Evaluation of an incentive scheme for the energy renovation of low-income households: micro-economic modelling of a great policy with marginal impact

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Abstract
With the objective of achieving carbon neutrality by 2050, the building stock will have to switch to low-carbon energy and be renovated through energy efficiency measures. However, access to capital to cover the initial cost is problematic for low-income households. A national grant program, which is part of the French Energy Efficiency Obligation system, has therefore been dedicated to helping low-income households replace their oil boilers with more efficient and lower carbon heat sources.

In this paper we will use a microsimulation model to evaluate the impact of this scheme. This model describes each housing unit individually, which makes it possible to retain a wide variety of situations, all of which have a specific renovation potential and differentiated profitability of actions. A discrete choice model represents the household's options when the space heating system must be replaced. The competition between different technologies relies on their technical and economic characteristics combined with the dwelling and household characteristics, for a given set of energy prices. The grant scheme provides subsidies depending on household income, the type of existing and new system.

The simulations show that even taking into account only monetary costs and in the absence of barriers to energy efficiency (e.g. preference inertia), the national support scheme would have very low added value compared to a "Business-as-Usual" trend (counterfactual scenario). Unfortunately, this scheme does not make it possible to reverse the current economic ranking for the least carbon-intensive equipment with the lowest running costs.

Introduction
With a climate change policy target of carbon neutrality in 2050, as the long-term strategy of the EU (European Commission 2021), the renovation of the building stock is of primary importance. In the French strategy to achieve the carbon neutrality in 2050 (SNBC – national low carbon strategy), existing buildings' Green House Gas (GHG) emissions are limited to 5 MtCO_2eq compared to 82 MtCO_2eq in 2020 (-95 % reduction for the residential and tertiary buildings). To achieve such a reduction, energy consumption must be reduced from around 750 TWh in 2020 to 450 TWh in 2050 and the energy used should be mainly low carbon (electricity, district heating, biomass, and biogas) (MTE 2020). In the short term, the French law on energy and climate (JORF 2019) sets the principle of a primary energy consumption ceiling of 330 kWh/(m^2.year) for housing by 2028 (MTE 2020). Thus, the renovation of the building stock to an entire low energy building stock on average in 2050 is an objective in the French energy and climate policy.

To achieve such a result, massive increase in building retrofitting is needed, consisting of a reduction of energy needs via an increased insulation of the building envelope and a decarbonization of the space heating and sanitary hot water end-uses via efficient equipment using renewable energies (Arquin et al. 2020).

The French building stock consists of 29 million main dwellings (CEREN 2021), 1.9 million of which are considered as low-consumption (Energy Performance Certificate (EPC) label A&B) and 4.8 million with the highest consumption (EPC label F&G). The share of F&G EPC label decreases slightly with the income of the occupants, but also depends on occupancy status (MTE 2020):

- The share of F&G EPC label is 28 % for the first quintile income against 22 % for the fifth quintile for tenants.
- The share of F&G EPC label is of 23 % for the first quintile income against 13 % for the fifth quintile for owners.

There is therefore a double penalty for low-income households; they are more likely to live in inefficient housing and have difficulty accessing the capital to engage in a renovation process that has a high up-front cost. It is necessary to help these low-income households to cover part of the renovation costs through incentives such as tax credit, soft loans, or grants.

In this context, we modelled the renovation of the heating equipment with or without a grant scheme on the basis of a discrete choice function (microeconomic modelling) in order to study the potential for energy savings and GHG mitigation for residential buildings in the long run (i.e. to 2050). Our modelling considers both technical and economic aspects of an incentive scheme and of a counterfactual scenario to assess the effectiveness of the subsidies.

The first section of this paper presents the input data and discrete choice model for the heating equipment retrofit. The next sections describe the grant scheme and present the modelling results. Finally, in the last section we will discuss the outcome of the incentive scheme modelled and the policy implications.

Methodology

Our model Bebop (Building, Energy, Bottom-up, Prospective) belongs to the general category of hybrid bottom-up models (Sathave & Sanstad 2004). It is also a disaggregated/microsimulation model in which each dwelling is individually described and computed. The bottom-up part is highly detailed at the level of envelope elements and undertakes an annual energy use calculation. This allows evaluation of the impact of explicit actions. Two top-down features are implemented: a behavioural model considering price effect and rebound effects and a microeconomic consumer choice model.

REPRESENTING THE HOUSING STOCK

We use as an input the 30,000 housing sample from the national housing survey (ENL 2013) in which every dwelling is described with variables such as type, year of construction, location (climatic zone, urban density), floor area, main fuel used for the heating system, number of occupants, income.

Then we use the Phebus survey (CGDD 2013) which contains a complete energy-oriented description of 2,500 dwelling representative of the national stock. This sample is too small for a direct use as an input in our model, in which we want to have sufficient heterogeneity in terms of household's types, climatic location, etc. So, we use this study to estimate missing variables in our input sample, such as the presence of a wood stove, the level of renovation of each envelope element (floor, walls, roof, windows), the type of ventilation system. For this we estimate linear or logistic regression models on the Phebus Study which we then apply to the ENL housing stock.

Heating systems are described with the fuel type and different efficiencies: generation, distribution, emission, and regulation. As a result, we get a synthetic population of dwelling-households representative of the national stock and described by key variables for three sub-systems:

- Building envelope insulation levels per element: walls, roofs, floors, windows.
- Heating equipment (fuel, efficiency).
- Household (size, income).

This detailed description makes it possible to cover a wide variety of situations, all of which have a specific renovation potential and differentiated profitability of actions.

ENERGY CONSUMPTION CALCULATIONS

With this complete set of variables, we can calculate conventional thermal losses on a yearly basis according to the EPC 3CL method which is the French conventional approach for the Energy Performance Certificates (JORF 2012). This provides energy consumptions and energy bills for 'standard behaviour'. This conventional consumption is considered as a proxy of the space heating use of housing. The effective energy consumption and energy bills from space heating can be calculated with a behavioural model representing the gap between effective and conventional consumption as a function of the conventional cost of heating service (Allibe 2009). However, in this paper we base our calculations on conventional energy consumption rather than effective consumption in order to reflect energy efficiency companies' practice (ADEME et al. 2020, EFFINERGY 2020), when comparing the merit order of different renovation actions.

MODELLING SYSTEMS REPLACEMENT CHOICES

The timing of heating system replacement is estimated for each dwelling assuming a lifespan probability normally distributed around 15 years, with a 5 years standard deviation. As a result, 80 % of dwellings are estimated to have a new system in 2025 and 80 % made a second replacement before 2042.

When a system needs to be replaced, we use a discrete-choice function to represent the competition between relevant alternative systems. Possible alternatives have different characteristics depending on the type of dwelling: Single Family Housing (SFH)/Multiple Family Housing (MFH), individual or collective heating system, social housing.

We adopt the formulation originally proposed by Jaccard et al. (1996) and implemented in the French context by Giraudet et al. (2012). For a given dwelling, the probability $P_{i,j}$ to switch from an existing system *i* to an alternative *j* is a function of the levelized Life Cycle Cost of the transition ($LCC_{i,j}$) compared to the life cycle cost of all other *i,k* transitions as shown in equation 1. The γ coefficient, representing market heterogeneity, is set to 8 as in Giraudet et al. (2012).

$$P_{i,j} = \frac{(LCC_{i,j})^{-\gamma}}{\sum_{k=1}^{K}(LCC_{i,k})^{-\gamma}} \qquad (1)$$

The levelized life cycle cost of the transition LCC_j is the sum of initial investments and lifetime discounted running costs, calculated using equation 2:

$$LCC_{i,j} = CC_j + TC_{i,j} + (MC_j + CEC_j) \times \frac{1-(1+r)^{-n_j}}{r} \quad (2)$$

Where CC_j is the capital cost of alternative *j*,
$TC_{i,j}$ is the transition cost for switching from *i* to *j*,
MC_j is the yearly non energy maintenance and operation cost of system *j*,
n is the system *j* lifespan.

Transition costs include, if necessary, the connections to the gas or district heating network, the installation or removal of the oil tank, the installation of an internal sanitary hot water network.

$$CEC_j = \frac{\text{CEN}}{\eta_j} \times P \quad (3)$$

CEC_j is the yearly conventional energy cost of alternative *j* for the year of transition, calculated using equation 3. It depends on the conventional energy need *CEN* resulting from individual dwelling's characteristics and the thermal calculation. The alternative system efficiency η_j allows calculating the resulting conventional final energy consumption. We consider the current energy prices *P* for the transition year which reflects a "myopic expectation".

For electricity and gas prices we consider the consumption volume to determine the relevant levels for the subscription's fixed and variable parts as well as the presence of a day/night tariff for electricity.

The private discount rate, *r*, depends on the dwelling type, the system type, the ownership status, and income. Following Bourgeois et al. (2019), we use higher discount rates for collective systems, in order to represent friction in community decision making, and also higher rates for renters to reflect the 'landlord-tenant dilemma'. Then we modulate these average values to obtain rates decreasing with income: a factor of two is applied for the first income quintile and a factor 0.4 to the fifth quintile. Such a correlation between the private discount rate and the income or the dwelling type was observed by Stolyarova (2016) and Cayla et al. (2011). The resulting private discount rates are shown in Table 1.

To summarize, we have undertaken a simulation which consider the diversity of configurations on both the technical and the household side. Despite this realism level, we don't try to forecast with precision the dwellings' stock evolution but make a detailed analysis of technologies' relative competitiveness based on monetary costs. This allows comparison of this competitiveness evolution with or without the national grant scheme.

As we are interested in the difference between scenarios with and without the grant scheme, rather than the absolute effect we don't model other market barriers such as the preference inertia, lack of information, etc. which could reduce the grant scheme impact. Stolyarova (2016) shows the existence of inertia of preferences in the case of a retrofit of a heating system i.e. at what level of investment the household will give up keeping the same equipment or the energy used. On the other hand, we don't model effects which could increase the uptake of more efficient or low carbon technologies, such as the spill over effect or the leverage effect of a premium. As reported by Stolyarova (2016), a grant given to a household for an energy efficiency action leads to a multiplier effect on the investment greater than one : the grant will encourage the household to increase his investment by more than €1 of subsidy.

The national grant scheme

The aim of the modelled scheme, based on an existing scheme implemented in 2019 (MTE 2021), is to foster the phasing out of fossil fuels in the residential sector and to mitigate fuel poverty through energy efficiency measures. The main condition is to replace a fossil fuel boiler fired with coal, oil, or gas if the boiler is not a condensing one. Seven technologies are eligible: efficient biomass boilers; water/water or air/water heat pumps; hybrid heat pumps; combined solar systems; district heating with a major share of renewable or waste energy, and very high efficiency gas boilers (i.e. condensing boilers).

The size of the grant depends on an income threshold which depends on household size and location (Île-de-France region vs other regions). A household is considered as low-income if its yearly disposable income is lower than €25,000 for a single person in Île-de-France region (€19,000 otherwise), €51,000 for a 4 people household in Île-de-France region (€39,000 otherwise). For larger households the threshold is raised by €7,300 per added capita in Île-de-France region and €5,600 otherwise. The grants by income status and technology type are shown in Table 2.

The scheme also provides grants for insulation actions, which we don't consider in this study.

Table 1. Average private discount rates.

Dwelling type	Ownership status	Heating system type	Average private discount rate *r*
Detached house (SFH)	Owner-occupied	individual	8 %
	renter	individual	45 %
Collective dwelling (MFH)	Owner-occupied	individual	10 %
		collective	15 %
	renter		55 %
Social housing			4 %

Table 2. Grant scheme depending on the replacement technology and income status.

Replacement technology	Income status	Grant (€)
Biomass boiler	Low income	4,000
	Other	2,500
Air/Water heat pump	Low income	4,000
	Other	2,500
Hybrid oil heat pump	Low income	4,000
	Other	2,500
District heating with >50 % RES	Low income	700
	Other	450
Very high efficiency gas boiler	Low income	1,200
	Other	600

Table 3. Domestic energy prices.

Fuel	2013	2050
Electricity	137	225
Gas	65	100
Wood	29	33
Oil	93	160
LPG	133	185
District heating	79	90

Prices in €2013/MWh inc. VAT.

Impact evaluation

We will compare a "grant scheme" scenario with a "reference" one (counterfactual). The differences will only relate to how the reduction of investment by the occupier resulting from the scheme affects the choice of heating system. All other variables are shared between the two scenarios: energy prices and systems characteristics: capital cost, non-energy maintenance and operation costs, efficiencies, transition costs.

HYPOTHESIS

All energy prices are expressed in constant €2013 and are presented in Table 3. We consider realistic evolutions with a higher growth for fossil fuels.

The characteristics of each type of technology, including capital and non-energy operational costs (e.g. servicing) are shown for one example, a detached house, in Table 4.

RESULTS

Evolution of the order of merit of alternative systems

The main effect of the grant scheme is to modify life cycle costs, and therefore the uptake of different technology types. However, our case study found this to only a limited extent. Figure 1 shows the average space heating levelized life cycle cost for a low-income household living in a detached house with and without the grant scheme. We can see that the grant scheme doesn't deeply modify the merit order of alternative systems:

- hybrid oil-electric heat pumps become a bit cheaper but remain the most expensive along with LPG boilers.
- Air/Water heat pumps become a bit cheaper but remain the third most expensive to 2040. The breakeven point with direct electric heating and oil boilers comes around six years earlier.
- Wood boilers, which were already very competitive with oil boilers become even more competitive. Their breakeven point with gas boilers comes ten years earlier.

Evolution of heating systems

The evolution of heating system by type for low-income households living in a detached house is shown for the two scenarios in Figure 2. One of the grant scheme objectives was to phase out heating using fossil energy sources. Our modelling shows that the grant scheme doesn't accelerate the trend of replacing oil boilers. It even shows a small increase for gas boilers due to the grant for condensing ones which might seem counterproductive, in terms of reducing carbon emissions.

We observe in both scenarios a strong penetration of electric heat pumps, which explains most of the oil boilers' decline. Wood-based systems retain about the same share and rely heavily on stoves. The picture is largely the same for collective housing, owners or renters and other types of household. The modelling shows that the grant scheme objective of accelerating fossil energy phase out is not achieved.

The second objective of the grant scheme was to help mitigate fuel poverty. We calculated the evolution of energy bills, in absolute terms and as a percentage of household income for space and water heating, based on conventional consumptions. That is, on the assumption that households don't follow real life behaviour, cutting very high bills with actions like reducing indoor temperatures and limiting space heating to fewer rooms. As a result, the percentage of income spent on heating may be lower than expected, indicating a loss of comfort and possible health troubles. More complex indicators have been developed to overcome the shortcomings of usual indicators (Hills, 2011), but their calculation and interpretation may be complex. Finally, the simple indicator used in this study seems sufficient to illustrate the main impact of the grant scheme.

Table 5 shows the effect of the grant scheme on energy bills. The first finding is that there would be a 14 % increase in energy bills for low-income households and no change for other households in the reference scenario. This difference can be

Table 4. Price and efficiency of space heating and Domestic Hot Water equipment – illustration for a detached house.

Replacement technology	**Supply-installation cost** (€ inc. VAT)	**Non-energy operation cost** (€/year inc. VAT)	**Efficiency** (LCV) **2014**	**Efficiency** (LCV) **2050**	**CO_2 intensity 2014** gCO_2/kWh of thermal energy produced	**CO_2 intensity 2050** gCO_2/kWh of thermal energy produced
Wood boiler	10,400	150	0.85	0.85	35	32
Wood stove & direct electric	7,500	100	Wood 0.9 Elec. 0.95	Wood 0.9 Elec. 0.95	124	42
Wood stove & Air/Air heat pump	8,600	150	Wood 0.9 Elec. 2.9	Wood 0.9 Elec. 3.65	92	26
Air/Air heat pump	4,750	100	2.9	3.65	67	13
Air/Water heat pump	16,000	100	2.9	3.65	67	13
Direct electric	5,000	0	0.95	0.95	204	51
Hybrid oil heat pump	15,000	150	Elec. 2.9 Oil 0.9	3.65 0.9	153	143
Condensing gas boiler	4,400	100	0.9	0.9	252	177
Oil boiler	5,000	120	0.85	0.85	374	374
LPG boiler	5,000	250	0.85	0.85	318	318

Wood stoves are supposed to cover 50 % (40 %) of heating needs when combined with a direct electric system (resp. A/A heat pump). Hybrid electric-oil heat pumps are supposed to cover 70 % of heating needs with the electric heat pump. Cost modulations are considered for double service boilers: +20 %, collective system: -30 %, social housing: -20 %. CO_2 emission factors come from the ADEME database (2020). LCV: Lower Caloric Value. Costs based on own hypothesis.

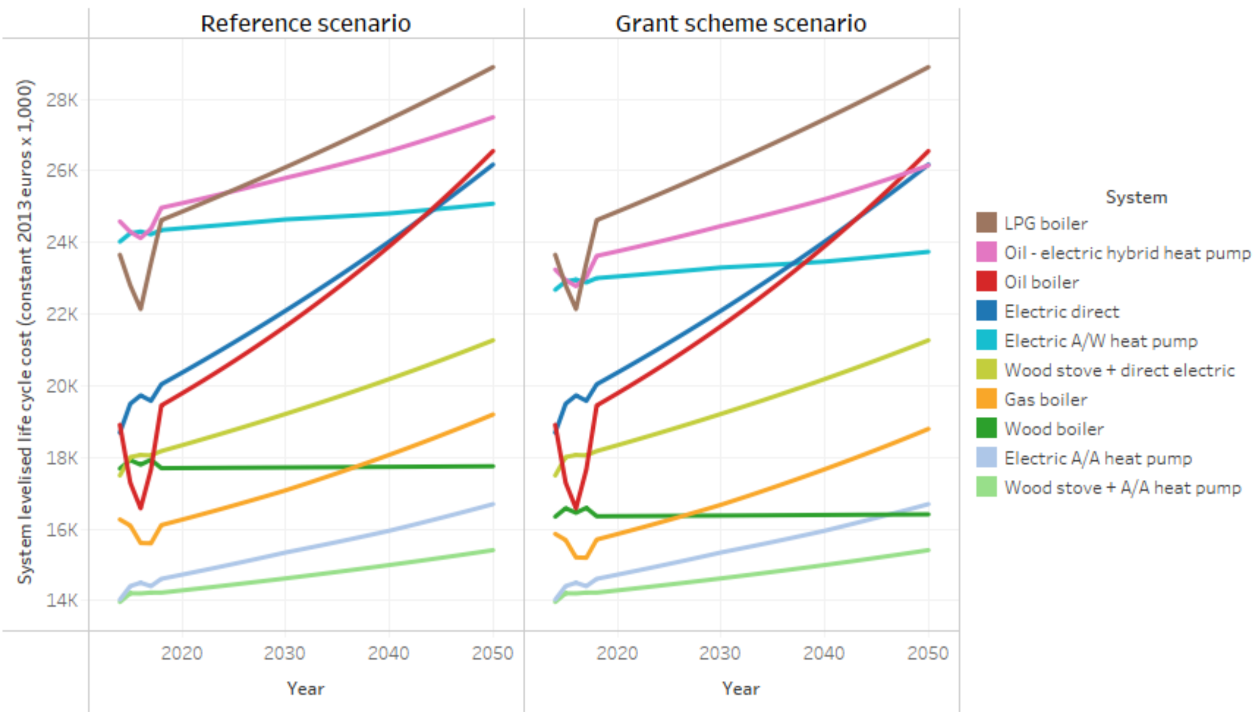

Figure 1. Average heating systems' life cycle cost with/without the grant scheme in low-income households in detached houses.

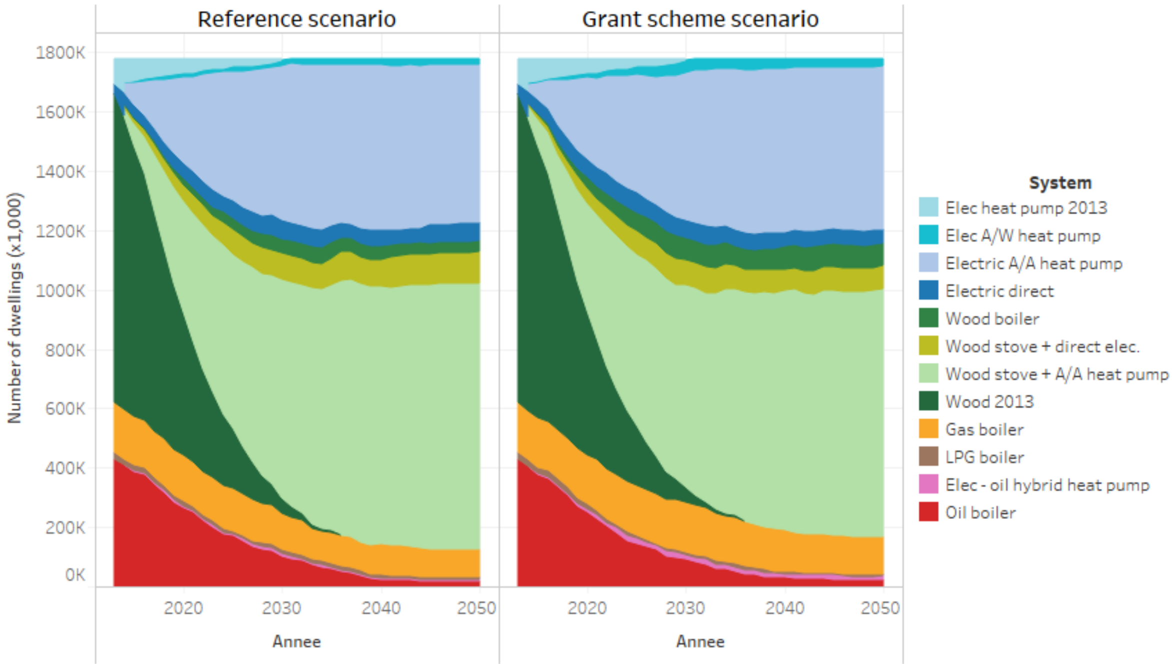

Figure 2. Space heating systems' stock evolution according to grant scheme and counterfactual scenarios in low-income households in detached houses.

Table 5. Modelled space heating bills (in €).

Scenario	Income status	av. energy bill 2013	av. energy bill 2050	change
Reference scenario	Other	1,075	1,084	1 %
	Low-income	777	889	14 %
Grant scheme scenario	Other	1,075	1,057	-2 %
	Low-income	777	854	10 %

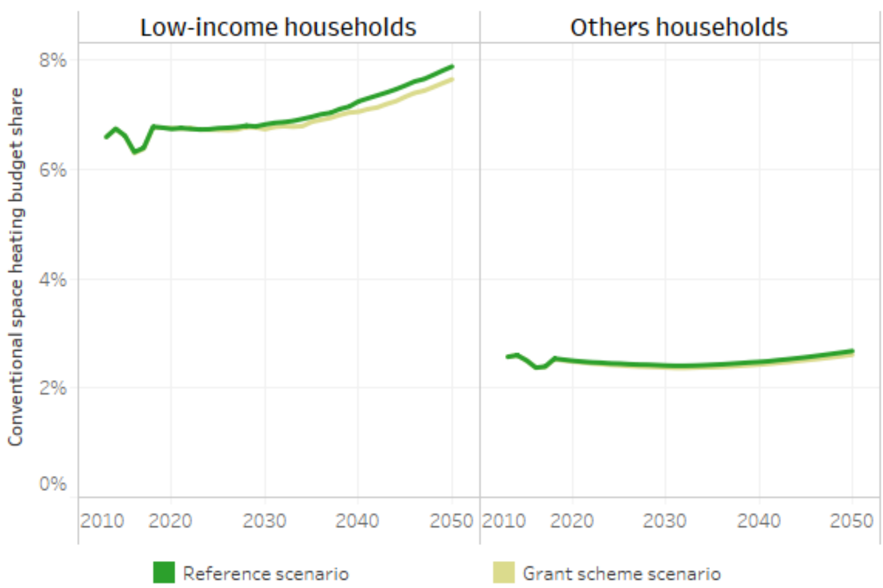

Figure 3. Space Heating bills as a proportion of budet. Based on conventional energy consumption and disposable income.

explained by the fact that low-income households have less capacity to invest in the more expensive technologies which provide energy savings in the long run. They need a quicker return on investment, have fewer renovation possibilities and face more friction in undertaking renovation as they are more likely to live in collective housing (52 % vs 36 %) and be tenants (36 % vs 23 %) than other households.

The grant scheme produces a small bill reduction relative to the reference scenario but doesn't prevent the increase. Similarly, the energy bill share of income increases from 6.6 % to 7.9 % in the reference scenario and to 7.6 % with the grant scheme for low-income households, whereas it stays stable at around 2.6 % for others (Figure 3). We considered stable incomes over the scenario's duration in order to highlight energy-related matters. A typical 0.8 %/year income increase would provide a 34 % absolute income growth over the period, which would decrease the energy burden but also the relative effect of the grant scheme.

The total cost of the subsidy scheme, if every eligible transition benefited, would be around €12 billion for the first systems' replacement, which is considerable compared to its small impact.

Discussion

Our objective was to compare the evolution of systems competitiveness for different combinations of dwelling and household, with or without a grant scheme. We could as well include insulation actions either as an external assumption if we still focus on heating systems, or as an endogenous choice model.

The model could also be used to simulate realistic evolutions. In this case we would include classical market barriers and non-economic effects (Knobloch et al. 2021, Giraudet et al. 2012). Model coefficients could be estimated thanks to a stated or revealed preference study (Stolyarova 2016, Jaccard and Dennis 2006).

Conclusion

To assess the effect of a grant scheme dedicated to help investment in energy efficiency actions by subsidizing up-front cost, we used a discrete choice model to simulate households' investment and their energy bills.

The simulations show that even taking into account only monetary costs and in the absence of barriers to energy efficiency (e.g. preference inertia), the national support scheme would have a very low added value compared to a "Business-as-Usual" trend (counterfactual scenario). Unfortunately, this scheme does not make it possible to reverse the current economic ranking for the least carbon-intensive equipment with the lowest running costs. The effectiveness of the scheme appears to be low compared to the counterfactual scenario.

Moreover, it shows that the effect on low-income households, the main focus of the scheme, is limited – their energy burden in the long run is slightly lower than in the reference scenario but still higher in 2050, in contrast to 'average' households.

It is well-known that investment subsidies are not sufficient to trigger all energy efficiency actions, especially for low-income households that do not have access to capital. The model allows us to understand how financial support modifies the competitiveness of technologies for different types of households and housing thanks to its disaggregated aspect.

Removing the barrier to investment for low-income households is a known issue. One of the solutions is to accompany them to reduce even more the remainder up-front cost by proposing solutions of financing like zero interest loan or third-party financing.

On GHG emissions, it is clear that subsidising efficient gas boilers is not sustainable in the long-run and must remain a temporary alternative, even if we consider a reasonable biogas rate. The limited biogas potential should indeed be dedicated to industry processes which have no alternative.

It can be noted that some economically and carbon efficient equipment, such as air-to-air heat pumps and wood stoves, are not currently supported by the grant scheme or only with some restrictions.

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