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Long-term efficiency and distributional impacts of energy saving policies in the French residential sector

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First draft – Comments welcome

Using an energy-economy model that integrates behavioural and technological detail, we evaluate the impact of key policies – energy efficiency subsidies (tax credits, zero-interest loans, reduced VAT, white certificates), the carbon tax and building codes – on residential energy demand for space heating in France. We find that the carbon tax is the most effective, yet most regressive, instrument. Taking into account all possible interactions among instruments, we find that they imply on average a 10% variation in policy effectiveness. Subsidies save energy at a cost of 0.05-0.08 euro per lifetime discounted kilowatt-hour, with a leverage of 0.9 to 1.4 in 2015, decreasing over time as the potential for energy-saving opportunities is being exhausted. Targeting subsidies towards low-income households, who tend to live in energy inefficient dwellings, increases leverage, thus reconciling economic efficiency and equity. The public cost of subsidies – 3 billion euros in 2013 – is outweighed by carbon tax receipts from 2025 onwards. Meeting the long-term energy saving targets set by the French Government however requires increasing subsidy rates and maintaining them through 2050. In particular, an order-of-magnitude discrepancy between simulated and observed numbers of zero-interest loans points to cognitive or strategic barriers that need to be removed to increase policy effectiveness.

Keywords: residential buildings, space heating, energy-economy modelling, energy efficiency subsidies, carbon tax, fuel poverty

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1 Introduction

Saving energy in the building sector is set as a priority in many of the nationally-determined contributions submitted by EU member states to comply with the Paris Agreement. A general pattern of ambitious energy saving targets, coupled with numerous instruments meant to fulfil them, can be observed across the EU. Do existing policies deliver? Are they economically efficient? Do they equally affect households with differing socio-economic characteristics? We examine these questions in a modelling exercise applied to France, the EU's second largest economy.

Since its inception in the 1970s, France's energy policy in the residential sector has been multifaceted. It mainly consisted in early decades in regulatory measures, essentially daylight saving time and regularly tightened building codes. In the second half of the 2000s, these measures were complemented with energy efficiency subsidy programmes – income tax credits (ITC) and reduced value-added tax (VAT) in 2005, white certificate obligations (WCO) in 2006 and zero-interest loans (ZIL) in 2009. In 2009, the Grenelle de l'environnement, a wide public consultation on energy and climate issues, led the Sarkozy administration to set a number of energy saving targets in the residential sector. These were recently revised by the Hollande administration within a broader framework called the Stratégie Nationale Bas-Carbone underpinning France's nationally-determined contribution. Meanwhile, a carbon tax (CAT) was implemented in 2014 and tightened building codes (BCO) are envisaged for 2020. The following targets now apply to residential buildings:

- Target 1: reduce energy use by 20% by 2030 and 50% by 2050, as compared to 2012 levels.
- Target 2: renovate 500,000 dwellings every year, including 120,000 in social housing.
- Target 3: eliminate the most inefficient dwellings – those with energy performance certificate (EPC) labels G and F – by 2025.
- Target 4: bring the whole dwelling stock to a minimum performance equivalent to EPC label B by 2050.
- Target 5: reduce fuel poverty by 15% by 2020.

In this paper, we assess how well key policies perform against these targets. We focus on actual incentives with the broadest coverage – ITC, VAT, WCO, ZIL and CAT. In addition, we embody the building code of 2012 in our reference scenario and simulate the tighter code envisaged for 2020. In turn, we disregard some important policies that either have a restricted eligibility – subsidies targeting low-income households – or cannot easily be modelled – information campaigns. We assess the impact of the policies considered on energy use for space heating in partial equilibrium. As residential buildings contribute 26% of final energy demand, of which 67% is dedicated to space heating, this scope covers 18% of final energy demand in France. We use Res-IRF, an energy-economy model that integrates behavioural and technological detail (Giraudet et al., 2012; Branger et al., 2015). The model has been used in previous policy assessments (Giraudet et al., 2011; Mathy et al., 2015). In this paper, we use a new version of the model parameterized with better data made available by the recent Phébus¹ survey. These new data have enabled us to segment household characteristics by income levels. Taken together,

¹ <http://www.statistiques.developpement-durable.gouv.fr/sources-methodes/enquete-nomenclature/1541/0/enquete-performance-lhabitat-equipements-besoins-usages.html>

these improvements permit a more comprehensive evaluation of policies; while previously limited to the effectiveness criterion, we are now capable of computing efficiency indices – cost-effectiveness and leverage – and examine distributional impacts. This provides a finer picture of the respective merits of each instrument.

We find that fulfilment of the different targets requires policies be set at their most ambitious level and maintained until 2050. In particular, subsidy programmes should be extended to better include rented dwellings. Even though target fulfilment commands as few restrictions as possible, eligibility could be restricted to most energy efficient measures and/or low-income households were budget constraints to bind. Such a targeting would improve economic efficiency while alleviating fuel poverty. Budget constraints are only likely to bind in the short term, however, as carbon tax revenues exceed subsidy payments by 2025. The carbon tax is the most effective, yet most regressive, instrument. Subsidies save energy at a cost of 0.05 to 0.08 euro per kilowatt-hour saved, and with a leverage of 0.9 to 1.4, an order of magnitude consistent with that of other public subsidies evaluated in France. The income tax credit is the most effective, yet least efficient, subsidy. The model accurately replicates recent estimates of ex post policy effects, except for the zero-interest loan programme, which it over-estimates by an order of magnitude. Policy interactions are mild, as they typically induce a 10% variation in an instrument's effectiveness.

Beyond the specific case of France, our modelling exercise sheds light on general economic issues. First, we examine the trade-offs between economic efficiency and fuel poverty alleviation. The win-win outcome we highlight is driven by the correlation found in the data between households' income and the efficiency of the dwellings they inhabit – a pattern arguably quite general to EU member states. Second, the discrepancy between simulated and observed numbers of ZILs suggests that some important yet little understood barriers hinder participation in this programme. As the instrument has counterparts in other EU member states, notably in Germany, this points to the need for further applied microeconomic work seeking to identify these barriers.

The remaining of this paper is organized as follows. Section 2 provides an overview of the Res-IRF model, emphasizing its latest developments. Section 3 proposes an evaluation method and details policy specifications. Section 4 presents the results. Section 5 discusses policy implications and concludes.

2 The Res-IRF 3.0 model in a nutshell

Res-IRF is a model of residential demand for space heating in France. Its most innovative aspect is to integrate a detailed description of the energy performance of the building stock with a rich description of household behaviours. Res-IRF has been developed to improve the behavioural realism that integrated models of energy demand typically lack (Mundaca et al., 2010, McCollum et al., 2017). Specifically, it incorporates a number of market barriers at the source of the so-called 'energy-efficiency gap' – the discrepancy between observed energy-efficiency levels and those predicted by engineering studies (Jaffe and Stavins, 1994; Allcott and Greenstone, 2012). These include landlord-tenant information asymmetries, technology adoption spillovers, and heterogeneity of preferences for heating services and

non-energy attributes. The latest developments of Res-IRF, version 3.0, incorporate a disaggregation of households by income category.

2.1 Structure and data

The model is fully described in Giraudet et al. (2012) and Branger et al. (2015). The latest version is detailed in Giraudet et al. (forthcoming). The section below provides an overview of key processes and details those developments that were not included in already published references.

The dwelling stock is parameterized with the Phébus survey that elicits the socio-economic characteristics of households and the energy efficiency of the dwellings they inhabit. The dwellings considered are main residences in continental France, which contain 23.9 million dwellings. The dwelling stock is segmented in 1,080 categories, split as follows:

- Nine categories of energy performance, corresponding to labels A to G of the French energy performance certificate (EPC) in dwellings built before 2012 (Figure 1), and labels 'low energy' and 'net zero energy' in dwellings built after 2012. 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 (altogether covering 91% of energy demand for space heating).
- 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, respectively weighing 61%, 24% and 15% of dwellings.
- Five levels of income for both owners and occupiers, closely aligned with the income quintiles of the French population given by INSEE (Figure 2).

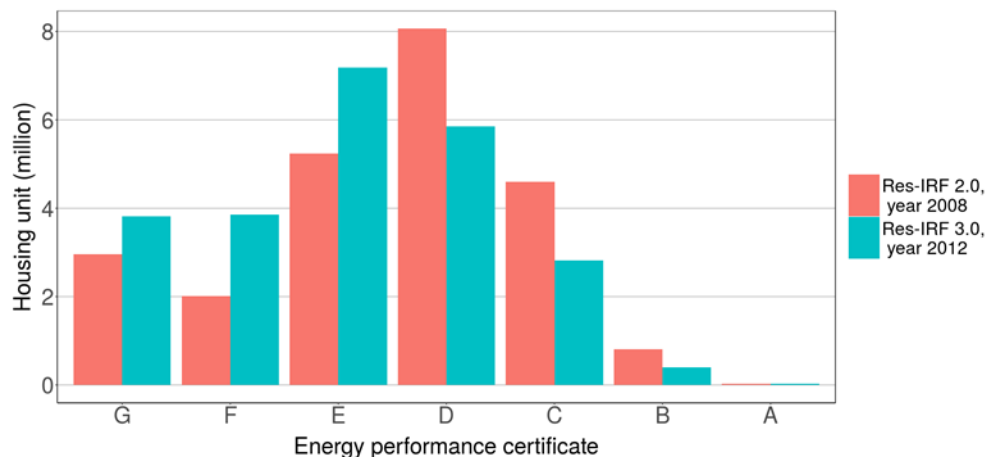


Figure 1: Distribution of energy performance in the dwelling stock

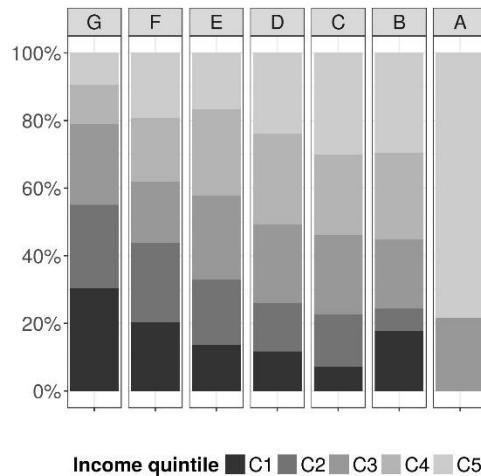


Figure 2: Distribution of income quintiles in EPC labels

The model is fed by three exogenous inputs: population, total income, and energy prices. These variables determine improvements in energy efficiency through new constructions, the renovation and existing dwellings, and the intensity with which occupants heat their dwelling.

2.1.1 Construction of new dwellings

The construction of new dwellings is determined by:

- An exogenous population projection, which determines the annual housing needs. Our reference scenario is based on a widely-used projection (INSEE, 2006) that can be summarized into an average annual growth rate of 0.3%.
- An exogenous household income projection, which determines the average square footage per capita. This, combined with the above projection of dwelling numbers, determines the total square footage needed. We assume that income grows at a constant annual rate of 1.2%, in line with recent trends.
- Part of these housing needs are met by existing dwellings – that is, dwellings built before 2012 – the stock of which however erodes at a constant annual rate of 0.35%.

New constructions are thus determined each year as total housing needs less the remaining stock of existing dwellings. The specification detailed above results in a cumulative stock of pre-2012 dwellings contributing 66% of the total surface and 75% of the total number of dwellings in 2050.

The energy efficiency and main heating fuel of each new dwelling are jointly determined by discrete choice functions allocating market shares to each option according to its life cycle cost, discounted at 7% over 35 years. Table 1 details the construction cost of each option².

² Construction costs at the net zero energy level is higher for electricity-heated dwellings than for those heated with other fuels, as the former require a heat pump.

Table 1: Construction costs, in €/m²

	Single-family units		Multi-family units	
	Low energy	Net zero energy	Low energy	Net zero energy
Electricity	979	1,112	1,199	1,308
Natural gas	1,032	1,059	1,242	1,253
Fuel oil	1,032	1,059	1,242	1,253
Fuel wood	1,094	1,121	1,323	1,350

2.1.2 Renovation decisions

Renovation decisions are made by homeowners – owner-occupiers, landlords and social housing providers. For of a dwelling labelled i , they proceed along two margins:

- Intensive margin: selection of one final label f among higher labels $\{i+1, \dots, A\}$. This process is similar to that of new constructions, in that the market share of each option is determined by a discrete-choice function based on the life-cycle cost of each option. It is however more detailed in four respects. First, heterogeneous credit constraints are captured by discount rates decreasing with income (Table 2). Second, frictions inherent in collective decision-making are captured by higher discount rates in multi-family units, as compared to those applied to single-family units (Table 2). Third, under-capitalization of energy savings in rents are captured by a short investment horizon of three years in rented dwellings, as opposed to 30 years in owner-occupied dwellings and social housing.³ Fourth, residuals are calibrated by confronting the model to observed upgrade patterns; these residuals are interpreted as intangible costs, capturing, for instance, the inconvenience caused by renovation works.
- 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 tastes and habits. It is calibrated against a renovation target of 3% of existing dwellings in 2012.

Life-cycle cost calculations rely on renovation cost data that are inherently difficult to obtain. Indeed, our representation of energy efficiency improvements through EPC label upgrades, rather than explicit measures on the envelope and the heating system, requires some data post-treatment that is not readily available. We therefore create a cost matrix in which part of the data is based on observations while the remaining is interpolated according to two standard economic rules: the marginal cost of energy efficiency is increasing; economies of scale make it cheaper to perform a given upgrade at once rather than sequentially. The resulting matrix, displayed in Table 3, has an average cost of 8 euros per lifetime discounted kilowatt-hour saved.

³ At least in the residential market, the phenomenon is more pregnant than under-capitalization in property value (Giraudet, 2018).

Table 2: Discount rates, by decision-maker and type of housing

Income quintile	Single-family units	Multi-family units	Social housing
C1	15%	37%	4%
C2	10%	25%	4%
C3	7%	15%	4%
C4	5%	7%	4%
C5	4%	5%	4%
Weighted average	8%	17%	4%

Table 3: Renovation costs, in €/m²

		Initial label					
		F	E	D	C	B	A
Final label	G	76	136	201	271	351	442
	F		63	130	204	287	382
	E			70	146	232	331
	D				79	169	271
	C					93	199
	B						110
	A						

Both construction and renovation costs are subject to endogenous decrease through learning-by-doing functions parameterized with learning rates of 25% and 10%, respectively.

2.1.3 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 (Figure 3), borrowed from Cayla and Osso (2013). While the previous version of the model did not factor in income in this relationship, the combination of information on a dwelling’s energy efficiency and its occupants’ income provided by the Phébus survey made this improvement possible. Note that an increase in heating intensity in response to efficiency improvements is interpreted in the model as a rebound effect.

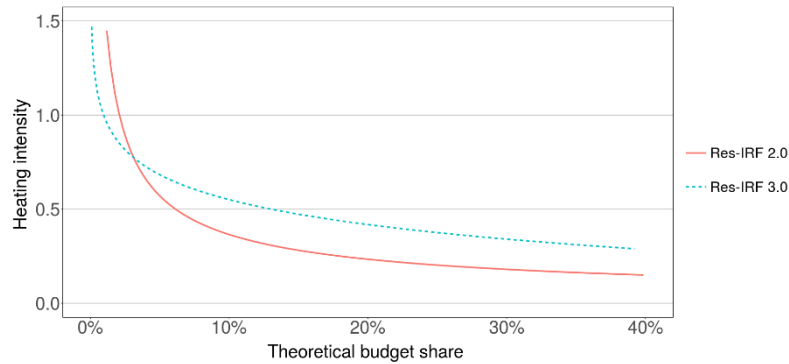


Figure 3: Heating intensity as a function of a household's income share dedicated to heating (source: Cayla and Osso, 2013)

2.2 Accuracy

Global sensitivity analysis of Res-IRF 2.0 has revealed that the model outputs were most influenced by three variables: the energy price input, the parameters of the heating intensity function and the renovation rate against which the model is calibrated (Branger et al., 2015). Since then, the accuracy with which the model replicates key trends and statistics documented in the residential sector has been examined in several exercises. One consisted in estimating the price-elasticity of energy demand over a range of 160 model runs fed by differing energy price scenarios. The exercise produced a short-term elasticity of -0.2 and a long-term elasticity of -0.4, which are both closely in line with previous estimates for France (Giraudet et al., forthcoming). Another exercise consisted in examining how well the model replicates past trends of residential energy demand for heating (Glotin, 2018). As Phébus was the first ever survey of its type, no description of the energy efficiency of the French dwelling stock is available for any year prior to 2012. Retrospective simulations therefore required extensive data collection to reconstruct the characteristics of the dwelling stock with which to initiate the model at an early year. Simulations over a wide range of scenarios covering multiple sources of uncertainty in dwelling stock characteristics revealed that the model replicates energy demand for the 1984-2012 period with a mean of absolute percentage errors of 3.7%. Altogether, these analyses suggest that the model accurately replicates key statistics and past trends and therefore provides a credible tool for long-term projections.

3 Evaluation method

3.1 Reference scenario

As stated earlier, the model is fed with the following inputs: population, growing at 0.3% p.a.; total household income, growing at 1.2% p.a.; and energy prices growing according to a scenario borrowed from French authorities (ADEME and DGEC). Price evolutions are equivalent to average annual growth rates of 1.4% for natural gas, 2.2% for fuel oil, 1.1% for electricity and 1.2% for fuel wood. In the reference scenario, the price index grows at an average annual rate of 1.1%, mostly driven by a slower decrease in electricity consumption than in that of other fuels (Figure 4).

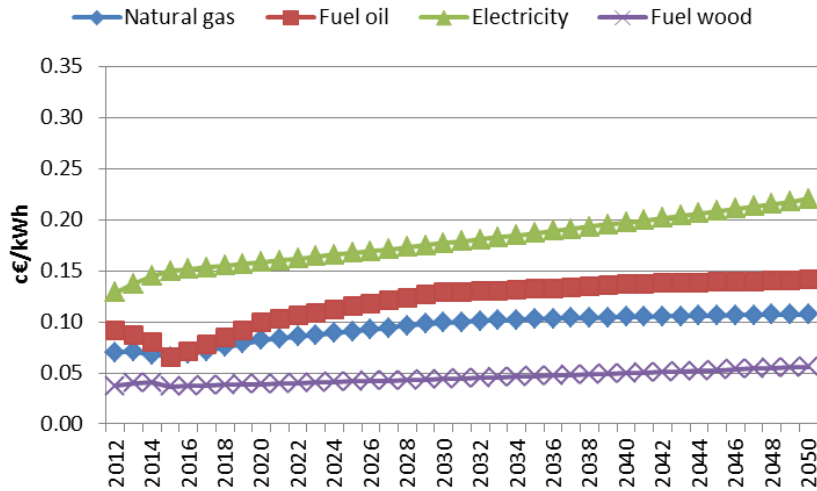


Figure 4: Time profiles of energy prices in the reference scenario

3.2 Policy specifications

We examine key policies implemented in the residential sector, concentrating on those policies with the broadest coverage. For each policy, we consider two cases: the reference variant and a tighter one, labelled ‘+.’ Key policy parameters are summarized in Table 4.

Table 4: Summary of key policy parameters

	Reference variant (AP)	Tighter variant (AP+)
ITC	Subsidy with uniform rate of 17%	Subsidy with 17% rate targeting high performance
ZIL	Subsidy targeting high performance, rate~9% of investment cost	Subsidy targeting high performance, rate~23% of investment cost
WCO	Subsidy of 5€/MWh lifet.disc. in 2017 (doubled for C1 households), later +2% p.a., + fee on energy sales	Subsidy of 15€/MWh lifet.disc. in 2017 (doubled for C1 households), later +2% p.a., + fee on energy sales
CAT	Myopically expected tax	Perfectly expected tax
VAT	5.5% instead of 10%	
BCO	Net zero energy level mandatory for new constructions in 2020	

3.2.1 Carbon tax (CAT)

The carbon tax has been implemented in France since 2014 with a pre-defined time profile (Table 5). It applies in the model to fuel oil and natural gas,⁴ with respective carbon contents of 271 and 206 gCO₂/kWh. The latter decreases from 2020 onwards at 1% p.a. to take into account decarbonisation targets set by the Government, supposed to be met by biomass. The carbon tax is subject to a 20% VAT. As tax revenue recycling is not specified in practice, we do not make any assumption in that regard.

Table 5: Carbon tax, in euros per ton of CO₂-equivalent (excluding VAT)

2014	2015	2016	2017	2018	2019	2020	2020-30	2030-50
7€	14.5€	22€	30.5€	39€	47.5€	56€	+6% p.a., 100€ in 2030	+4% p.a.

⁴ No carbon fee is levied on final electricity use, based on the premise that power generation is already covered by the EU ETS.

In the reference variant, the carbon tax is, just like the price of energy, myopically expected. In the CAT+ variant, in contrast, it is perfectly expected. The two scenarios are meant to provide two bounds of the behaviour of decision-makers. Note that these variants only affect investment decisions, but not utilization behaviour, which anyway relies on contemporaneous price signals.

3.2.2 Zero-interest loan (ZIL)

The ZIL programme has been implemented since 2009. It allows households to borrow money at zero-interest rate (but possibly with some fees) from any credit institution in order to invest in home energy retrofit. The lending institution in turn receives a compensatory payment from the Government. The programme does not impose restrictions on the socio-economic characteristics of borrowers, but does impose restrictions on the measures undertaken, which need to comply with certain performance requirements. We interpret these as a threshold set at label D (191 kWh/m²/year) for upgrades from labels G to E and a threshold set at label B (76 kWh/m²/year) for upgrades from labels D and C.

The instrument is modelled as a subsidy equal to the interest payments the borrower would be charged for a conventional unsecured loan of the same amount and duration. The ‘reference’ variant incorporates a range of restrictions based on key statistics provided by SGFGAS, the authority supervising the programme. These restrictions force the instrument to operate as close to reality as possible. They are all removed in the ‘ZIL+’ variant, which is meant to gauge the full potential of the instrument. When expressed in ad valorem terms, the ZIL variant has an average rate of 9% and the ZIL+ variant a 23% rate. The main differences between the two scenarios are outlined in Table 6.

Table 6: Parameters of the ZIL variants

	ZIL	ZIL+
Counterfactual interest rate	3% (OPEN)	4%
Loan duration	5 years (OPEN)	10 years
Borrowing ceiling	21,000 € for C5 ... 16,800€ for C1 (SFGAS)	60,000€
Performance targeting	Yes	Yes
<i>Equivalent subsidy rate</i>	<i>9%</i>	<i>23%</i>

3.2.3 Income tax credit (ITC)

The ITC programme has been implemented since 2005 (Nauleau, 2015). It grants deductions on income tax for investments in home energy retrofit. Eligible measures and subsidy rates are updated on an annual basis. The latest regime in order has a flat ad valorem rate of 30%. Eligibility applies to installation costs for insulation measures, but is otherwise restricted to equipment cost.

We model the instrument as a 17% rate subsidy applied to the full cost of a measure, which implicitly includes both equipment and installation. This value corresponds to the average rate faced by households in practice (OPEN, 2016). In the reference scenario, the same rate is applied to all measures; in the ITC+ scenario, the restrictions of the ZIL on high performance apply.

3.2.4 White certificate obligations (WCO)

White certificate obligations have been implemented in France since 2006 (Giraudet and Finon, 2015). The programme imposes energy saving obligations on energy suppliers, which they can fulfil either by sponsoring energy efficiency measures undertaken by their customers or by purchasing energy savings from another obliged party that exceeded its target. Either way, tradable energy savings are certified by pre-agreed calculations of lifetime discounted savings – the so-called white certificates. Energy suppliers can, to different extents depending on regulations specific to the fuel market in which they operate, recoup compliance cost by increasing their retail prices.

The programme covers all energy end-uses that are not subject to the EU ETS, with perfect fungibility of energy savings across sectors. For instance, a gasoline retailer can comply with its obligation by sponsoring energy saving measures in the building sector, the cost of which it will recoup through a fee levied on gasoline prices. There is therefore no constraint equating compliance cost with extra-revenue from energy sales within a given sector. Likewise, the market for white certificates is supplied with measures from different sectors. In theory, the market price should reflect the marginal cost of the most expensive sector. In practice, according to most observers, the market price has rather been driven by speculation over future targets on the one hand, banking of energy savings for compliance in future periods on the other. Short-term market fluctuations are therefore plausibly disconnected from the marginal cost of energy saving measures.

For this reason, modelling the impact of the instrument in the residential buildings requires important simplifications. Accordingly, we model the instrument as a hybrid tax-subsidy mechanism as follows:

- The subsidy component is proportional to the energy savings generated by a given upgrade, discounted at 4% over 15 years. The proportionality is given by the price of white certificates.
- The fee component is given by obligation coefficients (in kWh lifetime discounted to save per kWh sold) multiplied by the price of white certificates. The profile of obligation coefficients follows that set by the Government from 2012 to 2020; we increase the 2020 coefficients at 1% p.a. in subsequent years. A VAT of 20% is applied on these fees.

The price of white certificates is set at 4€ per lifetime discounted MWh from 2012 to 2015. It diverges in 2016 in the two scenarios – 5€ in WCO and 15€ in the WCO+. In subsequent years, in both scenarios, the price increases at an annual rate of 2% and is capped at 20 € per lifetime discounted MWh. Expressed in ad valorem terms against the renovation costs of Table 3, and valued at 4€ per lifetime discounted MWh over 15 years, the subsidy component exhibits a decreasing regime (Table 7). Weighted by the upgrades observed in 2012, the average rate is 5%.

Table 7: Equivalent ad valorem rates of the subsidy component of WCO

	F	E	D	C	B	A
G	11%	10%	8%	7%	6%	5%
F		8%	6%	5%	4%	3%
E			5%	4%	3%	2%
D				3%	2%	2%
C					2%	1%
B						1%

3.2.5 Reduced VAT (VAT)

Renovation measures are subject to a reduced VAT rate of 5.5%, instead of the normal rate of 10% which applies in the building sector. This assumption is embodied in our cost matrix.

3.2.6 Building code (BCO)

The low-energy level is mandatory for new constructions since 2012. This assumption is embodied in our reference scenario. The Government has announced that building codes would mandate every new construction to meet the net zero energy requirement in 2020. This policy option is activated in our reference scenario.

3.3 Evaluation criteria

Four key scenarios are run:

- AP (standing for ‘all policies’), which incorporates all policies in their reference variant. This is the scenario against which the model is calibrated.
- AP+, which incorporates all policies in their ‘+’ variant.
- ZP (standing for ‘zero policy’), in which all policies are removed.
- AP-LTD, in which the so-called landlord-tenant dilemma is removed. This is modelled by aligning landlord’s behaviour (captured by investment horizon) with that of owner-occupiers.

Subsidies are not mutually exclusive and can all be claimed at the same time. We additionally make the strong assumption that all subsidies to which a household or a measure is eligible are effectively claimed by the investor.

3.3.1 Choice of counterfactual

Given that multiple policies are combined, a variety of counterfactual can be thought of against which to evaluate the impact each policy. Two polar cases bound the impact of a given instrument. On the one hand, the reference scenario that includes all policies (AP) can be compared to a scenario including all instruments but one. This method, which we refer to as ‘AP-1,’ provides an assessment of the impact of the missing instrument in interaction with all others instruments. On the other hand, a scenario in which all policies have been removed (ZP) can be compared to the same scenario, only augmented with one policy. This method, which we refer to as ‘ZP+1,’ provides an assessment of the pure impact of the instrument, immune from interactions with other instruments. In between these two methods, a range of comparisons can be made between scenarios AP-k and AP-(k+1) (or, equivalently, between ZP+k and

ZP+k+1) which quantify the interaction of the (k+1)-th instrument with k others. Considering all possible combinations, 64 scenarios can be run (including AP and ZP) and the impact of each instrument can be assessed in 32 different ways.

3.3.2 Cost-effectiveness

We measure the cost-effectiveness of an instrument at a given year as the ratio between the relevant cost – subsidy payments or tax receipts – of the instrument that year and the lifetime discounted energy savings it generated, assessed by comparing a scenario with the instrument (and possibly others) to one in which the instrument is removed that year (but maintained in all previous years). We compute two variants of that indicator which respectively factor in predicted and realized energy savings at the denominator. In both cases, energy savings are discounted at 4% over 26 years, the typical lifetime of energy efficiency investments. Comparing the two metrics generates insights into rebound effects.

3.3.3 Leverage

We measure leverage as the ratio relevant cost of an instrument and the extra renovation expenditures it induces, here again assessed by comparing two scenarios with and without the instrument in place that year (but in both cases present in all previous years). So defined, our leverage indicator aggregates effects on the intensive and extensive margins of investment.

High leverage and low cost-effectiveness both reflect high efficiency. They however capture slightly different phenomena, as energy savings being marginally decreasing while marginal costs are marginally increasing.

3.3.4 Fuel poverty

Fuel poverty can be assessed in many different ways. Here we retain the commonly used energy to income ratio (EIR) index, which collects the number of households that allocate more than 10% of their income to heating expenditures. In 2012, 2.7 million households fall in this category.

4 Results

4.1 Effectiveness to targets

Figure 5 displays final energy use under the four main scenarios. Actual energy use is reduced by 18% in 2020 and 45% by 2050 with all policies (AP), as compared to 2012. This slightly falls short of Target 1. The target is met with policies either set at more ambitious levels (AP+) or redesigned so as to overcome the landlord-tenant dilemma (AP-LTD). One caveat is in order. Recall that Target 1 applies to all end-uses. Envisaged in the specific context of residential energy use for space heating, which is already declining at 1% p.a., the most pronounced rate of all end-uses (ADEME, 2015), it appears as a relatively modest target. Comparing scenarios AP and ZP suggests that the bulk of energy savings is due to autonomous progress driven by increasing energy prices and the building code of 2012. Policies account for about one third of energy savings. Looking at each fuel separately, we see that most reductions come from fossil fuels – natural gas, and, to a lesser extent, fuel oil. Heating intensity increases over the period by about 20% in ZP and AP scenarios (Figure 6). This can be interpreted as a 20% rebound effect.

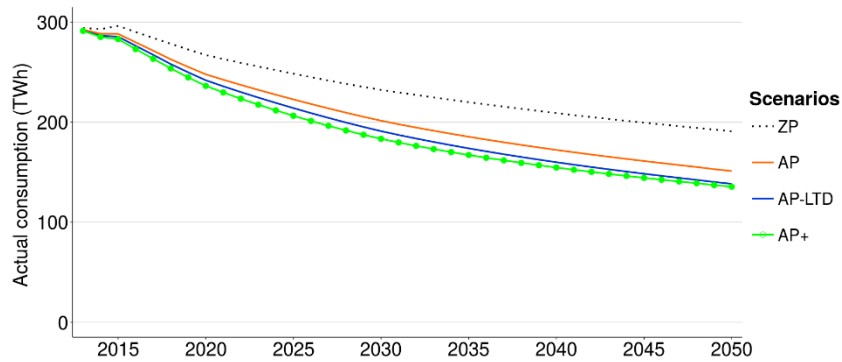


Figure 5: Final energy use

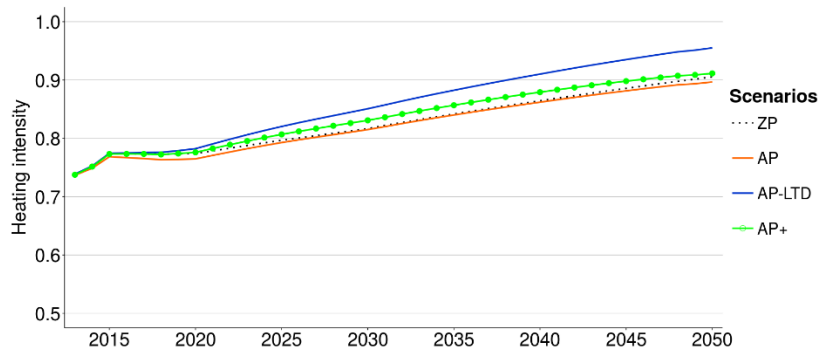


Figure 6: Heating intensity

The number of retrofits is displayed in Figure 7. It reaches 687,000 in 2012, of which 115,000 can be attributed to policies. At first sight, Target 2 is over-shot, even in the absence of any policy. Two caveats are however in order. First, we count as retrofits any upgrade by at least one energy label. Against this, no proper definition has been given by the Government as to what measure should be counted as a retrofit. Absent such a definition, our comparison bears little relevance. Second, we find that social housing contributes about 40,000 retrofits, hence 6% of total retrofits, whereas Target 2 would command 24%. Appraisal of Target 2 is therefore little conclusive. Anyway, retrofit numbers increase in the AP+ scenario and even further in the AP-LTD scenario. Given that these two scenarios produce very close demand reductions (cf. Figure 5), this illustrates that the AP scenario operates mainly on the intensive margin of investment – greater upgrades – whereas AP-LTD operates on the extensive margin – more upgrades.

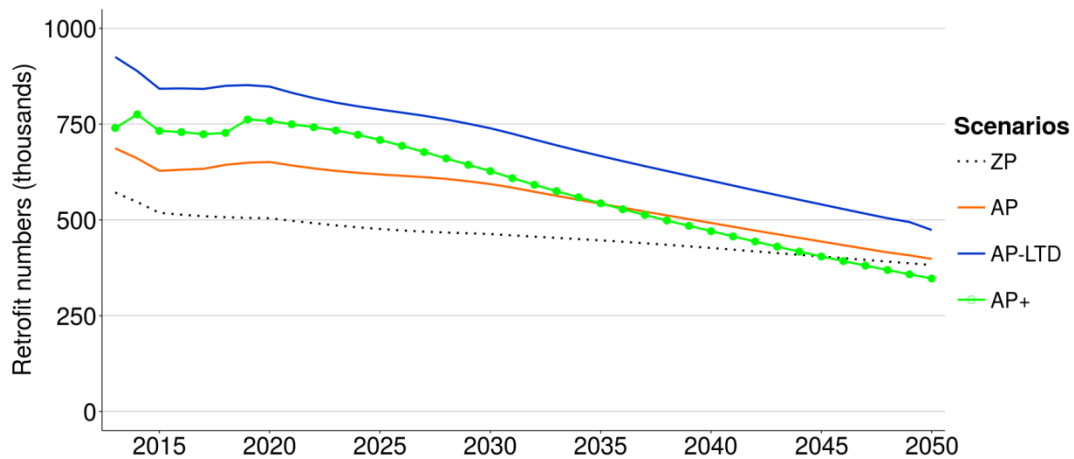


Figure 7: Retrofit numbers

The evolution of the dwelling stock, split by EPC, is displayed in Figure 8. The least energy efficient labels G and F follow a very similar evolution under scenarios ZP, AP and AP+. Their stock sharply declines by 75% by 2025, and more steadily thereafter. Target 3, mandating elimination of these two labels by 2025, therefore seems out of reach. Overcoming the landlord-tenant dilemma (AP-LTD) generates substantially more upgrades of those labels. A quasi-disappearance of them is, however, only achieved by 2040.⁵ At the other end of the performance spectrum, the group of most energy efficient dwellings – labels B and A of the EPC plus low and net zero energy – weighs, depending on the scenario considered, 50% to 70% of the total building stock in 2050. Anyway, these figures miss by a fair margin the 100% target (Target 4).

⁵ The model incorporates, in each EPC label, a constraint that prevents 5% of their 2012 stock to be renovated. These are meant to mimic architectural or urban constraints.

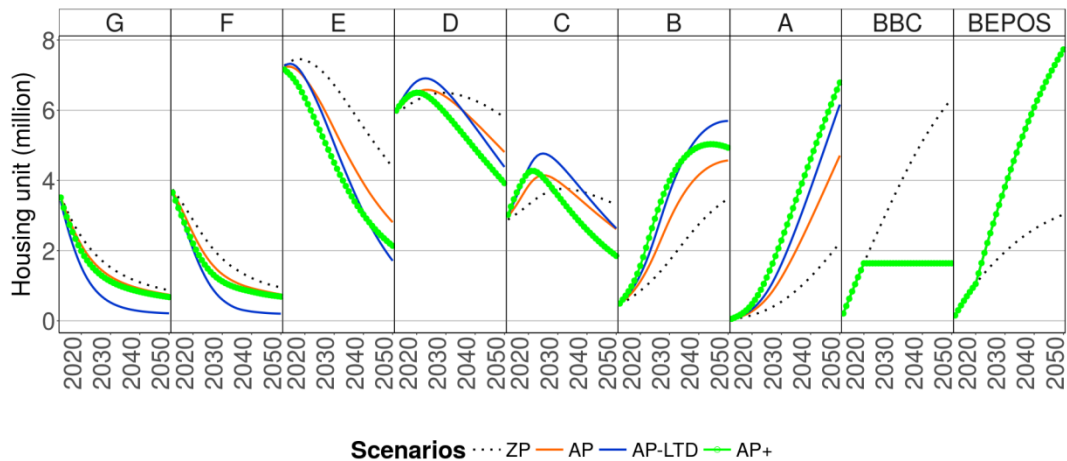


Figure 8: Dwellings split by Energy Performance Certificate

Figure 9 displays the evolution of the EIR index that collects households dedicating more than 10% of their income to heating. Thus measured, fuel poverty recedes by two-third by 2050 in the ZP scenario. The AP scenario slows this process down, with only a 7% reduction by 2020, which falls short of the 15% mark of Target 5. In contrast, AP+ and, to a greater extent, AP-LTD, speed up the process and allow the target to be met. As the EIR index relies on energy expenditures, the key difference it produces between the AP scenario on the one hand and AP+ and AP-LTD on the other is due to more lavish subsidy in the latter.⁶ The slowdown in scenario AP can therefore be attributed to the relatively heavier weight of the carbon tax in the policy mix. This result echoes the well-documented regressive effect of a carbon tax without further specification of revenue recycling (Combet et al., 2010). The effect is offset if accompanying subsidies are set at a sufficiently high rate (AP+), or re-designed to better target rented dwellings (AP-LTD), to the point of almost eliminating fuel poverty by 2050. Besides reductions in fuel poverty, comfort levels, as measured by heating intensities, grow at a similar rate across income categories, though from initial levels strongly correlated with income (Figure 10). This reminds us that fuel poverty alleviation and inequality reduction do not necessarily go hand-in-hand.

⁶ The effect of the carbon tax on energy expenditures is very close in the AP and AP+ scenarios.

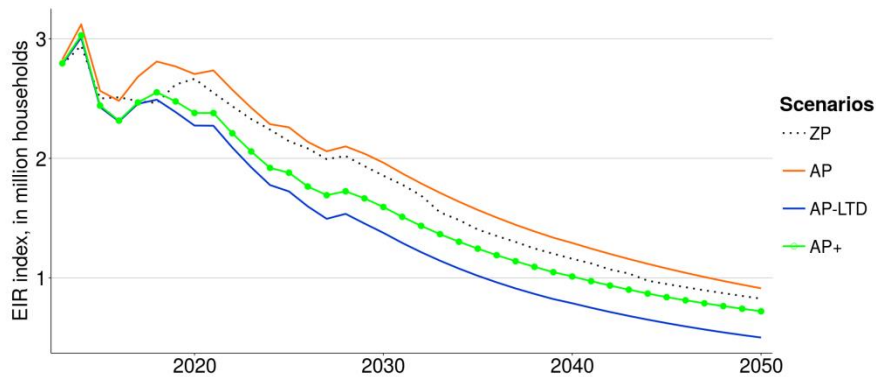


Figure 9: Fuel poverty index

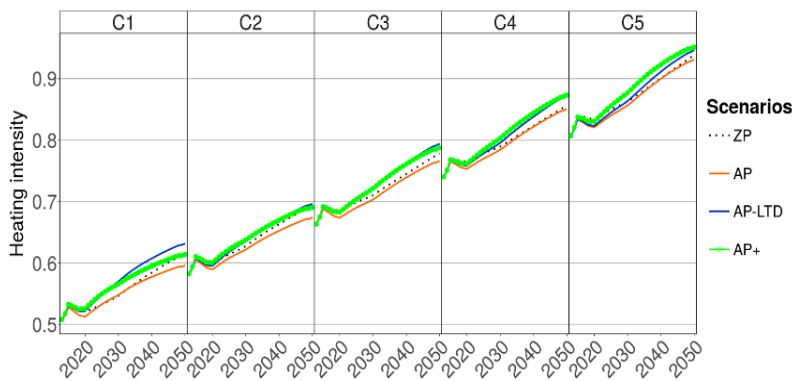


Figure 10: Heating intensity, by income quintile

Overall, our assessment suggests that progressing against targets requires at the very least that instruments be set at their most ambitious levels and maintained until 2050.

4.2 Comparative efficiency

Figure 11 compares energy savings brought about by each instrument over the 32 combinations in which each instrument can be assessed. The figure specifies average savings (the histograms), the standard error and singles out the ‘AP-1’ and ‘ZP+1’ estimates, which bound the effectiveness of the instrument (See Section 3.3.1). The carbon tax appears as the most effective instrument. This performance is primarily due to a combination of two effects: an incentive to renovate coupled with an incentive to reduce energy expenditures after renovation. In contrast, subsidies only operate on the former margin. Moreover, the carbon tax is tightened over time, whereas subsidies (except WCO, which are anyway set at a low level) are maintained at a constant rate. Among subsidies, the ITC has the strongest impact, which is due to its highest rate. The fact that energy savings are systematically larger in the ‘AP-1’ than in the ‘ZP+1’ scenario indicates that interactions are over-additive. The standard errors displayed in Figure

11 capture the interactions of each instrument in all possible combinations with other instruments. Expressed in coefficients of variation in Figure 12, interactions affect the ZIL the most (18% variation) and the carbon tax the least (2% variation). The former results owes to the targeting of the instrument towards high performance, which renders it highly sensitive to accompanying incentives. The latter owes to the fact that the carbon tax is the only instrument affecting yearly energy expenditure. Overall, policy interactions are responsible for a 10% variation in an instrument's effectiveness. As this can be considered fairly low, when evaluating each instrument in the remaining of the analysis, we confine our attention to the results obtained with the 'AP-1' method, which is the most relevant counterfactual.

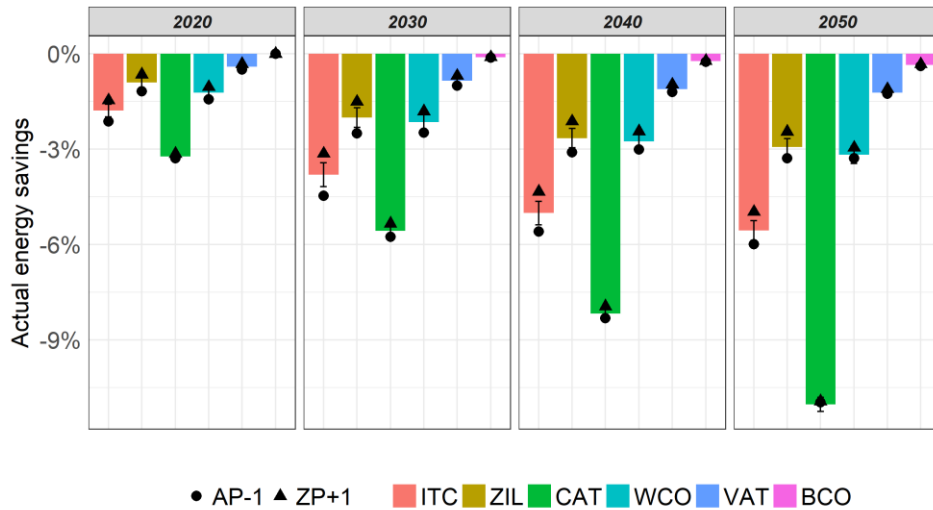


Figure 11: Policy effectiveness

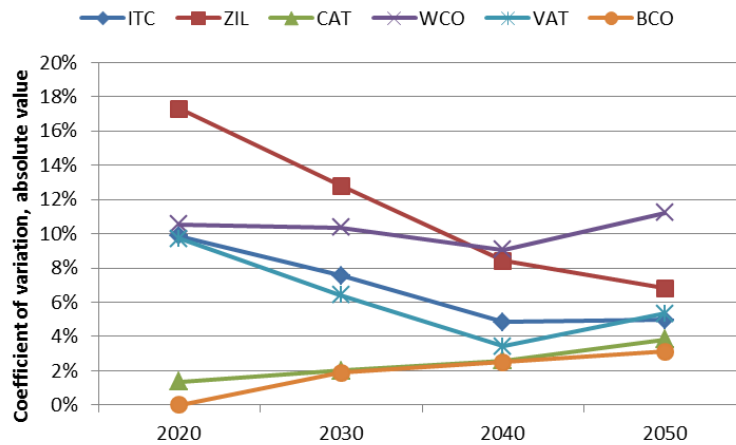


Figure 12: Coefficients of variation of policy effectiveness

Figure 13 compares the simulated costs of public subsidies to those estimated by the French Budget Office in recent years (IGF and CGEDD, 2017). The orders of magnitude of observations versus simulations are consistent regarding the VAT and ITC policies. They differ substantially when it comes to the ZIL programme. The discrepancy is confirmed by an order-of-magnitude difference between the simulated and observed numbers of ZIL: around 400,000 against the average 40,000 recorded between

2013 and 2016 by the authority supervising the programme (SGFGAS). Such a mismatch points to potential barriers that are missing in the model: on the demand side, one can think of cognitive barriers that prevent borrowers from computing interests and expressing them into an equivalent subsidy; on the supply side, one can think of strategic behaviour from credit institutions, which may charge substantial fees for ZILs in order to make their own credit offers more competitive. These barriers are an important area for future applied microeconomic work. Notwithstanding this shortcoming, cost projections suggest that, taking all policies together – both public (CAT, ZIL, ITC, VAT) and private (WCO) – tax receipts will outweigh subsidy payments by 2025 (Figure 14).⁷ This opens room for a better coordination between subsidy regimes and tax-revenue recycling. Net policy costs amount to 3 billion euros in initial year 2012. Meanwhile, total investment in home energy retrofits amounts to 7.5 billion euros in the ZP scenario, 10 billion in the AP scenario and 12.5 billion in both AP+ and AP-LTD scenarios.

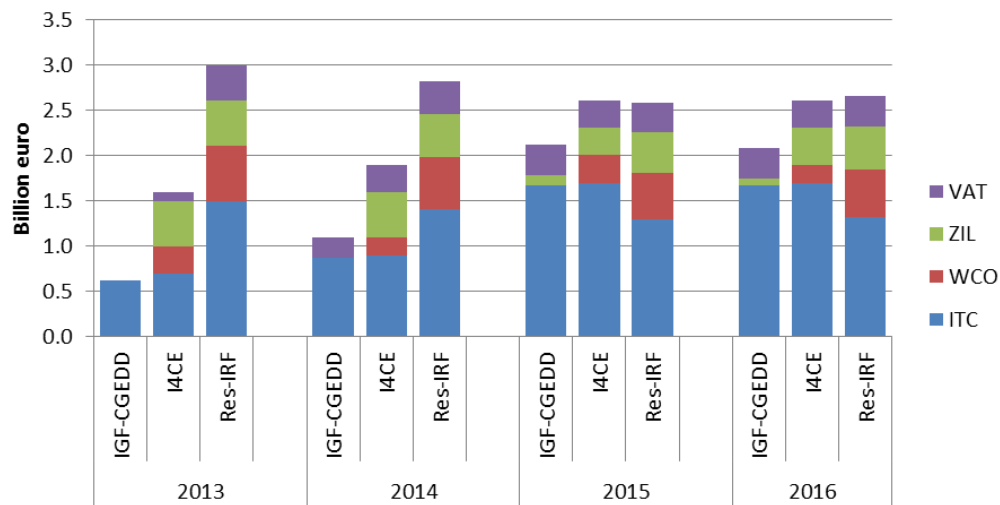


Figure 13: Simulated versus observed cost of the main subsidy programmes

⁷ We do not include building codes in the analysis, for they do not raise any direct public cost, though they obviously raise welfare costs which are not quantified in the model.

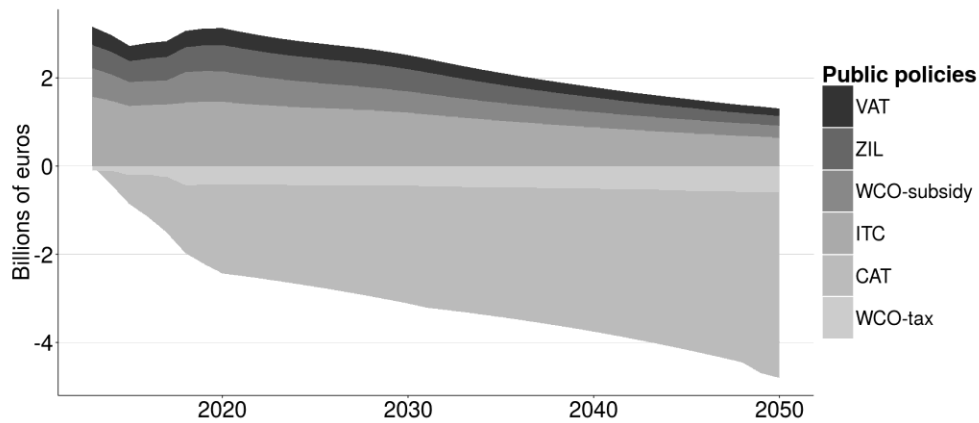


Figure 14: Projection of policy costs

Figure 15 compares the cost-effectiveness of each instrument, measured according to the method detailed in Section 3.3.2. Looking at the predicted-energy metric, we see that the carbon tax is less efficient than subsidies. Subsidies save energy at cost ranging from 0.05 to 0.08€ per lifetime discounted kWh in 2015; among them, the ITC is the least efficient. The indicator increases over time as the potential for energy saving opportunities exhausts. The realized-energy metric draws a different picture, in which the merit order between the tax and the subsidies is reversed. As predicted in Section 3.3.2, this is due to the latter metric taking into account variations in heating intensity unaccounted for by the former. In the same vein, we see that unlike other subsidies, and unlike measured in predicted energy, the cost-effectiveness of WCO decreases over time. This is due to the tax component, which produces additional energy savings not directly attributable to the subsidy cost considered in the index.⁸

⁸ Were the programme operating as a system closed around the building sector, the same subsidy cost would be equal to the revenues from energy fees.

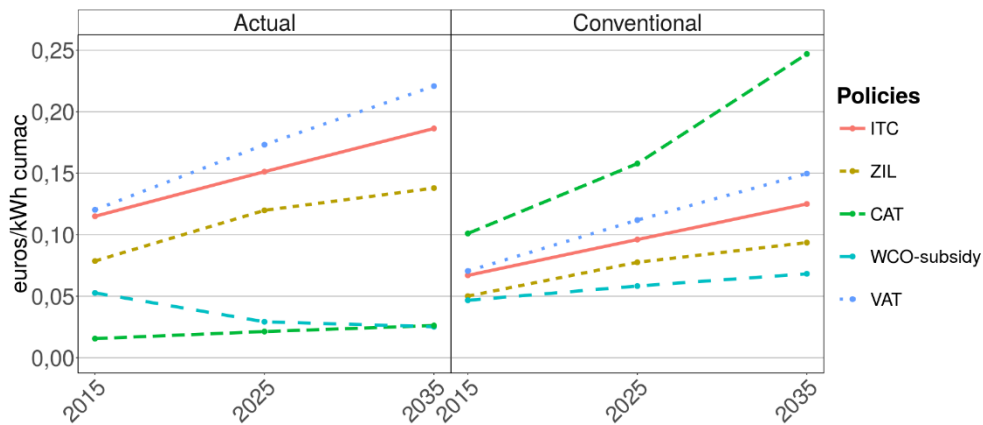


Figure 15: Policy cost-effectiveness

Figure 16 confirms insights from the predicted-energy cost-effectiveness through a different indicator: leverage. Recall that a high leverage and a low cost per kWh saved are two faces of the same coin – high efficiency. Leverage however decreases at a slower rate than the cost per kWh increases, which can be explained by the marginally increasing energy efficiency cost curves embodied in the model. The leverage of subsidies ranges from 1 to 1.4 in 2015, which is in line with estimates available for other public policies (e.g., Gobillon et al., 2005; Lentile and Mairesse, 2009). It is also consistent with the result that cost-effectiveness indices are of the same order of magnitude as the cost curves embodied in the model. Figure 17 shows how estimates vary across the 32 possible combinations of instruments for the year 2015. It confirms the overall over-additive interactions discussed above.

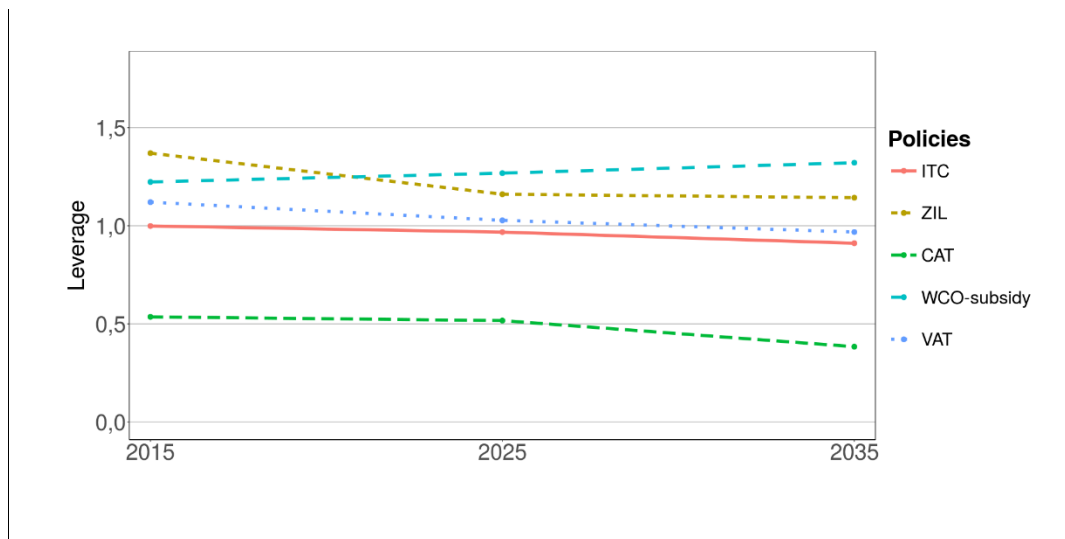


Figure 16: Policy leverage

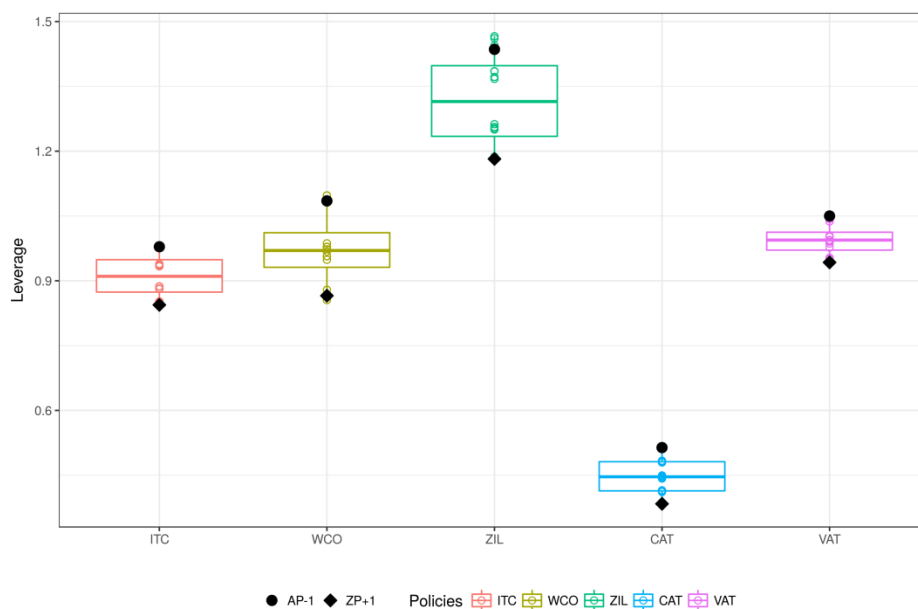


Figure 17: Leverage in 2015 over all policy combinations

The various regimes of subsidy considered – uniform ad valorem for the ITC, uniform ad valorem with a lower rate for the reduced VAT, targeted uniform ad valorem for the ZIL with still another rate, regressive ad valorem for WCO – make them difficult to compare to one another. To better understand the merit order exposed in Figures 15 to 17, and in particular to disentangle the shape and level effects, we focus on one instrument, the ITC, and run additional simulations in which we vary its regime. In addition to the reference and ITC+ (which borrows the restrictions of the ZIL on performance) variants, we consider the following: one with the rate kept uniform but halved (which mimics the low subsidy rate of the reduced VAT); one with eligibility restricted to the first two quintiles of household income; one that interacts the latter eligibility restriction with that of the ZIL on highest performance upgrades. The resulting leverage displayed in Figure 18 suggests that all of these adjustments bring about greater efficiency. The channels through which these adjustments operate however differ:

- The slightly higher leverage induced by a lowering of the uniform rate is due to a reorientation of investment towards the least-cost measures. This contributes to explaining the difference in performance between the reduced VAT and the ITC in Figure 16.
- The higher leverage induced by targeting low-income households is also due to a reorientation of investment toward least-cost measures, thanks to the correlation between income and energy efficiency depicted in Figure 2. It opens room for policies reconciling economic efficiency and fuel poverty alleviation.
- The higher leverage induced by targeting the most energy efficient upgrades has more of a persistent effect than the former two adjustments. It can be explained by a strong effect on the intensive margin of investment. This energy efficiency targeting effect, together with that of a lower uniform rate, contributes to explaining the difference in performance between the ITC and the ZIL in Figure 16.

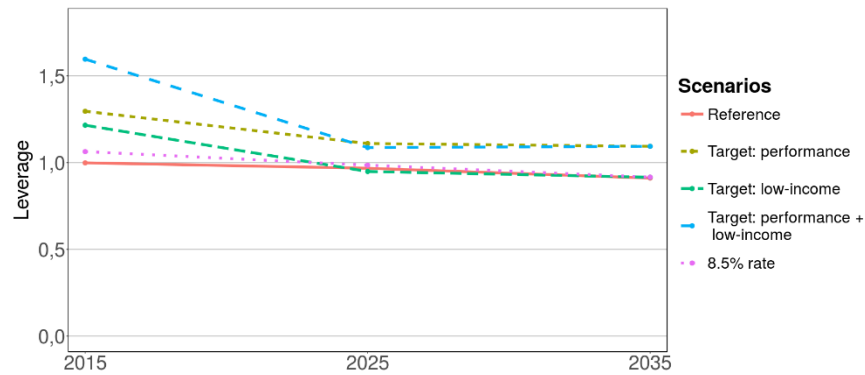


Figure 18: Leverage with further variants of ITC

5 Conclusion

Our study examines the short- and long-term impact of key policies implemented in the French residential sector. It uses the latest version of Res-IRF, a behaviourally-rich model of energy demand recently extended with household income data. We focus on electricity, natural gas, fuel oil and fuel wood demand for space heating in main residences. This scope covers 18% of France’s energy end-use. Previous sensitivity analyses have built confidence in the model – at least in its ability to accurately replicate key statistics and past trends within this scope.

We assess the partial-equilibrium impact of various energy efficiency subsidies – income tax credits, zero-interest loans, reduced VAT and white certificate obligations –, the carbon tax and the tightened building code envisaged for 2020. We find that the model accurately replicates the few ex post statistics available, except for the ZIL programme, the performance of which we over-estimate by an order of magnitude. Balancing this shortcoming with the fact that there are important policies – in particular targeted subsidies to low-income households granted by the French Housing Agency (ANAH), and recent information campaigns – which we do not model, we consider that our study provides a credible assessment of whether and how the targets set out by the French Government might be fulfilled.

We find that generally speaking, meeting targets requires at the very least that instruments be set at their most ambitious level and kept in place until 2050. In particular, the eligibility criteria of subsidy programmes should be redesigned so as to better target rented dwellings, which undergo much fewer renovations than owner-occupied ones. Our assessment produces mixed results against one target – retrofitting 500,000 dwellings annually, including 120,000 in social housing. Specifically, we find that the aggregate target is significantly over-shot, while the social-housing sub-target is significantly under-shot.

Such a bewildering outcome highlights the need for stakeholders to agree on a common accounting method to assess this politically sensible target.⁹

Among all policies, the carbon tax is the most effective, yet the most regressive, at least without further revenue-recycling specification. Policy interactions typically induce a 10% variation in an instrument effectiveness. Among subsidies, the ITC is the most effective, yet the least efficient. Lowering subsidy rates, or restricting eligibility to either most energy efficient upgrades or low-income households increases leverage. Even though target fulfilment calls for as few restrictions as possible, such targeting can be envisaged if budget constraints are to bind. In particular, targeting low-income households has the merit of increasing economic efficiency while alleviating fuel poverty. This could be achieved by specifically allocating part of the revenue from the carbon tax. Taking the policy portfolio as a whole, budget constraints should no longer bind by 2025, when carbon tax revenues begin to exceed subsidy costs. Lastly, the leverage of energy efficiency subsidies is in line with that of other public subsidies.

We see three directions for further research. First, as not all targets are met even with the most extensive policy portfolio, new policies might be needed. We could therefore model some instruments discussed in policy circles, such as a retrofit obligation or a feebate scheme applied to housing taxes. Note that some variants of these instruments have been simulated with the previous version of the model and assessed against former targets (Giraudet et al., 2011; Fuk Chun Wing and Kiefer, 2015). Second, the cognitive and strategic barriers that hinder participation in the ZIL programme should be taken into account. This however requires prior identification through applied microeconomic work, a research programme in itself. Third, a more complete policy assessment would include general-equilibrium effects and carbon savings. This could be achieved by updating a modelling exercise that linked Res-IRF to the IMACLIM-R France model and a bottom-up model of power generation in France (Mathy et al., 2015).

⁹ When Nicolas Hulot resigned from his position of Ministry of Sustainable Development on September 4th, 2018, one of the arguments he put forward was that no sufficient public funds were allocated to meeting the 500,000 renovations target. It is striking that according to our estimate, this target is already met by a fair margin.

Acknowledgements

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