Wired For Change? Clean Technology Adoption and Labor Market Transitions

Guillaume Wald*

Click here for the latest version

This version: November 8, 2025

Abstract

This paper explores worker transition costs in the adoption of clean technology. I study heating service firms transitioning from fossil fuel boilers to heat pump installation, a shift emblematic of SME-level electrification. Leveraging a subsidy shock that triggered exogenous adoption and matched employer-employee data, I find sharp increases in both job creation and separations, yet workers experience average gains of 10-12% in hours and earnings. Stayers drive this effect through increased hours, while displaced workers recover fully within one year. In contrast, hourly wage increase for those exposed early to the technology and those with smaller skill gaps—but only when moving to a new employer. The results show how market incentives can facilitate on-the-job skill updating, keeping transition costs low despite substantial reallocation. The adjustment mechanisms are generalizable to SMEs in other fossil fuel-dependent sectors, offering concrete guidance for policy design during decarbonization

Keywords: decarbonization, transition costs, labor reallocation, skills upgrading

JEL codes: Q52, J24, O33

*Mines Paris – PSL (email: guillaume.wald@minesparis.psl.eu).

Acknowledgements: This research is supported with funding from *Électricité de France (EDF)*. Access to some confidential data, on which this work is based, was made possible within a secure environment provided by CASD – Centre d'accès sécurisé aux données (Ref. 10.34724/CASD). I am grateful to Matthieu Glachant for his continuous advice and support. This paper greatly benefited from discussions with and comments by François Cohen, Misato Sato, and Aurélien Saussay.

1 Introduction

The energy transition raises significant concerns about job losses and reduced earnings, particularly for blue-collar workers in energy-intensive industries[1]. This fuels opposition to environmental regulations and contributes to anti-environmental political backlash[2]. Green investment programs, such as the Inflation Reduction Act or the European Green Deal, stand out as an important exception. By supporting the decarbonization of small and medium enterprises, they aim at creating new, local jobs, specifically for manual workers (European Commission 2020; The White House 2022). On the other hand, the transition requires major skills update, either internally through retraining programs, or externally through new hires. Skill mismatches could hinder workers' adaptation and lead to career's disruptions and foregone earnings, creating winners and losers in the energy transition[3].

This paper asks whether workers in small and medium-sized enterprises face significant transition costs when adapting to clean energy technologies. Prospects of a just transition are shaped by the case of workers in the fossil energy sector, especially coal-fired electricity generation and oil extraction[4]. Extending to hard-to-abate industries (e.g., cement, chemicals and petrochemicals, and steel industries), around 9% of the workforce in OECD countries is directly threatened by major earning losses and long run displacement costs (Barreto et al. 2024). Yet, effects may not generalize to SMEs, which gather 60% of workers (OECD 2023). According to Gross 2021, energy-intensive industries face fundamental technical barriers, such as high-temperature heat requirements, and structural challenges, such as capital intensity, long investment cycles and stranded assets. In contrast, the transition of SMEs may prove achievable through simple, proven technologies requiring minimal upfront investment (World Economic Forum 2024) and financing innovations that eliminate capital barriers entirely (European Investment Bank 2025).

[1] Workers in fossil-fuel extraction are at the forefront of this transition: "The Energy Transition Is Underway. Fossil Fuel Workers Could Be Left Behind" 2023. Heavy industry faces similar concerns: "The Guardian view on a carbon-free economy: no just transition in sight yet" 2025.

[2] In the US, see: "Trump is still courting coal workers. This county shows why it matters." 2024; "Reinvigorating America's Beautiful Clean Coal Industry and Amending Executive Order 14241" 2025. In the EU, see "EU to pare back sustainability rules for companies, draft shows" 2025.

[3] Green recovery packages have come with massive job creation promises, potentially alleviating the negative consequences of the energy transition. Skill gaps constitute a key barrier to achieve this objective: "Biden's 2024 challenge: green jobs" 2024; "Global jobs market shaken by green transition" 2025.

[4] Look et al. 2021 identify more than 100 US or European policies aimed at achieving "a widespread shift from coal to natural gas and renewables", while "prioritizing fairness for workers and communities that have historically depended on fossil energy".

In this study, I use an exogenous transition from fossil-fuel boilers to heat-pump installation among French heating service firms. This shift is emblematic of SME-level electrification as it implies major skill transformation. Workers should be trained for handling refrigerants contained in heat pumps and for working safely with electrical systems and high-voltage circuits, along with correctly sizing heat pump systems and programming their control systems[5]. I compare the labor market outcomes of workers in adopting versus non-adopting establishments for the period 2015-2023. In 2019, a generous subsidy is granted to French households replacing inefficient fossil-fuel boilers by a heat pump[6]. As heating firms switch to this new installation service, changes in earnings and career trajectories reflect the costs and benefits of adapting to this clean technology.

I find that technology adoption yields major labor reallocation at the establishment level. Using a staggered difference-in-difference estimation with matching, I estimate 1.5 job creation and 0.75 job destruction within 18 months. Second, I find little evidence of significant transition costs. In an event-study design on matched employer-employee data, I identify a +10% rise in hours and a +12% rise in labor earnings. Earning gains are mostly driven by stayers working longer hours, yet workers who separate after adoption experience only short-run losses. When moving to a new employer, workers with prior technology exposure or smaller skill gaps experience hourly wage increases, consistent with rising market demand for heat pump installation expertise.

These findings are relevant to a broad literature documenting the labor market consequences of environmental regulations. Workers displaced from polluting sectors and endowed with occupation-specific skills incur major welfare losses (Walker 2013, Yip 2018, and Marin and Vona 2021). A growing literature focuses on the adverse employment effects of resource extraction declines, exemplified by the phase out of coal mining (Haywood, Janser, and Koch 2021, Rud et al. 2024) or the contraction of oil extraction (Ellingsen and Espegren 2022, Garnache, Isaksen, and Nareklishvili 2025). These earning losses are compounded by the fact that workers rarely succeed at moving from more pollution-intensive to greener jobs (Bluedorn et al. 2023, Curtis, O'Kane, and Park 2024).

Yet, existing research has focused predominantly on declining energy-intensive industries rather than on clean energy technology adoption in transitioning SMEs. A potential explanation lies in

[5] Heat pump installers are required by law to hold a refrigerant handling certificate (Code de l'environnement 2007). Beside, since 2014, only works performed by firms holding an environmental quality certification (the so-called RGE certificate) qualify for energy efficiency subsidies granted by the state or energy suppliers (Code général des impôts 2014).

[6] As of January, 2019, all French households benefit from a minimum €2,500 subsidy, or around one fourth of the overall cost (installation included).

the empirical challenge to identify quasi-exogenous adoption of clean energy technology, a fundamentally endogenous decision with respect to each firm's own strategy and transition costs. As a result, existing literature cannot separate the effect of technology adoption at the establishment-level from that of the industry-level economic downturn. My empirical setting addresses this challenge by exploiting the unique context of energy efficiency policies in France. I leverage a subsidy shock and a legal requirement—the establishment-level environmental quality certification *RGE*—to identify technology adoption and evaluate its labor market effects. By isolating technology adoption from recessive dynamics, I observe both layoffs and hires, providing a much more nuanced understanding of the labor market effects of clean technology adoption.

The findings in this paper are also relevant to the literature on the skill-bias of clean technologies. The task-based framework developed by Autor, Levy, and Murnane 2003 and Acemoglu and Autor 2011 establishes that technological change reshapes labor markets by altering the skill content of jobs. Accordingly, Gathmann and Schönberg 2010 shows that worker mobility depends on task similarity between occupations. Applying this framework to green transitions, Vona et al. 2015 and Vona et al. 2018 leverage the O*NET classification and demonstrate that green occupations are systematically more intensive in technical, engineering, and managerial skills, while Consoli et al. 2016 confirm these skill differences persist when comparing green and non-green jobs within similar occupations. Saussay et al. 2022 advance this literature by using comprehensive job posting data, revealing that low-carbon vacancies have higher skill requirements across all five major skill groups (cognitive, IT, management, social, technical). They document substantial heterogeneity across occupations, suggesting highly context-specific retraining needs.

Using matched employer-employee data allows me to study how workers actually bridge the skill gaps during technology transitions at SME-level. Longer hours worked by stayers is consistent with on-the-job learning, dramatically reducing the cost of transition by avoiding layoffs. Hourly wage increases for movers endowed with the new technology reveal that green skills still have a genuine market value, but workers must signal these competencies by switching employers to realize wage gains.

The remainder of the paper is organized as follows. Section 2 provides background on France's energy efficiency policy and the 2019 subsidy shock. Section 3 describes the data. Section 4 outlines the empirical strategy. Section 5 presents the results. Section 6 discusses the mechanisms and future research directions, and Section 7 concludes.

2 Context

As the host-country of the Paris Agreement of 2015, France has set ambitious mitigation targets. This includes a 2.5% emission reduction by 2030 compared to 2012 (European Commission 2024)[7]. To achieve this goal, efforts concentrate on the decarbonization of the building stock, which represents 44% of the energy consumed and roughly one quarter of carbon emissions. According to the French Prime Minister's strategic planning agency *France Stratégie*, 72% of all 2030-targets green investments should go to buildings energy renovation (Pisani-Ferry and Mahfouz 2023). In this context, France's energy efficiency policy focuses on building renovation and promoting the use of renewable energy. This renovation effort relies on two main components, namely, the insulation of buildings enveloppe and the replacement of heating systems. In this paper, I focus on the second type of investment, and more specifically on the diffusion of heat pumps as a substitute for fossil fuels boilers.

2.1 The French EEOs

. France's energy efficiency policy relies on a mix of public and private subsidies, which largely benefits the residential sector. Both types of funding have changed in scale and scope since the mid-2000's, when the first tax credit and the pilot period of the energy efficiency obligations scheme (EEOs) were launched[8]. While public funding has transitioned to a means-tested subsidy mechanism in 2020 (France Stratégie 2024), the private sector remains involved through the EEOs. Each period-specific (3-4 years) national energy savings target breaks down into individual energy savings targets, assigned to retailers of electricity, gas, and gasoline in proportion to their sales, with differing coefficients depending on the type of fuel and their carbon content. This is a direct application of the polluter pays principle (*TFEU* 2016). Obligated parties must fulfill their individual obligations by obtaining energy savings certificates delivered by the regulator for efficiency improvements performed in either the residential, the industrial or the tertiary sectors; in practice, around two thirds of these investments are made in the residential sector. Each certificate

[7] The 2024 *National Energy and Climate Plan* targets 107 million tones of oil equivalent of final energy consumption in 2030, 21% below the 2022 level.

[8] The French government first launched a tax credit for energy efficiency investments in 2005. Called *Crédit d'Impôt Développement Durable (CIDD)*, it was renamed *Crédit d'Impôt pour la Transition Energétique (CITE)* in 2014. Since 2006, the French energy efficiency obligation scheme (*Certificats d'Economies d'Energie, CEE* in French) operates under the supervision of the General Directorate of Energy and Climate.

is worth one cumulative kWh of saved energy, corresponding to a decrease in future energy use[9].

In an energy efficiency obligation system, obligated parties seek to achieve their obligation at the lowest possible cost. For a set total investment cost, this leads to supporting more affluent household who require a smaller subsidy, creating an efficiency-equity tradeoff. Wealthier households facing fewer liquidity constraints are also generally more likely to invest in energy retrofits and receive subsidies (Darmais, Glachant, and Kahn 2024). Moreover, compliance costs are passed to all consumers through increased energy prices, leading to an indirect transfer from low- to high-income households (Rosenow, Platt, and Flanagan 2013). Since 2016, to compensate for these potential regressive impacts, the French EEOs requires that a share of certificates must be obtained from subsidizing renovation efforts from lower-income households (with annual income roughly below the median income in France). There are therefore two individual obligations per obligated party, a general obligation and a low-income obligation, and two types of certificates (general and low-income).

2.2 A subsidy shock for heat pumps

. The 4th period of the French EEOs started on January 1st, 2018, with a total energy savings target of 1,600 cumulative TWh over 2018-2020[10]. This doubling of the overall obligation was part of a broader *Climate Plan* announced by the Minister for the Environment Nicolas Hulot in September 2017, which specifically targeted the phase out of fuel oil boilers and conventional (i.e., non-condensing) natural gas boilers [11]. This announcement marked an important milestone in the energy transition. Indeed, fuel oil heating systems emit 324 grams of CO_2 per kWh, compared to 227 grams for natural gas boilers and only 49 grams for heat pumps, making the latter 4 to 7 times less carbon-intensive than conventional heating alternatives (CGDD 2024). In France in 2018, 3.9 million households relied on fuel oil and 11.9 million on natural gas as their main heating source. This represents respectively 13% and 41% of all main residences (Service des données et études statistiques 2022).

To address political acceptance and just transition concerns, the government implemented a bonus system on top of the low-income obligation. Under these new rules, suppliers supporting

[9]kWh are cumulative because the energy savings are calculated on the lifetime of the energy operation achieved.

[10]Part of this target (400 cumulative TWh) would go to projects benefiting to low-income households.

[11]The newly appointed Minister for the Ecological and Inclusive Transition Nicolas Hulot uncovered four key measures of his *Climate Plan*, including the phase out of inefficient fossil boilers, in an interview for *Libération* on September 17, 2017 ("Le plan Hulot: quatre mesures écologiques et solidaires" 2017, in French).

investments at low-income households could be awarded *bonus* certificates if they committed to specific minimum grant levels (Darmais, Glachant, and Kahn 2024). This approach diverges from the theoretical functioning of Energy Efficiency Obligations (EEOs), where governments typically set individual obligations and allow obligated actors to freely set subsidy levels that minimize overall system costs. This first agreement, formalized in April 2018 in the *Charte Coup de Pouce* (literally in French, *Boost Charter*)[12], set the minimum grant for a heat pumps installation at €3,000 for households in the first quartile of the income distribution [13] and €2,000 for those in the second quartile. Minimal grants were conditional on replacing a fuel oil boiler, a specific focus justified by Prime Minister Édouard Philippe describing fuel oil as an *"expensive, foreign, and polluting"* energy[14]. A few months latter in January 2019, the *Coups de Pouce* minimum grants were extended to conventional gas boiler replacements, i.e., any natural gas boiler except condensing ones, and all household types, with a minimum subsidy for heat pumps set at €4,000 for low-income households in the bottom half of the income distribution, and €2,500 for households in the top half of the income distribution (Assemblée Nationale 2021). Evolution in the level of minimal EEOs grants is depicted in Figure 1.

2.3 Policy-driven technology adoption

The increasing support for heat pumps installation created a sudden demand shock, which triggered the conversion of heating technicians to this new technology. This policy-driven technology adoption can be tracked at the establishment level through a unique feature of the French energy efficiency policy framework. Indeed, contractors operating on the market for subsidized energy efficiency works are required to hold an environmental certification, the *RGE* label[15]. Since 2015, both public and private subsidies are conditional on the exclusive use of RGE-certified professionals (JORF 2014). Each type of work (e.g., insulation, heat pump installation, efficient gas boilers, biomass systems, and photovoltaic installations) requires a specific certificate (France Rénov' 2025). The aim of this legal entry barrier is to ensure a minimum quality level for subsidized works. RGE

[12] See here for an example of such voluntary agreements between the French government and energy companies.

[13] Households in the first quartile are deemed in *extreme energy poverty*, or in French, *Grande Précarité Energétique*. Income thresholds are updated every year and vary for households residing in the Paris region vs. elsewhere, reflecting differences in the cost of living.

[14] Prime Minister Édouard Philippe in November 14, 2018, on RTL radio at the height of the Yellow Vest protests. The timing made this declaration particularly controversial, as it reinforced government policy that protesters viewed as burdensome to rural and working-class households dependent on heating oil. This is evidenced by the geographical distribution of reliance on fuel oil heating, depicted in Figure A.1

[15] *RGE* stands for *Reconnu Garant de l'Environnement*.

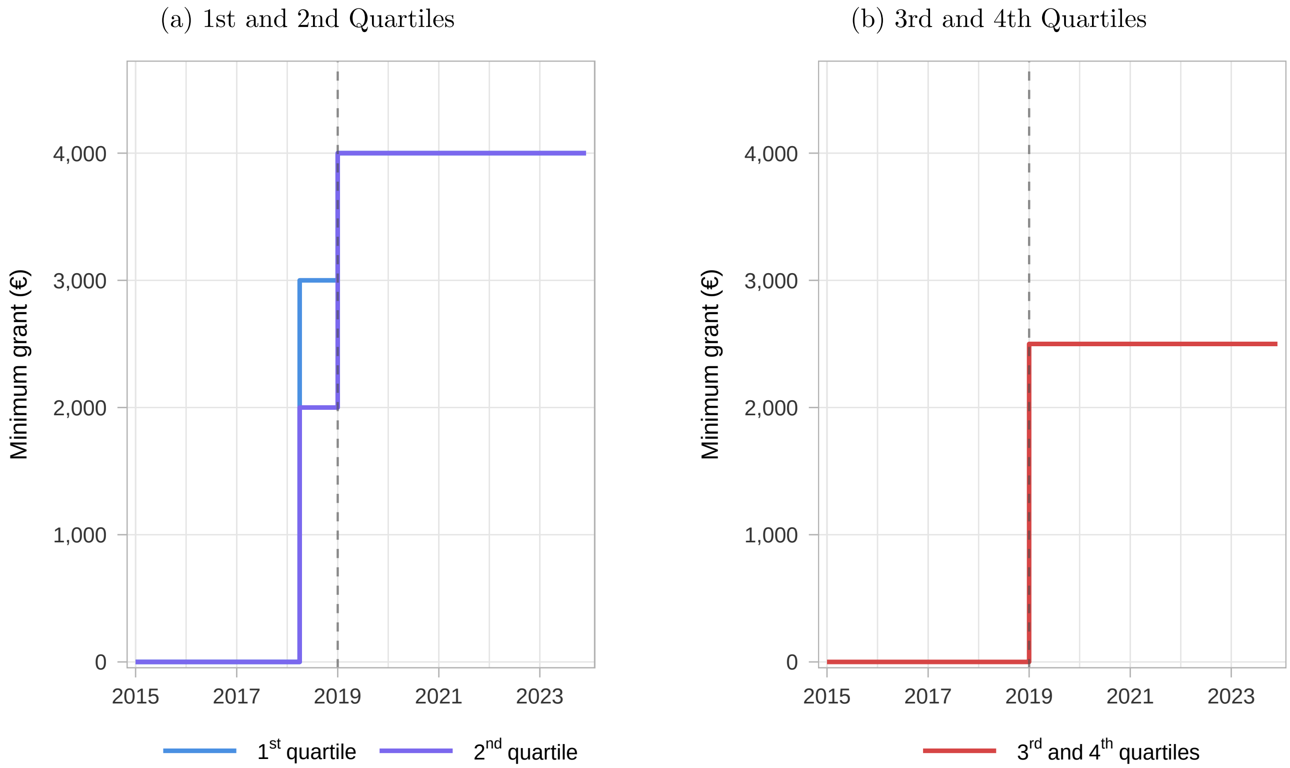


Figure 1: Minimum Grant Levels for Heat Pumps

Notes: The figure shows the evolution of minimum grant levels for heat pump installations under the French Energy Efficiency Obligation (EEO) scheme by income quartiles. The dashed vertical line in January 2019 marks a major policy reform that increased subsidy amounts. Quartiles are based on household income distribution.

certificates are granted at the establishment level and involve mandatory training for one employee who then becomes the establishment's technical referent. On-site audits are performed within two years of qualification and certificates remain valid for four years.

Focusing on the first year of the bonus mechanism reveals a sudden change in the dynamics of heat pumps certification. In Figure 2a, the cumulative adoption rate in the overall population of heating service firms increases sharply, from less than 5% in January 2019 to 7% by mid-2020. As shown in Figure 2b, the monthly count of new adoption, which fluctuates around 0 before the 2019 subsidy shock, becomes positive over a sustained period and reaches a monthly average of more than 100 new installers.

The 2019 subsidy shock created an unexpected and unprecedented incentive for heating service firms to enter the market for subsidized heat pumps. This exogenous shock isolates technology

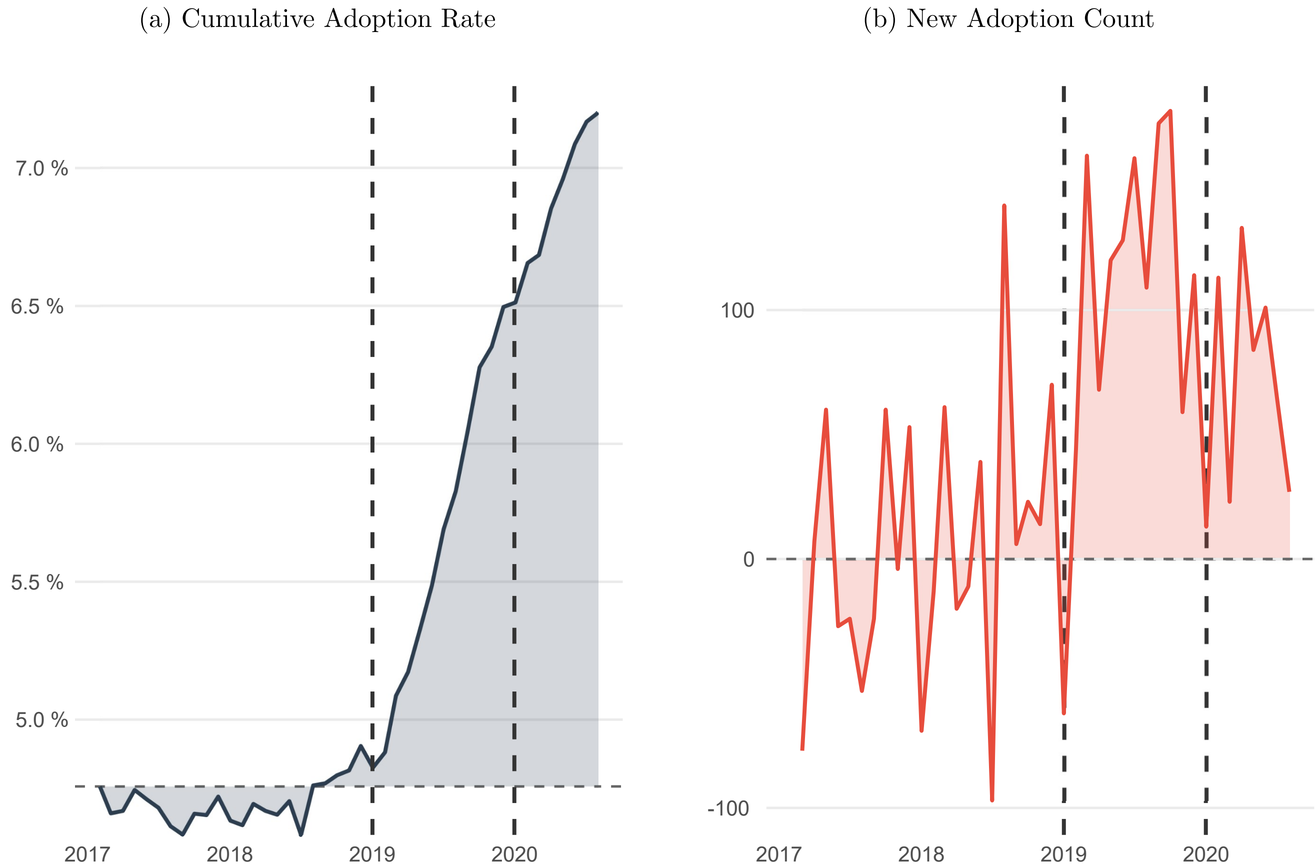


Figure 2: Heat Pumps Technology Adoption Patterns

Notes: The figure shows the supply-side response to the increase in heat pump subsidies introduced in January 2019 (first dashed line). The left panel displays the cumulative share of heating service establishments certified to install subsidized heat pumps in France. The right panel shows monthly certification counts.

adoption from firm fundamentals, hence offering a unique opportunity to causally estimate the labor market impacts of the clean energy transition.

3 Data

I combine several types of administrative datasets to construct the complete universe of heating services businesses in France and their workforce dynamics around the time of the reform.

The analysis primarily draws on employer-employee linked datasets. The first one is the *Mouvements de Main d'Œuvre (MMO)* dataset (DARES 2025) that provides daily records of all employees entries and exits from any establishment in France, including detailed information on contract types, reasons for exits (economic layoffs, retirement, etc.), and socio-professional categories. The second one is the Base Tous Salariés (INSEE 2025a), which provides yearly hours worked and labor earnings for each wage earner in each business in France. This exhaustive administrative dataset is derived from employer tax declarations. A key feature of these data is the construction of a quasi-exhaustive longitudinal panel, which required overcoming the challenge that individuals are assigned new pseudonymous identifiers each year. Babet, Godechot, and Palladino 2025 developed a matching algorithm that exploits overlapping annual files to track workers across time, achieving approximately 98% successful matching for 2002-2023. This "wide panel" represents a substantial improvement over the traditional narrow panel (1/12th sample) previously used for French labor market analysis, enabling more precise estimation of workers labor market outcomes by capturing the full universe of mobile workers (see Appendix B.1 for detailed methodology).

To identify heat pumps technology adoption, I use the RGE (Reconnu Garant de l'Environnement) registry (ADEME 2025) from the French Energy Management Agency. This certification system indicates whether an establishment is qualified to install subsidized energy-efficient equipment. Each type of work requires specific certification, enabling precise identification of the timing of technology adoption by any certified establishment.

Finally, I rely on the SIRENE database (INSEE 2025b), which serves as the national comprehensive directory for identifying French companies and their establishments. It includes the main activity code (APE at the 5-digit level, in 732 sub-classes), the exact geographic coordinates, and the date of creation of each establishment.

3.1 Defining treatment and control groups

A general concern when studying the labor market effects of technology adoption is the risk of spillovers from treated to untreated establishments and workers (the so-called *stable unit treatment value assumption – SUTVA*). Indeed, heating service firms operate on local markets, and any treatment effect of technology adoption could result in competition or equilibrium dynamics, contaminating the outcomes of seemingly untreated establishments and their workers. On the other hand, all heating system installers are exposed to common dynamics, which should not conflate the estimates of technology adoption itself. Accounting for the political momentum benefiting energy efficiency investments (heat pumps, but also energy efficient gas boilers) at the French and EU level in 2019-2022 allows to isolate the effect of heat pumps diffusion itself from the broader policy-driven stimulus[16].

These two objectives create a tradeoff between maintaining comparability within the heating system installation industry and avoiding heat pump adoption spillovers. To address this challenge, I exclude establishments that adopt heat pump certification after 2019, referred to as "not-yet-treated" units in the modern DiD literature (Chaisemartin and D'Haultfœuille 2020). The exclusion strategy leverages the daily register of heat pump certifications through 2023 to identify future adopters. The underlying rationale is that substantial spillovers should trigger non-adopters facing competitive pressure from early adopters to adopt themselves the certification after 2019. This is supported by the low cost of certification (approximately €500) and is further reinforced by two contemporaneous developments during the study period. First, the COVID-19 pandemic accelerated the availability of online training programs, substantially reducing both the administrative costs and practical barriers to certification (FEEBAT 2020). Second, this period coincided with a dramatic expansion of subsidies for energy-efficient heating systems, creating strong incentives for establishment-level adoption. Consequently, establishments remaining uncertified through 2023 despite the low adoption costs and the substantial policy incentives likely experienced very few competitive pressures from others, adopting firms. In practice, control establishments may be facing different markets less favorable to heat pumps adoption (e.g., multifamily dwellings), or different customers for whom the out-of-pocket cost remained too high even with the increased subsidies[17]. Never-treated establishments therefore provide a valid control group, largely insulated from local spillovers and equilibrium effects.

The sample construction follows a cross-referencing identification process. First, I identify establishments with heat pumps RGE certificates and extract the list of main activity codes (APE at the 5-digit level). Figure A.3 shows the top 10 main activity codes. Second, to distinguish systematic sectoral presence from occasional diversification, I retain only APE codes representing at least 5% of all certified establishments[18].

[16] In 2019, France enacted its *Energy and Climate Act*, which legislated a net zero emissions target for 2050. The law introduced several obligations attached to poorly insulated homes, such as mandatory energy audits before renting or selling, and a progressive ban on rental properties below a set level of energy efficiency. This is in line with the EU's *Renovation Wave Strategy* announced in 2020, which aims to renovate 35 million buildings by 2030, at least doubling the annual rate of energy renovations in the EU.

[17] The price of an average heat pumps installation in 2019 was at least €8,000, according to Observ'ER 2020.

[18] This includes heating and HVAC (43.22B), water and gas (43.22A), and electrical (43.21A) installation.

3.2 Descriptive statistics

The integration of these datasets creates a complete universe of heating service businesses in France from 2015 to 2023. I use this list of establishments to filter the two employment datasets separately.

Establishment-level analysis. From the establishment-level dataset, I create a monthly panel spanning from January, 2017 to December, 2021. It gathers 65,412 establishments that are either never treated or that become heat pump certified installers over the period of observation.

Table presents establishment-level characteristics for treated and control groups in the pre-

Table 1: Pre-treatment balance (Establishment level, 2017-2018)

	Treated		Control		Difference
	Mean (1)	SE (2)	Mean (3)	SE (4)	(T-C) (5)
N Establishments	7,153		58,259		
Headcount	6.07	(12.05)	5.80	(19.37)	0.27
Entries	2.75	(6.90)	2.49	(6.60)	0.26
Exits	1.21	(2.76)	1.03	(2.58)	0.18
Turnover rate	0.700	(1.11)	0.82	(3.92)	−0.12
Age (years)	6.71	(9.81)	6.92	(9.27)	−0.22
Population (CZ)	20,577	(48,058)	34,199	(60,580)	$-13,323$
Share Fuel Oil (CZ)	11.6	(8.4)	8.9	(7.4)	2.6

Notes: The table shows summary statistics for treated and control establishments in the pre-policy period (2017-2018). Treated establishments are those that adopt heat pump certification during the study period (2017-2021). Control establishments never adopt. Standard errors in columns (2) and (4). All statistics calculated as establishment-level averages over 2017-2018.

policy period (2017-2018). Average headcount is nearly identical at approximately 6 employees, and establishment age is also well-balanced at around 7 years, indicating that treated and control establishments are comparable in terms of size and maturity. Three main differences emerge between the groups. First, treated establishments are located in less populated areas, with an average population of 20,577 inhabitants in their commuting zone (CZ) compared to 34,199 for control establishments. Second, treated establishments operate in CZ with an average reliance on fuel oil of 11.6%. This is 2.6pp, or 30% higher than in controls' CZ. Third, control establishments exhibit lower baseline labor market turnover, with a rate of 0.7 compared to 0.82 for treated establishments. These differences point to the same direction: treated establishments operate in less populated, more rural markets where the share of detached housing units equipped with an old fossil boiler is higher. The result is a differential incentive regarding heat pumps installation certification, which supports the validity of the never-treated group as a credible counterfactual.

From the worker-level dataset, I create a yearly panel spanning from 2015 to 2023. It gathers more than 800,000 individuals with their yearly labor earnings and hours worked, and the unique identifier of their main employer's establishment.

Worker-level analysis. The matched employer-employee dataset gathers important information regarding workers characteristics. This includes standard socio-economic variables such as age and gender, as well as occupational classification assigned by employers following the comprehensive French occupational classification system (*Catégories Socioprofessionnelles, CSP*). It includes 429 distinct occupational codes (INSEE 2020). The workforce in heating services exhibits a clear division between specialized and non-specialized workers. Specialized workers represent 75% of the workforce and include three main categories of trained technicians. The largest group consists of trained plumbers and heating technicians (632f), who possess specific skills in heating system installation and maintenance. This is complemented by trained electricians specializing in installation work (633a) and those focused on maintenance activities (633d). These specialized occupations require formal training and certification, reflecting the technical complexity of modern heating systems. Non-specialized workers account for 25% of employment and are concentrated in two main categories: unskilled building finishing workers (681b) and various unskilled artisanal workers (685a). These positions typically involve general support tasks and do not require specialized technical training in heating technologies. This occupational structure reveals the technical bias of the heating services industry, where the majority of workers possess specialized technical competencies essential for installing and maintaining increasingly sophisticated heating equipment.

4 Empirical Strategy

To investigate the labor market outcomes of technology adoption, I exploit the surge in heat pumps installation subsidies and the subsequent response of local energy services contractors. My identification strategy leverages a key institutional feature: the requirement for installers to obtain RGE (Reconnu Garant de l'Environnement) certification to access the subsidized market. The certification process involves training workers in heat pump installation techniques and meeting quality standards. The price of the training is quite cheap, with an average cost of €500 per establishment. Moreover, only one worker per establishment has to go through the certification process for the establishment to become *certified*. It can thus be seen as a simple administrative barrier at the entry of the market for subsidized installations. I use two distinct strategies to document the causal effect of technology adoption. First, I focus on employment policy at the establishment level. Second, I analyze earnings and hours at the individual level.

4.1 Establishment-level analysis

The policy-driven adoption of heat pumps certification by heating service establishments exhibits a staggered timing, as shown by the total adoption curve in Figure 2. I leverage this behavior and the monthly frequency of my establishment-level dataset to estimate the effect of technology diffusion on employment policy. Staggered treatments pose several econometric challenges, and recent methodological advances have highlighted potential biases in traditional two-way fixed effects estimators when treatment effects are heterogeneous and treatment timing varies (Goodman-Bacon 2021; Callaway and Sant'Anna 2021). In this context, treatment intensity likely varies across establishments, with rural and smaller firms potentially experiencing larger effects due to their own and market characteristics. More importantly, early adopters should not be used as control units for late adopters as their treatment effect is not stable across time, which might bias the estimation. To address these concerns, I employ the Callaway and Sant'Anna 2021 methodology, which provides several advantages for my setting. First, I use never-treated establishments to define a clean control group, avoiding contamination from already-treated units. Second, I estimate group-time specific effects $ATT(g,t)$ for each cohort g (defined by certification timing) and time period t. Third, I use an inverse probability weighting on the establishment age and the headcount of the local industry (defined at the commuting zone level) to account for selection into treatment timing that may correlate with establishments and local market characteristics.

For each establishment i, cohort g and period t, I thus estimate:

$$ATT(g,t) = \mathbb{E}[Y_{it}(g) - Y_{it}(\infty) \mid G_i = g] \tag{1}$$

where $Y_{it}(g)$ represents the potential outcome under treatment timing g, $Y_{it}(\infty)$ represents the never-treated potential outcome, and $G_i = g$ indicates establishments first certified in period g. This approach allows me to examine dynamic treatment effects while avoiding the pitfalls of conventional difference-in-differences estimators in settings with staggered adoption and heterogeneous effects. I apply this estimation strategy to total employment (entries net of exits), only entries, or only exits.

4.2 Worker-level analysis

To estimate the causal effect of heat pump adoption on worker outcomes, I construct matched samples of workers at adopting and non-adopting heating service establishments. The matching procedure addresses potential compositional differences between workers at establishments that adopt heat pump technology in 2019 and those at non-adopting establishments. Since treatment occurs at the establishment level through the adoption decision, worker selection into treatment is not a primary concern. Rather, matching ensures that treated and control workers are comparable in terms of observable characteristics that may influence labor market trajectories independently of the technology shock.

The analysis sample comprises all full-time workers (employed at least 30 hours per week) in heating service establishments over the period 2015–2023. I define treatment as being employed at an establishment that adopts heat pump technology in 2019. To construct control groups, I match each treated worker to control workers at non-adopting establishments using exact matching on establishment activity code (APE), socio-professional category (CSP), and gender, followed by nearest-neighbor matching on age. I implement 1:20 matching, pairing each treated worker with up to 20 control workers. This n–to many matching allows me to leverage the full potential of my sample of 800,000+ worker trajectories.

The worker-level analysis proceeds in three parts, each focusing on a distinct subset of workers. First, I estimate the main effect of heat pump adoption on all workers employed at treated establishments in 2018 and 2019. Second, I decompose treatment effects by distinguishing between stayers and leavers to understand compositional changes within adopting establishments. Stayers are workers employed at the same establishment in both 2018 (pre-shock) and 2023 (the final year of the panel), while leavers are workers present at the establishment in 2018 or 2019 but no longer employed there in 2023. These two groups form complementary subsets of the treated workforce, enabling a comparison of outcomes for workers who remain versus those who separate. Third, I examine the labor market trajectories of movers, comprising both leavers and newcomers, in relative time. I define newcomers as workers not employed at a treated establishment in 2018 or 2019, but present in 2023, having entered the establishment in 2020 or later. For each analysis, I construct a new matched sample specific to the subgroup of treated workers under study, ensuring that treatment and control groups remain comparable within each estimation framework.

4.2.1 Dynamic difference-in-difference of heat pump adoption

The shift from gas boilers to heat pumps affects workers employed at treated establishments in 2019. I estimate the effect of technology adoption on worker outcomes using an event study specification. The baseline model is:

$$\log(y_{ist}) = \sum_{k\neq -1} \beta_k \cdot \mathbb{1}\{t=k\} \cdot \text{Treat}_{st} + \alpha_i + \gamma_s + \delta_t + \varepsilon_{ist} \tag{2}$$

where y_{ist} is hours worked or labor earnings for worker i in establishment s in year t, Treat_{st} is an indicator for establishment s ever adopting heat pump technology, and k measures years relative to 2019 (the adoption year). I include worker, establishment, and year fixed effects (α_i, γ_s, δ_t), and normalize 2018 ($k = -1$) as the reference period. The coefficients β_k trace out the dynamic treatment effects. The sample comprises all heating service establishments that either never adopted or adopted in 2019, covering approximately 800,000 workers of which 37,000 are employed at adopting establishments. Standard errors are two-way clustered at the worker and establishment levels.

4.2.2 Stayers vs. leavers: Calendar time comparison

To account for workforce composition effects, I decompose treatment effects for stayers versus leavers, both expressed in calendar time. For stayers (workers present at their 2018 employer through 2023), I estimate equation 2 on the restricted sample of treated workers. For leavers, following the job displacement literature (e.g., Schmieder, Wachter, and Heining 2023), I focus on workers with at least three years of tenure at their pre-separation employer. I estimate the following specification that allows for cohort-specific treatment effects:

$$\log(y_{itc}) = \sum_{k \neq -1} \beta_k^c \times \mathbb{1}\{t = c_i + k\} \times \text{Leaver}_i + \alpha_i + \delta_t + \varepsilon_{itc} \tag{3}$$

where c_i denotes the calendar year when worker i separates (exit cohort), k is years relative to separation, and Leaver_i indicates treatment status compared to matched controls. The interaction $\mathbb{1}\{t = c_i + k\}$ links relative time to calendar years, yielding cohort-specific coefficients β_k^c. I then aggregate these coefficients to calendar time by computing the average effect across all cohorts active in each year:

$$\gamma_t = \frac{1}{N_t} \sum_{\substack{c,k: \\ c+k=t}} \beta_k^c \tag{4}$$

where N_t is the number of cohort-relative time pairs contributing to year t. Standard errors for γ_t are computed using the variance-covariance matrix of the β_k^c estimates to properly account for covariance across the averaged coefficients. This approach, detailed in section D.1, allows direct comparison of treatment effects on stayers versus leavers in the same calendar-time framework.

4.2.3 Movers: Relative time dynamics

To understand the dynamics of worker mobility around the technology transition, I estimate relative-time event studies separately for leavers and newcomers. Leavers are workers with at least three years of tenure who separate from their 2019 employer; newcomers are workers not employed at a treated establishment in 2019 but present in 2023. For both groups, I estimate:

$$\log(y_{ist}) = \sum_{k \neq k_0} \beta_k \times \mathbb{1}\{t = T_i + k\} \times \text{Mover}_i + \alpha_i + \gamma_s + \delta_{z \times t} + \varepsilon_{ist} \tag{5}$$

where T_i is the year of the mobility event (separation for leavers, entry for newcomers), Mover_i indicates treatment status, γ_s are establishment fixed effects, and $\delta_{z \times t}$ are employment zone-by-year fixed effects that flexibly control for local labor market conditions. The reference period is $k_0 = -1$ for leavers (the year before separation) and $k_0 = -2$ for newcomers (two years before entry, as workers entering at $t = 0$ likely separate from their previous employer at $t = -1$). Both leavers and newcomers are compared to matched control workers selected using exact matching on age, socio-professional category (PCS), establishment main activity code, and gender. Standard errors are two-way clustered at the establishment and worker levels.

5 Results

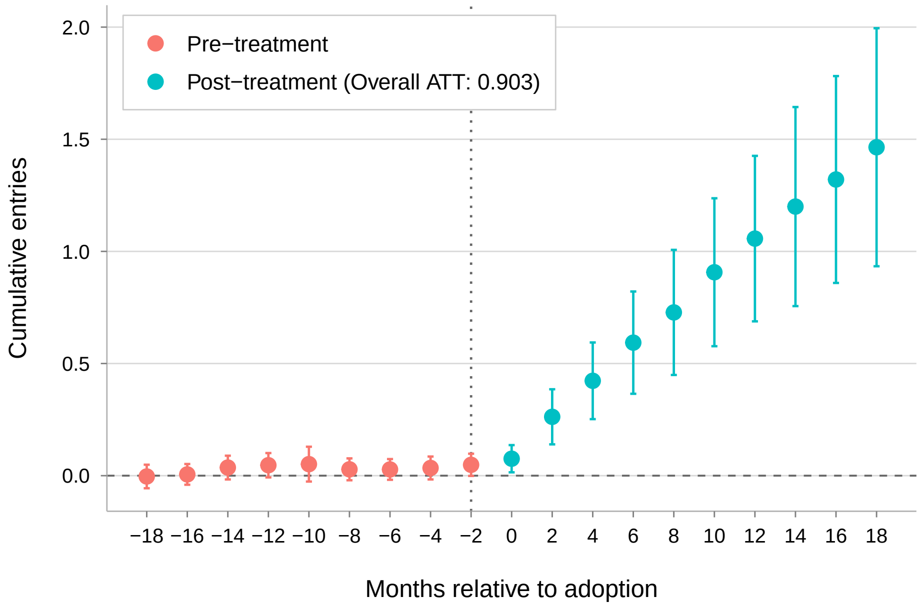
5.1 Effects on establishments employment behavior

I estimate the staggered difference-in-differences introduced in equation 1 separately on entries and exits at the establishment level on each odd-month from January, 2017 to November, 2021. This bi-monthly panel is centered on 2019, the year of the staggered adoption of heat pumps triggered by the subsidy shock. Averaging continuous variables on odd months allows to smooth idiosyncratic variations from high frequency employment data, while also reducing the the computational burden. Figure 3 presents the cumulative treatment effects over time, showing that 18 months after adoption, the average establishment experience both a higher job creation and a higher job destruction.

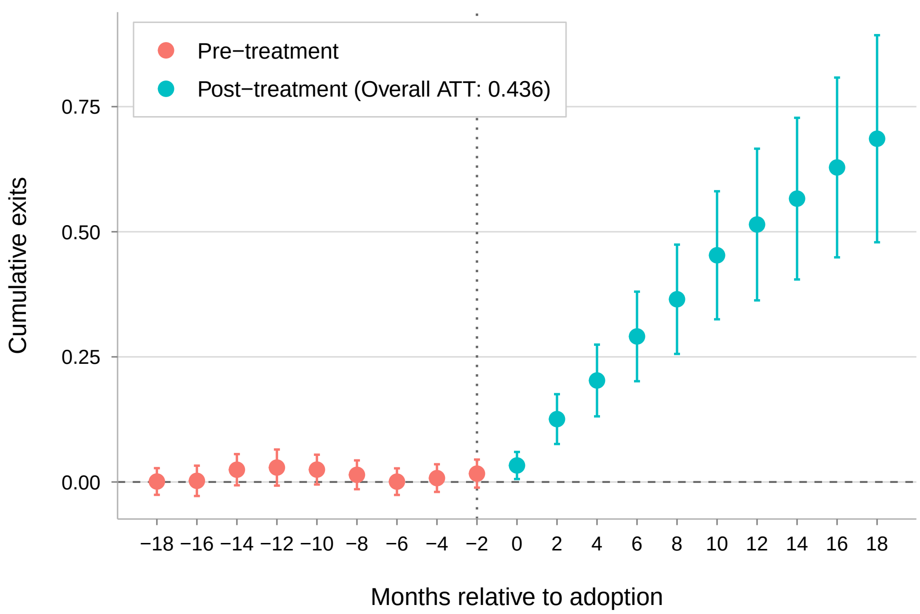
The pre-treatment estimates are statistically indistinguishable from zero, supporting the parallel trends assumption underlying the identification strategy. Employment effects emerge immediately upon certification, with adopting establishments experiencing approximately +0.75 job creation and +0.3 job destruction in the first 6 months post-adoption. These effects grow over time, reaching approximately +1.5 jobs created and +0.75 jobs destroyed 18 months after the certification. These are sizable effects considering the average headcount of 8 job-months.

While positive net job creation is consistent with expanding demand for heat pump services, the substantial job destruction occurring simultaneously is more concerning. The magnitude of worker separations, which represents approximately half the rate of new hires, suggests that certification triggers significant labor reallocation rather than simple workforce expansion. This pattern likely reflects changing skill requirements as establishments pivot toward heat pump technology, combined with productivity-based sorting as firms adjust their workforce composition. These dynamics create potential winners and losers among incumbent workers, raising distributional concerns central to just transition policy. Whether displaced workers successfully transition to new opportunities or bear substantial adjustment costs, and how these costs compare to gains for newly hired workers, cannot be assessed at the establishment level. I turn to individual worker trajectories in Section 5.2 to quantify these worker-level labor market effects.

Figure 3: Job entries and exits following heat pump adoption



(a) Entries



(b) Exits

Notes: Event-study estimates of heat pump certification effects on cumulative entries (a) and exits (b) using Callaway and Sant'Anna 2021. Sample: 7,153 treated and 58,259 never-treated control establishments, 2017–2021 (bi-monthly). Estimation by inverse probability weighting with covariates (establishment age, commuting zone heating industry headcount). Dynamic aggregation with 95% confidence intervals. Standard errors clustered at establishment level.

5.2 Workers-level Career Trajectories

5.2.1 Effect on incumbent workers

I start by estimating the effect of heat pump certification on all workers employed at treated establishments in 2018 and 2019, regardless of whether they subsequently remain at or separate from the establishment. This provides an overall assessment of exposure to technology adoption for the incumbent workforce. I construct a matched control group of workers at never-treated establishments as detailed in section 4.2. I then estimate standard dynamic difference-in-differences (DiD) specifications comparing outcomes for treated and control workers over 2015-2023. Figure 4 presents the results for three labor market outcomes: log. total hours worked, log. annual labor earnings, and log. hourly wages.

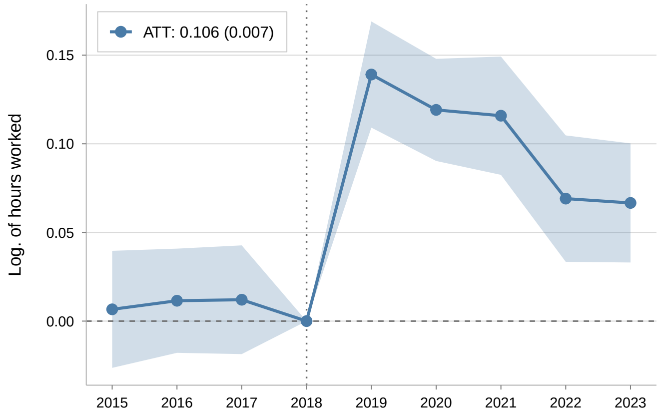
Several patterns emerge. First, treated workers experience substantial increases in both hours worked and labor earnings beginning immediately in 2019, the year of certification adoption. Hours worked and earnings increase by approximately 14 percent relative to matched control workers. These effects slightly decrease in subsequent years, but the average treatment over the treated (ATT) remains at or above 10 percent by 2020-2021. Second, the dynamics for hourly wages differ markedly from hours and earnings. Hourly wages show no significant effect in 2019 despite the large increases in hours and earnings. Significant hourly wage gains emerge only in 2020-2022, reaching approximately 2 percent above control workers. This pattern indicates that the primary adjustment margin in the immediate aftermath of certification is labor supply: workers increase hours at roughly constant hourly wages, with wage adjustments occurring only in subsequent years.

These average effects, while positive overall, mask substantial heterogeneity in outcomes between workers who remain at adopting establishments and those who separate. I turn to this decomposition in the next subsection.

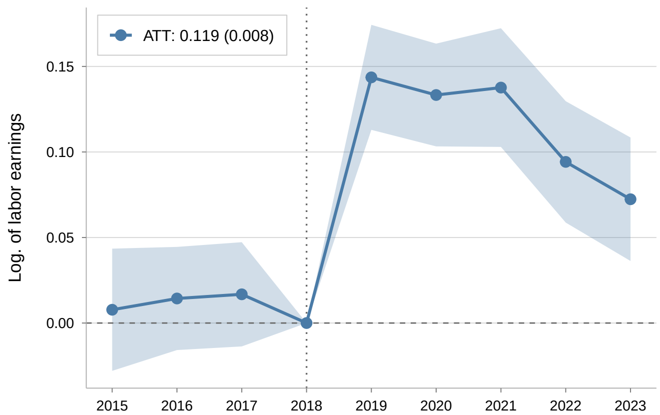
5.2.2 Decomposing Effects: Stayers versus leavers

The average positive effects documented for incumbent workers aggregate over two distinct groups: workers who remain at adopting establishments (stayers) and those who eventually separate (leavers). To understand the composition of these aggregate effects, I decompose treatment effects by employment continuity. I define stayers as workers employed at the same establishment in both 2018 (pre-adoption), 2019 (treatment year) and 2023 (the final year of the panel); and

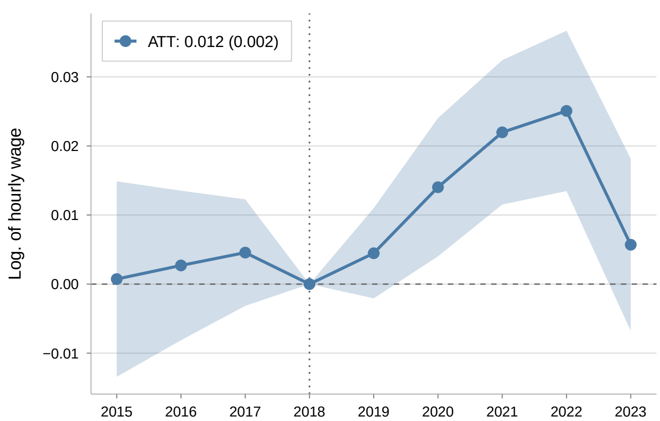
Figure 4: Effects of Heat Pump Certification on Incumbent Workers



(a) Log. Total Hours Worked



(b) Log. Annual Labor Earnings



(c) Log Hourly Wage

Notes: Event-study estimates of the effect of heat pump certification on labor market outcomes for workers employed at treated establishments in 2018 and 2019. The sample includes 11,229 treated workers and 117,748 matched control workers from never-treated establishments. Control workers matched exactly on establishment activity code (APE), socio-professional category (CSP), and gender, followed by nearest-neighbor matching on age. Shaded areas represent 95% confidence intervals based on standard errors clustered at the establishment level.Post-treatment ATTs in the legend are precision-weighted averages over 2019-2023.

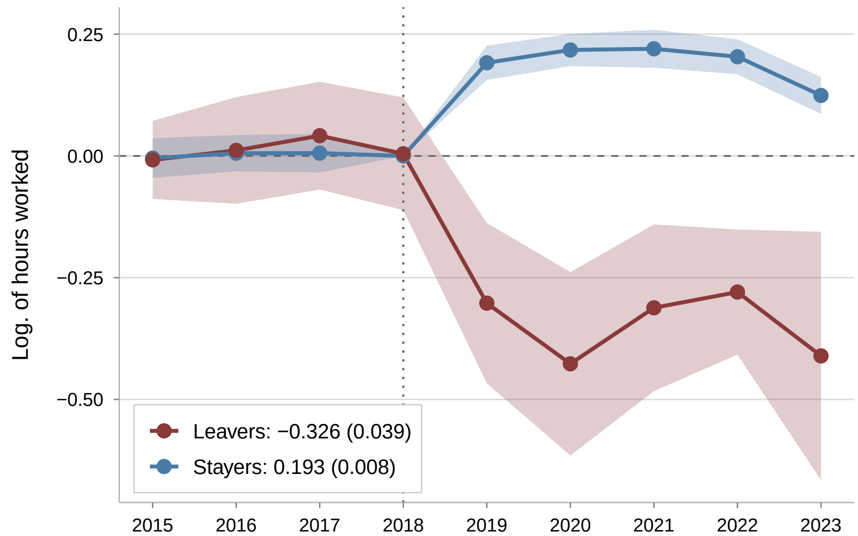
leavers as workers present in 2018 and 2019 but no longer employed at the establishment by 2023. As a result, the leavers group aggregates in one sample all cohorts of exits over 2020–2023.

For both groups, I construct a new matched control sample using the same matching procedure detailed in section 4.2, which yields 7,395 treated stayers matched to 100,890 controls. Following the job displacement literature (e.g., Schmieder, Wachter, and Heining 2023), I further restrict the treatment group to workers with at least three years of tenure at their pre-separation employer. This yields 2,523 treated leavers matched to 36,576 controls. Figure 5 present the results for hours worked and labor earnings. The contrast between stayers and leavers is stark. Stayers experience immediate and substantial gains beginning in 2019, with hours worked and labor earnings increasing by approximately 20 percent relative to matched controls. These gains persist through 2022 before moderating slightly to 12.5 percent in 2023. In sharp contrast, leavers experience deteriorating outcomes following certification adoption. Their hours and earnings decline progressively, stabilizing around -30 percent by 2021-2022 relative to matched control workers who also eventually separate from their establishments.

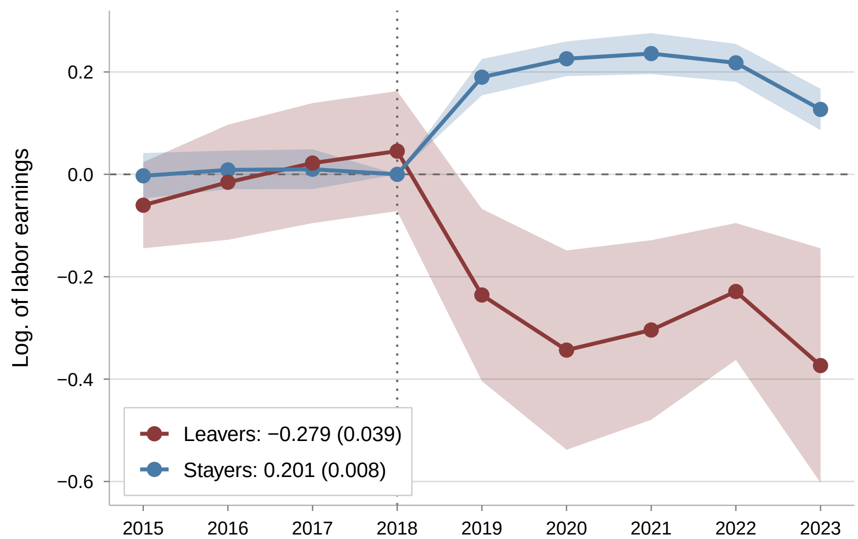
For stayers, I can additionally examine hourly wages. Figure 6 shows that stayers experience modest wage gains of around 1 percent beginning in 2020, consistent with the pattern observed for incumbent workers overall, although slightly lower.

The combination of increased hours and higher wages explains the substantial earnings gains observed for this group. The negative outcomes is consistent with substantial losses from separation. However, this interpretation requires careful consideration. The leaver sample in any given calendar year comprises workers who separated at different times following adoption, some immediately in 2019, others in 2020, 2021, or later. Consequently, the calendar-time effects aggregate over workers at different stages of their post-separation trajectories. A worker who separated in 2019 and found new employment appears in the 2022 estimate alongside workers separating for the first time in 2022. This aggregation obscures individual adjustment dynamics and may not reflect the true costs borne by displaced workers. Understanding whether movers actually get persistent individual-level losses or only incur a temporary transition requires tracking workers in event time relative to their displacement. I turn to this analysis in the next subsection.

Figure 5: Effects of Heat Pump Certification on Stayers versus Leavers



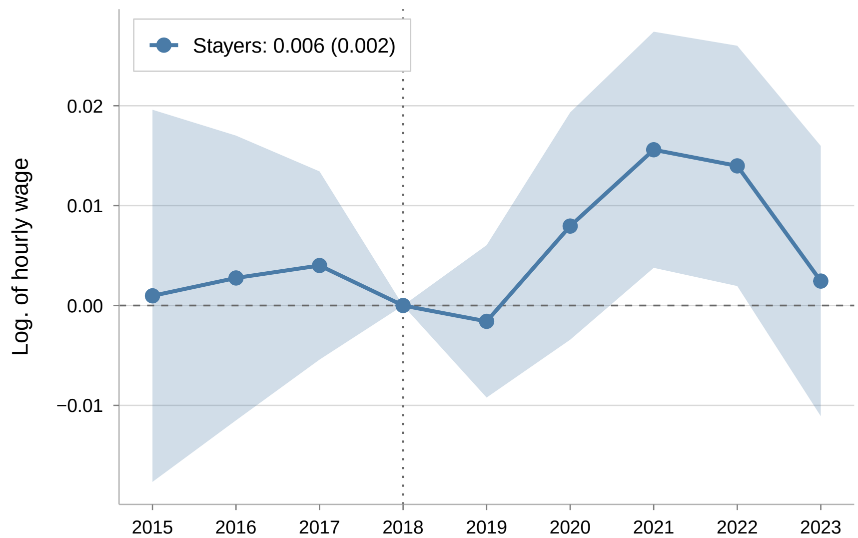
(a) Log. Total Hours Worked



(b) Log. Annual Labor Earnings

Notes: Event-study estimates of the effect of heat pump certification decomposed by employment continuity. Stayers (blue lines) are workers employed at the same establishment in both 2018, 2019, and 2023 (N = 7,395 treated, 100,890 matched controls). Leavers (red lines) are workers present in 2018 and 2019 but no longer employed at the establishment by 2023, having separated between 2020 and 2023 (N = 2,523 treated, 36,576 matched controls). Each treatment group is matched to its own control group of workers at never-treated establishments using the procedure detailed in section 4.2. Shaded areas represent 95% confidence intervals based on standard errors clustered at the establishment level. Post-treatment ATTs in legend are precision-weighted averages over 2019-2023.

Figure 6: Effects of Heat Pump Certification on Hourly Wages: Stayers



Notes: Event-study estimates of the effect of heat pump certification on log hourly wages for stayers—workers employed at the same establishment in both 2018, 2019 and 2023 (N = 7,395 treated, 100,890 matched controls). Hourly wage estimates for stayers only, as leavers experience unemployment following separation, precluding meaningful calendar-time comparisons across cohorts. Matching procedure and specification identical to Figure 5. Shaded area represents 95% confidence intervals based on standard errors clustered at the establishment level. Post-treatment ATTs in legend are precision-weighted averages over 2019-2023.

5.2.3 Worker Mobility and Adjustment Dynamics

The previous analysis revealed that workers who separate from adopting establishments experience deteriorating outcomes in calendar time, but this comparison aggregates workers at different stages of their post-displacement trajectories. To assess individual-level adjustment costs, I examine worker outcomes in event time relative to their mobility event. I focus on two groups of movers: leavers who separate from treated establishments, and newcomers who enter them. While both groups involve labor mobility, they represent distinct phenomena. Leavers exit establishments that adopted certification in 2019, while newcomers enter these establishments after adoption.

For leavers, I use the definition introduced in subsection 5.2.2, which requires workers to be at the same treated establishment from 2016 to 2019 onward, while leaving in one year of 2020-2023. For newcomers, I examine workers not employed at a treated establishment in 2019 but present in 2023, having entered between 2020 and 2023. As a result, treated samples comprises 2,523 leavers and 1,529 newcomers matched to control groups using the same matching procedure detailed in section 4.2. It yields 36,576 matched control workers for leavers and 27,131 for newcomers. I estimate relative-time event studies separately for each group as in equation 5. The reference period is $k_0 = 1$ for leavers (the year before separation) and $k_0 = 2$ for newcomers (two years before entry, chosen to capture the pre-exit baseline since workers entering at $t = 0$ likely separated from their previous employer at $t = 1$).

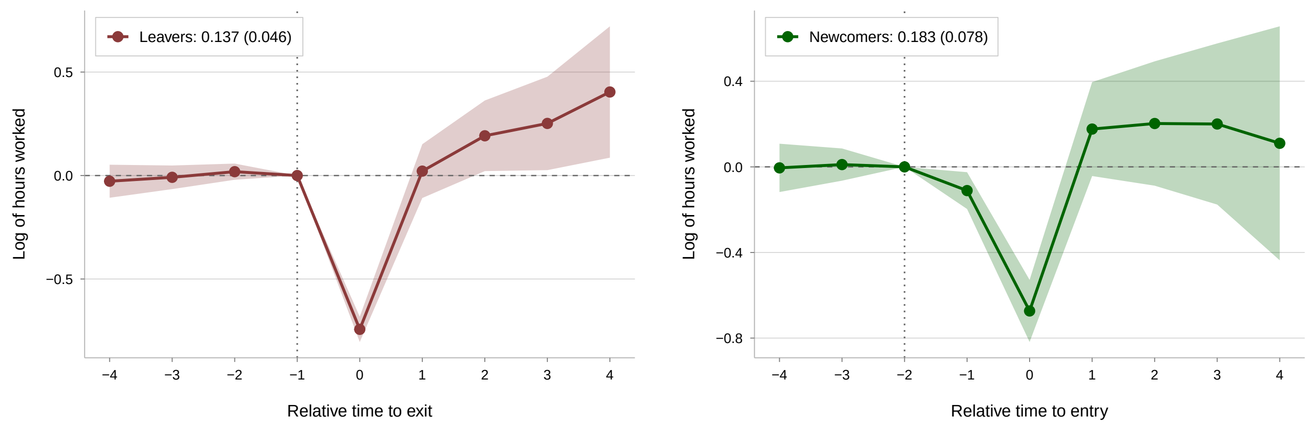
Figure 7 presents the results. For leavers (left column), outcomes exhibit a clear V-shaped pattern. Hours worked drop sharply by 80 percent in the separation year ($t = 0$), but recover fully by the following year ($t = 1$) where the point estimate returns to zero. In subsequent years, hours worked rise substantially, reaching approximately 20 percent above pre-separation levels by $t = 2$ and $t = 3$, following an upward trajectory similar to that observed for stayers. Labor earnings follow a parallel pattern: a 60 percent decline at separation, followed by rapid recovery that exceeds pre-displacement earnings as early as the first post-displacement year. The average treatment effect across all post-displacement years reaches nearly 40 percent. Most strikingly, hourly wages increase sharply following displacement, rising by more than 20 percent on average across post-displacement years. This wage premium, combined with increased hours, drives the substantial earnings gains.

For newcomers (right column), the dynamics differ notably. Hours worked drop by 70 percent at entry ($t = 0$), consistent with the interpretation that entry often follows separation from a previous employer at $t = 1$. Following entry, hours stabilize at around 15 percent above matched controls, and remains relatively constant across post-entry years, rather than exhibiting the rising trend observed for leavers. However, none of the point estimates is significant at any conventional level. Labor earnings show a similar pattern, with non-significant gains of around 20 percent in $t = 1$ that remain stable or decline slightly in subsequent years. Crucially, hourly wages for newcomers remain flat throughout the post-entry period, though estimates are imprecise as expected from the already non-significant results in both hours and earnings.

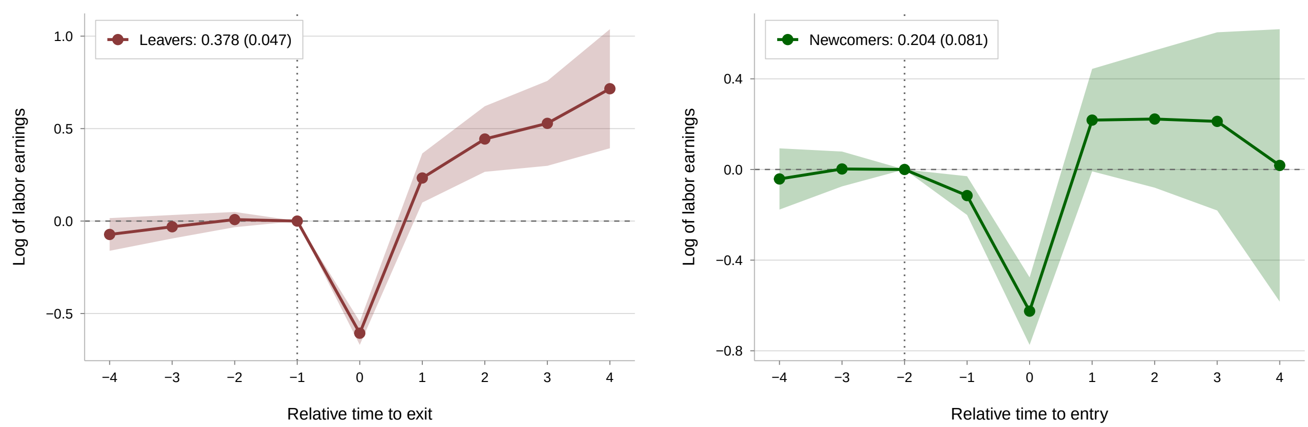
These patterns reveal rapid adjustment with minimal persistent displacement costs. Both leavers and newcomers experience sharp but temporary disruptions at the time of their mobility event ($t = 0$), but recover swiftly. Leavers not only recover their pre-separation employment levels but substantially exceed them, benefiting from both increased hours and higher hourly wages. The wage premium suggests that skills acquired at establishments adopting heat pump certification are valued in the broader labor market, enabling workers to secure improved matches following separation. Newcomers, while not experiencing wage gains, benefit from expanded employment opportunities and higher labor earnings through increased hours. The contrast between rising

Figure 7: Labor Market Dynamics for Movers in Event Time

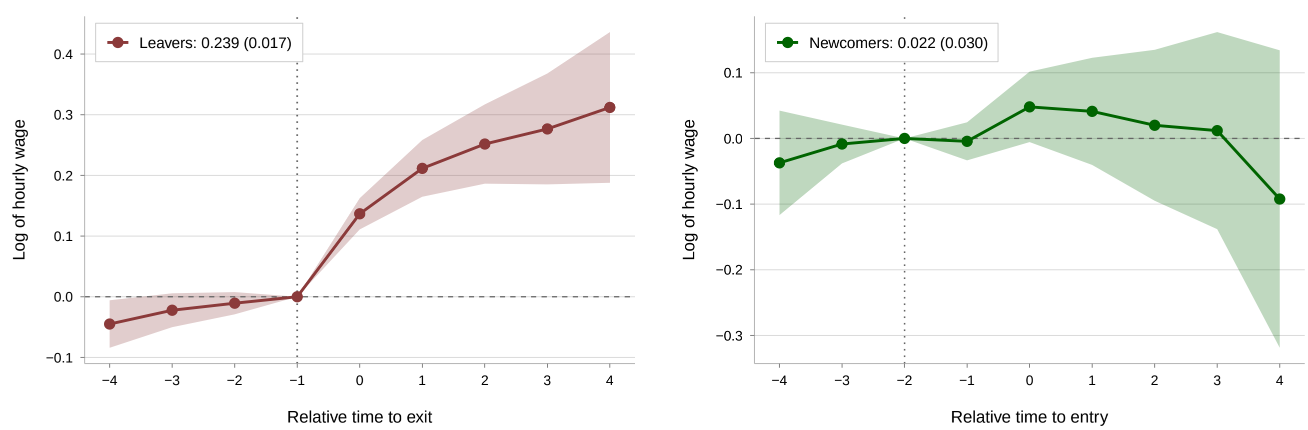
Leavers | **Newcomers**



(a) Log Total Hours Worked



(b) Log Annual Labor Earnings



(c) Log Hourly Wage

Notes: Event-study estimates in relative time around mobility events. Left column: leavers (N = 2,523 treated, 36,576 matched controls). Right column: newcomers (N = 1,529 treated, 27,131 matched controls). Matched controls selected using the matching procedure detailed in section 4.2. Specifications include worker fixed effects, establishment fixed effects, and employment zone-by-year fixed effects. Shaded areas represent 95% confidence intervals based on standard errors clustered at the establishment level. Post-treatment ATTs in legend are precision-weighted averages over 2019-2023.

wages for leavers and flat wages for newcomers suggests that experience at establishments engaged in heat pump installation confers valuable skills, while newcomers may be hired for their general labor capacity and trained on the job.

6 Discussion

The findings presented in section 5 documents substantial labor market reallocation following clean energy technology adoption, with simultaneous job creation and destruction at adopting establishments. Crucially, this reallocation occurs without imposing persistent costs on displaced workers. Both workers who separate from adopting establishments and those newly hired recover swiftly from initial disruptions and experience improved labor market outcomes. Workers who leave benefit from substantial wage premiums exceeding 20 percent; newcomers, while not experiencing wage gains, secure expanded employment opportunities and higher earnings through increased hours. These findings challenge pessimistic narratives about the labor market consequences of environmental transitions and suggest that a just and cost-minimizing transition may be achievable within key industries, including for blue-collar workers in small establishments.

Much firm and worker-level research on just transition focuses on the phase-out of fossil fuel industries, such as coal mine closures or power plant retirements. This study examines a different but increasingly relevant phenomenon: within-industry technological upgrading. This distinction matters because such incremental transitions may characterize the future of decarbonization. Indeed, achieving net-zero emissions requires transforming the thousands of small and medium enterprises that constitute local production systems at the bulk of the economy. In France alone, the heating services sector comprises over 100,000 establishments, predominantly small firms with fewer than 10 employees. Heat pump installation demands electrical competencies largely absent from traditional fossil fuel heating systems, which requires a genuine reskilling, not a simple substitution. Yet unlike large-scale industrial closures, this transition occurs through decentralized adoption by small establishments responding to subsidies and market demand.

The observed patterns reflect several interacting mechanisms. The 20 percent wage premium for leavers is consistent with workers acquiring skills and knowledge valued across employers in the heating sector. Heat pump installation skills appear portable: technical competencies in electrical systems, refrigerant handling, and system diagnostics transfer readily to other HVAC service establishments. On the reverse, newcomers work longer hours and get higher earnings without any significant wage gain. This is consistent with a re-skilling occurring within establishments for those workers who did not experienced heat-pumps installation at their previous employer. Finally, the absence of wage gains for stayers, despite equivalent technology exposure, aligns with canonical labor market theory: workers must change employers to capture full returns to general skills when firms possess monopsony power or when wages are sticky. Together, these findings are consistent with a higher demand for skills aligned with the energy transition, with only temporary adjustment costs for workers.

Findings from this analysis have important implications fir the design of the energy transition. First, policies aimed at reducing worker transition costs should prioritize supporting technology adoption and re-skilling within existing establishments rather than relying on creative destruction between firms. Instruments such as training subsidies, incentives for clean technology adoption, and technical assistance programs can facilitate this within-firm transition, minimizing disruption to workers. Second, early-exposed workers benefiting more than late adopters suggest that proactive skill development programs can smooth the transition and enhance equity. Rather than waiting for market forces to reallocate labor across firms, policies should set the right incentives not only on the demand, but also on the supply side of carbon emission intensive industries.

Selection likely plays some role in determining which workers separate. More able workers or those who acquired skills most effectively may selectively exit to pursue better opportunities, as evidenced by the positive effect on all labor market outcomes. This selection appears as the core mechanism: technology adoption equips workers with competencies that command market premiums, enabling successful transitions even if reallocation involves temporary disruption. Future versions of the analysis will focus on the heterogeneous effects across separation rationales, i.e., distinguishing voluntary quits from involuntary layoffs to document potential long-run losses for workers forced into displacement.

Finally, understanding destination and origin patterns would further clarify these mechanisms. Examining whether leavers transition primarily to other heat pump establishments or to traditional heating firms would reveal the breadth of skill transferability across different technology contexts. Similarly, identifying whether newcomers originate from related industries with partially transferable competencies or from unrelated sectors would reveal the sources of labor supply for the clean energy transition.

7 Conclusion

This paper examines labor market outcomes following clean energy technology adoption within small establishments in France's heating services industry. At the establishment level, heat pump certification triggers substantial labor reallocation, with simultaneous job creation and destruction rather than simple employment expansion. At the worker level, those exposed to technology adoption experience improved outcomes on average: workers who remain benefit from expanded hours, those who separate recover swiftly and secure substantial wage premiums, and newly hired workers gain employment opportunities. These findings challenge conventional narratives positioning incumbent workers in traditional sectors as inevitable losers of energy transitions. When existing establishments adopt new technologies rather than being displaced by new businesses, workers avoid persistent costs and often benefit from acquired skills valued in expanding markets. This study contributes to just transition research by providing systematic evidence on labor market effects of clean energy technology adoption, a phenomenon less documented by the existing literature, focused on industrial phase-outs and large-scale displacement. The results suggest policymakers should invest in equipping workers with portable skills through standardized certifications and training, as early exposure to emerging technologies generates advantages that facilitate successful transitions. Encouraging within-establishment technological adaptation rather than relying exclusively on the phase out of incumbent firms with old technologies may reduce adjustment costs while supporting decarbonization goals. The French heat pumps case, while specific, shares key features with broader electrification occurring across thousands of small and medium enterprises as economies pursue net-zero targets. Understanding where workers separating from adopting establishments move and where newly hired workers originate represents an important next step for assessing skill transferability and labor supply dynamics in the green economy. Current findings offer cautious optimism: technological transitions need not inevitably create mass displacement when workers acquire transferable competencies, labor demand remains strong, and policy supports skill development and mobility.

References

Acemoglu, Daron and David Autor (2011). “Chapter 12 - Skills, Tasks and Technologies: Implications for Employment and Earnings”. In: ed. by David Card and Orley Ashenfelter. Vol. 4. Handbook of Labor Economics. Elsevier, pp. 1043–1171.

ADEME (2025). *RGE: Reconnu Garant de l’Environnement Registry.* Contractors environmental certificates for energy efficiency installations.

Assemblée Nationale (May 2021). *Projet de loi de règlement du budget et d’approbation des comptes de l’année 2020. Annexe n° 18 : Écologie, développement et mobilité durables : énergie, climat et après mines.* Rapport fait au nom de la Commission des Finances, de l’Économie Générale et du Contrôle Budgétaire 4195. Quinzième Législature. Assemblée Nationale.

Autor, David, Frank Levy, and Richard J. Murnane (Nov. 2003). “The Skill Content of Recent Technological Change: An Empirical Exploration*”. In: *The Quarterly Journal of Economics* 118.4, pp. 1279–1333.

Babet, Damien, Olivier Godechot, and Marco G. Palladino (Mar. 2025). *In the Land of AKM: Explaining the Dynamics of Wage Inequality in France.* Working Paper 987. Banque de France.

Barreto, César et al. (2024). *The “Clean Energy Transition” and the Cost of Job Displacement in Energy-Intensive Industries.* OECD Social, Employment and Migration Working Papers 310. Paris: OECD Publishing.

“Biden’s 2024 challenge: green jobs” (Jan. 2024). In: *Politico.*

Bluedorn, John et al. (2023). “Transitioning to a greener labor market: Cross-country evidence from microdata”. In: *Energy Economics* 126, p. 106836.

Callaway, Brantly and H.C. Pedro Sant’Anna (2021). “Difference-in-Differences with multiple time periods”. In: *Journal of Econometrics* 225.2, pp. 200–230.

CGDD, Commissariat général au développement durable (Nov. 2024). *Les facteurs d’émission de gaz à effet de serre.* Basé sur les données de l’ADEME (Agence de la transition écologique). Ministère de la Transition écologique et de la Cohésion des territoires.

Chaisemartin, Clément de and Xavier D’Haultfœuille (Sept. 2020). “Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects”. In: *American Economic Review* 110.9, pp. 2964–96.

Code de l’environnement (2007). *Articles R. 543-75 à R. 543-123.* Légifrance. Relatif aux fluides frigorigènes.

Code général des impôts (July 2014). *Décret n°2014-812 du 16 juillet 2014 pris pour l'application du second alinéa du 2 de l'article 200 quater du code général des impôts et du dernier alinéa du 2 du I de l'article 244 quater U du code général des impôts*. Légifrance. Définit les domaines de travaux sur lesquels le signe de qualité RGE porte.

Consoli, Davide et al. (2016). "Do green jobs differ from non-green jobs in terms of skills and human capital?" In: *Research Policy* 45.5, pp. 1046–1060.

TFEU (June 7, 2016). *Consolidated Version of the Treaty on the Functioning of the European Union*. Treaty. Article 191(2).

Curtis, E Mark, Layla O'Kane, and R Jisung Park (2024). "Workers and the green-energy transition: Evidence from 300 million job transitions". In: *Environmental and Energy Policy and the Economy* 5.1, pp. 127–161.

DARES (2025). *Mouvements de Main d'Œuvre (MMO)*. Daily entries and exits from any position in each business in France.

Darmais, Amélie, Matthieu Glachant, and Victor Kahn (2024). "Social equity provisions in energy efficiency obligations: An ex-post analysis of the French program". In: *Energy Policy* 195, p. 114348.

Ellingsen, Jon and Caroline Espegren (Dec. 2022). *Lost in transition? Earnings losses of displaced petroleum workers*. Working Papers No 06/2022. Centre for Applied Macro- and Petroleum economics (CAMP), BI Norwegian Business School.

"EU to pare back sustainability rules for companies, draft shows" (Feb. 2025). In: *Reuters*.

European Commission (Mar. 2020). *An SME Strategy for a Sustainable and Digital Europe*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2020) 103 final. Brussels: European Commission.

European Commission, Directorate-General for Communication (July 2024). *France - Final updated NECP 2021-2030 (submitted in 2024)*.

European Investment Bank (Sept. 2025). *More than 350,000 European Companies to Get Energy Efficiency Support Under Major EU Financing Initiative*. Press Release.

FEEBAT (July 2020). *FEEBAT adapte RENOVE en classes virtuelles : un module de formation pour préparer son entreprise à la qualification RGE sans se déplacer en centre*. URL: https://web.archive.org/web/20201029104638/https://www.feebat.org/actualites/feebat-adapte-renove-en-classes-virtuelles-un-module-de-formation-pour-preparer-son-entreprise-a-la-qualification-rge-sans-se-deplacer-en-centre/ (visited on 11/02/2025).

France Rénov' (2025). *Recognized Environmental Guarantor (RGE) Craftsman*. Official presentation of the RGE system and qualifying organizations.

France Stratégie (Jan. 2024). *Le dispositif MaPrimeRénov'. Comité d'évaluation du plan France Relance – Rapport final, Volume II – Évaluation des dispositifs, Chapitre 6*. French. Rapport d'évaluation. Paris: France Stratégie, p. 85.

Garnache, Cloé, Elisabeth Isaksen, and Maria Nareklishvili (2025). *Labor Market Impacts of the Green Transition: Evidence from Contraction in Oil*. Working Paper 12057. CESifo Working Paper. CESifo.

Gathmann, Christina and Uta Schönberg (2010). "How General Is Human Capital? A Task-Based Approach". In: *Journal of Labor Economics* 28.1, pp. 1–49.

"Global jobs market shaken by green transition" (Sept. 2025). In: *Financial Times*.

Goodman-Bacon, Andrew (2021). "Difference-in-differences with variation in treatment timing". In: *Journal of Econometrics* 225.2, pp. 254–277.

Greene, William H. (2018). *Econometric Analysis*. 8th ed. New York, NY: Pearson. Chap. 4, pp. 79–82.

Gross, Samantha (June 2021). *The Challenge of Decarbonizing Heavy Industry*. Tech. rep.

Haywood, Luke, Markus Janser, and Nicolas Koch (June 2021). *The Welfare Costs of Job Loss and Decarbonization– Evidence from Germany's Coal Phase Out*. IZA Discussion Papers 14464. Institute of Labor Economics (IZA).

INSEE (2020). *Nomenclature des Professions et Catégories Socioprofessionnelles (PCS)*. French occupational classification system with 429 occupation codes.

— (2025a). *DADS Postes: Déclarations Annuelles de Données Sociales*. Wages offered to each worker in each business in France.

— (2025b). *SIRENE: Système d'Identification du Répertoire des Entreprises*. National comprehensive directory for the identification of French companies and their establishments.

JORF, Journal Officiel de la République Française (July 18, 2014). *Decree No. 2014-812 implementing the second paragraph of section 2 of article 200 quater of the general tax code and the last paragraph of section 2 of I of article 244 quater U of the general tax code*.

"Le plan Hulot: quatre mesures écologiques et solidaires" (Sept. 2017). French. In: *Libération*.

Look, Wesley et al. (Mar. 2021). *Enabling Fairness for Energy Workers and Communities in Transition: A Review of Federal Policy Options and Principles for a Just Transition in the United States*. Tech. rep. 21-07. Washington, DC: Resources for the Future and Environmental Defense Fund.

Marin, Giovanni and Francesco Vona (2021). "The impact of energy prices on socioeconomic and environmental performance: Evidence from French manufacturing establishments, 1997–2015". In: *European Economic Review* 135.C, S0014292121000921.

Observ'ER (July 2020). *Suivi du marché 2019 des pompes à chaleur individuelles*. Rapport d'étude. Avec le soutien de l'ADEME. Paris, France: Observ'ER.

OECD (2023). *OECD SME and Entrepreneurship Outlook 2023*. Tech. rep. Accessed: November 8, 2025. Paris: Organisation for Economic Co-operation and Development.

Pisani-Ferry, Jean and Selma Mahfouz (2023). "The economic implications of climate action". In: *France Stratégie*.

"Reinvigorating America's Beautiful Clean Coal Industry and Amending Executive Order 14241" (Apr. 2025). In: Accessed: 2025-11-07.

Rosenow, Jan, Reg Platt, and Brooke Flanagan (2013). "Fuel poverty and energy efficiency obligations–A critical assessment of the supplier obligation in the UK". In: *Energy Policy* 62, pp. 1194–1203.

Rud, Juan-Pablo et al. (2024). "Job displacement costs of phasing out coal". In: *Journal of Public Economics* 236, p. 105167.

Saussay, Aurélien et al. (2022). "Who's fit for the low-carbon transition? Emerging skills and wage gaps in job ad data". In.

Schmieder, Johannes F., Till von Wachter, and Jörg Heining (May 2023). "The Costs of Job Displacement over the Business Cycle and Its Sources: Evidence from Germany". In: *American Economic Review* 113.5, pp. 1208–54.

Service des données et études statistiques (2022). *Chiffres clés du logement 2022 – Consommation d'énergie*. Ministère de la Transition écologique. URL: https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-du-logement/29-consommation-denergie (visited on 10/22/2025).

"The Energy Transition Is Underway. Fossil Fuel Workers Could Be Left Behind" (July 2023). In: *The New York Times*.

"The Guardian view on a carbon-free economy: no just transition in sight yet" (Jan. 2025). In: *The Guardian*.

The White House (Sept. 2022). *FACT SHEET: How the Inflation Reduction Act Will Help Small Businesses*. The White House. URL: https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2022/09/12/fact-sheet-how-the-inflation-reduction-act-will-help-small-businesses/ (visited on 11/07/2025).

"Trump is still courting coal workers. This county shows why it matters." (June 2024). In: *The Washington Post*.

Vona, Francesco et al. (2015). *Green skills*. Tech. rep. National Bureau of Economic Research.

— (2018). "Environmental regulation and green skills: an empirical exploration". In: *Journal of the Association of Environmental and Resource Economists* 5.4, pp. 713–753.

Walker, W. Reed (Sept. 2013). "The Transitional Costs of Sectoral Reallocation: Evidence From the Clean Air Act and the Workforce". In: *The Quarterly Journal of Economics* 128.4, pp. 1787–1835.

World Economic Forum (Sept. 2024). *SMEs Should Link Growth with Environmental Sustainability*. World Economic Forum.

Yip, Chi Man (2018). "On the labor market consequences of environmental taxes". In: *Journal of Environmental Economics and Management* 89.C, pp. 136–152.

A Energy efficiency policy in France

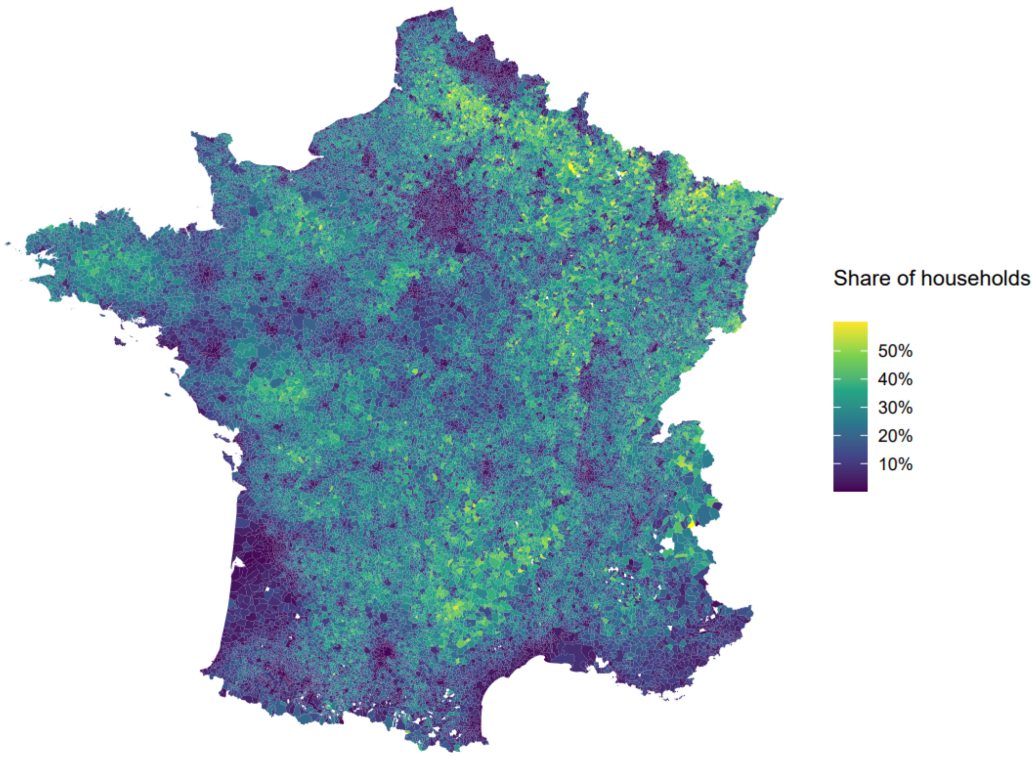


Figure A.1: Reliance on fuel oil as main heating source, 2017

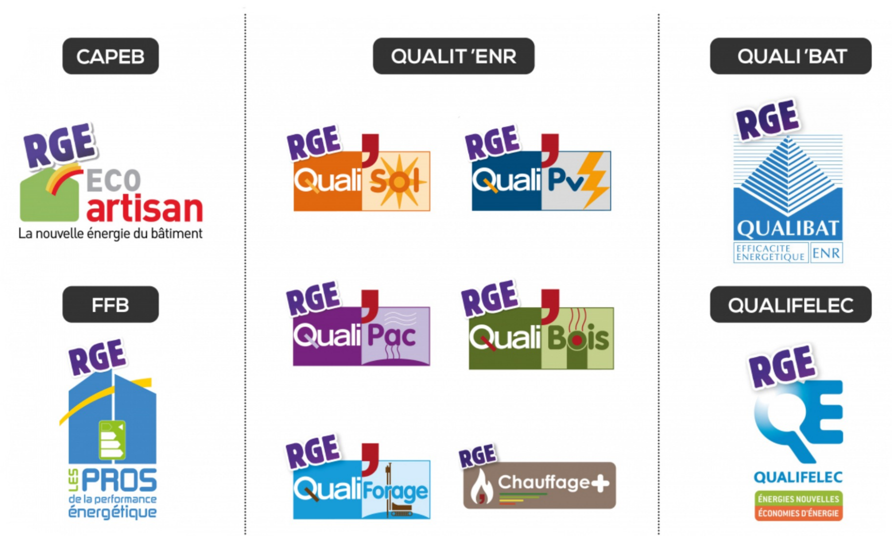


Figure A.2: RGE certificates by field of work & provider

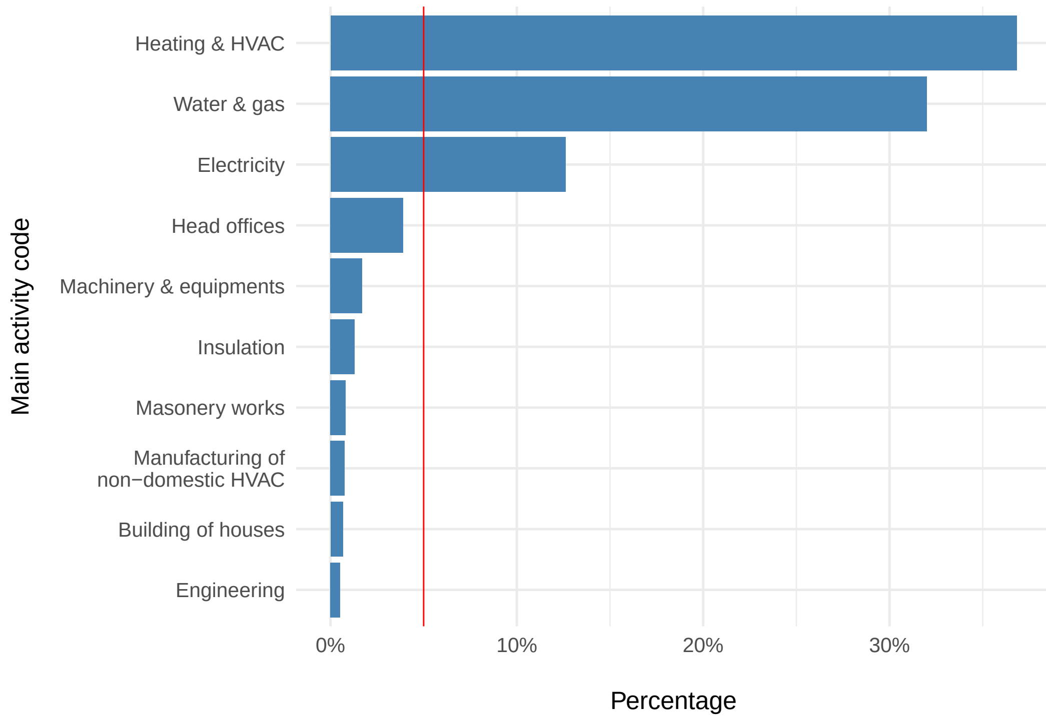
B Data sources

B.1 Worker-level data

I use the *Base Tous Salariés (BTS)*, formerly known as *Déclarations Annuelles de Données Sociales (DADS)*, an exhaustive administrative dataset of French wage earners compiled from employer tax declarations. A key methodological challenge is that the raw data assign each individual a new pseudonymous identifier each year, preventing direct longitudinal tracking. To overcome this limitation, Babet, Godechot, and Palladino 2025 developed a matching algorithm that exploits the overlapping structure of the annual files: each year's file contains data for both the current and previous year. They match individuals across consecutive years using a combination of stable characteristics including establishment identifier, gender, hours worked, job duration, start and end dates, earnings, age, and municipality of work and residence. This procedure achieves approximately 98% successful matching for the 2002-2023 period, creating what the authors term a "wide panel"—a quasi-exhaustive pseudo-panel that dramatically improves upon the traditional narrow panel (1/12th sample) previously used for French labor market research. The matching algorithm is publicly available and documented in their Appendix C. This enhanced dataset enables more precise estimation of worker and firm fixed effects in the Abowd-Kramarz-Margolis (AKM) framework by including the full universe of mobile workers across firms.

C Sample construction

Figure A.3: Top 10 main activity codes across heat pumps certified establishments



D Empirical appendix

D.1 Standard Error Calculation for Calendar-Time Aggregation

The calendar-time coefficients γ_t are linear combinations of the cohort-specific event-study coefficients β_k^c. To compute standard errors for γ_t, I use the delta method, which accounts for the covariance structure across the underlying coefficients (Greene 2018).

Let $\boldsymbol{\beta}$ denote the vector of all estimated cohort-specific coefficients $\{\beta_k^c\}$, with corresponding variance-covariance matrix $\boldsymbol{V}$ obtained from equation (3). Each calendar-time coefficient can be expressed as:

$$\gamma_t = \boldsymbol{w}_t' \boldsymbol{\beta} \tag{6}$$

where $\boldsymbol{w}_t$ is a weight vector with elements:

$$w_t^{(c,k)} = \begin{cases} \frac{1}{N_t} & \text{if } c + k = t \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

and $N_t = \sum_{c,k} \mathbb{1}\{c + k = t\}$ is the number of cohort-relative time pairs contributing to calendar year t.

By the delta method, the variance of γ_t is:

$$\text{Var}(\gamma_t) = \boldsymbol{w}_t' \boldsymbol{V} \boldsymbol{w}_t \tag{8}$$

Expanding this expression yields:

$$\text{Var}(\gamma_t) = \frac{1}{N_t^2} \sum_{\substack{c,k: \\ c+k=t}} \sum_{\substack{c',k': \\ c'+k'=t}} \text{Cov}(\beta_k^c, \beta_{k'}^{c'}) \tag{9}$$

The standard error of γ_t is then:

$$\text{SE}(\gamma_t) = \sqrt{\text{Var}(\gamma_t)} \tag{10}$$

This calculation properly accounts for two sources of correlation: (1) correlation between different relative-time coefficients within the same cohort, which arises from shared individual fixed effects and common shocks affecting that cohort; and (2) correlation between coefficients from different cohorts that contribute to the same calendar year, which can occur due to overlapping observations or common calendar-time shocks captured in the residuals.

For inference, I construct confidence intervals using:

$$\text{CI}_{1-\alpha}(\gamma_t) = \gamma_t \pm z_{\alpha/2} \times \text{SE}(\gamma_t) \tag{11}$$

where $z_{\alpha/2}$ is the appropriate critical value from the standard normal distribution.