The End of Coal: Labor Market Transitions in Coal-Dependent Regions*

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October 23, 2026

Abstract

The transition away from coal-fired power raises concerns about its local labor-market consequences, yet little empirical evidence exists on how affected communities and workers adapt. This paper studies the closure of ten coal-fired power plants in Spain—eight on the same date—during a period of rapid renewable energy expansion. Using an event-study design, we find that closures led to significant declines in local employment (13% after five years) and population (4.2%), but, paradoxically, to falling rather than rising unemployment—a pattern explained by outmigration concentrated among working-age residents, which leaves behind an older, poorer population. Plant-by-plant synthetic control estimates reveal heterogeneous effects: the sharpest joint declines in employment and population occur in small, rural municipalities with few economic alternatives. Using gravity-equation estimates of internal migration, we also show that displaced residents are significantly more likely to relocate toward nearby municipalities receiving renewable energy investment. Linked Social Security microdata further reveal a rise in direct job-to-job transitions from thermal to renewable electricity generation, a channel that was virtually absent before coal closures. Renewable expansion thus offers a real, but geographically bounded and only partial, channel for reallocating displaced coal workers and communities.

Keywords: coal, energy transition, renewable energy, employment, unemployment, migration, labor reallocation, just transition.

JEL Classification: J61, J62, L94, Q48, R23, O25, C33.

*Emails: natalia.fabra@cemfi.es, eduardo.gutierrez@bde.es, and roberto.ramos@bde.es. We are grateful for the comments and feedback received from seminar participants at Fondazione Eni Enrico Mattei (Milano). Fabra has benefited from funding by the European Union, ERC Advanced project *ENERGY-IN-TRANSITION* (Grant number 101142583). Views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union, the European Research Council, Banco de España, or the Eurosystem.

1 Introduction

The power sector is central to the energy transition, as it can supply the clean electricity needed to decarbonize high-emission sectors like transportation and industry. To play this role, it must first decarbonize itself by phasing out fossil fuels—especially coal, the most polluting—while scaling up investments in renewable energies and storage. However, this transformation might face social challenges: the regions that benefit from the low-carbon investments are not necessarily the same as those harmed by the coal plant closures. This disconnect between winners and losers creates distributional tensions and risks eroding political support for the energy transition (see Gazmararian and Tingley, 2023; Colantone et al., 2024; Bosetti et al., 2025).

Despite growing interest, there is little empirical evidence on the local impacts of this transition or on how communities adapt. This paper exploits the rapid closure of coal power plants in Spain—coinciding with a surge in renewable energy investments—to provide detailed evidence on the local effects of the coal phase-out. It examines impacts on employment, unemployment, and population dynamics, with a particular focus on whether displaced workers find alternative jobs in regions attracting new renewable projects.

We perform the empirical analysis along three complementary dimensions to uncover potential heterogeneities across locations and workers. To construct comparable units, we draw circles of 15 km around the treated coal plants and split the country into a grid of squares of the same area as the circles. Treated regions are within the circles, and control regions are within the squares. First, we conduct an event study with staggered closures *à la* Callaway and Sant'Anna (2021) to assess the aggregate effects on local employment, unemployment, demographics, and income. Second, to capture heterogeneity across individual closures, we construct a synthetic control for each plant, comparing its post-closure trajectory to that of a weighted combination of untreated units with similar pre-closure characteristics. Third, using gravity-equation estimates of internal migration and individual-level Social Security microdata, we examine where displaced residents relocate to regions with renewable energy investments, and whether workers previously employed in fossil-fuel generation transition into jobs in the renewable-energy sector.

We find that the coal plant closures led to significant reductions in local employment—13.1% five years after the announcement—but, paradoxically, also to falling rather than rising

unemployment, which drops by 6.4% over the same horizon.[1] This apparent paradox is explained by a substantial decline in population (4.2%), a phenomenon also documented in coal-exposed counties in the US (Hanson, 2023). The population decline is concentrated among working-age residents, so that the municipalities left behind become older and poorer: per-capita income falls relative to unaffected areas over the same period.

These aggregate patterns mask substantial heterogeneity across individual closures. Plant-by-plant synthetic control estimates show that joint declines in employment and population are concentrated in the smallest, most coal-dependent municipalities, which lack economic alternatives and ties to nearby urban labor markets. By contrast, in municipalities with a more diversified economy, closer connections to cities, or stronger just transition support, the effects are muted, limited to employment alone, or in one case reversed, with employment rising after closure.

What happens to the residents who leave, and to the workers who lose their jobs? This is, to our knowledge, the least understood—and we think, the most novel—part of the coal-to-renewables transition, one to which this paper contributes. Using gravity-equation estimates of internal migration flows, we find that, following a coal plant closure, migrants become significantly more likely to relocate toward municipalities receiving renewable energy investment—by around 10% relative to destinations without such investment—and that this pull is roughly twice as large when the renewable-investment destination lies within 100 kilometers of the closing plant. We complement this municipality-level evidence with worker-level Social Security microdata that let us follow individual employment histories over time. These data reveal a marked increase in direct job-to-job transitions from thermal to renewable electricity generation following the coal plant closure announcements, rising from virtually zero beforehand to a positive but still low number: a cumulative 33 transitions over the five years following the announcements. Although modest in absolute terms, this represents a non-negligible 11% of all observed worker reallocation from thermal generation, equivalent to 7.7% of the initial thermal-generation workforce in the provinces affected by the coal closures. While recent work documents worker flows into and out of green jobs more generally (Curtis et al., 2024), to the best of our knowledge this is the first evidence linking coal plant closures to direct job-to-job transitions from fossil-fuel to renewable

[1] Our estimates are expressed in log points. For ease of interpretation, throughout the text we report them as percentage changes.

electricity generation.

Taken together, our findings speak to a central question in the political economy of the energy transition: can the places and people that bear its costs also share in its benefits? We find that renewable investments attract displaced residents and, to a lesser extent, redeploy fossil-fuel workers directly into green jobs, suggesting that decarbonization need not condemn coal communities to permanent decline. Yet this reallocation channel is geographically concentrated and modest relative to the scale of local job losses, leaving municipalities without nearby renewable investment or a diversified economic base to absorb most of the adjustment through population decline and aging alone. In such cases, place-based policies, including those supported by the Just Transition Fund,[2] remain essential for mitigating the adverse local consequences of coal-fired power plant closures.

Related Literature. Our paper relates to four strands of the literature: on the local costs of coal decline, on the labor-market response to local shocks more broadly, on green jobs and the reallocation of workers out of polluting activities, and on the political economy of the energy transition.

A first strand documents that the decline of the coal industry imposes high and persistent local costs. In the United States, the 1980s coal bust led to employment and wage losses that persisted for decades (Black et al., 2005), leaving behind communities that are smaller, older, sicker, and poorer, as outmigration is concentrated among younger, more mobile residents (Hanson, 2023). Worker-level evidence from Colmer et al. (2024) similarly shows that neither switching industries nor relocating geographically does much to cushion the earnings losses of displaced coal workers, with non-employment absorbing much of the adjustment instead. Krause (2026) documents that the residents most likely to leave declining coal areas are precisely those with the best outside options, reinforcing the deterioration of the population left behind, while Blonz et al. (2026) find that the financial health of those who remain in coal mining counties deteriorates. Holland et al. (2026) quantify the environmental benefits of the US coal phase-out, underscoring the trade-off between local costs and aggregate gains. Evidence from coal closures outside the US points in the

[2]The Just Transition Fund supports coal-dependent and carbon-intensive EU regions by financing economic diversification, worker reskilling, and job creation as they transition toward a climate-neutral economy.

same direction, including Rud et al. (2024) for the UK, and Haywood et al. (2024) for Germany.

A second strand studies whether, and how, local labor supply adjusts to negative demand shocks. A recurring finding is that migration responses are muted: workers in declining areas tend to stay rather than relocate, so that local demand shocks translate into persistent local unemployment or non-participation rather than being smoothed away through mobility (Bound and Holzer, 2000; Autor et al., 2013). Recent work emphasizes that labor supply responds not only to conditions in the local labor market but also to those prevailing in alternative destinations (Borusyak et al., 2022), and that local labor demand itself depends on conditions in nearby, connected labor markets (Adão et al., 2019; Redding, 2022). Limited migration responses help explain why the effects of local demand shocks are so persistent (Dix-Carneiro and Kovak, 2017, 2019; Autor et al., 2021), and in labor markets affected by large downturns, joblessness can become entrenched (Austin et al., 2018).

Whether coal communities can escape this pattern is an open and policy-relevant question, because the energy transition—unlike the coal boom and bust of the 1970s and 1980s (Black et al., 2005)—pairs a negative shock (job losses in fossil-fuel generation) with a simultaneous positive one (the roll-out of renewable capacity), whose local labor market effects we studied in previous work (Fabra et al., 2024). A third strand of the literature, to which we most directly contribute, asks whether displaced fossil-fuel workers benefit from this green counterpart. Descriptive evidence for the US documents what green jobs look like and where they are located (Curtis and Marinescu, 2023), and how workers transition into and out of them (Curtis et al., 2024). Frattini et al. (2025) document local employment multipliers from renewable investment, motivating the question of whether these multipliers reach the very communities that decarbonization leaves behind. Closest to our worker-level analysis, Walker (2013) uses linked employer–employee data to follow workers in industries newly regulated under the 1990 Clean Air Act Amendments, and finds sizeable transitional costs of this reallocation. Like Walker (2013), we follow individual workers over time using administrative employment histories. Unlike his data, however, our Social Security records do not contain earnings, so we cannot quantify the earnings cost of reallocation; instead, we focus on its direction, asking which sectors—and, in particular, whether renewable electricity generation—absorb workers displaced from fossil-fuel generation.

Relatedly, the uneven regional distribution of the costs and benefits of decarbonization has

been linked to political backlash against climate policy (Colantone et al., 2024; Bosetti et al., 2025), public opposition to coal phase-out (Gazmararian and Tingley, 2023), and lasting political consequences in the communities most exposed to coal decline, including the positive response to just transition policies (Bolet et al., 2024). In turn, Gowrisankaran et al. (2026) and Aspuru (2026) study how the regulatory environment has shaped the pace of the US coal-to-gas transition; Aspuru (2026) in particular shows that state regulators in mining states approve costly plant upgrades specifically to protect local coal-mining revenue, thereby delaying closures despite the resulting increase in electricity prices.

Our contribution is to move beyond documenting local costs and to trace the transition itself: where displaced residents go, and which sectors absorb displaced workers. To our knowledge, this is among the first papers to link coal-plant closures directly to (i) internal migration flows toward areas receiving renewable energy investment, using gravity-equation estimates, and (ii) individual job-to-job transitions from fossil-fuel to renewable electricity generation, using matched Social Security microdata. In doing so, we connect the literature on the local costs of coal decline with the literature on green jobs and labor reallocation, providing some of the first direct evidence on whether, and under what conditions, the energy transition offers a reallocation channel to workers and communities exposed to the end of coal.

The remainder of the paper is organized as follows. Section 2 provides background on the end of coal in Spain. Section 3 describes the data used in the analysis. Section 4 presents the empirical strategy and results for the aggregate effects of coal-plant closures on local employment, unemployment, population, and income. Section 5 examines heterogeneity across individual plant closures using synthetic control methods. Section 6 studies the transition itself, analyzing migration patterns and worker-level labor transitions from fossil-fuel to renewable-energy jobs. Section 7 concludes. The Appendix contains further analyses and results.

2 Background: the End of Coal in Spain

Coal has shaped the economic geography of several Spanish regions for over a century. Two distinct clusters of activity emerged historically. The first is a network of *cuencas mineras* (mining basins) in the north and northwest—Asturias, the Bierzo area of León, and Palencia—alongside

the lignite basin of Teruel in Aragón, where coal was mined and burned locally. These basins experienced a mining boom that peaked around the middle of the twentieth century, and coal mining, together with the heavy industry it sustained, became the backbone of local labor markets for generations. The second cluster comprises coastal plants built from the 1970s onward to burn cheaper imported coal, typically sited near ports in provinces such as A Coruña, Córdoba, Almería, and Cádiz. By 2018, Spain's coal fleet still comprised fifteen plants and 9.6 GW of installed capacity, spread across a dozen provinces.

Coal mining itself had already been in secular decline for decades before the plant closures examined in this paper. Employment in the sector fell continuously from its mid-century peak, sustained in its final years mainly through state aid to uncompetitive domestic mines, which were entirely phased out at the end of 2018. By then, fewer than 1,700 workers were directly employed in the sector (Bolet et al., 2024). The phase-out of coal for electricity generation followed a slower timeline: coal remained the single largest source of Spanish electricity through the 1980s, accounting for around 45% of generation in 1986, and it continued to be one of the two or three leading technologies—alongside nuclear and, increasingly, natural gas—throughout the 1990s and into the 2000s, well before the wave of closures analyzed here.

A regulatory deadline, rather than a single, discrete policy decision to phase out coal, triggered the closures. Under the EU Industrial Emissions Directive (2010/75/EU), plants that did not invest in additional pollution-abatement equipment had to cease operations by June 30, 2020. Faced with this deadline, and with coal's competitiveness further eroded by rising EU carbon allowance prices and falling renewable costs, Spain's major utilities concluded that the required investments were not economically viable.[3] Between late 2017 and December 2018, the plant owners filed closure requests with the Ministry for the Ecological Transition (MITECO) covering their domestic coal-fired fleet. In parallel, in October 2018, the government signed a Just Transition framework agreement with mining unions and employers, establishing early-retirement schemes and a five-year, EUR 250 million fund to support economic diversification in the mining regions, later complemented by *Convenios de Transición Justa* (Just Transition agreements) for the specific municipalities and counties hosting the closing plants.

[3]Unlike in the United States, where some coal-fired power plants are owned by regulated utilities (Gowrisankaran et al., 2026), all coal-fired power plants in Spain were privately owned and operated by unregulated firms.

Of Spain's fifteen coal plants still operating in 2018, ten—accounting for just over 7 GW of capacity—closed between 2018 and 2021, the period covered by our sample (Table 1). Consistent with the national pattern, in which most of the remaining coal fleet disconnected on a single day to meet the Industrial Emissions Directive deadline, eight of these ten plants share that same 2020 disconnection date; the remaining two closed just before (Anllares, 2018) or after (Litoral de Almería, 2021). The remaining five continued operating for several more years before Spain's coal fleet was retired almost in its entirety.[4]

This collapse in coal-fired generation was mirrored by the rapid expansion of renewable capacity. Coal's share of Spanish electricity generation fell from 16.5% in 2017 to 4.2% in 2019, and to 1.2% by 2024. Wind and solar photovoltaic capacity expanded rapidly, and the resulting generation growth allowed renewables to reach just over 50% of total generation in 2023 and 56.8% in 2024. Figure 1 illustrates this transition, plotting the evolution of Spain's electricity generation mix by technology over the period. The decline of coal and the expansion of wind and solar power provide the context for the local labor-market effects examined in this paper.

3 Data Description

3.1 Sample plants

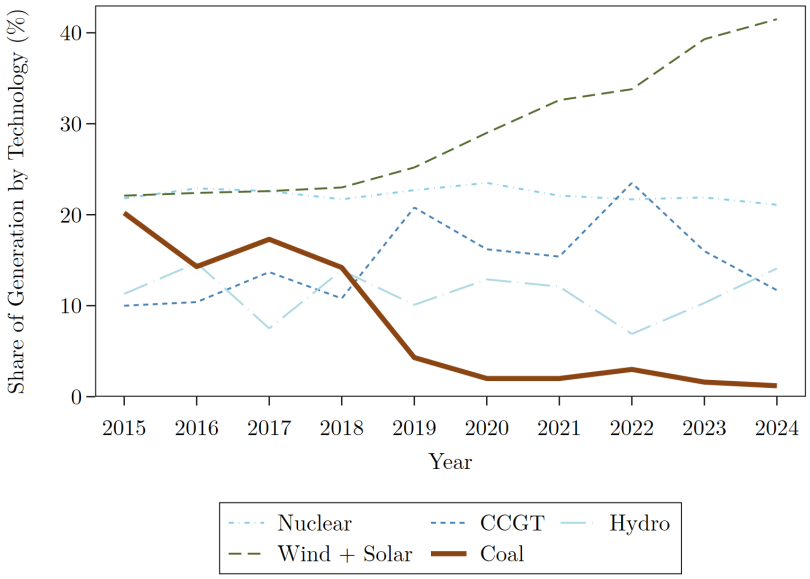
In this paper, we document the closure of ten coal-fired power plants in Spain between 2018 and 2021, with announcement dates ranging from 2017 to 2019. We compile data from the Global Coal Plant Tracker (Global Energy Monitor), supplemented with news media and official records, to systematically identify key milestones in the coal phase-out—specifically, the official closure announcements and the dates of disconnection from the power grid.

Table 1 lists the coal plant closures included in our sample. We exclude plants that ceased operations before 2018, those retaining active power-generating units, and those phased out near the end of the study window. In addition, the Alcúdia facility is omitted because it is located in a municipality with a strong tourism orientation and was closed a year before the onset of the pandemic, which could confound the assessment of local closure impacts. Its workforce is also

[4] As of 2026, only one coal-fired unit remains operational, Soto de Ribera III, and it is used only occasionally as backup capacity.

FIGURE 1

EVOLUTION OF ELECTRICITY GENERATION BY TECHNOLOGY IN THE SPANISH POWER SECTOR



Notes: This figure shows the evolution of the share of each technology in the Spanish electricity generation mix. Source: Red Eléctrica.

registered in the provincial capital rather than in the municipality where the plant is located. Table B.2 in the Appendix details the characteristics of the excluded plants and the reasons for their exclusion.

3.2 Treated and control units

To construct comparable units and identify the local effects associated with plant closures, we define treated and control units as follows. Treated units are municipalities whose geographic centroid lies within a 15-kilometer radius of the plants included in the sample. Throughout the paper, the unit of analysis is the aggregate of these municipalities around each plant: each of the ten plants thus defines one treated unit, which we refer to as a treated grid cell for symmetry with the control units described next. For control units, we aggregate all Spanish municipalities into grid cells of similar area to that of the treated units (approximately 700 square kilometers).[5] Grid cells are excluded from the pool of control units if they contain any municipality located

[5]We exclude municipalities from the Canary Islands. We also harmonize the municipality data used throughout the paper to account for boundary changes (divisions and mergers) since 2000.

Table 1
Coal Plant Closures

Plant	Municipality	Province	Power (MW)	Announcement	Disconnection	Demolition
Anllares	Páramo del Sil	León	365	May 2017	Dec 2018	Jan 2025
Lada	Langreo	Asturias	563	Nov 2017	Jun 2020	2024
Velilla del Río Carrión	Velilla del Río Carrión	Palencia	516	Nov 2017	Jun 2020	Jun 2022
Compostilla	Cubillos del Sil	León	1,341	Nov 2018	Jun 2020	Ongoing[a]
Meirama	Cerceda	A Coruña	580	Nov 2018	Jun 2020	Jan 2024
Narcea	Tineo	Asturias	595	Nov 2018	Jun 2020	2025
La Robla Fenosa	La Robla	León	655	Dec 2018	Jun 2020	Aug 2022
Puente Nuevo	Espiel	Córdoba	400	Dec 2018	Jun 2020	Dec 2020[b]
Teruel	Andorra	Teruel	1,102	Dec 2018	Jun 2020	2025
Litoral de Almería	Carboneras	Almería	1,159	Sep 2019	Dec 2021	Ongoing[c]

Notes: This table presents the list of plant closures included in the sample. The Demolition column reports the month/year in which physical dismantling of the main structures (chimneys, cooling towers, boiler) was completed. [a]Demolition of the main chimney completed in Feb 2026; full site dismantling expected late 2026. [b]Only partial dismantling (approx. 20% of the site) carried out in 2020. [c]Approx. 62% complete as of October 2025; expected completion in 2026.

within 15 kilometers of a coal plant, regardless of whether the plant is included in the sample, so as to avoid contaminating the control group with units exposed to a closure.

Figure 2 shows the spatial distribution of municipalities (red and gray dots), the grid cells (squares), the treated units (red circles), and the municipalities near coal plants excluded from the sample (gray circles).

3.3 Outcome variables

We use municipality-level data on employment, unemployment, population, and per-capita income, which are subsequently aggregated to the level of the 700-square-kilometer grid cells.

Employment and unemployment. For employment, we rely on the Social Security affiliates register at the municipality level, available from January 2003 onward (see Ministry of Inclusion, Social Security and Migration (2023)). In these records, workers are assigned to the municipality where their employer's Social Security account is registered. A firm must hold at least one distinct account in each province where it owns physical infrastructure. While firms may, in principle, maintain multiple accounts to report employees at different sites within a province, in practice new accounts are typically opened only for large, long-term projects requiring fixed

Figure 2
Treated and control units



Notes: This figure portrays the spatial distribution of municipalities in Spain (red and gray dots). Treated municipalities (i.e., those lying within a 15-kilometer radius of the coal plants included in the sample) are enclosed within red circles. Municipalities enclosed within gray circles are located within a 15-kilometer radius of coal plants not part of the sample. All municipalities are aggregated into grid cells, as depicted in the figure. Grid cells containing any municipality within a red or a gray circle are excluded from the pool of control units.

facilities. As a result, the number of workers recorded for a municipality does not necessarily correspond to the number actually working there.[6] Additionally, employment data are available for 87 sectors, classified according to the two-digit NACE Rev. 2 code; this sectoral breakdown comprises end-of-year employment figures from 2012 to 2024.[7]

Registered unemployment data at the municipality level are available from May 2005 (see Ministry of Labor and Social Economy (2023)). Unlike employment data, unemployment figures correspond to the individual's municipality of residence. Not all unemployed persons appear in

[6]The dataset censors figures if total municipal employment falls within the range of 1 to 4 individuals. Furthermore, since February 2019, censorship also applies when employment in a specific Social Security regime (general, self-employed, agrarian, sea, coal, and domestic work) is between 1 and 4. In such instances, the total number of employees is reported as a lower bound. For example, a figure such as "$> 1,067$" is reported if the aggregate number of employees in uncensored regimes equals 1,067 and at least one regime contains between 1 and 4 employees. To circumvent this limitation, our analysis is restricted to workers covered under the general regime of the Social Security system. This regime is the most prevalent, and thus, the number of employees typically exceeds the censoring threshold. Moreover, unlike the total figures, it remains unaffected by the censoring applied to less common regimes. Note that, consequently, self-employed individuals and agricultural workers are excluded from the sample.

[7]Data for 2011 are also available but are not consistent with subsequent years. Observations pertaining to establishments with 1 to 4 employees are censored. The affected municipalities are excluded.

these registers—some are ineligible for unemployment benefits, while others choose not to engage with public employment offices.[8]

Given that not all residents work in the municipality where they live, and firms do not always register their accounts where employees are physically located, employment and unemployment statistics should not be expected to match exactly.

Two features of the data warrant caution when interpreting changes in employment and unemployment. First, job creation is not fully captured by public employment offices: many hires occur outside these channels, and individuals may hold multiple Social Security affiliations, so additional affiliations do not necessarily correspond to a one-for-one drop in registered unemployment.

Second, since employment records are linked to the location of a firm's registered office rather than the actual worksite, there might be an underestimation of the local employment effects, particularly in sparsely populated areas where firms are less likely to register locally. By contrast, the unemployment registers are based on workers' municipality of residence and are not subject to this spatial mismatch, though they are sensitive to changes in labor-force participation.

Given these complementary strengths and weaknesses, combining both employment and unemployment data provides a more complete picture of the local labor markets.

Individual-level Social Security microdata (affiliation life-history). To study labor reallocation patterns, we additionally use individual-level microdata from the Social Security affiliation *vida laboral* (employment history) register between 2013 and 2024. The data are organized at the level of an individual employment relationship and include individual identifiers, demographic characteristics (gender, birth date, nationality), and detailed information on the job and the employer's Social Security account.

In particular, each spell records the employer account identifiers (main and secondary Social Security contribution account codes), the Social Security regime, and the industry code (four-digit CNAE-2009).[9] The register further reports the province associated with the account. Each employment spell contains start and end dates, which allow us to reconstruct workers' employment

[8] As a result, unemployment rates reported in the Labor Force Survey tend to exceed those from the registries.

[9] CNAE-2009 is the Spanish national version of NACE Rev. 2.1. It coincides with NACE at the two-digit level but subdivides NACE class 35.11 (production of electricity) by technology: 3515 (hydroelectric), 3516 (conventional thermal), 3517 (nuclear), 3518 (wind), and 3519 (other, mostly solar). For simplicity, we refer to these four-digit codes as NACE codes throughout.

histories and identify job-to-job movements across industry–province cells.

In our implementation, we define a transition as a change between two consecutive employment spells in a worker's history. A transition occurs whenever either the four-digit NACE code or the province changes. We aggregate transitions by origin industry–province and destination industry–province cells at the annual level. Self-employed workers are excluded from the analysis, as their labor market dynamics and hiring arrangements are not directly comparable to those of wage and salary employees.

Population, births, deaths, and migration. Population figures are drawn from the Continuous Register Statistics of the Spanish National Statistics Institute (INE), reported as of January 1 for each year from 1996 to 2025, except for 1997 (INE, 2026a). Under Spanish law, all residents are required to register their habitual place of residence in the municipal population register (*Padrón Municipal*). These official population counts, validated by the central government, serve several administrative and institutional purposes, including the allocation of parliamentary seats across provinces, the distribution of municipal funding, and other legally mandated functions. Our analysis tracks population dynamics using these records, beginning with the population counts as of 1 January 2004.

Data on natural population growth, used to decompose overall demographic change, are obtained from INE statistics on births and deaths for each municipality between 1996 and 2024 (INE, 2026b). Combining these records with the annual population counts from the Continuous Register allows us to split the yearly change in municipal population into two components: natural growth (births minus deaths) and net migration, the latter computed as the residual.

We also draw on the *Residential Variation Statistics* (RVS) and the *Migration and Changes of Residence Statistics* (MCRS) compiled by the INE to analyze migration patterns. These administrative datasets record all changes of residence within Spain and include both internal and international movements, along with information on gender, age, nationality, country of birth, and the origin and destination of each move. The RVS covers the period 1988–2021, while the MCRS provides data for 2022 and 2023. Both sources derive internal migration figures from changes reported to the Continuous Register, whereas the MCRS supplements international migration counts by inferring additional flows from population statistics. In this study, we focus exclusively on internal migration flows.

Per-capita income. We use municipality-level data on per-capita income covering the period 2015–2023. These data are provided by INE, which compiles detailed income information from administrative tax records. Specifically, INE receives microdata from the tax authorities on income subject to personal income taxation, classified according to taxpayers' municipality of residence.

To preserve statistical and tax confidentiality, INE only publishes municipal income indicators for municipalities with at least 100 residents in all years prior to 2020. Municipalities above this threshold account for approximately 85% of all Spanish municipalities. Per-capita income at the grid-cell level is therefore constructed using only municipalities for which income information is available throughout the sample period. As a consequence, two control grid cells do not contain any municipality with published income data and are excluded from the income analysis.

Table 2 presents summary statistics for 2017 —the year preceding the first closure announcement in the sample— comparing 10 treated units with 732 control units. On average, treated units exhibit lower levels of employment, unemployment, and population, but higher per-capita income. Specifically, employment in treated units is approximately 53% lower than in control units, while unemployment and population are roughly 19% and 26% lower, respectively. In contrast, per-capita income is about 10% higher in treated units. Treated units were also already losing residents through net out-migration (an average of 88 residents per year, compared with a net inflow of 218 in control units).

TABLE 2
DESCRIPTIVE STATISTICS BY TREATMENT STATUS (2017)

	Treated			Control		
	N	Mean	SD	N	Mean	SD
	(1)	(2)	(3)	(4)	(5)	(6)
Employment	10	8,024	10,431	732	16,970	90,545
Unemployment	10	3,455	4,829	732	4,249	14,323
Population	10	42,674	55,429	732	57,971	218,590
Net migration	10	-88	322	732	218	1,696
Per-capita income (euros)	10	11,162	1,175	730	10,108	1,776

Notes: This table reports summary statistics for 2017, the year preceding the first closure announcement, at the grid-cell level. Treated units are the areas within a 15-kilometer radius of a coal-fired power plant included in the sample; control units comprise the grid cells not excluded from the control pool. Employment, unemployment, and population are measured in number of individuals; per-capita income is measured in euros. Municipal income data are unavailable for municipalities with fewer than 100 residents before 2020. As a result, per-capita income is observed for 730 control units instead of 732.

4 Aggregate Effects of the Coal Plant Closures

To estimate the aggregate effects of the coal-fired power plant closures on local annual employment, unemployment, population, and income, we implement the doubly robust estimator proposed by Callaway and Sant'Anna (2021). The event-study is specified as:

$$y_{it} = \sum_{h=\underline{h}}^{\bar{h}} \beta_h C_{it}^h + \alpha_i + \lambda_t + \epsilon_{it}, \tag{1}$$

where y_{it} is either (log) employment, unemployment, population, or per-capita income in grid cell i in year t, α_i denotes grid cell fixed effects, and λ_t are time fixed effects. The treatment indicators, C_{it}^h, are binary variables that take the value one if, in year t, grid cell i is h years away from the year in which a coal-plant closure was announced within it, and zero otherwise.

The event window spans from five years before the announcement to five years after it, so that $\underline{h} = -5$ and $\bar{h} = 5$. In the figures below, we present estimates using a varying reference period: for pre-treatment years ($h < 0$), each estimate is expressed relative to the immediately preceding period, while for post-treatment years ($h \geq 0$), the reference period is fixed at the year immediately before the announcement ($h = -1$). This choice improves the interpretability of the plots, particularly for assessing potential anticipation effects in the years leading up to the formal closure announcement.

Figure 3 reports the estimated coefficients from equation (1) for employment, unemployment, population, and per-capita income, while Table 3 summarizes the post-treatment effects. Across the analyzed outcomes, no systematic differences are observed between treated municipalities and the control group during the pre-announcement period, supporting the validity of the parallel trends assumption. The only exception is employment, for which treated municipalities exhibit slightly lower growth rates in the two years prior to the announcement.

Panel A shows that announcements are followed by a decline in employment in treated units, reaching -13.1% five years after the announcement.[10] Paradoxically, as Panel B indicates, this contraction is not accompanied by a rise in unemployment: post-treatment effects remain statistically indistinguishable from zero during the first two years, and unemployment even falls

[10] As already noted, the coefficients in Table 3 are in log points; we report the implied percentage changes, $100\,[\exp(\hat{\beta}_h) - 1]$, in the text.

by 6.4% by year 5. Panel C helps reconcile these patterns, revealing a steady population decline starting at the announcement and reaching −4.2% after five years. Consistent with these trends, per-capita income falls in treated units by a cumulative 2.6% relative to the control group by year 4.[11]

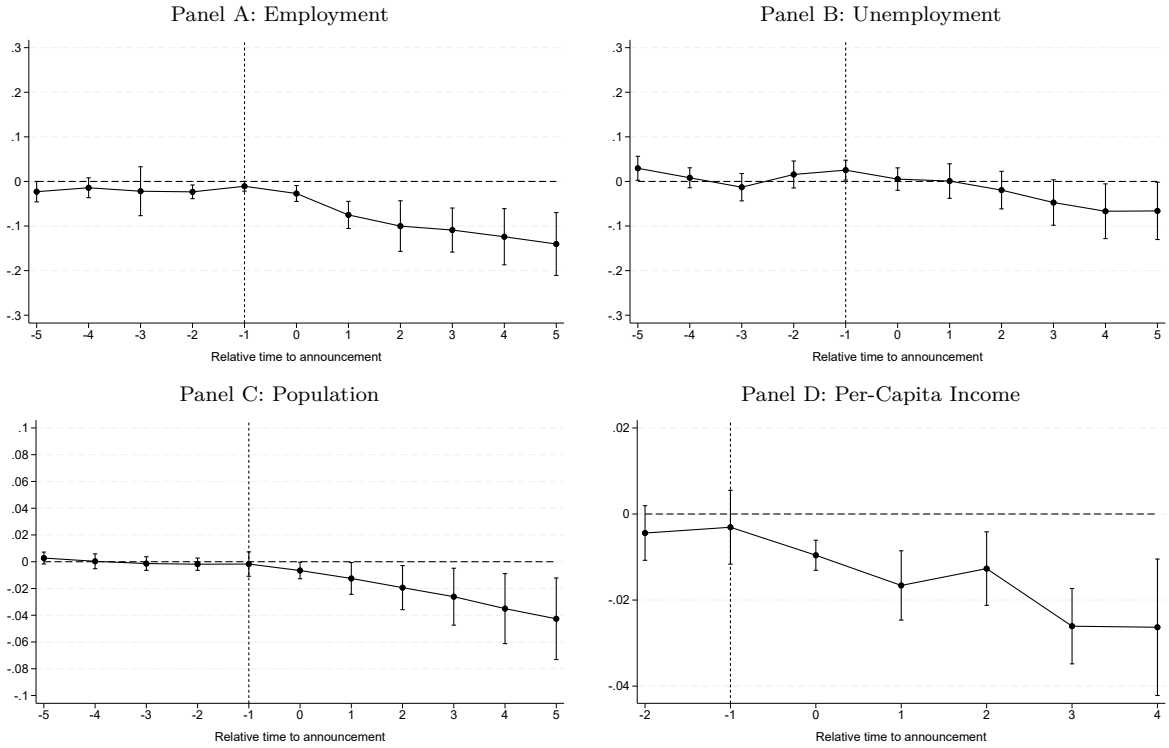
To assess the robustness of our baseline results, the appendix presents alternative event-study specifications that rely on different estimators and reference-period normalizations. Figures C.2, C.3, and C.4 report results separately for employment, unemployment, and population. Each figure compares the baseline Callaway and Sant'Anna estimates —where pre-treatment coefficients are expressed relative to the immediately preceding period— with three alternative approaches: (i) Callaway and Sant'Anna estimates that adopt a universal reference period fixed at the year before the announcement ($h = -1$), (ii) a standard two-way fixed effects (TWFE) event-study specification, and (iii) the interaction-weighted estimator of Sun and Abraham (2021). Reassuringly, the results are highly consistent across specifications, displaying very similar dynamic patterns and magnitudes for all outcomes. In particular, the post-announcement decline in employment and population, together with the lack of a sustained increase in unemployment, is preserved across all methods. Furthermore, pre-treatment coefficients are generally statistically indistinguishable from zero under all specifications —aside from the previously noted exception for employment in the two years preceding the announcement— thereby providing additional support for the plausibility of the parallel-trends assumption.

It is instructive to examine the employment effects by industry. Figures C.5 and C.6 in the Appendix display the estimated employment impulse–response functions for each two-digit NACE Rev. 2 industry (87 in total) for the years preceding and following the closure announcements.

The results reveal no statistically significant effects in any industry prior to the announcements. In contrast, the post-announcement period shows pronounced employment declines in three industries: 35 (Electricity, gas, steam and air conditioning supply), 49 (Land transport and transport via pipelines), and 10 (Manufacture of food products), with the sharpest contraction observed in industry 35. These findings indicate that the closures generated both direct effects—evident in

[11] Figure C.1 shows results using treatment defined from plant disconnection onward. While the overall patterns are similar to those in Figure 3, two differences emerge. Pre-trend coefficients are more pronounced, reflecting adjustment between announcement and disconnection, and unemployment effects are concentrated after disconnection. Population declines begin at announcement, whereas workers tend to remain in unemployment registers until plants are physically disconnected.

Figure 3
Event Study for Employment, Unemployment, Population and Per-Capita Income



Notes: These figures show the effects of coal-fired power plant closures on employment (Panel A), unemployment (Panel B), population (Panel C), and per-capita income (Panel D); t years before and after the announcement date. The vertical dashed black line marks the year prior to the announcement date. Error bands depict the 95% confidence interval. Standard errors are clustered at the grid cell level.

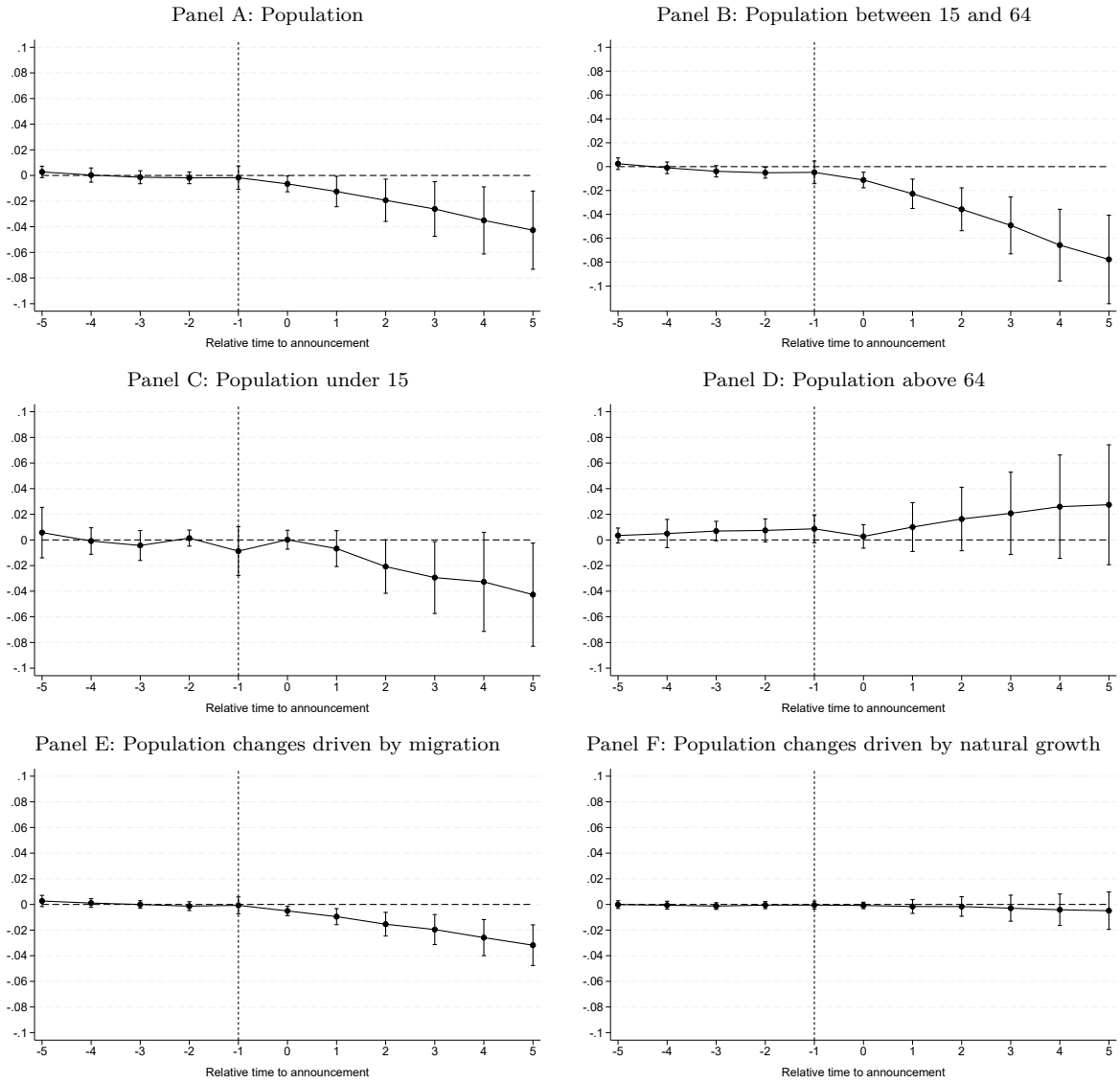
industries 35 and 49—and indirect effects, as illustrated by the decline in industry 10.

Figure 4 examines the population response in greater detail by decomposing the overall effect into age-specific changes and distinguishing between components driven by migration and by natural growth (births minus deaths). The results indicate that the overall population decline is primarily driven by a pronounced reduction in the working-age group (15–64 years). This outflow is accompanied by a decrease in the number of children (under 15) and a modest decline in net births by year 5 following the announcement. In contrast, the elderly population (65 and older) exhibits a small, statistically insignificant increase. These patterns are further reinforced by a decline in net migration.

Overall, the event-study evidence points to a scenario of declining employment, with younger cohorts migrating away and leaving behind a relatively older, poorer population—and, conse-

quently, a local economy offering fewer opportunities for incoming migrants.

Figure 4
Event Study for Population by Age and Driver



Notes: These figures show the effects of coal-fired power plant closures on total population (Panel A), population aged 15–64 (Panel B), population under 15 (Panel C), population over 64 (Panel D), population assuming only migration (Panel E), and population assuming no migration (Panel F); t years before or after the announcement date. The vertical dashed black line marks the year prior to the announcement date. Error bands depict the 95% confidence interval. Standard errors are clustered at the grid cell level.

Table 3

Aggregate effects of coal plant closures

	Employment (1)	Unemployment (2)	Population (3)	Per-capita income (4)
$h = 0$	-0.027***	0.005	-0.007**	-0.010***
	(0.009)	(0.013)	(0.003)	(0.002)
$h = 1$	-0.075***	0.001	-0.013**	-0.017***
	(0.016)	(0.020)	(0.006)	(0.004)
$h = 2$	-0.100***	-0.020	-0.019**	-0.013***
	(0.029)	(0.022)	(0.008)	(0.004)
$h = 3$	-0.109***	-0.047*	-0.026**	-0.026***
	(0.025)	(0.026)	(0.011)	(0.004)
$h = 4$	-0.124***	-0.067**	-0.035***	-0.026***
	(0.032)	(0.031)	(0.013)	(0.008)
$h = 5$	-0.140***	-0.066**	-0.043***	
	(0.036)	(0.033)	(0.016)	
# Obs.	15,950	14,455	15,950	6,507

Notes: This table reports the estimated effects of coal-fired power plant closures on employment, unemployment, population, and per-capita income h years after the announcement date. The specification follows the event-study design described in equation (1). Standard errors are clustered at the grid cell level.

5 Heterogeneous Effects across Coal Plant Closures

Our previous analysis quantified the aggregate effects of the ten coal-plant closures that occurred in Spain between 2018 and 2021. However, given the heterogeneity in plant characteristics, it is plausible that the effects vary substantially across closures. To explore this heterogeneity, we estimate plant-specific impacts by constructing a synthetic control for each plant and measuring the effect as the difference between the observed outcome in the closing plant's area and that of its synthetic counterpart.

Formally, let Y_{it} denote the outcome of interest for unit i at time t, where $i = 1$ indexes the treated area and $i = 2, \ldots, J+1$ denote the donor pool. The synthetic control is defined as

$$Y_{1t}^{SC} = \sum_{j=2}^{J+1} w_j Y_{jt}, \quad \text{with } w_j \geq 0, \ \sum_{j=2}^{J+1} w_j = 1,$$

where the weights $\{w_j\}$ are selected to minimize the mean squared prediction error between the treated unit and its synthetic counterpart in the pre-treatment period subject to matching on a set of predictors X_{it} (including employment normalized with initial population, unemployment normalized with initial population, population density, and working-age population over initial population).

The outcomes of interest are employment, unemployment, and working-age population normalized by initial population, as well as population density. Letting T denote the year of the closure announcement, the predictors are the averages of these variables from the beginning of the sample period to $T-3$, together with lags 3, 6, 9, and 12 of the outcome variable.

The estimated treatment effect at time $t \geq T-2$ is then given by

$$\hat{\tau}_{1t} = Y_{1t} - Y_{1t}^{SC}.$$

The pre-treatment period serves for weight estimation up to $T-3$ and as a diagnostic for model validity in $T-2$ and $T-1$. If the treated unit and its synthetic counterpart diverge systematically before the intervention, this would indicate that the synthetic control fails to replicate the untreated trajectory, casting doubt on the reliability of subsequent treatment effect estimates.

To improve the credibility of the counterfactuals, we impose restrictions on the donor pool.

First, we exclude grid cells located within 100 kilometers of a treated plant, as well as those located beyond 300 kilometers. This ensures that potential controls are neither too close to the treated unit (and thus potentially affected by spillovers) nor too distant (and thus subject to very different regional dynamics).

Second, we exclude donor units whose pre-treatment population or employment levels are highly dissimilar to those of the treated area. Specifically, we require that the population and employment levels of donor units never exceed twice the corresponding values of the treated unit. This filter ensures that the synthetic control is constructed from units that are broadly comparable in scale to the treated area.

This framework allows us to capture the dynamic effect of coal plant closures by comparing the observed trajectory of the treated area with that of its synthetic counterpart. For each closure event, we construct a plant-specific synthetic control and compute $\hat{\tau}_{1t}$ over the post-treatment horizon. To evaluate the robustness of our findings, we implement placebo tests by reassigning the treatment to donor units and comparing the distribution of placebo effects with the estimated effects of actual closures. This procedure provides a benchmark for inference and enables us to assess whether the observed deviations are statistically meaningful. Figures D.17–D.20 report these placebo tests for employment, unemployment, population, and working-age population for each of the six closures included in the average effects discussed below.

Figure 5 reports the average of estimated treatment effects for employment over population in 2003, unemployment over population in 2003, population density, and working-age population over population in 2003. These averages are computed for the six plant closures announced in 2018 that were disconnected in June 2020—Compostilla, Meirama, Narcea, La Robla Fenosa, Puente Nuevo, and Teruel—thus excluding Anllares (which closed in 2018), Lada and Velilla del Río Carrión (which closed in 2020 but the announcement was in 2017), and Litoral de Almería (which closed in 2021). On average, and in line with our aggregate estimates reported in Figure 3, the analysis shows that employment, total population, and the working-age share decline following the closures, whereas unemployment remains essentially unchanged. These average patterns are driven by marked reductions in employment and population in Compostilla, Teruel, and La Robla Fenosa; by declines limited to employment in Puente Nuevo; by the absence of noticeable changes in Narcea; and by an increase in employment following disconnection in

Meirama.[12]

Table 4 summarizes the main characteristics of these plants' locations. These six municipalities differ along several dimensions that map well onto the estimated impacts. The three municipalities with large declines in both employment and population share a deep dependence on coal. Cubillos del Sil, home to the Compostilla plant, is a very small municipality (around 1,800 inhabitants) that saw both employment and population fall despite being only about 10 km from Ponferrada, itself undergoing a parallel, region-wide contraction that limited its job opportunities. The plant was one of the largest coal-fired stations in Spain and, together with the associated El Bierzo mining basin — already contracting since the closure of the coal mines in 2018 — accounted for a very high share of local employment, with few non-coal alternatives. Andorra is a large town (7,500 inhabitants) but sits in Teruel, one of the least densely populated provinces in Europe. Both the share of local employment linked to the plant and the absence of nearby urban labor markets made household relocation the dominant response. La Robla is only 25 km from the provincial capital (León), and this short distance may have facilitated household relocation rather than commuting, reinforcing the population decline.

Espiel (home to Puente Nuevo) shows declines concentrated in employment but more muted population effects, consistent with its structural profile. The municipality is roughly 60 km from Córdoba (325,000 inhabitants), has a diversified non-coal base (dehesa agriculture, livestock, hunting tourism, small-scale forestry), and offers meaningful commuting potential toward the city. These features dampen the population response while still allowing employment to fall, since the plant itself was a large direct employer.

Tineo (home to Narcea), where we find essentially no detectable effects, is a large municipality with 9,000–10,000 inhabitants spread across many parishes, and its economy rests on cattle, dairy, forestry, agrifood, and a substantial public-sector footprint. The coal power plant was an important employer, but it accounted for a smaller share of local employment than in any of the other five cases. Equally important, the region has received by far the largest share of EU and national Just Transition funds, and its coal-region reconversion infrastructure is the most developed. The combination of a pre-existing diversified base and unusually strong institutional

[12]The individual trajectories underlying these averages are shown in Figures D.7–D.12 (Compostilla, Meirama, Narcea, La Robla Fenosa, Puente Nuevo and Teruel). Figures D.13-D.16 present results for the remaining closures (Anllares, Lada, Velilla del Río Carrión and Litoral de Almería).

support may have helped neutralize the shock.

Cerceda (home to Meirama) stands apart from the other five municipalities: employment rises rather than falls after the plant's closure. Unlike the smaller, coal-dependent municipalities above, Cerceda is a more diversified town (5,000 inhabitants) only about 25 km from the city of A Coruña (close to 250,000 inhabitants), which had already built a substantial non-coal industrial base well before the plant closed. Direct coal-linked employment at Meirama was also comparatively modest at closure (around 110 workers). At the same time, the closure coincided with the designation of Cerceda as the core of the Meirama Just Transition Zone, which channeled a large renewable-energy tender (408 MW of grid access) and new investment, including a pumped-hydro project, into the area. The combination of a pre-existing diversified economic base, proximity to a large urban labor market, and sizeable Just Transition-linked investment appears to have more than offset the loss of coal jobs.

Taken together, the plant-level evidence suggests that our aggregate findings —declines in employment and population, alongside stable unemployment— are broadly shared, except in places where a diversified economy and strong institutional support helped cushion, or even reverse, these trends. Several factors appear to explain why the effects of coal plant closures differ in magnitude, and even in direction, across plants: (i) the share of plant-and-mine-linked employment in total municipal employment pre-closure; (ii) distance and quality of connection to an urban labor market; (iii) sectoral diversification and availability of public services; (iv) demographic structure, particularly the working-age share and the share of retirees, which conditions whether the adjustment shows up in population or only in employment; (v) municipal size and administrative capacity, which affect the ability to attract replacement activity; and (vi) regional Just Transition policy intensity.

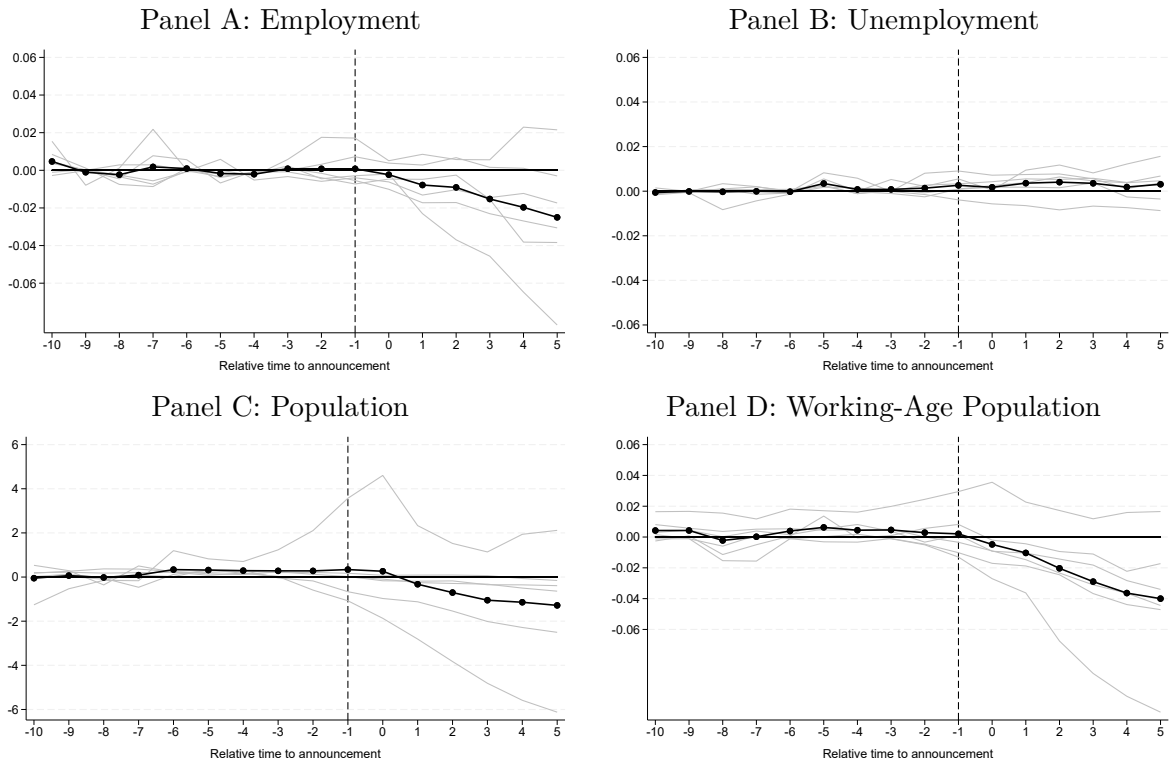
Table 4

Pre-closure characteristics of municipalities with coal plant closures, by outcome pattern

Municipality	Province / CCAA	Plant (owner)	Pop.	Dist. (km)[a]	Main non-coal activities	Coal-linked empl.[b]	Just Trans.[c]
Panel A. Employment and population decline							
Andorra	Teruel / Aragón	Teruel–Andorra (Endesa)	7,500	100	Lignite mining; small retail/services; scarce private sector	Very high	High
La Robla	León / CyL	La Robla (Naturgy)	4,000	25	Ancillary services to plant; some commuting to León	High	Medium
Cubillos del Sil	León / CyL	Compostilla II (Endesa)	1,800	10	DO Bierzo viticulture; El Bayo industrial estate; coal-logistics storage; commuting to Ponferrada	Very high	High
Panel B. Employment decline only							
Espiel	Córdoba / Andalucía	Puente Nuevo (Viesgo)	2,000	60	Dehesa agriculture, livestock, hunting tourism, commuting to Córdoba	Medium–High	Low
Panel C. No noticeable changes							
Tineo	Asturias	Soto de la Barca / Narcea (Naturgy)	9,500	65	Cattle/dairy, agrifood (PDO cheeses, Cangas wine), forestry, public services	Low–Medium	High
Panel D. Employment increases							
Cerceda	A Coruña / Galicia	Meirama (Naturgy)	5,000	25	O Acevedo industrial estate (diversified manufacturing); commuting to A Coruña metro area; livestock/agriculture	Medium–High	High

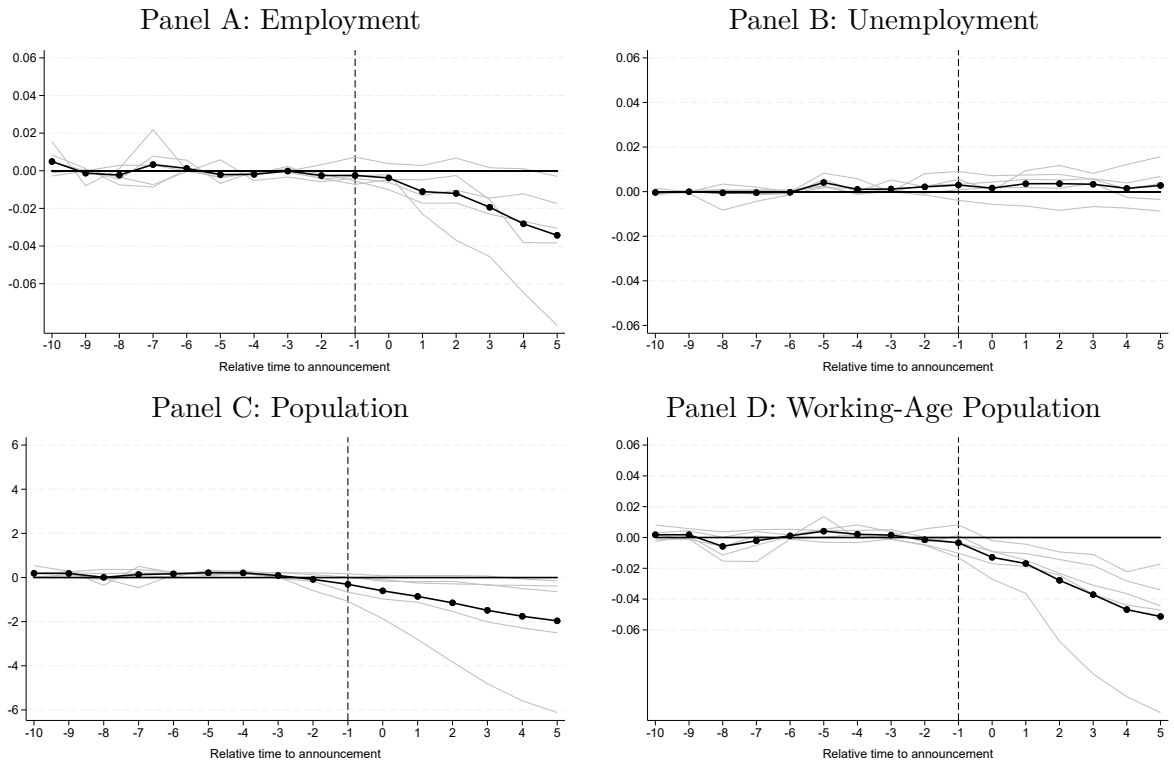
[a] Road distance to the nearest municipality with population above 50,000 inhabitants.
[b] Qualitative classification of the share of pre-closure local employment directly or indirectly linked to the coal plant and associated mining.
[c] Qualitative indicator of exposure to EU/ITJ Just Transition funds and *convenios de transición justa* signed in the municipality or its *comarca*.

Figure 5
Average Effects



Notes: These figures show the average gap between the treated grid cells and their synthetic controls for the six closures announced in 2018 and disconnected in June 2020 (Compostilla, Meirama, Narcea, La Robla Fenosa, Puente Nuevo and Teruel). The closures of Anllares, Lada, Velilla del Río Carrión and Litoral de Almería are excluded. The horizontal axis shows years relative to the closure announcement.

Average Effects excluding also Meirama



Notes: These figures exclude the closures of Anllares, Lada, Velilla del Río Carrión, Litoral de Almería and Meirama.

6 From Brown to Green: Migration and Labor Transitions

Having documented the aggregate and plant-level consequences of coal-plant closures for local employment, unemployment, and population, we now examine how affected communities and workers adjust: this section studies where displaced residents relocate, and to which sectors.

6.1 Migration

Our previous results show that coal-fired power plant closures lead, on average, to population declines in the affected municipalities. In this section, we examine the underlying migration patterns in greater detail. Specifically, we ask where residents leaving these municipalities relocate, whether they are disproportionately drawn to areas experiencing investment in renewable energy generation, and how geographic proximity shapes these choices. We also investigate whether the timing of migration responds to the plant closure itself.

In particular, we estimate the following gravity equation for the period 2003–2023, where i denotes the origin (restricted to grid cells affected by coal-plant closures), and j denotes the destination:

$$Y_{ijt} = \exp\Big(\alpha_{ij} + \gamma_t + \beta_1 C_{it} + \beta_2 R_{jt} + \beta_3 C_{it} R_{jt} + \beta_4 C_{it} N_{ij} + \beta_5 R_{jt} N_{ij} + \beta_6 C_{it} R_{jt} N_{ij}\Big)\eta_{ijt}. \tag{2}$$

The dependent variable Y_{ijt} measures migration flows from origin grid i to destination grid j in year t. The specification includes three binary indicators and their interactions. The *closure* indicator C_{it} equals one from the year in which the coal plant closure is announced at the origin municipality i. The *renewable* indicator R_{jt} equals one if destination j hosts renewable energy capacity (at least 5 MW) at time t, either in operation or within the two years preceding start-up, during which construction takes place. Finally, the *neighbor* indicator N_{ij} equals one if the distance between origin i and destination j is less than 100 km. The regression controls for time-invariant characteristics of each origin–destination pair (e.g., distance) through origin-destination fixed effects α_{ij}, and for time-varying factors common to all pairs (e.g., macroeconomic conditions) through γ_t. Standard errors are clustered at the origin–destination grid-pair level.

We estimate equation (2) using the Poisson Pseudo–Maximum Likelihood (PPML) estimator

proposed by Silva and Tenreyro (2006), which takes as the dependent variable the absolute number of migrants between each origin–destination grid pair.[13] Identification comes from within-pair variation over time, comparing changes in migration flows towards destinations with renewable investments before and after coal-plant closures relative to changes in flows towards destinations without renewable investments.

Table 5 presents the estimates based on 3,716 origin–destination pairs. Because the specification includes interaction terms, individual coefficients are not directly interpretable. We therefore organize the discussion around two economically meaningful post-closure effects.

Column 2 asks whether, after a coal-plant closure, migrants are more likely to relocate to destinations hosting renewable energy investments. The results indicate that this is indeed the case. Following a closure, migration flows towards destinations with renewable investments increase by around 10% relative to destinations without renewable projects. This effect is statistically significant and suggests that renewable investments act as a pull factor in the spatial reallocation of population after large negative labor-demand shocks linked to coal-plant closures.

Column 3 examines whether this post-closure renewable-attraction effect depends on geographic proximity. The estimates show that proximity plays a key role. When the renewable-energy destination is located within 100 km of the origin, the post-closure migration response rises to roughly 20%—about twice as large as the average effect. By contrast, the corresponding effect for more distant destinations is smaller and statistically insignificant. This pattern indicates that spatial frictions strongly condition migration responses: while renewable investments attract migrants after closures, their effect is concentrated in nearby locations where mobility costs are lower. The point estimates are similar across groups—women and men, Spanish nationals and foreign-born residents (Table E.3)—although less precisely estimated for the smaller groups, and the result is robust to the inclusion of various fixed effects (Table E.4).

Taken together, these results indicate that renewable investment acts as a closure-specific pull factor rather than a pre-existing driver of migration. Neither the closure indicator nor the renewable-destination indicator is significant on its own (Column 1); it is specifically their interaction—migration towards renewable-hosting municipalities after a nearby coal-plant closure—

[13] Log-linearizing the dependent variable in a gravity model estimated by OLS would drop all origin–destination pairs with zero observed migration. Since the absence of migration is unlikely to be random, such truncation could bias the estimates downwards.

that is significant. The sharp spatial decay in the proximity results reinforces this interpretation: the pull of renewable investment is significant only within 100 km of the closing plant, and small and statistically insignificant beyond it. Renewable capacity thus functions as a channel of adjustment—albeit geographically narrow—whose reach is unlikely to fully offset population losses in municipalities without nearby renewable projects—a pattern consistent with the plant-level heterogeneity documented in Section 5.

TABLE 5
MIGRATION AFTER CLOSURE

	(1)	(2)	(3)
Closure	0.015	-0.020	-0.021
	(0.044)	(0.047)	(0.053)
Renewable destination	0.043	0.022	0.048
	(0.036)	(0.037)	(0.039)
Renewable after closure		0.068**	0.018
		(0.033)	(0.035)
Closure, <100 km			0.021
			(0.046)
Renewable destination, <100 km			-0.045
			(0.073)
Renewable after closure, <100 km			0.160**
			(0.072)
# Obs.	78,036	78,036	78,036
# Grid Pairs	3,716	3,716	3,716
Renewable after closure effect		0.091**	
		(0.043)	
Renewable after closure effect, <100 km			0.180**
			(0.089)
Renewable after closure effect, >100 km			0.066
			(0.049)

Notes: This table reports the results of estimating equation 2 using the PPML estimator. The dependent variable for each column is the number of migrants between grid pairs in each year. The regression includes origin-destination fixed effects and time fixed effects. Standard errors are clustered at the grid-pair level.

6.2 Labor Transitions

The last question we analyze is whether workers directly exposed to the decline in fossil-fuel activities can reallocate to the sectors driving the energy transition. To address it, we use Social Security microdata to track worker flows across industry–province cells and examine transitions originating in NACE 3516, which encompasses conventional thermal electricity generation (coal, natural gas, and fuel oil).

Figure 6 provides a first descriptive illustration of these patterns. As shown in Panel A, before the closure announcements, transitions from conventional thermal electricity generation (NACE 3516) to renewable electricity generation (NACE 3518 and 3519) were virtually non-existent; following the announcements, they increased steadily, reaching a cumulative total of around 33 transitions five years later.[14] This channel appears closure-specific rather than a by-product of broader trends: transitions from other industries into renewables (Panel B) and from thermal generation into non-energy sectors (Panel D) both follow steady, pre-existing trajectories with no discernible break around the closures, whereas Panel A's acceleration is concentrated precisely at the closure dates. Panel C shows that displaced thermal workers also move into adjacent energy, water, and waste-management activities, indicating that the reallocation extends across the broader energy value chain rather than being confined to renewables alone. Taken together, Panels A–D point to a distinct, closure-associated brown-to-green transition channel, separable from both pre-existing sectoral trends and generic worker turnover.

Although modest in absolute terms, these 33 transitions represent a non-negligible share of overall worker reallocation out of thermal generation and mark a clear break from the pre-announcement pattern. Between the announcement year and five years later, renewable destinations account for 11% of the 300 transitions originating in conventional thermal electricity generation (NACE 3516), with a further 35% flowing to other energy-related activities and the remaining 54% to non-energy sectors; one year before the first announcement, by contrast, essentially all transitions (95%) were directed to non-energy sectors, 5% to other energy activities, and none to renewables. Relative to the initial stock of workers, the magnitude is also economically meaningful: the treated provinces employed 426 workers in conventional thermal electricity generation at the start of the sample, so the 33 transitions to renewable generation correspond to 7.7% of this initial workforce.

Table 6 compares the 33 workers who moved from conventional thermal electricity generation to renewable electricity generation with the 257 workers who remained in thermal generation. The two groups are similar in terms of gender and contract type: the vast majority are male (91% of transitioners and 94% of non-transitioners) and hold permanent contracts (97% and

[14] For the subset of closures for which longer follow-up is available, an additional 2 and 1 transitions occur in years six and seven, respectively.

94%, respectively), and neither difference is statistically significant. Moreover, workers holding permanent (temporary) contracts in thermal generation almost always move into permanent (temporary) positions in renewables. Transitioners are somewhat less likely to be Spanish nationals (94% compared with 100%). The main difference between the two groups is age. Transitioners are about five years younger on average (43 compared with 48 years) and are concentrated in prime working ages: 76% are between 35 and 54 years old, compared with 55% among non-transitioners. By contrast, workers older than 54 account for only 9% of transitioners, compared with 34% of those who remain in thermal generation. These patterns suggest that brown-to-green reallocation is led by experienced, mid-career workers rather than by new labor-market entrants or by workers approaching retirement.

TABLE 6

CHARACTERISTICS OF WORKERS TRANSITIONING TO RENEWABLE ELECTRICITY GENERATION

	Transitioners (1)	Non-transitioners (2)	Difference (3)	p-value (4)
Male (%)	90.9	94.2	-3.3	0.467
Spanish (%)	93.9	100.0	-6.1	0.000
Permanent contract (%)	97.0	94.2	2.8	0.508
Mean age	43.1	47.9	-4.8	0.009
Age <35 (%)	15.2	10.9	4.3	0.470
Age 35–54 (%)	75.8	55.3	20.5	0.025
Age >54 (%)	9.1	33.9	-24.8	0.004
N	33	257		

Notes: This table compares workers who transitioned from conventional thermal electricity generation (NACE 3516) to renewable electricity generation (NACE 3518–3519) with workers who remained in thermal generation. Columns (1) and (2) report group means. Column (3) reports the difference between transitioners and non-transitioners. P-values are obtained from a two-sample t-test.

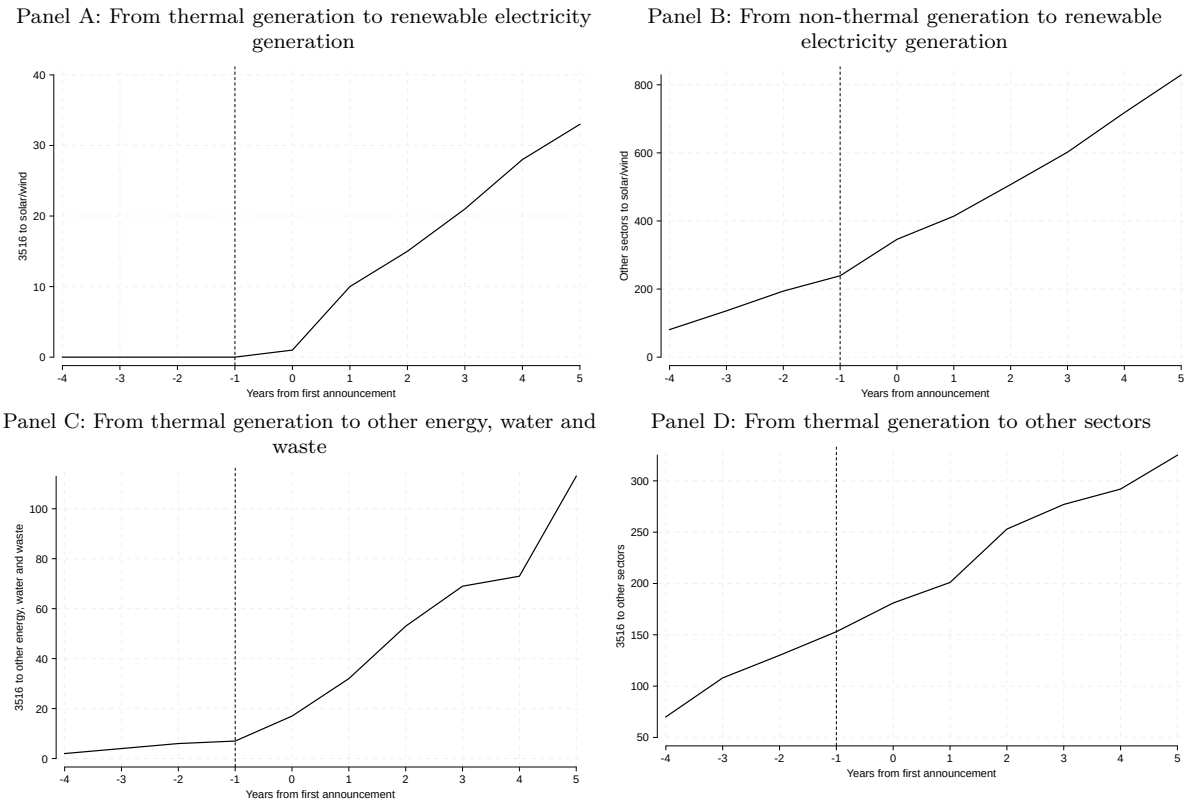
To formally assess these patterns, we estimate an additional gravity equation in which the dependent variable, T_{ijt}, denotes the number of workers moving from industry–province i to industry–province j in year t:[15]

$$T_{ijt} = \exp\left(\alpha_{ij} + \gamma_t + \beta_1 C_{it} + \beta_2 C_{it} R_j\right)\eta_{ijt}. \tag{3}$$

The closure indicator C_{it} equals one when origin cell i corresponds to thermal electricity generation (NACE 3516) in a province affected by a coal-fired power plant closure, and year t follows the first

[15]Labor transitions are only observed at the industry–province level, whereas the variables analyzed in the previous sections are measured at the municipality level.

Figure 6
Transitions of workers



Notes: These figures report the cumulative number of workers transitioning from provinces affected by coal plant closures—Almería, A Coruña, Asturias, Córdoba, León, and Palencia— since 4 years before the closure announcement. Destination sectors are grouped into three categories: renewable electricity generation (NACE 3518 and 3519); other energy, water, and waste management activities (the remaining NACE D and E); and all other sectors. Origin sectors are classified into two groups: thermal-related activities (NACE 3516) and all other sectors.

announcement of a coal-plant closure in that province.[16] The renewable-industry indicator R_j equals one when destination industry j corresponds to renewable electricity generation, namely wind (NACE 3518) or solar (NACE 3519). The coefficient β_2 on the interaction term $C_{it}R_j$ captures the differential effect of coal-plant closures on labor transitions from thermal generation into renewable industries, relative to transitions into other destination industries. In particular, a positive β_2 would indicate that brown-to-green labor transitions intensify following coal-plant closures.

[16]The treated provinces are A Coruña, Almería, Asturias, Córdoba, León and Palencia. Treatment starts in 2017 for Asturias, León, and Palencia; in 2018 for A Coruña and Córdoba; and in 2019 for Almería. Because treatment is defined at the province level, provinces are considered treated from the first coal-plant closure announcement affecting them. Teruel is excluded from this analysis because the province experienced a prior coal-plant closure (Escucha, announced in 2011), which would require assigning treatment before the announcement of the Andorra closure. Provinces with only excluded plants (Barcelona, Cádiz, Cantabria, Ciudad Real, Guipúzcoa, Illes Balears, Teruel, and Zaragoza) are not included in the estimation sample. Tables 1 and B.2 provide further details.

The specification also includes origin–destination industry–province pair fixed effects α_{ij}, which absorb time-invariant characteristics of each pair, such as geographic proximity and the degree of skill relatedness between origin and destination industries. The time fixed effects γ_t control for common shocks, including macroeconomic conditions affecting all industries. Equation (3) is estimated using a fixed-effects Poisson estimator with robust standard errors allowing for arbitrary within-pair dependence.

Table 7 reports the estimated coefficients β_1 and β_2.[17] As shown in column (1), there is no statistically significant evidence that overall labor transitions from thermal generation increase following coal-plant closure announcements when all destination industries are considered together. By contrast, column (2) shows a large and highly statistically significant coefficient on the interaction between the closure indicator and the renewable-industry indicator. This result indicates that transitions from thermal generation to renewable electricity generation increase substantially following closure announcements, relative to transitions to non-renewable destination industries.

Columns (3) and (4) restrict the destination industries to NACE 35, which comprises electricity, gas, steam and air conditioning supply. Within this narrower set of destination industries, the closure coefficient is positive and highly statistically significant, indicating a substantial increase in transitions from thermal generation following closure announcements. The interaction coefficient in column (4) is also large and highly significant, showing that the increase in transitions to renewable electricity generation is considerably greater than the increase in transitions to other industries within NACE 35.

Finally, column (5) focuses exclusively on transitions from thermal generation to renewable electricity generation. The closure coefficient is positive and highly statistically significant, confirming that brown-to-green labor transitions rise sharply following coal-plant closure announcements. Since all destination industries in this specification are renewable, the coefficient captures the total effect of closure announcements on transitions to renewable electricity generation, rather than a differential effect relative to non-renewable destinations.[18]

[17] The coefficients in Table 7 are Poisson regression coefficients expressed in log points. A coefficient b corresponds to a multiplicative effect of $\exp(b)$ on the expected number of transitions. Thus, the associated percentage change is $100[\exp(b) - 1]$.

[18] In the baseline specification, labor transitions are defined as moves between two consecutive employment spells occurring within one year of the termination of the previous spell. Appendix Tables E.5 and E.6 show that the

The magnitude of the coefficients in columns (2), (4), and (5) should be interpreted in light of the very low pre-closure number of transitions from thermal to renewable electricity generation. These large coefficients are therefore best understood as evidence of a sharp increase from an initially very small flow, rather than as evidence of a large increase in the absolute number of transitions. In levels, as documented above, the closures were followed by a cumulative 33 transitions to renewable generation over five years—11% of the 300 transitions out of conventional thermal generation over that period, and 7.7% of the 426 workers employed in thermal generation in the treated provinces at the start of the sample.

TABLE 7

LABOR TRANSITION FROM THERMAL GENERATION IN THE AFFECTED PROVINCES AFTER THE CLOSURE ANNOUNCEMENTS

	(1)	(2)	(3)	(4)	(5)
Destination industry	All		NACE 35		Renewables
Closure (β_1)	0.157	0.041	2.481***	2.044***	16.617***
	(0.183)	(0.187)	(0.537)	(0.505)	(0.363)
Renewable after closure (β_2)		16.099***		14.033***	
		(0.408)		(0.616)	
# Obs.	15,232,010	15,232,010	105,956	105,956	33,754

Notes: This table reports the results of estimating equation 3 using a fixed-effects Poisson estimator. The dependent variable in each column is the number of transitions between industry–province pairs in each year. In the baseline specification, a labor transition is defined as a move between two consecutive employment spells occurring within one year of the previous spell's termination. The regressions include origin–destination industry–province pair fixed effects and year fixed effects. Standard errors are robust to arbitrary heteroskedasticity and within-pair dependence.

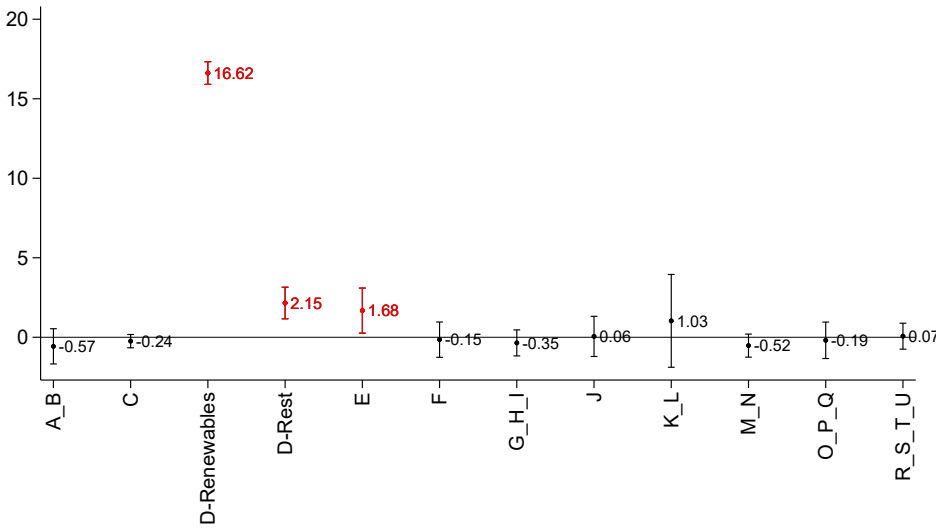
Table 7 compares renewable destinations with all other destinations combined. It therefore cannot tell whether the closures raised transitions only towards renewables and related activities, or towards a broad range of sectors. To explore this possibility, we compare the closure effect of column (5)—focusing exclusively on transitions from thermal generation to renewables—to the effects towards other destinations.

Panel A of Figure 7 shows that the increase in transitions is confined to energy-related destinations. In addition to the large increase in transitions to renewables, substantial increases are observed for non-renewable energy activities ("D-Rest") and for waste and water management ("E"), where transitions approximately double following the closure (in line with Panel C of

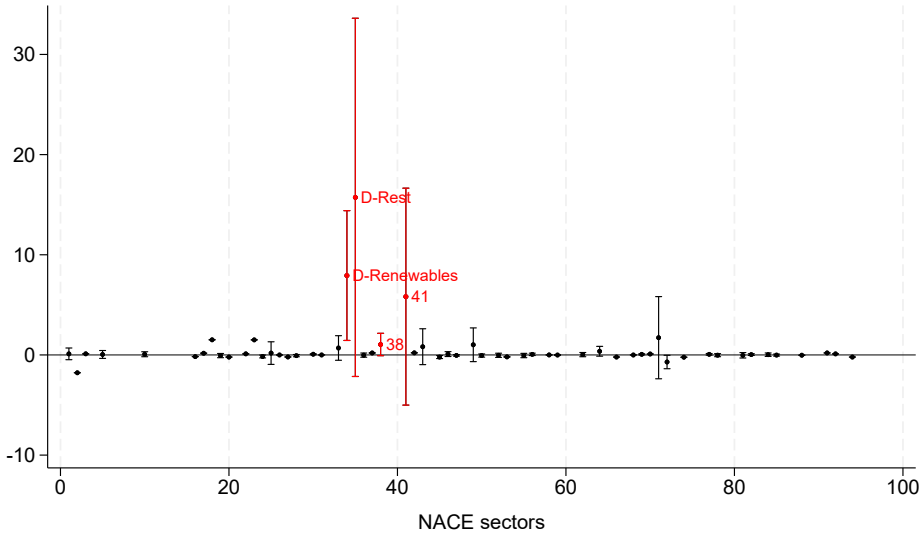
results are virtually unchanged when transitions are alternatively defined using a maximum gap of two years or when all observed transitions are considered, irrespective of the time elapsed between jobs.

Figure 7
Labor Transitions by Destination Sector

Panel A: By destination sector



Panel B: By two-digit NACE industry



Notes: Both panels report the estimated effects of coal plant closures on worker transitions across destination sectors; each dot represents the estimated transition multiplier and the vertical bars denote 95% confidence intervals. Labor transitions are defined as moves between consecutive employment spells occurring within one year of the termination of the previous spell, and standard errors are robust to arbitrary heteroskedasticity throughout. Panel A follows the Eurostat aggregation, with the energy aggregate further decomposed into renewable electricity generation (D-Renewables), other electricity and gas activities (D-Rest), and waste and water management (E). Panel B examines heterogeneity at the two-digit NACE level, using as the dependent variable the number of transitions normalized by initial employment in each industry–province cell; industries are arranged in ascending order of their NACE Rev. 2 code, and sectors D-Renewables, D-Rest, 38, and 41 are highlighted in red.

Figure 6). Effects for the remaining sectors are statistically insignificant. Panel B repeats the exercise at the two-digit NACE level, normalizing transitions by initial employment in each industry–province cell, and confirms the strong reallocation of workers towards electricity, utilities and waste (NACE 35 and NACE 38).

Taken together, the evidence in this section indicates that direct job-to-job transitions from fossil-fuel to renewable-energy activities constitute a genuine, if still modest, channel of labor reallocation, concentrated precisely in the sectors most closely linked to the energy transition (NACE 35 and NACE 38). This channel complements, rather than substitutes for, the migration response documented above: migration operates mainly through the relocation of residents towards renewable-investment hubs, whereas the transitions examined here capture workers who switch from thermal to renewable activities. Both channels, however, remain limited in scale relative to the magnitude of the local employment losses documented in Section 4, underscoring that renewable expansion so far offers only a partial cushion for displaced coal workers and communities.

7 Concluding Remarks

This paper sheds light on a central question in the political economy of the energy transition: can those who bear its costs also share in its benefits? It does so by analyzing the local labor-market consequences of the coal phase-out, and how the affected communities and workers adjust to it. Studying the closure of ten coal-fired power plants in Spain between 2018 and 2021—a period of rapid renewable energy expansion—this paper documents significant and persistent declines in local employment (13% five years after the announcement) and population (4.2%). These losses are accompanied by falling, rather than rising, local unemployment, a pattern explained by substantial outmigration concentrated among working-age residents. The municipalities left behind consequently become older and poorer, with per-capita income falling relative to unaffected areas.

These aggregate patterns conceal considerable heterogeneity across individual plant closures. Plant-by-plant synthetic control estimates show that the sharpest joint declines in employment and population occur in the smallest, most coal-dependent municipalities, which have few

economic alternatives and poor connections to urban labor markets. By contrast, municipalities with a more diversified economy, closer ties to larger cities, or stronger Just Transition support experience smaller, employment-only, or even reversed effects. This heterogeneity suggests that pre-existing economic diversification and the timely deployment of transition-support policies can materially soften—or even offset—the local costs of decarbonization.

We move beyond documenting local costs to tracing the transition itself: where displaced workers go, and what they do next. Using gravity-equation estimates of internal migration, we find that displaced residents are significantly more likely to relocate toward municipalities attracting renewable energy investment, an effect roughly twice as large when the destination lies within 100 kilometers of the closing plant. Linked Social Security microdata further reveal a rise in direct job-to-job transitions from thermal to renewable electricity generation—a channel that was virtually non-existent before the closures and that, while still modest in absolute terms, grew steadily in their aftermath.

These results carry direct implications for the design of Just Transition policies. Because the benefits of renewable investment appear to be geographically bounded, siting new renewable capacity, grid connections, and reskilling programs close to closing plants may be an effective, low-cost lever for cushioning local transition costs. The contrasting experiences of the municipalities in our sample—from the sharp joint declines in the most coal-dependent, poorly connected areas to the muted or even positive outcomes where the local economy was more diversified and institutional support more developed—suggest that combining renewable investment with pre-existing economic diversification and active institutional support can meaningfully alter the trajectory of coal-dependent regions.

Our analysis is not without limitations. It is based on ten plant closures, which limits statistical power for detecting more granular sources of heterogeneity. Our worker-level data do not contain earnings, so, unlike Walker (2013), we cannot assess whether workers who move into renewable generation do so at higher or lower pay, nor quantify the earnings losses of those who do not. Our migration and labor-transition analyses focus specifically on renewable electricity generation and may therefore understate broader green-economy reallocation into related activities such as manufacturing, storage, or grid infrastructure. Finally, our post-closure window, while informative, remains too short to establish whether the brown-to-green transitions

we document will continue to grow, stabilize, or fade as the initial pool of displaced workers is absorbed. As more coal plants close across Europe and additional years of post-closure data become available, these are avenues for future research.

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