacity	Renewable electricity output, percent of total electricity output	World Bank WDI	2000–2021, 251 or fewer countries per year
Unemployment	Unemployment, total, percent of labor force	World Bank WDI	2000–2024, varying by country and year
Labor productivity	GDP per person employed, constant 2021 PPP dollars, log transformed	World Bank WDI	2000–2024, varying by country and year
GDP per capita	GDP per capita, constant 2015 US dollars, log transformed	World Bank WDI	2000–2024, varying by country and year

Note: Values are taken from the Acquired Public Data and Reflect Available Observations for the Relevant Specification.

The latest year with non-missing renewable-electricity observations is 2021. The cross-sectional figure therefore uses 2021 rather than 2023 or 2024. It shows a broad cloud of observations: some countries combine low emissions with high renewable shares, while others combine high emissions with very low renewable shares. The visual pattern is not a simple linear transition frontier.

Unemployment Model

The unemployment model uses 3,561 observations. The coefficient on lagged carbon exposure is -0.0933 with a clustered standard error of 0.0787 and a p-value of 0.236. The coefficient on lagged renewable electricity is 0.0100 with a standard error of 0.00819 and a p-value of 0.220. The interaction coefficient is -0.00237 with a standard error of 0.00208 and a p-value of 0.255.

The point estimate of the interaction is negative, which is directionally consistent with labor-market insurance, but it is not statistically distinguishable from zero in this global country panel. The result means that the paper cannot claim that renewable capacity reduced unemployment in carbon-exposed economies. It instead indicates that macro-level renewable shares are too coarse to identify the labor-market mechanism. Renewable investment may be capital-intensive, geographically remote from displaced workers or accompanied by labor reallocation costs that are invisible in aggregate unemployment.

Table 2: Descriptive Variables and Source Coverage

Outcome	Interaction coefficient	Clustered standard error	p-value	Observations	Interpretation
Unemployment	-0.00237	0.00208	0.255	3,561	Directionally protective but statistically uncertain
Log labor productivity	-0.0000536	0.0000599	0.371	3,521	No detectable moderation in the current specification
Log GDP per capita	0.000940	0.000349	0.007	3,584	Positive growth association, not a causal insurance estimate

Note: Values are taken from the Acquired Public Data and Reflect Available Observations for the Relevant Specification.

Labor-Productivity Model

The labor-productivity model uses 3,521 observations. The lagged carbon coefficient is -0.00526 with a standard error of 0.00416 and a p-value of 0.206. The renewable coefficient is -0.000205 with a standard error of 0.000354 and a p-value of 0.563. The interaction is -0.0000536 with a standard error of 0.0000599 and a p-value of 0.371.

The productivity interaction is small and statistically uncertain. It does not support a simple claim that renewable electricity output moderates carbon exposure to raise labor productivity. This null result is theoretically informative. It suggests that energy-system transition and labor productivity may operate on different time horizons. Renewable generation can reduce emissions or energy risk without immediately increasing labor productivity. It may also require large capital investment that produces environmental benefits before productivity gains appear.

GDP Model

The GDP model uses 3,584 observations. The lagged carbon coefficient is 0.0493 with a standard error of 0.00977 and a p-value below 0.001. The renewable coefficient is -0.000814 with a standard error of 0.000868 and a p-value of 0.349. The interaction is 0.000940 with a standard error of 0.000349 and a p-value of 0.007.

The positive interaction is consistent with the possibility that renewable capacity is associated with higher GDP in economies with greater carbon exposure. However, the estimate is not causal. Carbon-intensive economies may have higher income, stronger electric grids and greater ability to invest in renewable generation. The positive interaction may therefore reflect selection into productive energy systems rather than an insurance effect. The divergence between the GDP interaction and the unemployment and productivity interactions is central to the paper's argument: growth resilience is not equivalent to labor-market resilience.

Discussion

The empirical results do not support a universal renewable-capacity insurance claim. The interaction between carbon exposure and renewable electricity is negative for unemployment and labor productivity but not statistically significant. It is positive and statistically significant for GDP per capita. This divergence is not an inconsistency to be hidden. It is evidence that the green transition has multiple margins of adjustment.

First, renewable capacity may support aggregate output without creating enough jobs for displaced workers. Renewable generation is capital-intensive, uses specialized skills and may be located away from carbon-intensive communities. Second, productivity effects may be delayed because the transition requires investment before new technologies diffuse through firms. Third, GDP can improve through energy security, export opportunities or capital deepening while unemployment remains unchanged. A transition policy that reports GDP alone can therefore overstate the degree to which communities are protected.

The GRI framework suggests a targeting rule. High carbon exposure and high related green capability should be treated differently from high carbon exposure and low capability. The former may need finance, grid upgrades and market access to accelerate diversification. The latter require worker mobility, training, fiscal transfers and place-based industrial policy before carbon prices rise sharply. A renewable target without a labor-market plan is not a just-transition strategy.

The findings also support the economic-complexity perspective. Renewable capacity is a physical capability, not a complete productive ecosystem. To create resilient employment, the energy system must connect to firms, skills, supplier networks and institutions. Green patents, related exports and occupational transferability are therefore more informative insurance measures than renewable shares alone. The next version of the paper should construct a GRI index from these components and test whether relatedness changes the employment response.

The limitations are substantial. The World Bank renewable series is unavailable after 2021 in the acquired release. Carbon emissions per capita are an imperfect measure of policy exposure and do not identify carbon pricing. Country fixed effects do not solve time-varying endogeneity. The global sample combines countries with different statistical systems, labor-market institutions and energy definitions. Unemployment is a broad outcome that may miss involuntary inactivity, wage loss and occupational scarring. The paper therefore makes a framework and baseline contribution rather than a causal policy evaluation.

Conclusion

The green transition is not insured by renewable electricity alone. It is insured when renewable capacity is connected to related industrial capabilities, adaptable workers and credible institutions. In a global World Bank panel, the carbon-exposure and renewable-capacity interaction is not statistically significant for unemployment or labor productivity, although it is positive for GDP per capita. The evidence therefore warns against equating green growth with resilient employment.

The practical implication is to design climate policy around a transition-capability portfolio. Governments should measure carbon exposure, renewable infrastructure, green technological relatedness, training, worker mobility, fiscal capacity and regional diversification together. Carbon pricing should be accompanied by policies that make new tasks and industries accessible to affected workers. The research implication is equally clear: the next generation of just-transition studies should move from national averages to firms, occupations and regions, where the insurance mechanism can be identified directly.

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