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# A retrofitting obligation for French dwellings - A modelling assessment

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## Abstract

Retrofitting obligations are gaining traction among policy makers to overcome the sluggishness of energy efficiency improvements in residential buildings and the low effectiveness of most incentive programmes in changing this. Such an obligation was for instance the flagship proposal submitted by the Citizens' Convention for Climate to the French government. What are the costs and benefits of this little-studied measure? We examine this question using Res-IRF, a building stock model of French dwellings with endogenous retrofitting dynamics. We find that a retrofitting obligation is essential in allowing a net-zero energy target to be met in the residential sector. Crucially, the obligation makes up for the failure of most other programmes (subsidies, white certificate obligation, zero-interest loan, energy taxes) to trigger retrofits in private rental housing. As a result, the obligation is the most effective measure to eliminate the least efficient dwellings (EPC labels G and F) and its impact on energy savings and fuel poverty alleviation is twice that of all other existing measures combined. Against these benefits, we find the obligation to increase annual investment needs by 4 to 6 billion euros.

## Introduction

The European commission recently set the target of cutting greenhouse gas (GHG) emissions by 55% by 2030 compared to their 1990 levels.<sup>1</sup> The residential sector, which contributes 30% of total CO<sub>2</sub> emissions, is expected to be a key contributor in achieving this goal. Yet despite a widely shared belief that the sector is replete with cost-effective abatement opportunities, the myriad incentive programmes aimed to tap them have proved largely ineffective since their implementation in the mid-2000s. This is for instance the case in France, where a tax credit programme for home energy retrofit was found to mostly benefit non-additional participants (Nauleau 2014)(Risch 2020), a zero-interest rate green loan programme (ZIGL) performed well below expectations (Eryzhenskiy et al. 2022), utility-sponsored insulation measures were subject to widely publicized quality issues and the carbon tax was key in the ignition of what came to be known as the Gilet Jaunes crisis.

The question therefore arises as to what measures are “fit for 55”? Putting a retrofitting obligation in sync with housing turnover has early been invoked to overcome the shortfall of extant policies (Giraudet et al., 2011). The measure is receiving increasing attention after the Citizens' Convention for Climate made it its central proposal to the government to achieve France’s climate targets.

In this paper, we assess the effectiveness and socio-economic benefits of this little-studied policy option. We do so using Res-IRF (Giraudet et al., 2012), an energy-economy model interacting housing features (single vs. multi-family, energy efficiency, heating fuel) with key household characteristics (tenancy status, income of both owners and occupants). We compare several obligation designs and find that all generate net socio-economic benefits. Our results emphasize the need to consider supply-side effects to conduct a more comprehensive assessment.

The paper is organized as follows. First, we provide an overview of the modelling framework. Second, we introduce the policy scenarios considered, and the indicators used to evaluate them. Fourth, we assess the effectiveness of the retrofitting obligation under contrasted design options. Fifth, we discuss the results and some avenues for further research.

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<sup>1</sup> [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_21\\_3541](https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541)

## Modelling framework

Res-IRF models energy demand for heating in main residences in France.<sup>2</sup> Building on a rich description of the dwelling stock, it features endogenous renovation processes that take into account several barriers at the source of the so-called “energy efficiency gap” (Jaffe and Stavins, 1994), including the rebound effect, credit constraints, the landlord-tenant dilemma and non-energy attributes to housing energy efficiency.

### Structure

Dwellings are characterized by their type, their energy performance, their main heating fuel (ignoring secondary heaters) and the socio-economic characteristics of the owner and the occupant. The dwelling stock is parameterized with the most up-to-date data (Merly-Alpa, Riedinger, and Baudry 2020). 26 million dwellings are split into 1,080 categories as follows:

- Nine categories of energy performance, corresponding to labels A to G of the French energy performance certificate (EPC) in dwellings built before 2018, and the ‘net zero energy’ label in dwellings built after 2018. These categories summarize the technical characteristics of the envelope and the heating system.
- Four fuels used as the primary source for space heating: electricity, natural gas, fuel oil and fuel wood (together covering 91% of energy demand for space heating).<sup>3</sup>
- Two categories of housing: single- and multi-family units, respectively weighing 61% and 39%.
- Three categories of property owners: owner-occupiers, landlords of rented dwellings, and social-housing organizations.
- Ten income categories for both owners and occupants, closely aligned with the income deciles of the French population given by INSEE.

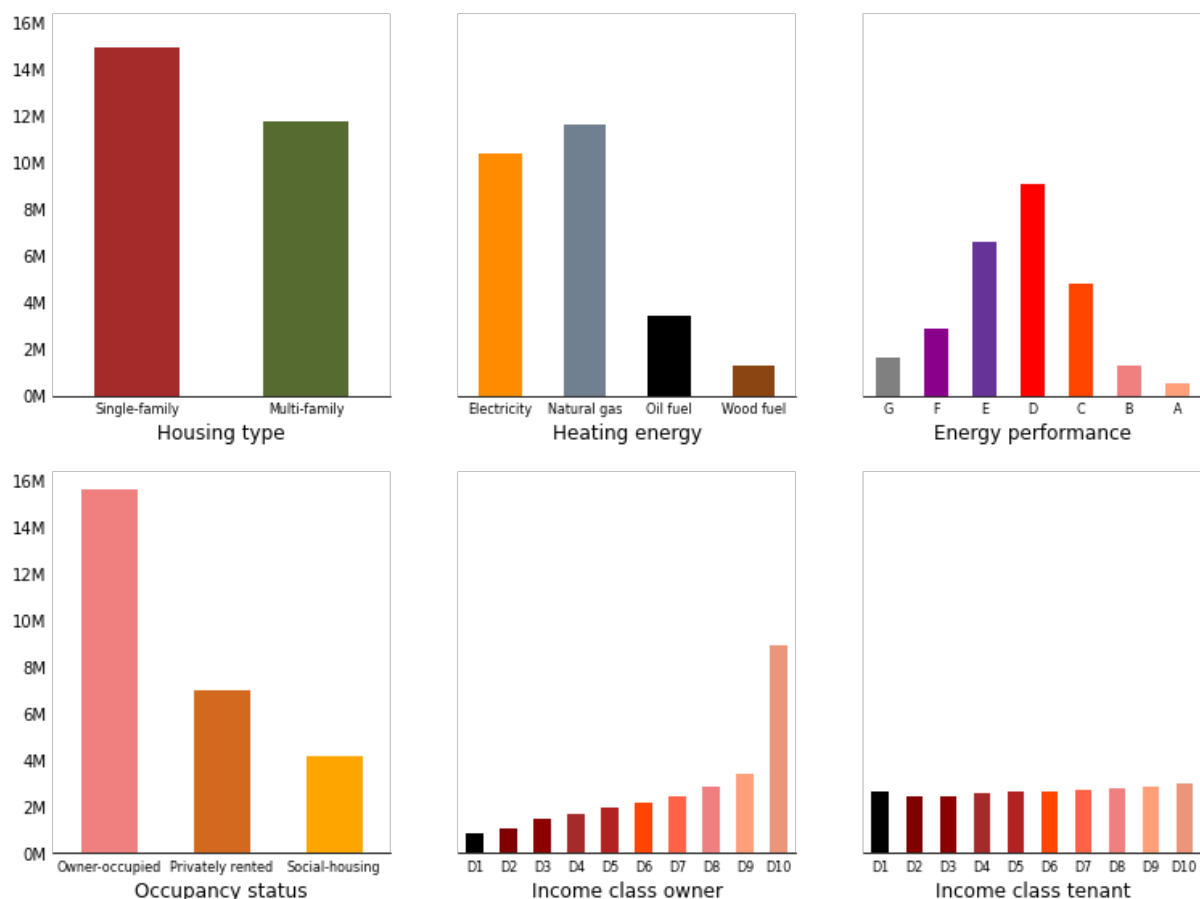


Figure 1. French building stock in 2018 by attributes based on (Merly-Alpa, Riedinger, and Baudry 2020).

<sup>2</sup> The Python code has recently been made available at <<https://github.com/CIREN/Res-IRF>>. The documentation is available at <<https://cired.github.io/Res-IRF>>.

<sup>3</sup> Implicitly, electricity is used for electric heating up to dwellings labelled C and heat pumps for higher labels.

The dwelling stock data used in the model vintage presented here significantly differ from the earlier Phébus data (Ministère de la Transition écologique 2013) with which the previous vintage was parameterized. In particular, the newer data include 4 million of dwellings labelled G and F, as opposed to 8 million in the older data. Importantly, only a fraction of the discrepancy can be explained by the renovation that occurred between 2012 and 2018. The two datasets were assembled following different methodologies, which makes it difficult to conclude which one is more reliable. To take into account such uncertainty around a key policy variable, we ran our simulations with the most recent data and use the older data in sensitivity analysis.

### ***Dwelling stock dynamic***

The various processes included in the model – the demolition and renovation of existing buildings, the construction of new buildings and occupants’ behavioural adjustment – are determined by three exogenous inputs – energy prices, population and income.

#### **Demolition**

Each year, a small fraction of the pre-2018 building stock is demolished every year. Building on the correlation observed in the data between the age of the dwelling and its energy efficiency performance, the process is targeted towards the least efficient dwellings. According to the (Ministère de la Transition écologique 2021b), demolition equally affects labels G, F and E. Since 1999, the demolition of approximately 31,000 dwellings has been recorded annually (INSEE 2017), representing 0.12% p.a. of the total dwelling stock. In contrast, a recent governmental report estimates an annual demolition rate of 80,000, or 0.35% (Ministère de la Transition écologique 2021b). The discrepancy between the two could be explained by the government’s goal to keep construction at a high level despite the reduction in population and consequently of housing needs. We therefore set our reference value to 0.35% p.a. and use the 0.12% p.a. alternative in sensitivity analysis.

#### **Renovation decision**

The equations of the model are fully detailed in (Giraudet, Bourgeois, and Quirion 2021). In a nutshell, renovation decisions are made by homeowners – owner-occupiers, landlords and social housing providers. For a dwelling labelled  $i$  before retrofit, they proceed along two margins:

- Intensive margin: selection of a post-retrofit efficiency label  $f$  from among labels  $\{i+1, \dots, A\}$ . The market share of each post-retrofit label is determined by a discrete-choice function based on the life-cycle cost of each option, including investment costs and lifetime discounted operating costs. This specification is adjusted to capture a number of barriers to energy efficiency. First, heterogeneous credit constraints are captured by a negative association between discount rates and income. Second, frictions inherent in decision-making in homeowner associations are captured by higher discount rates in multi-family units, as compared to those applied to single-family units. Third, under-capitalization of energy savings in rental housing are captured by a short investment horizon of three years – the typical duration of a lease contract – as opposed to 30 years in owner-occupied dwellings and social housing. These assumptions mimic full capitalization of the green value in owner-occupied dwellings and a very limited capitalization in rental housing, as empirical evidence from various countries suggest (Giraudet, 2020). Fourth, intangible costs are calibrated by confronting the model to observed retrofitting patterns; they capture the non-energy attributes of a retrofit, for instance peer effects and the inconvenience caused by renovation works. The patterns used to calibrate intangible costs borrow from the most up-to-date TREMI survey, which focuses on single-family dwellings (Ministère de la Transition écologique 2020).

*Table 1. Retrofitting market shares based on the TREMI survey for single-family building.*

		<b>Post-retrofit label (f)</b>					
		<b>F</b>	<b>E</b>	<b>D</b>	<b>C</b>	<b>B</b>	<b>A</b>
<b>Pre-retrofit label (i)</b>	<b>G</b>	60%	26%	12%	1%	1%	0%
	<b>F</b>		61%	29%	9%	1%	0%
	<b>E</b>			79%	14%	6%	1%
	<b>D</b>				80%	18%	2%
	<b>C</b>					86%	14%

- Extensive margin: the decision-maker decides whether or not to upgrade a dwelling of label  $i$  to a higher label  $f > i$ . This decision depends on the net present value of an average renovation project, measured as the life-cycle cost difference between the status quo and the different upgrade options

weighted by their market share. The correspondence between net present value and renovation numbers follows a logistic function capturing heterogeneity in heating preference and habits. It is calibrated against the same TREMI data.

Table 2. Renovation rate calculated from TREMI survey for single-family building (%/year).

	Single-family	Multi-family
Homeowners	6.3%	3.5%
Landlords	3.1%	0.8%
Social-housing	4.9%	2.7%

Life-cycle cost calculations rely on a carefully specified renovation cost matrix reflecting two standard economic rules: the marginal cost of energy efficiency is increasing (i.e.,  $C_i^{f+2} - C_i^{f+1} > C_i^{f+1} - C_i^f$ ); economies of scale make it cheaper to perform a given upgrade at once rather than sequentially (i.e.,  $C_i^f < C_i^k + C_k^f$  for all  $i < k < f$ ). The matrix used in the previous version of the model (Giraudet, Bourgeois, and Quirion 2021) was adjusted to account for the latest field data<sup>4</sup>. The Effnergie observatory points to an average renovation cost of €366/m<sup>2</sup> before tax (BT) estimated from a sample of 59 deep retrofit projects, with half of the cost distribution lying within €267-413 /m<sup>2</sup> before tax. The institute attributes this dispersion to variations in age and building typology. The Perf in mind study points to an average renovation cost of €526/m<sup>2</sup> including VAT, or €500 /m<sup>2</sup>, to reach label B. Our adjusted matrix (see below) is consistent with the orders of magnitude found in these studies. We expect to project too much incremental renovations, for our matrix likely overestimates the cost of deep retrofits – upgrading from label D to B costs twice as much as from G to B at odds with field observations.

Finally, we allow investment costs to decrease with cumulative renovation, following a classical learning-by-doing process. The learning rate – the cost reduction induced by of a doubling of cumulative renovation – is set to 10%.

		Post-retrofit label (f)					
		F	E	D	C	B	A
Pre-retrofit label (i)	G	100	179	264	356	461	581
	F		83	172	268	377	502
	E			92	192	306	435
	D				104	222	356
	C					122	262
	B						145

Fuel switch decisions are known to be hindered by an array of technical constraints (Stolyarova et al. 2015). Accordingly, we hold fuel switch market shares constant over time for single-family housing and ignore fuel switch in multi-family housing.

### Heating behaviour

The intensity with which occupants – owner-occupiers and tenants – heat their dwelling is defined as the ratio between realized energy use, as disclosed in energy bills, and that predicted by the EPC label. It is determined endogenously by three variables: the price of energy, the energy efficiency of the dwelling, as measured by its EPC label, and the income of the occupying household. This is modelled through an iso-elastic, negative relationship between heating intensity and the household’s income share dedicated to heating, parameterized with empirical estimates from (Cayla and Osso 2013). An increase in heating intensity in response to efficiency improvements can be interpreted in the model as comfort gains (i.e., rebound effect).

### Policy scenarios

<sup>4</sup> Recent studies have pointed out that the cost of reaching high performance depends very little on the initial performance level, and significantly differs between single-family homes and apartments (Effnergie and ADEME 2021) (Enertech et al. 2021). These facts are at odds with the guiding principles of our matrix. They were established for only a few of our matrix entries, however, which prevented us from fully integrating them into our matrix.

## Exogenous inputs

The three exogenous inputs – population, total income, and energy prices – follow the guidelines provided by the French authorities (Ministère de la Transition écologique 2021a). Electricity prices increase at an average rate of 1.3% p.a, natural gas at p.a, fuel oil at p.a and fuel wood at 1.4 p.a. Population increases at an average rate of 0.2% p.a., and income at a constant rate of 0.12% p.a. The same assumptions apply to all scenarios.

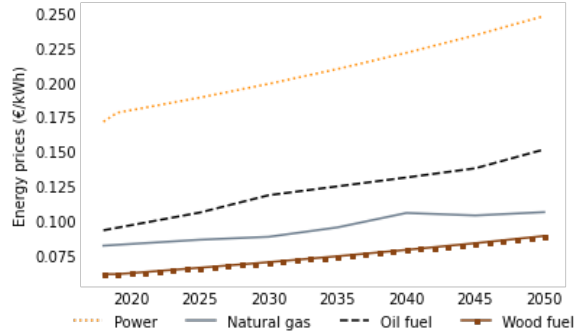


Figure 2. Energy prices projection in €/kWh (Ministère de la Transition écologique 2021a)

## Reference scenario

The reference scenario includes the main policies currently in place in the residential sector. The policies are specified as in (Giraudet, Bourgeois, and Quirion 2021) – see Table 3 for a summary of the key parameters.<sup>5</sup>

Table 3. Summary of key policy parameters.

Income tax credit	ITC	Subsidy with a uniform rate of 17%.
Zero-interest loan	ZIL	Subsidy targeting high performance, rate 9% of investment cost.
White certificate obligation	WCO	Subsidy of €5/MWh lifet. disc. in 2017 (doubled for C1 households), growing at +2% p.a., + fee on energy sales
Carbon tax	CAT	Myopic expectation: the carbon tax is taken as constant in the economic evaluation.
Reduced VAT	VAT	Subsidy that reduces tax from 20% to 5.5% rate.
Building code	BCO	Net zero energy level mandatory for new constructions in 2018.

This scenario is labelled ‘AP’, for “all policies”. To disentangle the different drivers at play in this scenario, we run two additional scenarios:

- *ZP*, standing for ‘zero policy’, in which all policies are removed,
- *ZP, price constant* in which all policies are removed and energy prices are kept constant over time

## Retrofitting obligation

A retrofitting obligation has been introduced in private housing by the recent “Loi Climat et resilience”, forbidding a landlord to rent out a dwelling falling below certain performance requirements, to be enforced from 2025 on. The Citizens' Convention for Climate recommended a more ambitious agenda, extending the measure to owner-occupied dwellings and adding minimum upgrade requirements for all.

Based on this recommendation, we design a retrofitting obligation policy that forces all homeowners, both owner-occupiers and landlords, to retrofit their dwelling when a change occurs (sale or new lease) if the dwelling falls below a minimum standard (see Table 4). We model four retrofitting obligation options:

- A retrofitting obligation that forces investment without restricting the choice set, meaning that the owner of a G dwelling can retrofit it to, say, label F in 2023, and then to E in 2030.
- An obligation to reach at least label C. The choice set is therefore restricted to labels A, B and C.

<sup>5</sup> The tax credit has been replaced in 2021 by a fully-fledged subsidy programme called ‘Ma Prime Renov’. The latter involves higher subsidy amounts, differentiated by income levels. Due to lacking feedback, we were not able to account for this recent change.

- An obligation to reach at least label B, with the objective of generalizing the “low-energy” label in all dwellings – pre- and post-2018 – by 2050. Such deep retrofits are recommended by experts so as to avoid dissipating part of the potential. Indeed, a recent study indicates that incremental upgrades create technical deadlocks that prevent further renovation from being conducted, in particular when it comes to carefully adjusting the capacity of the heating system to the building envelope (ADEME 2021).
- Finally, we model an obligation to reach label A.

Table 4. Enforcement schedule for the retrofitting obligation

Energy performance certificate	> G	> F	> E	> D
Application year	2023	2025	2030	2040

According to a national survey (INSEE 2017), the rotation rate is around 12.1% p.a. in privately rented housing, 5.2% p.a. in social housing, and 2.1% p.a. in owner-occupied housing. The turnover rate sets an inherent pace for our retrofitting obligation that is kept unchanged across policy scenarios.

Under all obligation specifications, we implicitly assume that the homeowners claim the subsidies they are entitled to and pay the energy taxes imposed on them. We discuss this hypothesis later.

### Indicators

We assess the effectiveness of various obligation options in achieving the sectoral goals set by the government and their socio-economic net present value. For both indicators, the impact of the renovation obligation is calculated as the marginal difference between the scenario considered and the reference scenario.

### National objectives

France has set the following targets (IGF and CGDD 2017): upgrading the most inefficient dwellings – labels G and F, together representing between 5 and 8 million units – by 2025 (Target 1); having a minimum performance equal to label B by 2050 (Target 2). In addition, the European Commission’s *Fit for 55* agenda plans to cut CO<sub>2</sub> emissions by at least 55% by 2030 compared to their 1990 level.<sup>6</sup>

### Socio-economic assessment

The socioeconomic net present value indicator allows one to put in perspective the positive and negative social impacts of the retrofitting obligation. This indicator is intended to help policy makers determine whether the gains from the programme under consideration outweigh its costs. Our analysis considers the main market and non-market marginal effect associated with the retrofitting obligation, building on the following variables:

- The additional retrofitting costs,
- The reduction of energy expenditure,
- The benefit of avoided CO<sub>2</sub> emissions, valued at their social cost (Quinet 2019),
- Health benefits, including avoided mortality and morbidity due to cold indoor environments, as estimated in (Ezratty et al. 2018).

We discount the benefits at the social discount rate of 4.5% over a lifetime of 30 years. Other sources of cost and benefit were not considered in the current study. This includes:

- Impacts on public spending caused by (i) an increased public support for renovation and (ii) a reduced revenue from energy taxes. A recent study assessing the renovation of the least-efficient rented dwellings (Domergue, Chabrol, and Giraudet 2021) finds that the effect is offset by a decrease in social security costs. Moreover, the increased activity in the construction sector is expected to further tilt the balance towards net benefits.
- Impacts in terms of fuel poverty alleviation and the resulting gains in heating comfort and standard of living (other than health benefits).
- Embodied emission of renovation and construction works.
- Impacts on the power generation sector (including the cost of managing the electricity grid and the level of electricity exports due to changes in consumption patterns),
- Impacts on property value (green premium).

We briefly discuss what relaxing these assumptions would imply in the conclusion.

<sup>6</sup> Hence 40% compared to the 2018 level, considering that the EU cut emissions by 23% between 1990 and 2018. <https://www.ecologie.gouv.fr/fit-55-nouveau-cycle-politiques-europeennes-climat>.

## Results

Figure 3 depicts the evolution of final energy use for the residential sector under different scenarios. Final energy use in the reference scenario is 235 TWh/year in 2030, an average reduction of 11% since 2018. Comparing the AP and ZPs scenarios indicates that the increase in energy prices explains 30% of the reduction while the various policies together contribute 70%. The removal of the carbon tax and the tax component of the white certificate obligation in the *ZP* scenarios increases heating utilization, thus explaining the differences in initial energy consumption.

Final energy use is reduced by 7 TWh p.a. in 2030 and 17 TWh p.a. in 2050 when the retrofitting obligation is set to B and by 6 and 12 TWh p.a., respectively, when it is set to C. The retrofitting obligation is the only policy enabling elimination of the least efficient dwellings G and F by 2040. It is not sufficient, however, to upgrade all G and F dwellings by 2030 (Target 1). The natural turn-over of the stock, with which the renovation obligation is synchronized, appears too slow to achieve this objective. Additional incentives would therefore be needed to accelerate these dynamics.<sup>7</sup>

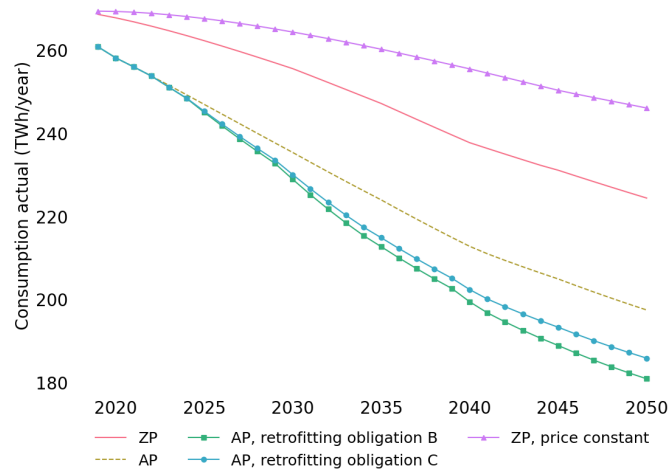


Figure 3. Simulation of final energy use under various scenarios (TWh/year).

The retrofitting obligation is the only policy tapping the potential for retrofits in rental housing. Indeed, the landlord-tenant dilemma – a well-documented phenomenon contributing to the energy efficiency gap in the residential sector (Gillingham, Newell, and Palmer 2009) – dampens the participation of landlords in subsidy programmes. The problem is captured in Res-IRF by setting the investment horizon to 3 years for landlords, instead of 30 years for homeowners. The retrofitting obligation will increase the demand for retrofits by more than 200,000 per year, an increase by more than 20%. The impact of this shock on the construction industry and the banking industry (to meet the surging demand for financing) is beyond the scope of this study but merits further research.

We assess fuel poverty with the commonly used energy-to-income ratio (EIR), which collects the number of households allocating more than 10% of their income to heating expenditure. Figure 4 shows that the measure drives 200,000 households out of fuel poverty.

<sup>7</sup> The non-modelled MaPrimeRenov programme should not change this conclusion, because the subsidies it offers are capped at 15,000 euros for very low-income households and 10,500 for low-income households, which is unfit to cover the investment needed to achieve comprehensive retrofits.



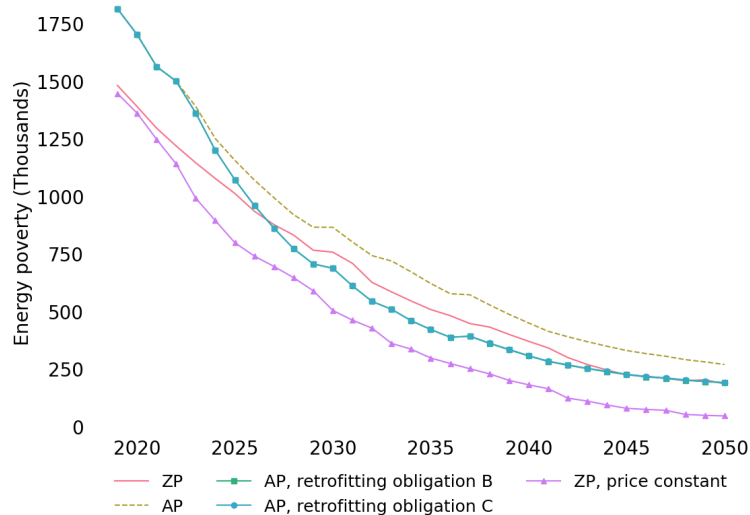


Figure 4. Share of energy poverty in the total building stock for various scenarios (%).

Our estimate of yearly renovation expenditure is consistent with the size of the French market for home energy retrofits, estimated to amount to 20 billion euros in 2019 (Figure 5). In the Reference scenario, the total amount spent on renovation decreases over time due to a depletion of the stock of profitable projects, not compensated by the stock-deepening effect of the increasing carbon tax and technical progress. The investment surplus associated with the various retrofitting obligation options varies over time as non-conforming dwellings get renovated. In 2025, when label-F dwellings become not compliant, investment increases by 4 to 6 billion euros; when the obligation is applied to label-E dwellings in 2030, investment increases by 6 to 8 billion euros.

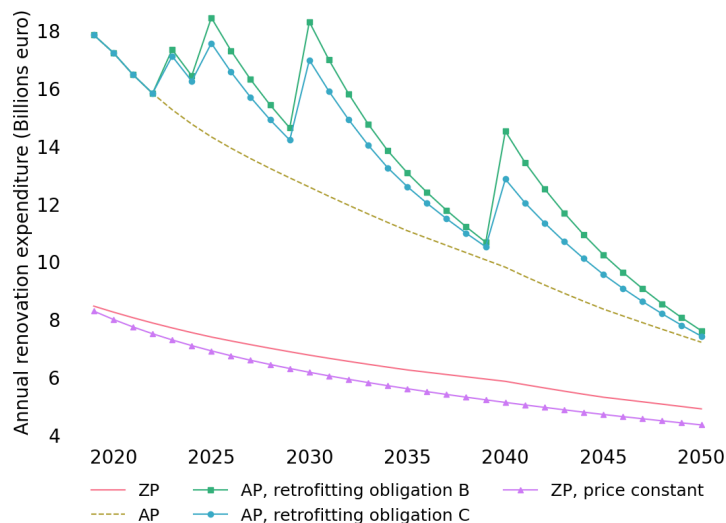


Figure 5. Annual renovation expenditure for various scenarios (Billions euros).

### Socio-economic assessment

Our results suggest that a retrofitting obligation forcing homeowners to reach at least performance level C has positive socio-economic returns (Figure 6). The energy savings induced and the reduction in CO<sub>2</sub> emissions make up for increased capital expenditure. Health improvement among tenants provides substantial extra benefits.

Figure 6 compares the social cost-benefit balance of the four obligation options. The balance is in any case beneficial, in particular when a minimum performance is included (with only minor variation across the three options). The substantial health benefits highlight the effectiveness of the instrument at eliminating the most energy inefficient dwellings subject to cold indoor environments. The basic obligation without a minimum performance requirement falls short of achieving the emission reduction targets. The obligation set to label C might create the aforementioned technical deadlock problems typically associated with incremental renovation,

thus making the most ambitious mitigation targets impossible to achieve. Unable to account for this in our cost matrix, we therefore consider that our assessment is too optimistic about the net benefits associated with the label-C obligation option. With this qualification, our results suggest that setting the obligation to label B is the most advisable option.

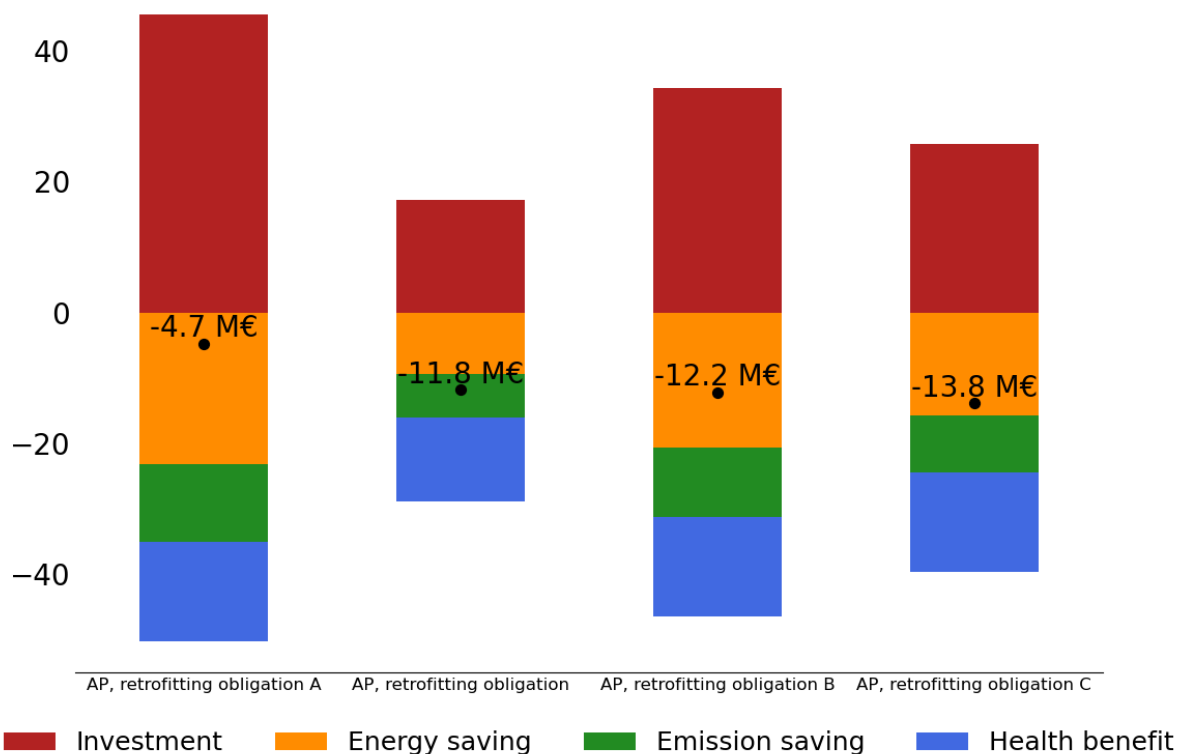


Figure 6. Socio-economic NPV comparison for different retrofitting obligation.

### Acceptability

Our study assumes that households can only claim the subsidies they are entitled to under existing programmes. It goes to show that these programs will not suffice to cover the additional financing needs induced by the obligation, thus leaving many households with several (tens of) thousands euros to finance. In the prevailing social context, enduringly marked by the Gilet Jaunes crisis, it is politically difficult to envisage such an obligation without strong financial support. In this spirit, the Citizen's Climate Convention (CCC) proposed to differentiate the entitled amount by income as follows: 90% of upfront cost covered for the very low-income category (first and second decile), 70% for the low-income category (third and fourth decile) and 30% for other households.<sup>8</sup> This is quite a difference compared to the prevailing system, covering only up to 35% of upfront cost, with no income differentiation.

We assess the impact of the subsidy schedule proposed by the CCC, with and without a retrofitting obligation set to label B, previously identified as the most advisable option. In both cases, we substitute the new subsidisation schedule for all currently existing subsidy programmes.<sup>9</sup>

Figure 7 shows that the retrofitting obligation coupled with the CCC subsidy programme provides net benefits. This is potentially a key enabler to implementing the retrofitting obligation. The results also show that the proposed subsidy programme could be counterproductive without the retrofitting obligation. Indeed, even if they weigh more heavily on the least efficient dwellings, owing to the positive correlation observed in the data between income and energy efficiency, such targeted subsidies miss the low-efficiency dwellings occupied by middle- and high-income households, where health benefits can also be enjoyed when upgraded (Scenario CCC).

<sup>8</sup> <https://propositions.conventioncitoyennepourleclimat.fr/pdf/pr/coc-seloger-rendre-obligatoire-la-renovation-energetique-globale-des-batiments-d-ici-2040.pdf>

<sup>9</sup> This implies that we remove the white certificate obligation, including its tax component. We nonetheless keep the carbon tax.

The combination of the CCC subsidy programme and the retrofitting obligation results in additional financing needs of roughly €10 billion per year until 2030. This raises important questions as to the capacity of the credit market to meet increased demand. Figure 2 shows that the public cost of that alternative system is twice that of the current one.

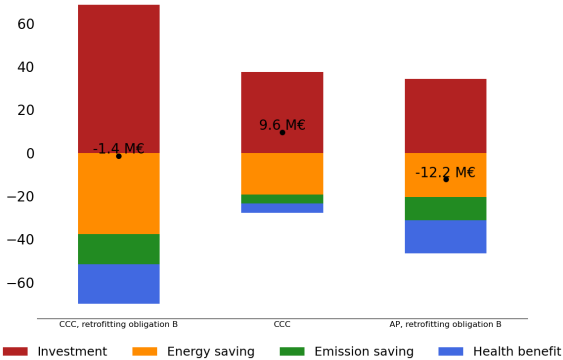


Figure 7. Socio-economic NPV (Billions euros).

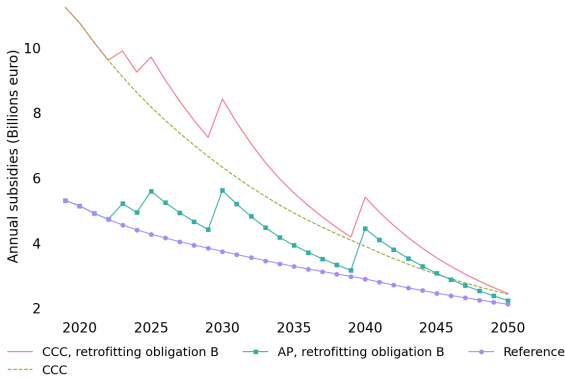


Figure 8. Annual subsidies expenditure (Billions euros).

**Sensitivity analysis**

Running the model with older building stock data, which are more skewed towards low-efficiency dwellings (with more F and G labels, in particular) generates a more beneficial net balance, primarily driven by larger health benefits in the more numerous least-efficient dwellings (Figure 9). Using a lower demolition rate (0.012%) slows down the natural turn-over, thereby magnifying the net benefits of the obligation.

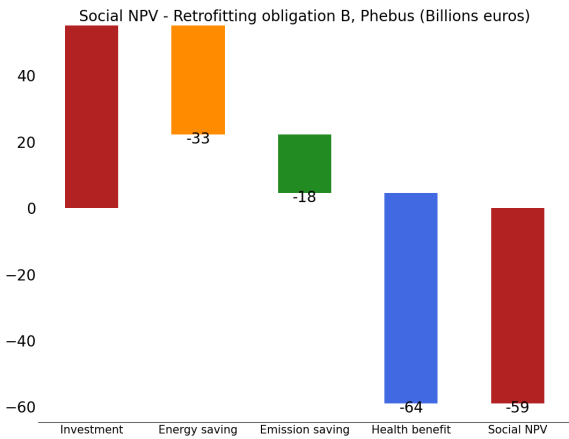


Figure 9. NPV using older building stock data.

**Conclusion**

This paper suggests that a retrofitting obligation imposed on French dwellings would generate net socio-economic benefits. Compared to existing policies, it is particularly effective at triggering investment among landlords, which is instrumental in eliminating the least efficient dwellings by 2040. Within the scope of our modelling framework, a retrofitting obligation has the same impact with a minimum performance requirement set to label B as without one. Our intuition, however, is that the retrofit-to-B option would look more favourable were more up-to-date data and processes added to the picture. Finally, we find that the progressive subsidy programme proposed by the CCC, covering 30% to 90% of upfront cost depending on the beneficiary’s income, could provide the much-needed support to make the obligation politically acceptable. Whatever the design considered, a retrofitting obligation shows positive social returns and therefore is an advisable option.

These results are established within a partial-equilibrium framework which ignores broader economic effects. With a minimum of €6 billion additional financing requirements each year, it will be crucial in further research to take into account demand-supply interactions in the market for home energy retrofits. Indeed, we anticipate that a surge in demand will be faced with bottlenecks in the renovation industry, resulting in increasing prices. Likewise, the increased demand for credit may result in higher interest rates. This might in turn create credit rationing among low-income households and induce low- and middle-income landlords to engage in premature sale in an attempt to avoid paying the mandatory retrofitting in the future. Finally, we anticipate that the obligation will increase the green penalty on low efficiency property in the real estate market. These are just a few examples of potential adverse effects of the measure that need to be carefully taken into account in order to produce a more comprehensive assessment.

## Acknowledgement

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- ADEME. 2021. “Rénovation performante par étapes.” <https://bibliothèque.ademe.fr/urbanisme-et-batiment/4168-renovation-performante-par-etapes.html>.
- Cayla, and Osso. 2013. “Does Energy Efficiency Reduce Inequalities? Impact of Policies in Residential Sector on Household Budget.” *ECEEE Summer Study*. [https://www.eceee.org/library/conference\\_proceedings/eceee\\_Summer\\_Studies/2013/5a-cutting-the-energy-use-of-buildings-projects-and-technologies/does-energy-efficiency-reduce-inequalities-impact-of-policies-in-residential-sector-on-household-budget/](https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2013/5a-cutting-the-energy-use-of-buildings-projects-and-technologies/does-energy-efficiency-reduce-inequalities-impact-of-policies-in-residential-sector-on-household-budget/).
- Domergue, Silvano, François Chabrol, and Louis-Gaëtan Giraudet. 2021. “Projet Loi Climat et Résilience: Évaluation de l’obligation de Rénovation Des Logements Indécents Du Parc Locatif Privé.” [https://www.ecologie.gouv.fr/sites/default/files/thema\\_essentiel\\_07\\_projet\\_de\\_loi\\_climat\\_et\\_resilience\\_evaluation\\_de\\_l\\_obligation\\_de\\_renovation\\_des\\_logements\\_indecents\\_du\\_parc\\_locatif\\_privé\\_juin2021.pdf](https://www.ecologie.gouv.fr/sites/default/files/thema_essentiel_07_projet_de_loi_climat_et_resilience_evaluation_de_l_obligation_de_renovation_des_logements_indecents_du_parc_locatif_privé_juin2021.pdf).
- Effinergie, and ADEME. 2021. “Les Maisons Renovés à Basse Consommation, L’Observatoire BBC.” [https://www.effinergie.org/web/images/attach/base\\_doc/2912/20210429etude-renovation.pdf](https://www.effinergie.org/web/images/attach/base_doc/2912/20210429etude-renovation.pdf).
- Enertech, Effinergie, Médiéco, and Institut négaWatt. 2021. “Perf in Mind.” [https://www.effinergie.org/web/images/Page\\_PerfinMind/2020118\\_Synth%C3%A8se\\_et\\_r%C3%A9sum%C3%A9\\_1\\_pagev2\\_compressed.pdf](https://www.effinergie.org/web/images/Page_PerfinMind/2020118_Synth%C3%A8se_et_r%C3%A9sum%C3%A9_1_pagev2_compressed.pdf).
- Eryzhenskiy, Ilya, Louis-Gaëtan Giraudet, Mariona Segú, and Maryam Dastgerdi. 2022. “Zero-Interest Green Loans and Home Energy Retrofits: Evidence from France.” <https://doi.org/10/document>.
- Ezratty, Véronique, David Ormandy, Marie-Hélène Laurent, Fabienne Boutière, Anne Duburcq, Laurene Courouve, and Pierre-André Cabanes. 2018. “Assessment of the Health-Related Costs and Benefits of Upgrading Energy Efficiency in French Housing.” *Environnement, Risques & Santé* 17 (4): 401–10. <https://doi.org/10.1684/ers.2018.1200>.
- Gillingham, Kenneth, Richard G. Newell, and Karen Palmer. 2009. “Energy Efficiency Economics and Policy.” *Annual Review of Resource Economics* 1 (1): 597–620. <https://doi.org/10.1146/annurev.resource.102308.124234>.
- Giraudet, Louis-Gaëtan, Cyril Bourgeois, and Philippe Quirion. 2021. “Policies for Low-Carbon and Affordable Home Heating: A French Outlook.” *Energy Policy* 151 (April): 112140. <https://doi.org/10.1016/j.enpol.2021.112140>.
- IGF, and CGDD. 2017. “Aides à La Rénovation Énergétique Des Logements Privés.” <https://www.igf.finances.gouv.fr/files/live/sites/igf/files/contributed/IGF%20internet/2.RapportsPublics/2017/2016-M-114.pdf>.
- INSEE. 2017. “Les Conditions de Logement En France.” <https://www.insee.fr/fr/statistiques/2586377>.
- Merly-Alpa, Thomas, Nicolas Riedinger, and Mathieu Baudry. 2020. “Le parc de logements par classe de consommation énergétique.” SDES. <https://www.statistiques.developpement-durable.gouv.fr/le-parc-de-logements-par-classe-de-consommation-energetique>.
- Ministère de la Transition écologique. 2013. “Enquête Performance de l’Habitat, Équipements, Besoins et Usages de l’énergie (Phébus).” <https://www.statistiques.developpement-durable.gouv.fr/enquete-performance-de-lhabitat-equipements-besoins-et-usages-de-lenergie-phebus>.

- . 2020. “Enquête Sur Les Travaux de Rénovation Énergétique Dans Les Maisons Individuelles (TREMI).” <https://www.statistiques.developpement-durable.gouv.fr/enquete-sur-les-travaux-de-renovation-energetique-dans-les-maisons-indivuelles-tremi>.
- . 2021a. “Synthèse Du Scénario ‘Avec Mesures Existantes’ 2021 (AME 2021).” [https://www.ecologie.gouv.fr/sites/default/files/Synth%C3%A8se\\_du\\_sc%C3%A9nario\\_AME2021\\_postQAQC%5B1%5D.pdf](https://www.ecologie.gouv.fr/sites/default/files/Synth%C3%A8se_du_sc%C3%A9nario_AME2021_postQAQC%5B1%5D.pdf).
- . 2021b. “Ambition Climatique et Rénovation Performante Pour 2028 et 2050.” <https://www.ecologie.gouv.fr/sites/default/files/Note%20r%C3%A9novations%20secteur%20r%C3%A9sidentiel%202028-2050-v1.3.pdf>.
- Nauleau, Marie-Laure. 2014. “Free-Riding on Tax Credits for Home Insulation in France: An Econometric Assessment Using Panel Data.” *Energy Economics* 46 (November): 78–92. <https://doi.org/10.1016/j.eneco.2014.08.011>.
- Quinet, Alain. 2019. “La valeur de l’action pour le climat.”
- Risch, A. 2020. “Are Environmental Fiscal Incentives Effective in Inducing Energy-Saving Renovations? An Econometric Evaluation of the French Energy Tax Credit.” *Energy Economics* 90. <https://doi.org/10.1016/j.eneco.2020.104831>.
- Stolyarova, Elena, Hélène Le Cadre, Dominique Osso, Benoit Allibe, and Nadia Maïzi. 2015. “Residential Space Heating Determinants and Supply-Side Restrictions: Discrete Choice Approach.” <https://hal.archives-ouvertes.fr/hal-01113230>.