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WORKING PAPER

#8 - November 2026

Do Residential Energy Renovation Programs Deliver?

Evidence on Workers, Firms, and Emissions

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This working paper is adapted from the general introduction of the author's PhD dissertation, *Do Residential Energy Renovation Programs Deliver? Evidence on Workers, Firms, and Emissions*, Mines Paris, PSL University. The doctoral research received the financial support from The Transition Institute 1.5 (TTI.5).

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DOI : 10.23646/y35n-nk63

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ABSTRACT

Energy renovation programs play a pivotal role in climate policy, yet their actual effects on emissions and local labor markets remain poorly understood. This working paper reviews the motivations and challenges of residential energy renovation policy and presents three contributions to filling that gap, combining French administrative data with credible quasi-experimental designs. First, an evaluation of the French CEE program, the largest energy efficiency obligation in Europe, estimates a carbon abatement cost of €103 per ton of CO_2 equivalent. This cost falls to €54 once program-induced energy price effects are accounted for, suggesting overall cost-effectiveness despite a large energy performance gap. Second, the first ex-post estimate of employment creation from a large-scale energy efficiency policy finds 2.2 job-years per million euros, far below the 8.52 full time equivalent (FTE) assumed by the European Commission, with installers' market power capturing 28% of subsidies into higher margins. Third, an analysis of clean technology adoption in the heating services industry shows within-establishment labor reallocation with low transition costs, as workers' skills are updated on the job. Together, these results point to concrete recommendations for the design of renovation policy in the energy transition.

Keywords: Energy efficiency; Climate policy; Green jobs; Greenhouse gas emissions; Applied econometrics; Distributive effects.

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1. Introduction

This working paper is adapted from the general introduction of my PhD dissertation (Wald, 2026), which received financial support from The Transition Institute 1.5 (TTI.5)[1]. It serves three main purposes. I first present the core motivations for residential energy renovation programs, with a specific focus on France's policy setting which is the empirical context of my dissertation. Beyond the decarbonization of the building stock, I discuss complementary rationales, both as co-benefits and necessary steps towards an inclusive energy transition. Second, I discuss the main challenges faced by energy renovation policies: the energy performance gap, the energy efficiency gap, and environmental externalities, that combine to explain why renovation systematically falls short of policy targets. Third, I survey actual policy tools designed to address these challenges and introduce the French energy efficiency obligation program. Finally, I present the key contributions of this dissertation and derive policy recommendations.

This research agenda sits at the intersection of several of TTI.5's research axes. It speaks directly to *Axis 1 — The transition design*, by confronting the ex-ante projections that underpin renovation policy with causally identified ex-post evidence and deriving implications for instrument design. It relates to *Axis 2 — An electric planet?*, since the electrification of residential heating through heat pumps is a central margin of the decarbonization studied here. Finally, it contributes to *Axis 3 — An inclusive planet*, through its focus on fuel poverty, the distributive effects of energy prices and subsidies, and the labour market outcomes of workers expected to deliver the transition.

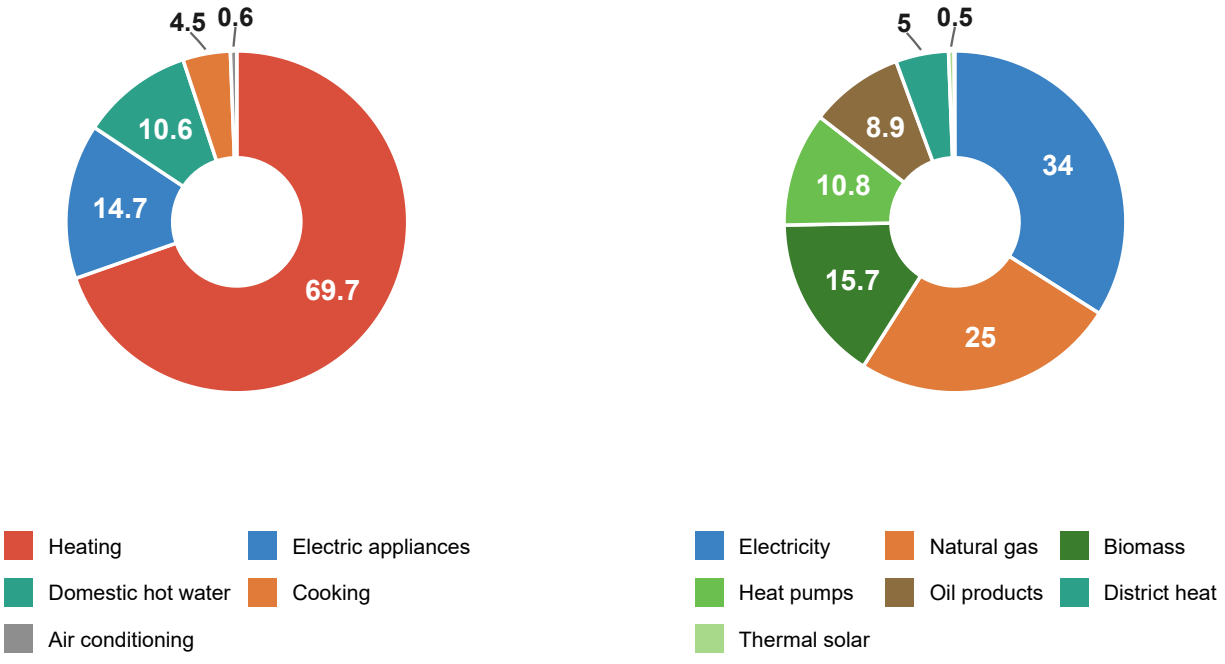
1. The full dissertation is available at https://pastel.hal.science/tel-05688480.

2. Why You Should Care About Buildings Energy Renovation

2.1 Buildings energy renovation is a pillar of the energy transition

Buildings account for 30% of global energy consumption and 26% of global greenhouse gas (GHG) emissions according to the International Energy Agency (International Energy Agency, 2025), making it a leading sector in terms of emissions. Reaching net zero by 2050 requires a near-complete decarbonization of the sector: in the IEA's Net Zero Emissions scenario, direct CO_2 emissions from buildings must fall by more than 95%, from almost 3 Gt in 2020 to around 120 Mt in 2050, driven primarily by energy efficiency improvements and the electrification of heating systems (IEA, 2025). Because 55% of buildings in use in 2050 already exist (IEA, 2022), energy renovation of the existing stock is a key channel to decrease emissions globally.

In France, residential energy use is concentrated in space heating with a share of nearly 70% (Figure 1a). The sector relies on different sources: electricity accounts for 34%, followed by natural gas at 25% and biomass at 10.8% (Figure 1b).



(a) Residential energy consumption by end use, 2024

% of total (climate-corrected)

Source: SDES, Bilan de l'énergie 2024 (Ceren).

(b) Residential energy consumption by fuel type, 2024

% of total (climate-corrected, ~ 426 TWh)

Source: SDES, Bilan de l'énergie 2024 (Ceren).

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Buildings energy renovation is widely regarded as one of the most cost-effective mitigation strategies (Allcott and Greenstone, 2012). Due to France's high reliance on nuclear electricity generation, building use represents only 15% of national GHG emissions, or 57.1 Mt CO_2eq in 2024 (SDES, 2025). Yet 75% of 2030-green investments needed to meet the EU's −55% target should be dedicated to buildings, according to Pisany-Ferry and Mahfouz (2023).

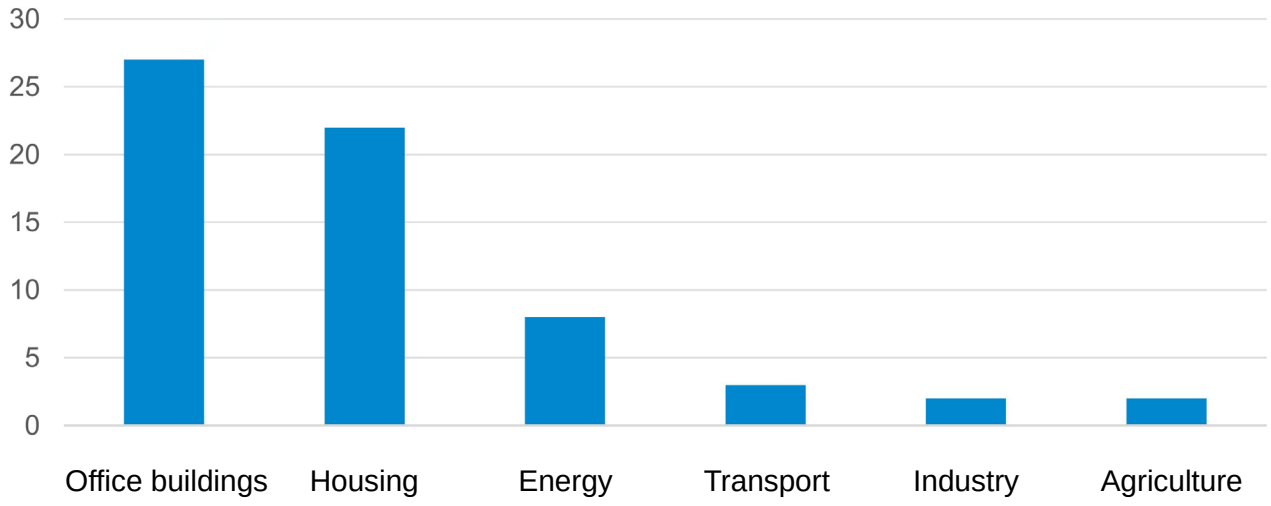


Figure 2: Net additional investments required to achieve 2030-targets related to the baseline scenario without decarbonization, in billion euro 2023

Source: Pisani-Ferry and Mahfouz (2023), authors own calculations.

This is because the technologies required — heat pumps and insulation — are commercially mature and widely available today, unlike the low-carbon solutions still needed for heavy industry or long-distance transport, which depend on innovations not yet at scale (IEA, 2022).

2.2 The (Too?) Many Co-Benefits of Energy Renovation

Alongside the direct effect on emissions, buildings energy renovation is deemed to generate a wide array of co-benefits that have become central to the political justification for policy intervention. These range from reduced energy bills and the alleviation of energy poverty to comfort gains and public health improvements, as well as the creation of local, non-relocatable jobs in the construction sector. Those benefits have been explicitly mobilized in official discourse at both EU and national level. The European Commission's 2020 Renovation Wave strategy, "Greening our buildings, creating jobs, improving lives," invokes social inclusion, health, job creation and post-COVID economic recovery alongside climate targets in a single policy rationale (European Commission,

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2020). France's MaPrimeRénov' announcements and the UK's 2021 Heat and Buildings Strategy follow a similar pattern, framing renovation as simultaneously a climate, social and economic policy.

Energy efficiency and electrification investments represent a well-established hedging strategy against rising energy bills, decreasing exposure to price volatility and lowering average bills in the long run, as shown by higher long-run price elasticities compared to short-run ones (Gillingham et al., 2009). This long-established view has gained renewed attention in the last few years, which have seen significant natural gas price fluctuations in the context of the Russian invasion of Ukraine. In the short term, households exposed to price surges primarily reduce electricity use and modestly increase labor earnings (Ahlvik et al., 2026; Herrmann et al., 2026). In the mid run, they adjust by increasing energy-efficiency investments relative to pre-crisis levels (Singhal et al., 2026; Lang et al., 2025). On the policy side, both the war in Ukraine and the blockade of the Ormuz Strait have triggered new decarbonization initiatives to reduce dependence on foreign fossil energy sources. In France, a new electrification roadmap was announced on 23 April 2026, with a doubling of subsidies to heat pumps and electric vehicles from 5.5 to 10 billion euro annually (Climate Interministerial Team, 2026).

Renovation also has direct relevance for energy poverty. Defined as the inability to keep one's home adequately warm, fuel poverty affects 10% of households in Europe and up to 12% in France, according to the European Energy Agency (European Environment Agency, 2025). It is a central concern for both policymakers and economists, as shown by the growing amount of evidence on the distributive consequences of energy price shocks and policies (Shang, 2023). In Finland, Ahlvik et al. (2026) and Herrmann et al. (2026) show that budget-constrained households were particularly harmed by the 2022 European energy crisis, with rising defaults and cutbacks in other spending. In non-crisis periods, even moderate energy price increases can lead low-income households to restrict consumption below comfort levels (Charlier and Kahouli, 2019). Energy renovation can substantially reduce fuel poverty, yet permanently exiting fuel poverty requires expensive deep retrofits, limiting the scope for large-scale policies (Best and Sinha, 2021).

Importantly, the reduction in energy bills might be partially offset by a rebound effect, whereby improved thermal efficiency leads households to increase indoor temperatures. As it reflects households consuming more of a service that has become cheaper to provide, the rebound effect is still welfare-improving rather than wasteful (Chan and Gillingham, 2015). Nevertheless, empirical evidence consistently points toward a limited rebound in the residential sector. Fowlie et al. (2018) directly measure indoor temperatures using sensors placed in both weatherized and control homes, finding a small and statistically insignificant increase in thermostat set points. Christensen et al. (2023b) corroborate this, esti-

mating that the rebound effect accounts for at most 6% of the wedge between projected and realized energy savings.

In line with the improved thermal comfort, an emerging strand of evidence points to significant health co-benefits of renovation. Recent studies have found that weatherization reduces hospital admissions for cardiovascular issues, with larger benefits for the elderly, especially on extremely cold or hot days (Künn and Palacios, 2024). Insulation and mechanical ventilation upgrades prove especially helpful in reducing children's reliance on asthma and allergy medication (Roberdel et al., 2026).

Finally, the creation of green jobs has become one of the most prominently invoked co-benefits in the political economy of renovation policy, positioned both as a condition for the energy transition and a way to make it socially just. The European Commission's Renovation Wave (2020), which targets 35 million building renovations by 2035, projects the creation of nearly one million green jobs. In France, Jolly et al. (2023) project a need for 170,000 to 250,000 additional jobs in energy renovation by 2030. These expectations are partly driven by concerns about the distributional costs of the transition itself: environmental regulations imply major welfare losses for workers in polluting sectors endowed with occupation-specific skills (Walker, 2013; Marin and Vona, 2021; Rud et al., 2024), reinforcing the pressure on green jobs to serve as a compensatory mechanism for those most exposed to transition risks.

Yet a first challenge is that environmental regulation rarely moves workers from pollution-intensive to greener jobs (Bluedorn et al., 2023; Curtis et al., 2024; Garnache et al., 2025). This points to a skill gap that must be bridged, particularly for new clean energy technologies such as heat pumps, whose adoption may produce divergent outcomes depending on workers' existing skill endowments (Marin and Vona, 2019; Saussay et al., 2022). Beyond this reallocation challenge, the broader empirical record on employment effects remains thin and, where it exists, sobering. Ex-post evidence on employment effects in energy renovation is virtually absent, and findings from adjacent sectors such as renewable energy infrastructure are at best mixed (Fabra et al., 2024; Popp et al., 2021). This raises questions about whether the promised co-benefits will materialize at the scale and for the workers that policy rhetoric implies.

2.3 Building's Energy Renovation Is Lagging Behind Policy Targets

Despite the strong political commitment to accelerating renovation, the gap between targets and actual progress is substantial and persistent. According to the IEA, the global renovation rate of the existing building stock stands at around 1% per year, well below the 2.5% per year required by 2030 under its Net Zero Emissions scenario.

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At the EU level, operational emissions from buildings decreased by an average of 16.5 $MtCO_2e$ per year over 2018–2023. This is roughly half the annual reduction rate of 33 $MtCO_2e$ required between 2024 and 2030 to meet the EU Renovation Wave's target of a 60% cut in buildings' GHG emissions by 2030 relative to 2015 (ECNO, 2025). In line with this slow decarbonization, investment in renovation in the EU is around 40% lower than required to achieve climate neutrality by 2050 (Elnagar and Kockat, 2026).

France is no exception to this pattern of underperformance. According to France's High Council on Climate (Haut Conseil pour le Climat, 2025), the buildings sector is experiencing what the Council describes as a "broken momentum." On the renovation side, the shift away from fossil heating systems has stalled: air-to-water heat pump sales fell by more than 40% in 2024, while gas boiler sales rose by nearly 15%, a direct reversal of the trend observed in previous years. On the emissions side, the picture is equally sobering. Although gross emissions from the buildings sector edged down slightly in 2024 (−0.4 $MtCO_2e$), the HCC notes that once corrected for weather variations, emissions actually *increased* by +0.3 $MtCO_2e$ relative to 2023, meaning that the apparent progress is entirely attributable to a mild winter rather than structural decarbonization. To meet France's 2030 target under the draft third National Low-Carbon Strategy (SNBC 3), the HCC estimates that the annual pace of emission reductions in the buildings sector would need to be 9.3 times faster than the rate recorded between 2023 and 2024.

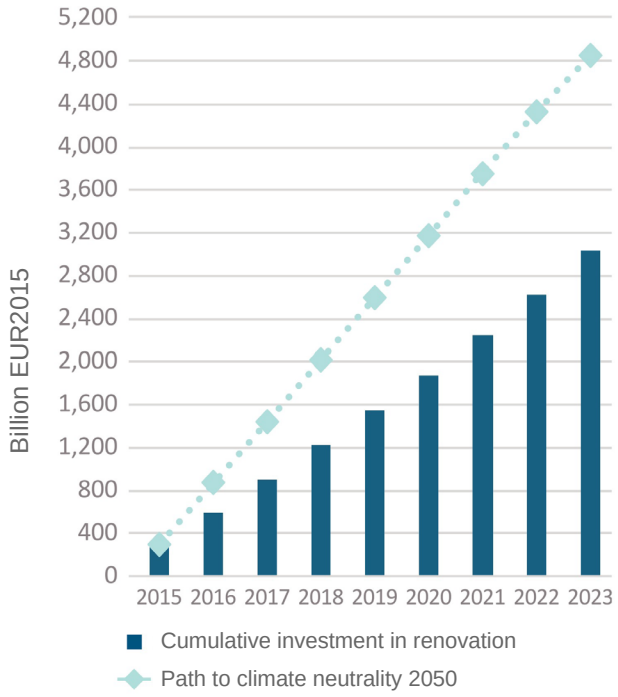


Figure 3: Cumulative investment in renovation within the EU, 2015-2023.

Note: By 2023, investments reached 3,000€ billion, compared to a required cumulative level of 4,853.9€ billion. This represents a shortfall of approximately 40.6%.

Source: "On and off: buildings at the crossroads of the energy and climate crisis", Buildings Performance Institute Europe (BPIE).

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3. Why Energy Savings from Buildings Renovation Fall Short: Three Challenges

Three distinct mechanisms help explain why building energy renovation falls short of policy targets.

3.1 The Energy Performance Gap: Inflated Projections Undermine Policy Targets

A first reason why realized savings fall below targets is the so-called energy performance gap (EPG), defined as the wedge between ex-ante engineering predictions and ex-post realized savings of energy renovation. Evidence of the EPG predates modern program evaluation (Giraudet and Missemer, 2023); quasi-experimental evidence confirms that ex-post actual savings range from 25 to 50% of ex-ante projections (Davis et al., 2014; Fowlie et al., 2018; Papineau et al., 2025). The most precise decomposition comes from Christensen et al. (2023b), who use machine-learning-based counterfactuals to cleanly separate model bias from workmanship quality. They find that engineering model bias in the US Weatherization Assistance Program (WAP) accounts for up to 41% of the performance wedge.

Beyond the average bias, engineering models are not uniform across homes or renovation measures. Christensen et al. (2023b) document substantial heterogeneity, with top-quartile homes generating highly attractive abatement costs while bottom-quartile homes destroy value. Papineau et al. (2025) document a similar pattern in a Canadian retrofit program: realized savings amount to roughly 50% of pre-retrofit engineering projections, and several individually recommended retrofits generate zero measured savings.

An emerging – and to some respects radical – solution suggests entirely replacing engineering models with machine-learning predictions derived from actual billing data. This would shift the information basis to ex-post data-driven predictions of marginal returns and allows ex-ante targeting of the most cost-efficient retrofits, which dramatically increases net social benefits, from $0.93 to $1.23 per dollar invested (Christensen et al.,2024).

3.2 The Energy Efficiency Gap: Why Privately Profitable Investments Go Unmade

Beyond engineering predictions, households fail to make investments in energy efficiency that would still appear profitable even from a purely private perspective. This energy efficiency gap, defined as the wedge between privately profitable and actual investment levels, has been debated among environmental and resource economists since the oil shocks of the late 1970s (Giraudet and Missemer, 2023). The concept was popularized outside academic circles most notably through the McKinsey Curve (McKinsey, 2009), which estimated that 23% of US non-transportation energy demand was eliminable at negative private cost. Several distinct market and behavioral failures contribute to this gap.

A first market failure stems from imperfections in capital markets, as budget-constrained households often cannot access credit to finance the substantial upfront costs that energy efficiency improvements require. Early evidence for this constraint came from the observation that only a small share of home improvements were funded by loans, a sign of binding liquidity barriers (Berry, 1984). This mechanism has since become a standard explanation for the energy efficiency gap (Gillingham et al., 2009; Allcott and Greenstone, 2012; Gerarden et al., 2017). Yet credit constraints remain surprisingly underexplored empirically, despite the strong extensive-margin response to zero-interest loans suggesting substantial untapped energy efficiency gains (Eryzhenskiy et al., 2025).

Alongside financial barriers, a cluster of informational challenges depresses investment below privately optimal levels. Incomplete information arises when households face high costs to assess their current energy efficiency: pre-retrofit audits require time, money, and technical literacy that many households are unwilling or unable to provide. Asymmetric information generates a distinct problem. On the rental market, landlords cannot fully recover investment costs through higher rent because energy efficiency is unobserved to potential tenants (Myers, 2020; Gillingham et al., 2009). As a result, rental properties are significantly less likely to have efficient appliances as compared to owner-occupied ones (Davis, 2012) and to benefit from building energy renovation (Charlier, 2015; Gillingham et al., 2012; Aydin et al., 2026). Similar asymmetric information may affect transactions in owner-occupied housing markets, as sellers own private information on energy efficiency that is unobserved to buyers (Kahn and Kok, 2014). However, evidence suggests a very modest role for this channel: Myers (2019) documents full capitalization of fuel price changes into house prices in the US. In the Dutch housing market, Aydin et al. (2019) estimate that energy efficiency improvements affect transaction prices, regardless of the provision of additional information to buyers.

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Additional challenges emerge in the principal-agent relationship between households and renovation contractors (Giraudet, 2020). Because the quality of works is inherently difficult to observe or verify, both during and after installation, energy renovation falls into the class of *credence good* (Dulleck and Kerschbamer, 2006). Under asymmetric information, moral hazard can arise between households and contractors as the latter may systematically overtreat (in the diagnosis step) and shirk on unobservable dimensions of work quality (in the execution step). Accordingly, Giraudet et al. (2018) study home energy retrofits in Florida and document that energy savings installed on a Friday are significantly lower for hard-to-observe tasks such as attic insulation. In Illinois, Christensen et al. (2023b) analyze the WAP and estimate that workmanship heterogeneity account for 43% of the wedge between projected and realized savings, making it a key determinant of renovation performance. In France, the rapid expansion of renovation markets as part of the post-Covid recovery plan attracted a wave of opportunistic contractors. More than half of inspected firms failed to meet legal obligations toward consumers (DGCCRF, 2024), with recurring infractions including deceptive pre-contractual information and aggressive canvassing targeting vulnerable households.

Compounding the moral hazard problem, local market power may allow contractors to increase prices above competitive levels, hence capturing the many energy efficiency subventions (Weyl and Fabinger, 2013). Evidence mostly come from energy appliances and are rather context dependent. Pless and Van Benthem (2019) focus on solar PV in California, a market dominated by big players. They estimate a subsidy pass-through above one, which is evidence of imperfect competition. Conversely, Buettner and Madzharova (2024) study consumers rebate in energy efficient appliances within the EU single market. Their almost full subsidy pass-through estimates is consistent with high producer-level competition and very few on-site work. Evidence for insulation and heating systems is missing, despite the local nature of the installation service, often performed by SMEs. The think-tank *Federation of American Scientists* alerts that without market-shaping interventions, federal and state subsidies for energy-efficient products like heat pumps tend to raise prices, leaving the overall market worse off once rebates end (Staple et al., 2024). In France, Grandclément et al. (2018) identify high search costs and the difficulty of comparative shopping in local renovation markets as structural features conferring local contractors with pricing leverage.

In close connection, an understudied supply-side failure is the shortage of qualified renovation workers. The report from the IEA (2022) identifies installer shortages as the more pressing bottleneck for scaling up heat pump deployment, a diagnosis that generalizes to energy renovation. The European Labour Authority (2023) finds that half of occupations facing severe shortages belong to the construction sector. Jolly et al. (2023) provide a granular assessment for France: recruitment tensions are already severe

and large waves of retirements are imminent by 2030. Industry federations attribute this shortage primarily to the low attractiveness of building trades to younger workers (CAPEB, 2024; France Travail, 2022). Yet labor economics offers a complementary, and largely overlooked, explanation: higher barriers to entry in product markets reduce the number of competing firms, shrink workers' outside options, and thereby raise employers' labor market power, enabling wage markdowns and suboptimal employment levels (Calì and Presidente, 2026). On this reading, the labor shortage in renovation is not solely driven by worker preferences: it may also reflect the labor market counterpart of the same local market power that enables incumbent firms to appropriate subsidy transfers. Finally, behavioral barriers may depress profitable investments while information is technically available (Gillingham and Palmer, 2014). Non-standard preferences such as *prospect theory* and *loss aversion* (Kahneman and Tversky, 1979) imply that households may be especially averse to the risk that upfront costs are not recovered, which deters investment even when lifecycle calculations favor it (Tsvetanov and Segerson, 2014).

Beyond preferences, non-standard decision-making, including *inattention* and *bounded rationality*, further depresses investment (Gillingham and Myers, 2025). Inattention manifests when consumers have finite cognitive capacity, which leads them to systematically overlook future energy costs when making investment decisions (Sallee, 2014; Maćkowiak et al., 2023). In practice, this channel might vary across investment types. While Allcott and Taubinsky (2015) identify a significant inattention bias in the light bulb market, Myers (2019) finds full capitalization of fuel price changes into house prices, suggesting more attention for large, salient investments. Houde and Myers (2021) further documents heterogeneity: consumers respond to local energy prices for appliances, but higher-income households weight operating costs more heavily. Beyond inattention, *bounded rationality* may lead agents to rely on simplified decision rules when faced with multi-dimensional information (McFadden, 1999). For complex renovation decisions involving technical trade-offs and financing options, heuristic processing is likely. Certification schemes designed to reduce cognitive burden can also backfire: Houde (2018) shows that coarse, grade-like energy labels induce a "class valuation effect" that may crowd out more nuanced cost processing.

3.3 Environmental Externality: Underinvestment Relative to the Social Optimum

A third, fundamental challenge is the existence of environmental externalities (Pigou, 1920). The combustion of fossil fuels — either directly through a fossil boiler or to generate electricity used in buildings — emits greenhouse gases, what Stern (2008) famously called

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"the greatest market failure the world has ever seen." Because the social costs of carbon are diffuse, long delayed, and largely borne by third parties, they are not reflected in energy prices. As a result, consumers overconsume fossil fuels and underinvest in energy renovation relative to the socially optimal level. Importantly, environmental externalities should not be conflated with rationales of the "energy efficiency gap" or "paradox" as they cannot explain consumers making decisions that appear to go against their best private interests (Gillingham and Myers, 2025).

Abstracting from all other failures, the first-best policy response to environmental externalities would be to internalize them directly, either through a carbon tax or a cap-and-trade system. Energy efficiency policies — whether standards, subsidies, or information programs — are only second-best instruments in this respect. By targeting capital stock rather than emissions directly, they fail to discriminate across fuels by carbon intensity and do not confront consumers with the true social cost of their usage decisions (Gillingham et al., 2009; Allcott and Greenstone, 2012).

Yet first-best instruments remain rare in the residential sector, as carbon pricing has historically been concentrated in industry and power generation. Existing evidence from early adopters is instructive: the Swedish carbon tax is estimated to have reduced annual CO_2 emissions per capita by up to 800 kg (Runst and Thonipara, 2020). Crucially, the political and social acceptability of carbon pricing is significantly higher when revenues are earmarked for abatement measures or returned to households (Dechezleprêtre et al., 2022; Bourgeois et al., 2021). Moreover, the ranking of instruments as first- and second-best does not hold in the presence of additional market and behavioral failures. The co-existence of multiple market failures provides an economic rationale for subsidies that goes beyond the simple internalization of environmental externalities. Allcott et al. (2014) develop a framework for optimal policy when consumers of energy-using durables undervalue energy costs relative to their own private optimum — what they call an *internality*. They derive two key results with direct relevance for energy renovation policy.

First, there is an *Internality Dividend from Externality Taxes*: energy taxes not only reduce environmental externalities, they also offset the distortion from underinvestment in energy efficiency caused by internalities. Discrete-choice simulations suggest this dividend could more than double the social welfare gains from a carbon tax set at marginal damages. Second, they establish an *Internality Targeting Principle*, which posits that the optimal combination of instruments depends on the average internality of consumers marginal to each instrument. Consumers who undervalue energy costs are also less responsive to energy taxes. Therefore, the optimal policy combines an energy tax below marginal damages and a large subsidy for energy-efficient products. Applied to building renovation, these two results provide a formal justification for using energy efficiency subsidies *alongside* carbon pricing rather than as a substitute for it.

4. Implementing Energy Renovation Policies

4.1 Policy Instruments for the Energy Efficiency Gap

A rich policy toolkit has emerged to target the challenges at the core of the energy efficiency gap.

Where the binding constraint is financial, dedicated green loan programs are the natural instrument. France illustrates both the policy response and its limits, with the zero-interest loan introduced in 2009 on top of public subsidies and private grants from energy providers. Although initially effective for liquidity-constrained homeowners, uptake collapsed after 2011, with evidence that banks substituted their own commercial products for the subsidized loans, exploiting borrowers' incomplete information (Eryzhenskiy et al., 2025).

Informational challenges call for a more differentiated set of tools. Incomplete information on households' current energy efficiency status can be addressed through commercial outreach and information campaigns, including the prospect-finding step embedded in energy efficiency obligation programs, as well as free pre-renovation energy audits. Providing missing information could improve allocative efficiency at relatively low cost, as shown by Davis and Metcalf (2016) for the case of energy appliances. However, evidence from Fowlie et al. (2015) shows that take-up of a zero-out-of-pocket-cost energy renovation program increased by only 5 percentage points despite extraordinary information efforts worth 20% of the average investment cost, suggesting that non-monetary barriers extend beyond incomplete information.

For asymmetric information, building energy performance certification provides a direct fix: by making efficiency observable to prospective tenants or buyers, it allows efficiency to be capitalized into rents and prices and aligns the incentives of both parties (Eichholtz et al., 2013). Evidence shows that dwellings with energy efficient certification are sold at higher prices and are more liquid in terms of time on the market (Brounen and Kok, 2011; Kahn and Kok, 2014; Aydin et al., 2019; Myers et al., 2022). Minimum energy efficiency standards for rental properties provide another approach to stimulate investments in energy retrofits. In the UK, Clara et al. (2026) shows how this requirement for low-graded properties triggered significant investment in low capital expenditure retrofit, without any economically significant impact on rents, so that landlords are not compensated for them. Yet this may come at the price of a reallocation of low-rated dwellings away from rental use and toward owner-occupation, with uncertain consequences for rental market supply

and tenant welfare (Civel et al., 2026). Moreover, energy performance certificates can be subject to manipulation in the absence of verification, casting doubt on the actual effects on investment (Collins and Curtis, 2018; Aja et al., 2024), with Civel et al. (2024) showing higher manipulation when certifiers face higher competition.

Stimulated by advances in behavioral economics, so-called *nudges* have also gained significant traction in energy efficiency policy (Giraudet and Missemer, 2023). For non-standard preferences such as loss aversion, voluntary energy-saving target-setting programs exploit reference-dependence and commitment to achieve persistent savings (Harding and Hsiaw, 2014). Regarding non-standard decision-making, operating cost information added on energy labels, as under EU energy labeling rules, improves choices through increased attention to costs and reduced anchoring on label categories (Andor et al., 2019). Social comparison nudges and proximity nudges also help reduce inattention and have been proved effective to increase take-up in communities with strong social norms (Gillingham and Tsvetanov, 2018), though effects on actual investment remain modest for most households (Allcott and Greenstone, 2024).

Turning to moral hazard from energy efficiency contractors, minimum quality standards can rely on product certification (Giraudet et al., 2018). The limitation, however, is that firms respond strategically to certification thresholds rather than the underlying quality objective. Houde (2022) shows how bunching at label boundaries serves price discrimination across consumer segments rather than genuine quality improvement. Another approach is to certify contractors instead of works (Giraudet, 2020), which France implements through the *Reconnu Garant de l'Environnement* (RGE) label conditioning access to renovation subsidies on contractor accreditation. Yet certification credibility lies on verification (Lanz and Reins, 2021), which is harder for energy efficiency and fails to prevent defects in hard-to-observe features (Laprie et al., 2024). Alternatively, contractors and households' incentives can be aligned by restructuring worker-level compensation schemes: Christensen et al. (2023a) provides the first experimental evidence on this instrument, testing performance-based pay (P4P) in the Weatherization Assistance Program. Worker compensation is tied to the quality of measured outputs, such as a blower door test measuring the "leakiness" of a home post-retrofit: the result is increased natural gas savings, in line with reduced workmanship moral hazard.

Growing concerns related to local installers' market power also trigger innovative solutions. In the context of the Inflation Reduction Act in the US, the think-thank *Federation of American Scientists* recommends requiring rebate-eligible contractors to submit illustrative bids for standardized installation scenarios and to publish their hourly labor rates, to create benchmark price data accessible to consumers (Staple et al., 2024). They further propose tiring the rebate itself to contractor pricing, conditioning market access on

reasonable pricing. A growing awareness of the subsidy-capture problem is also happening in France, with the embryo of a price-monitoring infrastructure through the *National Observatory for Energy Renovation (ONRE)*, but it operates in a purely informational and retrospective mode.

Finally, green training policies are gaining traction on both sides of the Atlantic. In the US, the Training for Residential Energy Contractors (TREC) program dedicates $200 million to fund the training, testing and certification of residential energy efficiency and electrification contractors. In the EU, the BUILD UP Skills initiative operationalizes the reskilling effort of the Renovation Wave (2020) by supporting the development of training and qualification schemes across the building value chain. In France, young new entrants cover only 40% of anticipated recruitment needs, meaning on-the-job reskilling — through formats such as workplace-based training actions and validation of prior experience (VAE) will have to play a central role (Jolly et al., 2023).

4.2 Energy Efficiency Obligations: A Hybrid Instrument

Energy efficiency obligations (EEOs) are a widely deployed instrument, operating in at least 48 active programs across 23 jurisdictions, including 15 EU countries, the UK and China, and 24 US states (IEA, 2022). Institutional design varies considerably across jurisdictions. In the United States, so-called Energy Efficiency Resource Standards (EERSs) impose obligations on regulated local distribution monopolies, with compliance costs recovered through regulated charges on all customers. In Europe, by contrast, obligations are imposed on energy retailers operating in liberalized, competitive markets. The EU's Energy Efficiency Directive 2023/1791 establishes EEOs as a core mechanism for achieving national energy consumption reduction targets.

France's CEE program (*Certificats d'Économie d'Énergie*) is the largest such program in Europe, with total investment of around e6 billion per year (Cour des Comptes, 2024). Every three to four years, individual energy savings targets are assigned to retailers of electricity, gas, and gasoline in proportion to their sales. Retailers predominantly meet their targets by providing grants for residential energy retrofitting; for each investment subsidized, they receive certificates from the regulator in proportion to projected lifetime energy savings. At the end of each compliance period, suppliers must return enough certificates to cover their obligation. Certificates are tradable, enabling retailers to purchase compliance from one another in a secondary market.

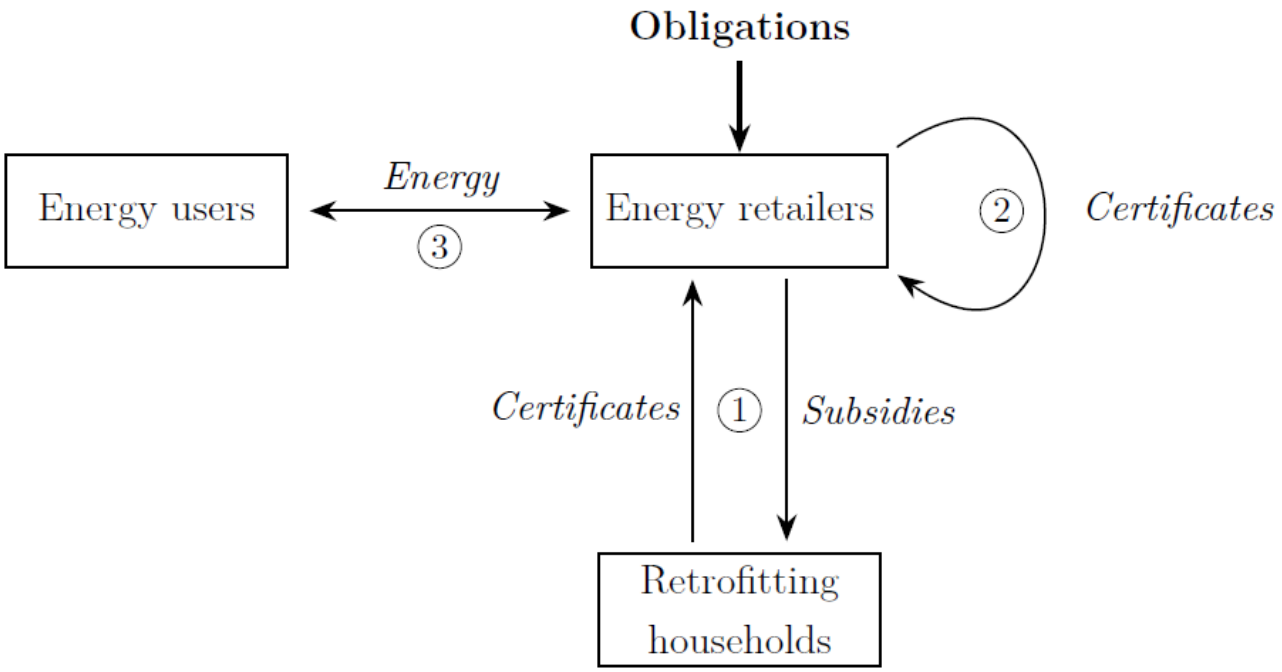


Figure 4: The market organization of the CEE program

Notes: In the primary certificate market (1), energy retailers compete to fund the least costly household retrofits through subsidies and earn certificates in return. In the secondary certificate market (2), these can then be traded among obligated parties. In the energy markets (3) where the obligated parties operate, the program's cost is passed through to consumers via energy prices.

From the perspective of the Allcott et al. (2014) framework, EEOs are particularly well suited to a context of co-existing externalities and internalities, for one structural reason: they operate through both channels simultaneously. On the subsidy side, by providing grants to households for energy efficiency investments, EEOs directly addressfinancial barriers and internalities, targeting the investment margin. On the tax side, the costs borne by energy retailers to generate certificates are ultimately transmitted to end- user energy prices. This pass-through mechanism induces all households to reduce energy consumption, not only those undertaking renovations (Giraudet and Quirion, 2008). The resulting implicit carbon price acts similarly to a partial carbon tax, correcting the environmental externality for all energy users. In this way, the CEE program simultaneously provides an investment subsidy and generates an energy price signal, combining the two instruments identified as optimal by Allcott et al. (2014) in a single policy instrument.

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5. The Dissertation: Contributions, Methods and Policy Recommendations

The three chapters of this dissertation provide microeconomic evidence on the demandand supply-side barriers that hinder large-scale energy renovation. All three use France's Energy Savings Certificates (CEE) program as a common empirical backdrop. Each chapter confronts specific ex-ante projections or macro-model estimates that currently underpin the design and political justification of renovation policy and replaces them with causally identified microeconomic estimates. In doing so, the dissertation highlights key mechanisms that the existing literature has either overlooked or been unable to quantify at scale and draws implications for the design of more effective public interventions in the energy transition.

5.1 Contribution by Chapters

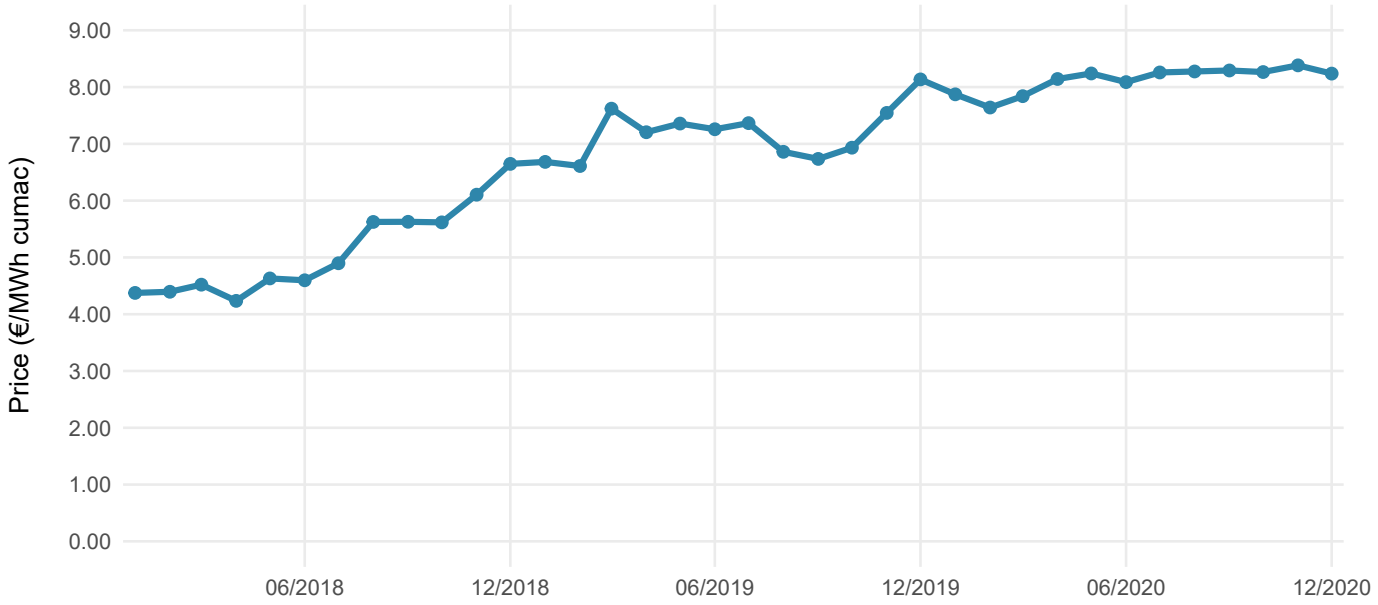
The first chapter, *How Costly Is Carbon Abatement in the Residential Sector? Evidence from Energy Efficiency Obligations*, is joint work with Matthieu Glachant. We evaluate the French CEE program using sub-municipal electricity and natural gas consumption data from 5 million housing units over 2018–2021. We first estimate the program's impact on energy use and carbon emissions, then develop a novel revealed-preference approach to measure the average carbon abatement cost, exploiting the tradability of certificates. Combining certificate prices with estimated energy savings and emissions factors yields a preferred estimate of €103 per tCO_2e, falling to €54 when accounting for the pass-through of program costs into retail energy prices. The program thus appears cost-effective overall, despite official reports overstating realized energy savings by 69%.

The chapter speaks to the three challenges identified in this introduction. On the energy performance gap, the 69% overstatement of engineering projections places France at the high end of international estimates and shows that compliance reports based on projected savings are systematically misleading. On the externality, the program's energy price channel — which accounts for three-quarters of total savings — functions as a partial carbon tax, exactly the mechanism emphasized by Allcott et al. (2014). On the energy

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efficiency gap, the revealed-preference approach makes a deeper contribution: because obligated parties compete to trigger the least-cost household investments, the equilibrium grant reflects households' full willingness to accept investing, encompassing all private costs and benefits as perceived by households when making their decision. This includes non-monetary participation costs and post-renovation comfort gains from rebound that standard abatement cost calculations have traditionally failed to account for (Bernheim and Taubinsky, 2018).

Figure 5: Evolution of the certificate spot price, 2018-2020



Notes: Certificates associated with each project are valued using the spot market price on the contract signature date emmy. We rely on official records of savings with bonus in this calculation, because the value of each work is defined by the (annualized) amount of certificates it delivers, including bonuses. Certificates are divided into two categories: standard certificates and so-called "Précarité" certificates, which are issued for investments in dwellings occupied by fuel-poor households. Since early 2018, the prices of both categories have converged, justifying the use of the average price in the graph and subsequent analysis. The reasons for this convergence are detailed by Darmais et al. (2024).

The second chapter, *Overpromising Green Jobs? Evidence from the French Energy Efficiency Obligations Program*, is co-authored with François Cohen and Victor Kahn. We provide the first ex-post microeconomic estimate of the employment impacts of a large-scale energy renovation program. Using a policy discontinuity in subsidy provision and a synthetic control method on disaggregated firm-level data, we find 2.2 job-years created per million euros, roughly one quarter of the EU macro-model benchmark. This gap cannot be explained by labor shortages or adjustment costs, as wages remain stable throughout the entire period. Instead, the dominant explanation is rent capture: only 10% of each additional euro of subsidy translates into new hires, while 28% is absorbed into firms' value added.

The chapter's first contribution is to challenge the green jobs narrative in the political justification for renovation programs. The second contribution speaks to the mechanisms behind this overestimation: it is not primarily tied to labor supply shortages, but rather to market structure. The rent capture we document shows that local market power diverts environmental subsidies away from their intended beneficiaries. We provide the first causal evidence of this mechanism in the context of energy renovation: local energy- efficiency installers absorb a disproportionate share of the subsidy increase into margins rather than passing it through to households or workers. This suggests that the cost- effectiveness of renovation subsidies cannot be assessed from the demand side alone, and that the market structure of the renovation services sector is a first-order determinant of program outcomes.

The third chapter, *Wired For Change? Clean Technology Adoption and Labor Market Transitions*, investigates the effect of clean technology adoption on labor market outcomes. on labor market outcomes. I study French heating-service SMEs shifting from fossil-fuel boilers to heat-pump installation, a fundamental trade for large-scale electrification. This transition is a canonical example of green reskilling, as it requires new technical, regulatory, and customer communication skills. I exploit a demand-side subsidy surge (+€2,500) which drives staggered certification of installers. Leveraging matched employer-employee data, I estimate the effect on hours worked, annual earnings and hourly wages for workers in the industry.

The contribution is twofold. I first demonstrate that monopsonistic employers fund green reskilling by holding the wage below the productivity gain. Indeed, workers who remain attached to their incumbent employer see earnings rise about 19%, but this is entirely driven by longer hours, while their hourly wage remains constant. Second, I identify a sharp +20% wage premium for workers who separate once reskilled. This is evidence that the skills are portable rather than firm-specific, and that trained workers are poached once outside options materialize.

5.2 Data and Methods

A defining feature of this dissertation is its reliance on microeconomic evidence with credible causal identification, in contrast to the ex-ante engineering projections and macro- model estimates that dominate the policy debate on energy renovation. Each chapter exploits a distinct source of quasi-experimental variation and a distinct administrative dataset accessed through the French Secure Data Access Center (CASD), and each challenges a different form of systematic overestimation.

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Chapter 1 uses sub-municipal electricity and natural gas consumption at the neighborhood level, matched to CEE certificate issuance data. The identification strategy exploits within-neighborhood variation in renovation program intensity over 2018–2021, using panel data methods with neighborhood fixed effects to control for time-invariant unobserved heterogeneity and a weather-related instrumental variation, namely, lagged heating degree days. The key methodological innovation is the revealed-preference approach to abatement cost estimation: rather than computing costs and benefits separately, the chapter uses the observed market price of tradable certificates as a sufficient statistic for the program's marginal cost, recovering the average abatement cost without relying on external parameters and assumptions.

Chapter 2 uses disaggregated, monthly frequency establishment-level data on employment, wages and value added in the renovation sector. The identification strategy exploits a policy discontinuity in the provision of subsidies to households, combined with a state-of-the-art synthetic control method that builds a counterfactual for the renovation industry from a weighted combination of control firms. The resulting estimates are directly comparable to the EU's ex-ante macro-model projections, enabling a clean assessment of the gap between predicted and realized employment effects.

Chapter 3 leverages rich matched employer-employee administrative data — recording hours, earnings, and employer identifiers for the universe of French heating service employees — linked to establishment-level heat pump installation certificates. The identification strategy exploits a demand-side subsidy shock, which triggers establishment-level adoption of the new technology. I estimate the causal effect of this transition on labor real- location within-firm and worker-level outcomes. Using a staggered difference-in-difference estimator, I decompose aggregate effects into contributions from stayers, leavers, and newcomers, offering a unique and comprehensive perspective on the labor market effects of the energy transition.

5.3 Policy Recommendations

The three chapters share a common diagnostic: causal ex-post estimates of what energy renovation programs deliver systematically fall short of ex-ante projections. Taken together, the results point to three concrete recommendations.

Recommendation 1: Resist calls to dismantle energy efficiency obligations; complement them with redistributive provisions. The cost-effectiveness of energy efficiency obligations has come under institutional scrutiny, with the Cour des Comptes (2024) opening the debate on deep reform or outright dismantling, and energy suppliers calling for suspension in the context of the Hormuz Strait crisis (La Tribune, 2026). Chapter 1 provides a microe-

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conomic counterargument: even accounting for the large energy performance gap, the direct renovation channel alone delivers abatement at €103/tCO_2e, well below France's official carbon value of €250/tCO_2e for 2030. The overall cost falls further to €54/tCO_2e once the pass-through of program costs into retail energy prices is included. Crucially, this indirect channel creates an energy price signal that delivers more savings than the investment channel itself, at far lower cost. In this way, the EEO acts as a partial substitute for a carbon tax, circumventing the political difficulty of directly raising energy prices while generating the same behavioral response across all households. The political backlash against the program partly reflects a legitimate distributional concern — rising fuel prices weigh disproportionately on low-income households but suspension would be self-defeating, since decarbonization is precisely the appropriate long-run hedge against fossil fuel price volatility. The right response is to complement energy efficiency obligations with energy renovation subsidies targeting more specifically energy-poor households, who are particularly inelastic to energy prices (Goulder et al., 2019).

Recommendation 2: Do not overpromise on green jobs, and account for local market structure in the design of subsidies. Renovation programs create far fewer jobs than ex-ante multipliers imply. Thus, they cannot be relied upon to smoothly reabsorb workers displaced from polluting sectors. The shortfall is driven by rent capture where installers hold local market power. Two implications follow. First, policy appraisal should replace inflated employment multipliers with the realistic ex-post figures and stop resting the case for renovation on its job-creation potential. Second, subsidy design must account for local market structure to prevent installers' rent capture. Measures that intensify local competition and price transparency, e.g., benchmarking installer prices and lowering barriers to entry for new firms, would channel more public money to households and workers rather than to incumbent rents.

Recommendation 3: Fund green reskilling through training subsidies and worker certification. Subsidy-driven adoption generates on-the-job reskilling for incumbent workers. However, firms fund it through monopsonistic wage compression, creating a tension between reskilling and attractiveness. Workers' returns to their new skills materialize only upon separation, and in tight labor markets, firms train less and poach more, so hiring stalls precisely where skilled installers are scarcest. Capping wage markdowns, for instance through wage floors, would raise workers' capture of the returns but blunt firms' incentive to train. The instrument that instead relaxes the trade-off is to lower the cost of reskilling directly, through publicly subsidized training and portable worker certification. Subsidized training lets firms reskill without funding it through wage markdowns, while

portable certification makes green skills verifiable and portable, strengthening workers' outside options.

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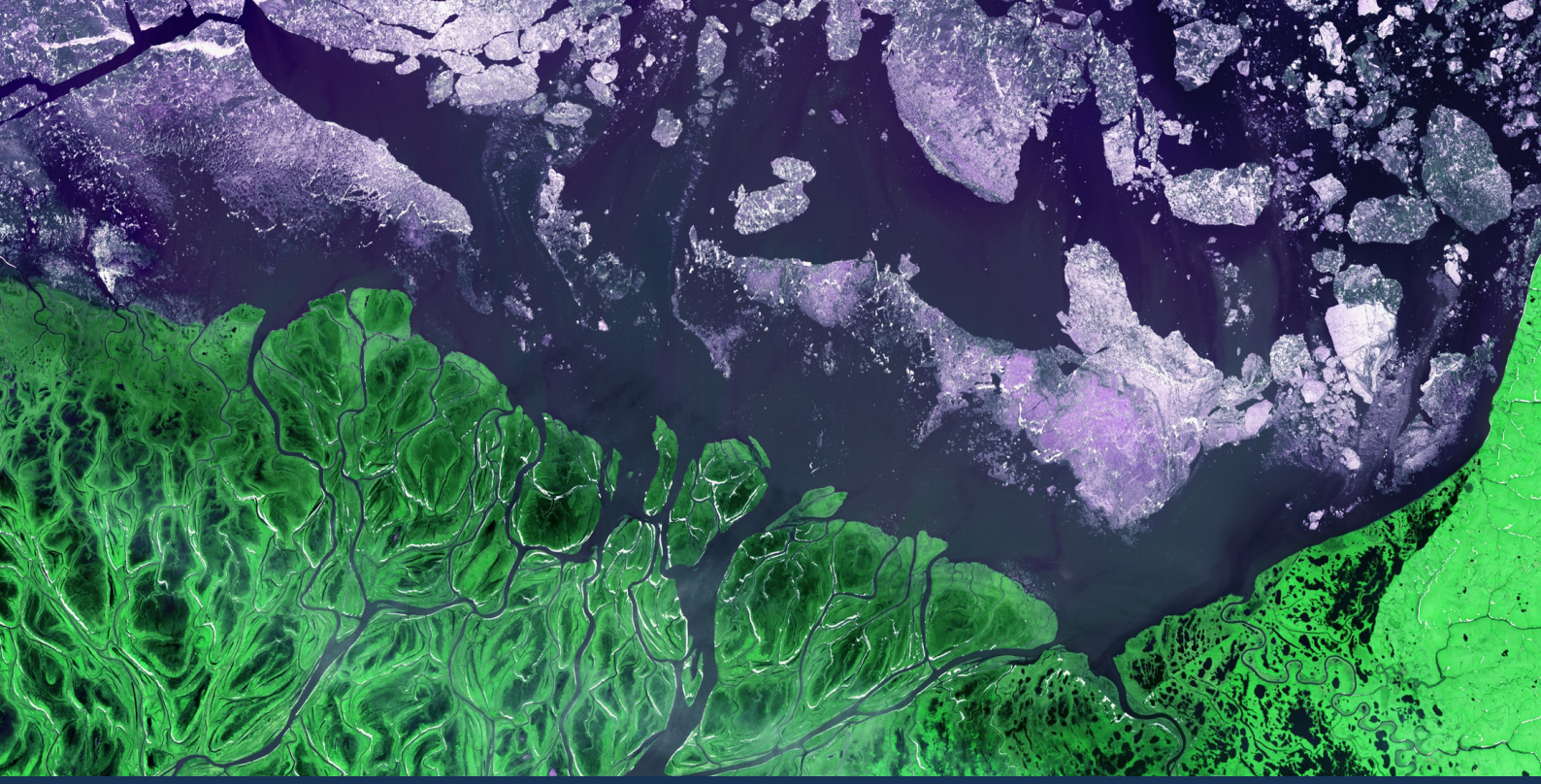
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TTI.5° The Transition Institute

This research is supported by The Transition Institute 1.5 (TTI.5).
TTI.5 is a research and teaching institute
driven by Mines Paris - PSL and dedicated to the low-carbon transition.

Ce travail de recherche bénéficie du soutien de The Transition Institute 1.5 (TTI.5).
TTI.5 est un institut de recherche et d'enseignement de Mines Paris - PSL
dédié à la transition bas-carbone.

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