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# Does energy efficiency reduce inequalities? Impact of policies in residential sector on household budgets

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## Keywords

bottom-up approach, policy evaluation, consumer behaviour, economic impact, equity issues

## Abstract

The European energy and political context suggests that households will have to face up to making significant reductions of their energy consumption over the coming decades. Indeed European Union has adopted a 20 % reduction in energy consumption by 2020 in its climate energy package. The aim of this paper is not only to study the refurbishment and technological changes implied by such targets but also to show its impact on household budget as this ambitious target may imply strong efforts from households.

Studies that deal with efficiency of policy tools generally adopt a global economic point of view and rarely consider distributional impacts on final consumers and if so, do not consider possible differences in consumer behavior patterns regarding energy use. How can we therefore assess the suitability of such policies without clearly anticipating their repercussions on households, whose behavior is obviously heterogeneous? In order to provide useful insights about the impact of such policies on residential sector, it appears crucial to capture both household heterogeneity and household behaviour in long-term planning models.

Our analysis relies on the TIMES-Households model which is a bottom-up optimization model from the MARKAL/TIMES family of energy models that allows for a very significant disaggregation of demand and technological processes. The building stock and its inhabitants are then represented in a very detailed manner considering both technical and socio-demographic characteristics. Moreover, thanks to analyses picked from a

detailed household survey we are then able to differentiate access to technologies, level of energy demand and equipment purchasing behaviour according to household characteristics (income, size, type of housing, occupation status). We show the impact on household budget of the 38 % reduction target of primary energy consumption in residential building stock by 2020 adopted by the French government.

## Introduction

The existence of a large potential of energy savings in EU building stock is acknowledged and is relying mainly on space-heating end-use [European Commission 2005] even if some uncertainties remain on the amount of the potential savings [Lechtenböhrer & Schüring 2011]. Moreover energy policies usually focus on these two end-uses in buildings since they appear to offer more flexibility regarding reduction of consumption and one of the largest potential of savings [Anisimova 2011, IEA 2009]. Thus, in our analysis we mainly focus on space-heating and domestic sanitary hot-water (DHW) energy consumption as these two thermal end-uses account for 80 % of residential energy consumption.

Especially in France, the article 5 of the Grenelle's law, issued from the environmental roundtable that occurred in 2007, targets a primary energy consumption reduction of 38 % in existing buildings compared to 2008 [JORF 2009]. This means that the average building stock annual energy consumption expressed in primary energy should decrease from 240 kWh/m<sup>2</sup> to 150 kWh/m<sup>2</sup> by refurbishing of around 400,000 dwellings per annum. However, all the impact studies were done considering "average" households without taking into account the dispersion of their characteristics, in particu-

lar in term of income and budget notably for the less wealthy households.

Fuel poverty is usually a combination of low income and large energy needs and is strongly linked to the housing characteristics [Dubois 2012] leading to energy restriction [Allibe 2009]. The low thermal performance of the dwelling is clearly identified as a component of the fuel poverty [Roberts 2008]. Considering the poor housing quality (i.e. energy efficiency) associated with fuel poverty, the reasons to not invest in energy efficiency were information gap and financial constraints [Healy & Clinch 2004]. The financial barriers were mainly: inability to pay and more pressing priorities for expenditure.

The specific case of fuel poor households facing more and more stringent energy policies, that targets the lowest efficient buildings where they live, add to them new constraints to bear. Moreover, the potential impacts of energy efficiency policies to reduce or increase the level of fuel poverty (i.e. impact on the household budget) need to be studied.

### The TIMES-Households modelling framework

The model we used here is based on the residential part of the TIMES-Households model described in detail in Cayla [2011]. This model relies on a classical TIMES framework which is an inter-temporal optimization bottom-up approach [Loulou 2005] allowing a high level of detail both on the supply side and on the demand side. Indeed in TIMES-Households model household energy demand is represented according to a very detailed segmentation based on the main significant variables in household energy consumption: income, type of family, type of housing, ownership status, space-living area and quality of insulation [Druckman & Jackson 2008, Uitdenbogerd 2007]. The level of detail and the impact of the variables in the model are presented in Table 1.

Households are classified according to these variables resulting in 180 household segments<sup>1</sup> with homogeneous characteristics. Quantitative impacts of the variables retained here for segmentation on space-heating energy consumption and purchasing behavior are obtained from a survey undertaken at EDF R&D [Cayla et al 2011]. The other characteristics for each of these segments, such as population numbers, living space area, or initial market shares of equipment, are obtained from the National Housing survey database [INSEE 2006].

Access to technologies is restricted according to the type of housing and to ownership status. Indeed some technologies are not available in flats, such as geothermal heat pumps. We take the landlord/tenant dilemma into account by assuming that tenants are associated by landlords to middle-term decisions concerning space- heating. Indeed tenants spent in average 12 years in the same housing, we could thus imagine that they might be associated to decisions whose results last 10–20 years. In the model we thus consider that tenants are able to choose their space-heating system and to undertake minor refurbishment such as windows or ventilation. Conversely, only landlords are able to choose to refurbish the walls or the roof of their housing.

1. In fact this level of detail would result in 720 types of households but some crossings are empty and others are non-significant and we have only kept segments of households that represent more than 0.15 % of the whole population.

Space heating energy demand is obtained from a thermal calculation derived from the DPE-3CL<sup>2</sup> methodology [MEC-SL 2006]. Nevertheless this kind of calculation is known to overestimate energy consumption and to ignore variation in household behavior [Allibe 2009]. In order to take household behavior into account, we then correct this normative value obtained from the calculation by a service factor depending on household income following Allibe [2009] as shown in Figure 1. Effective energy consumption is also recalculated at each time period of the model to take into account rebound effects and price elasticity.

In the TIMES modeling framework equipment is chosen by minimizing their global discounted cost on the whole horizon of time (investment, maintenance and fuel costs). Equipment purchasing behavior is then encapsulated both in the discount rate used to evaluate available investments in refurbishment and equipment and in a capital constraint that bound the global amount of potential investment. These two parameters vary with household income according to Cayla et al. [2011].

Figure 2 shows the energy consumption for space-heating<sup>3</sup> by energy source in 2006 according to CEREN [2010] and obtained with the model.

We observe very slight difference between CEREN data and consumption designed with our model. This tends to prove that the methodology retained to model space-heating energy consumption is quite robust since the calculation relies on EDF survey and INSEE data but not on CEREN data.

### Reference scenario

In the reference scenario the model runs without specific environmental target. Households then consume energy for space-heating and invest in equipment according to energy prices, technology prices and to their characteristics (i.e.: access to technologies, initial level of demand, purchasing behavior). Energy and technology are two of the most important drivers of energy consumption and their evolution over time is quite difficult to predict; we thus assume two different price scenarios for each of them.

We first consider a “medium” energy price scenario based on a study from UFE [2011] for the price of electricity, on the New Policies scenario from the IEA [2011] for fossil fuels and on FCBA [2010] for wood. The second energy price scenario (“low” price scenario) relies on the prices<sup>4</sup> retained by the French government [CGDD 2011] in its study on the impacts of the Grenelle policy. Table 2 presents the differences between the two price scenarios.

We can observe that fuel oil is more expensive than in the medium scenario, natural gas is less expensive and electricity is far less expensive. The main noticeable difference between

2. The DPE-3CL methodology is employed by French Government to label the quality of dwellings (Energy Performance Certificate).

3. Final energy corresponds to the amount of energy consumed in space-heating systems when useful energy corresponds to the amount of energy really obtained after conversion. The difference between final and useful energy also depends on the global efficiency of space heating systems.

4. Commissariat Général du Développement Durable: “Évaluation des mesures du Grenelle de l’environnement sur le parc de logements”. These results are obtained with the IMACLIM-R model [Crassous et al. 2006] for electricity, natural gas and fuel-oil. As there is no result concerning wood price it is assumed unchanged compared to “medium” scenario.

Table 1. Variables retained to model the residential sector and their impact.

Role	Variable	Segmentation	Effect
Access to technologies	Type of housing	House/Flat	Specific technologies
	Ownership status	Landlord/Tenant	No insulation for tenants
Level of Demand	Space-living area	House: 70m <sup>2</sup> /100m <sup>2</sup> /150m <sup>2</sup> Flat: 42m <sup>2</sup> /67m <sup>2</sup> /94m <sup>2</sup>	Level of demand for space-heating
	Insulation	3 quality levels	Initial thermal quality for roof, walls, windows and ventilation
	Income	Income quintiles	Space heating service factor
	Size of household	Single/Couple w/wo children	Level of demand for sanitary hot water
Behavior	Income	Income quintiles	Implicit Hurdle rate Capital constraint

the two scenarios then lies in the fact that the price difference between electricity and natural gas increases in the “medium” scenario and decreases in the “low” scenario.

We also consider two alternatives for the price of the refurbishment measures. In the “Equipment” scenario we consider the prices retained in a study from UFE [2012]. We also assume a learning effect on the price in the case of insulation to take expected structuring effects of the building sector into account. Making assumptions about price of equipment is generally a tricky task but making assumptions about price of insulation is even more difficult as it is well known that there is a great heterogeneity in real price paid by households for refurbishment [ANAH 2010]. In the “Insulation” scenario, relative price of insulation are then assumed to be lower compared to heating systems in order to take price uncertainty into account. The relative differences between the two scenarios are summed up in Figure 4.

We can observe that equipment is 20–30 % more expensive in the “Insulation” scenario whereas insulation costs around 50 % less than in the “Equipment” scenario in 2010. In the “Equipment” scenario insulation is quite expensive but it is assumed that those costs decrease at the end of the period to the “Insulation” case levels thanks to a structuring effect of the building sector.

We then observe the impacts of these four reference scenarios on the stock of space-heating systems and on energy consumption (see Figures 5 and 6).

We can notice that in the medium energy price scenario heat pumps and wood systems take market shares to gas boilers and convectors (direct electric heating). In the case of low price equipment efficient systems such as heat pumps are more widely diffused. Conversely, there are more convectors and gas boilers when price of insulation is low because once the housing gets insulated then the profitability of invest into efficient heating systems decreases. Figure 6 also confirms that a large amount of energy is saved thanks to insulation when its price is low compared to those of equipment. Energy consumption varies accordingly to the stock of heating systems but we can observe that when energy price is low more energy is consumed and this is especially the case for natural gas. Indeed when prices are low there are less retrofit measures done.

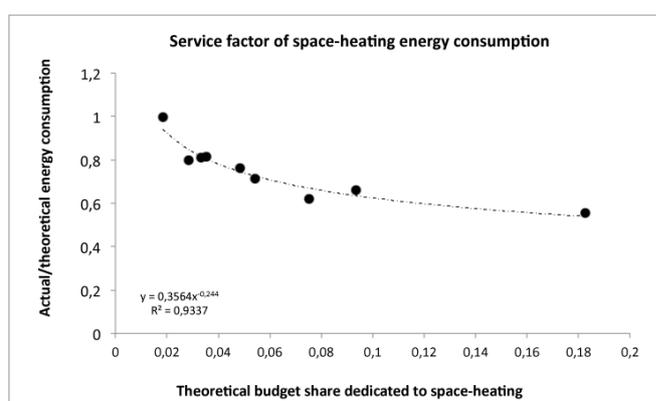


Figure 1. Service factor for space-heating energy consumption.

It is also important to point out another effect linked to the energy price. When price increases, the amount of energy consumed for space heating purpose decreases according to Figure 1, but when it increases to a certain extent, it leads households to invest in refurbishment measures which become cost effective. Since efficiency increases, global price of space-heating decreases and energy consumption increases due to a classical rebound effect. We then can observe what we call an “apparent rebound effect” that would thus encapsulate both a classical rebound effect, which occurs with the diffusion of efficient equipment, and a price-elasticity effect, that occurs when energy prices vary. Table 2 presents the apparent rebound effect observed in the different scenarios for space-heating energy consumption.

Indeed, rebound effects depend at least on initial efficiency of equipment, initial level of comfort, available substitutes, prices of new equipment, efficiency of new equipment, and most of all initial price of energy sources and their evolution over time and household income [Boonekamp 2007]. As we can see, this apparent rebound effect may vary from 6 % to 16 % according to the energy prices and the amount of efficiency measures done consequently. These results tend to explain the strong heterogeneity of values generally found in literature for rebound effect or price-elasticity [Grenning et al. 2000, Sorell et al. 2009].

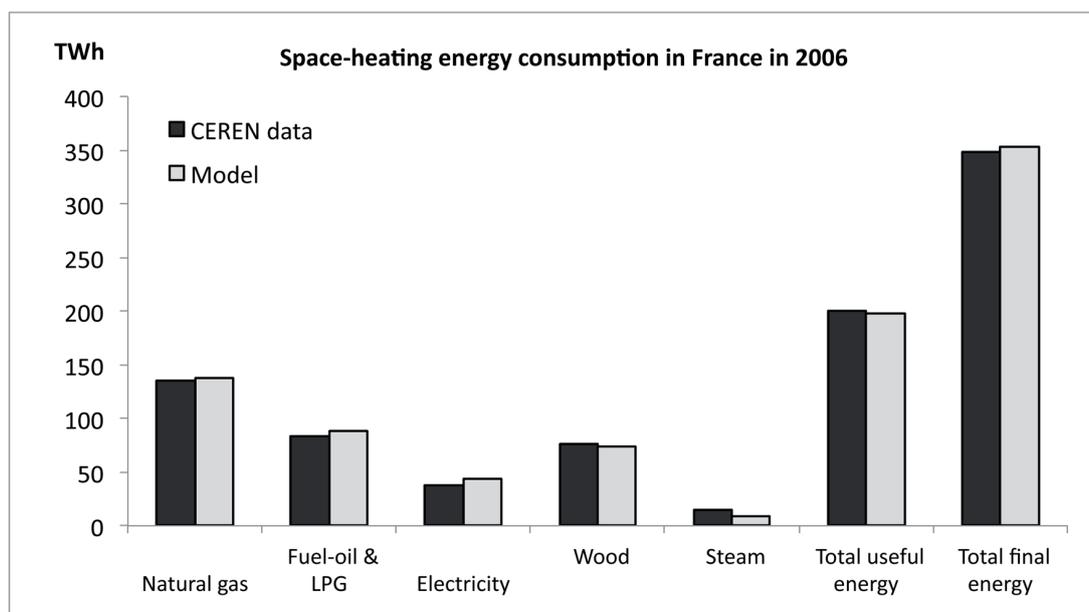


Figure 2. Space-heating energy consumption by source in 2006.

Table 2. Apparent rebound effect according to the reference scenarios.

Scenario	Equipment + low price	Insulation + low price	Equipment + medium price	Insulation + medium price
2020	13 %	13 %	8 %	6 %
2030	16 %	16 %	10 %	10 %

### Estimating the impact of energy efficiency policy on household budget

We have seen that the TIMES-Households model provides useful insights on technology diffusion and reaction of households to energy price scenarios. It would then be possible to observe their reaction to an energy consumption curtailment constraint. As we have previously presented, the French government has adopted an energy efficiency target that would lead to a 35 %<sup>5</sup> reduction of primary energy consumption for space-heating and DHW in the residential sector.

We thus model such a reduction constraint for 2020 that we suppose to remain constant until 2030. Indeed we do not want to model a “shock of efficiency” but we assume that government would maintain its effort to save energy after 2020.

First, it is interesting to note that the amount of additional effort in insulation compared to the reference scenario depends on the energy price scenario but not on the price of equipment. Indeed when prices are low insulation of oil heated dwellings is profitable whereas prices are high it is more interesting to directly switch to an alternative efficient heating system such as heat pump. Then once the dwelling is equipped with heat pump, insulation become less profitable. In the case

of the low prices for equipment we can also observe a switch from direct electric heating to heat pumps; and the lower the energy prices the more effort is required to reach the constraint (i.e. an increase of additional measures). In the case of high prices for equipment (“Ins” scenario) we observe that the main switch is not from convectors to heat pumps but from convectors to gas boilers. Hence, we can observe a strong increase of natural gas consumption and a decrease in electricity and wood consumption compared to the reference scenario. Indeed, as the energy reduction constraint is set in primary energy this implies that a reduction of 1 kWh of electricity is equivalent to a reduction of 2.58 kWh of natural gas. Whereas wood systems also disappear because of their poor efficiency compared to gas systems.

As the model represents households in a very detailed manner we can observe the evolution of the budget share dedicated to domestic energy bill and investment for different types of households. Figure 8 shows the evolution of budget share over time for the different income quintiles.

It is first noticeable that reaching the Grenelle constraint in 2020 implies a strong increase of investments for all the households and this effort then decreases in 2030. Indeed the budget share dedicated to investments in equipment and insulation measures increases from 1.5 % to 2.5 % compared to the reference in 2020 according to the scenario and income. After the 2020-peak, we can also notice that for most households the

5. The -38 % for existing dwellings and that would lead to -35 % including new building construction for the period 2010–2030 [DGEC 2011].

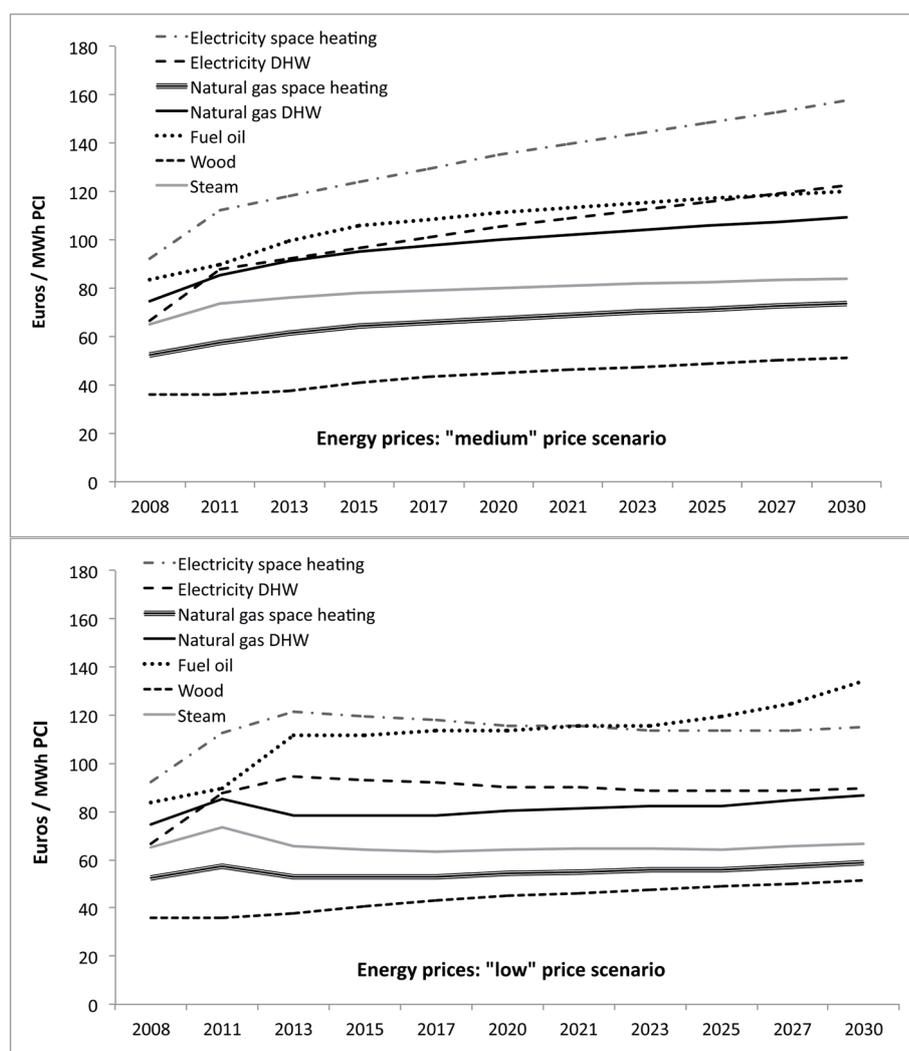


Figure 3. Energy price scenarios.

global budget share (CAPEX + OPEX) decreases to its 2006 value or less. Unfortunately this is not the case for the first quintile of households as their global budget share dramatically increases. Indeed as households of the first income quintile (36 % of which are fuel poor in 2006) are constrained in their access to capital they are not able to invest in energy efficiency. They thus experience an increase from 7.2 % to around 8.5 % of their budget share dedicated to energy bill despite strong efforts in investment, whereas it remains almost constant in 2020 and 2030 for the other households.

We have seen that reaching a target in primary energy would imply efforts in insulation and equipment efficiency but it would also require a switch from electricity and wood to natural gas. It is especially in the case when electricity is competitive – otherwise the switch to natural gas is already effective in the reference case – and when the price of insulation is low because once a dwelling gets insulated the level of demand has decreased and convectors become competitive as their investment costs are very low.

As low carbon content fuels (electricity and especially wood) disappear in favor of natural gas that is a fossil fuel we can wonder if the Grenelle constraint is in line with ambitious target in term of CO<sub>2</sub> emissions reduction.

### Primary energy consumption target and CO<sub>2</sub> emissions target: Do we have to aim before shooting?

French government has decided in 2005 [JORF 2005] an ambitious target of 75 % reduction in CO<sub>2</sub> emissions by 2050. Some studies made by CLIP [2010] have tried to evaluate a pathway of CO<sub>2</sub> emissions reduction in the residential sector that would lead to such a 75 % reduction. All of their scenarios obviously imply strong efforts in the period 2010–2030 in order to be able to reach the target in 2050. We have tried to evaluate the impact of a constraint on CO<sub>2</sub> emissions in addition to the Grenelle constraint and to observe whether or not a Grenelle constraint would easily lead to a coherent pathway in term of CO<sub>2</sub> emissions.

In France there is a strong debate about the CO<sub>2</sub> emissions due to electricity use in space heating because some may argue that the whole electricity production is very low CO<sub>2</sub> emitting, leading to an average carbon content of 60 gCO<sub>2</sub>/kWh produced; when other argue that electricity use for space-heating occurs during peak periods in which the production of electricity is very carbon emitting. In order to avoid strong controversy we would therefore consider the value retained by CLIP [2010] in their scenarios and based on ADEME [2005]: 180 gCO<sub>2</sub>/

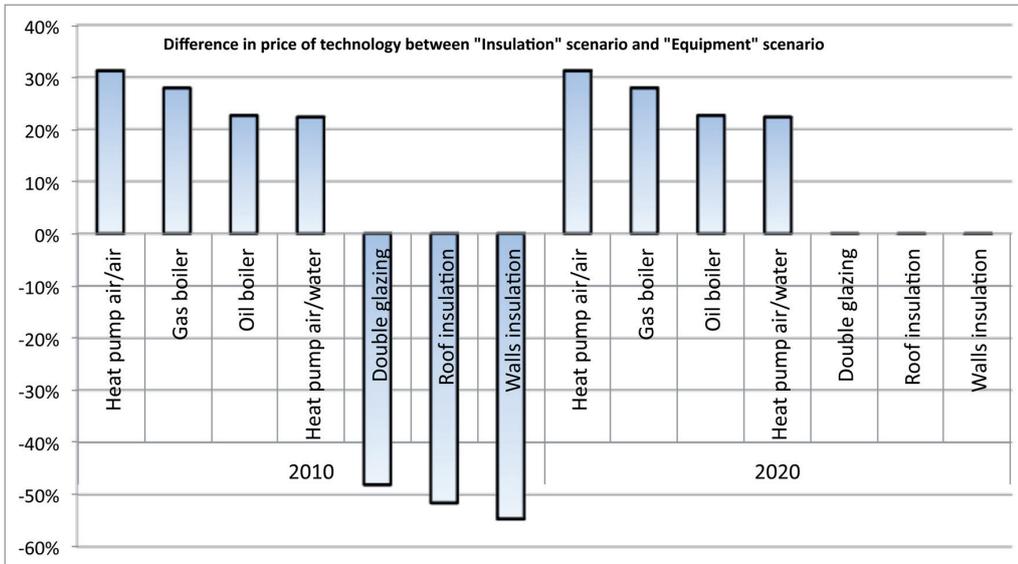


Figure 4. Difference in price of technology between "Insulation" scenario and "Equipment" scenario.

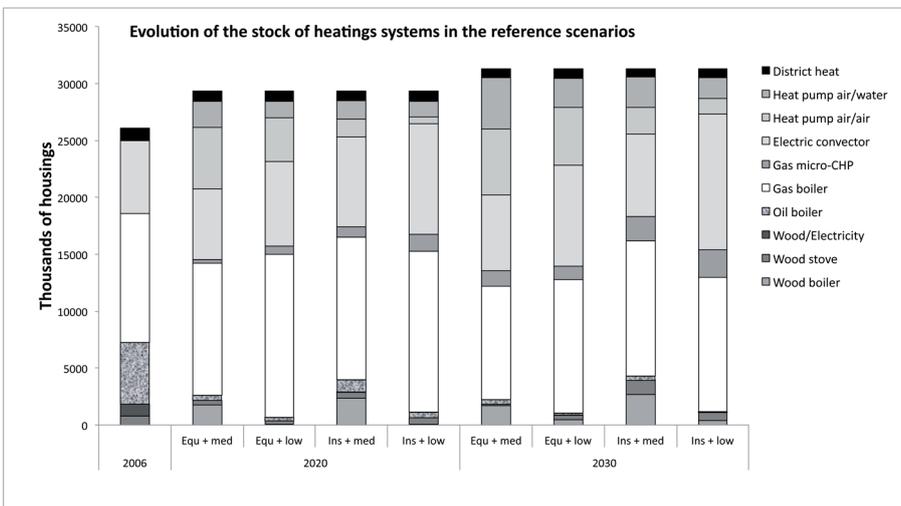


Figure 5. Evolution of the stock of heating systems in the reference scenario according to different energy prices (medium, low) and cost of measures (equipment, insulation).

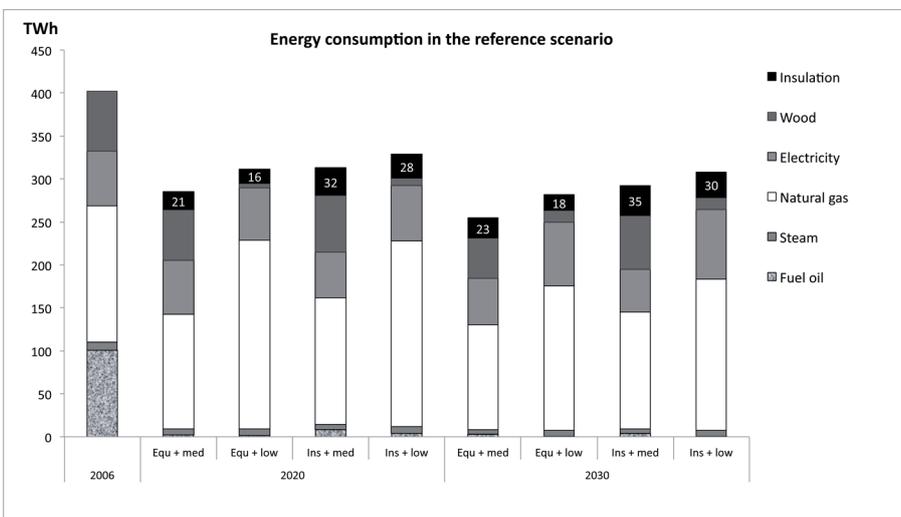


Figure 6. Energy consumption in the reference scenarios. "Insulation" represents the avoided useful energy consumed due to insulation measures undertaken.

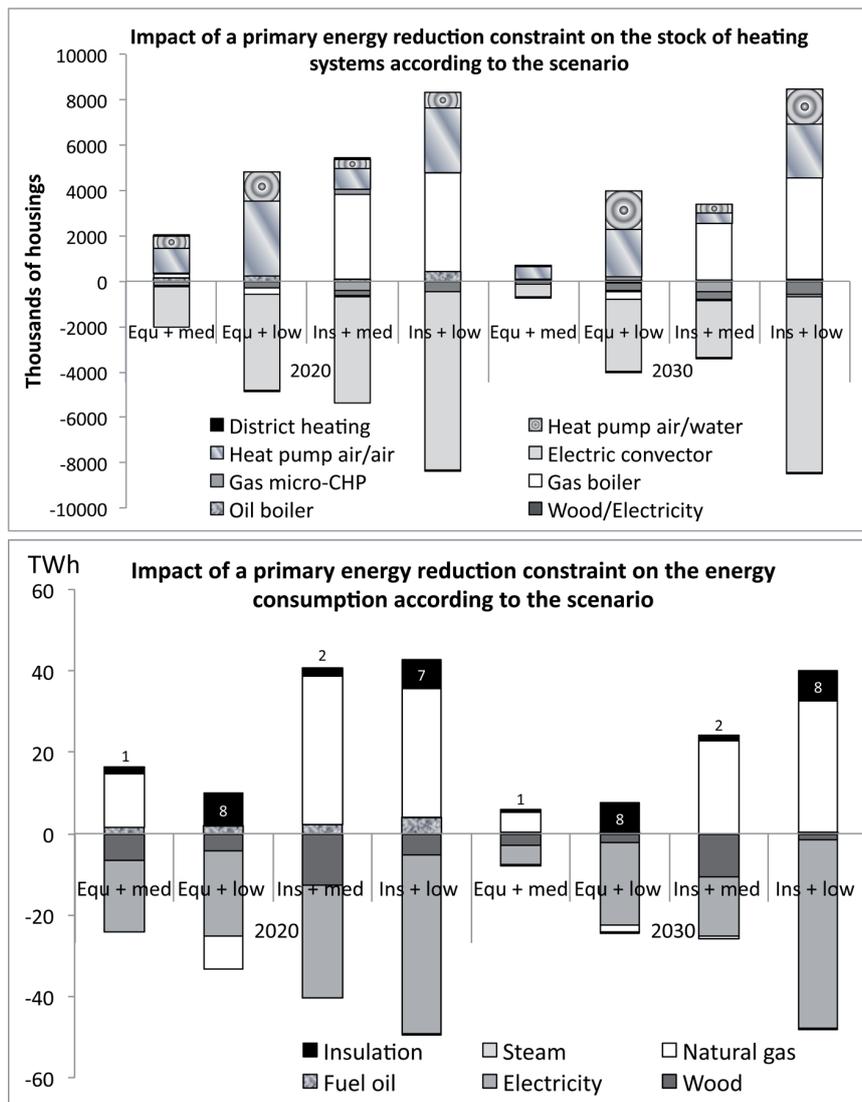


Figure 7. Impact of the Grenelle constraint on heating systems and energy consumption. “Insulation” represents the avoided useful energy consumed due to insulation measures undertaken.

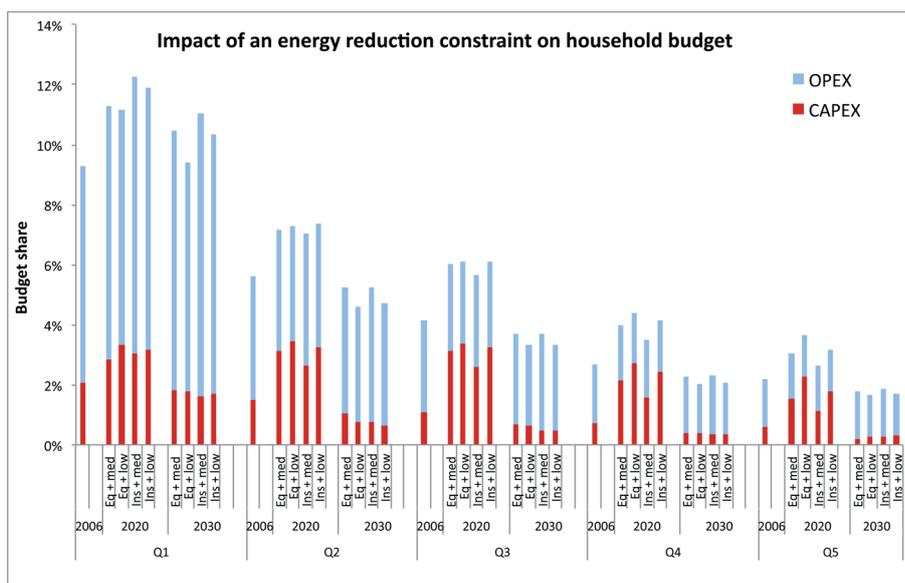


Figure 8. Impact of a Grenelle constraint (primary energy reduction) on household budget by income quintile. CAPEX: Capital expenditures, OPEX: Operational expenditure.

kWh for space heating and 40 gCO<sub>2</sub>/kWh for DHW (off-peak electricity).

Figure 9 shows the CO<sub>2</sub> emissions reduction achieved by the Grenelle constraint scenarios and the level of reduction achieved in the less stringent “factor 4” scenario produced by CLIP. We can see that an additional constraint in CO<sub>2</sub> emissions reduction is needed in order to follow a sustainable pathway for residential sector. This constraint lies between an additional 10–30 % in 2020 and 15–30 % in 2030 according to the energy price scenario.

In Figure 10 we can see the impact of an additional CO<sub>2</sub> emissions constraint on heating systems and energy consumption. We can observe a strong switch from gas boilers and gas micro-CHP (Combined Heat & Power) to heat pumps and wood systems, which appear in the energy consumption. In the case of low price of equipment the difference appear to be lower because these efficient pieces of equipment were already diffused. Indeed biomass and low-carbon electricity are generally found to be the only way to reach a strong CO<sub>2</sub> emissions reduction [Marchand et al. 2008, CLIP 2010, Cayla 2011]. Obviously we can observe that the more CO<sub>2</sub> emissions reduction achieved by Grenelle constraint is low, the more important are the additional efforts.

Figure 11 presents the additional efforts induced on household budget compared to the impact of the Grenelle constraint. It seems that this additional effort is of the same order of magnitude and that low-income households are not especially favored by this new constraint.

It is quite clear that a primary energy reduction target such as proposed by the Grenelle law is not in line with a 75 % in CO<sub>2</sub> emissions reduction target and this is especially true when the price of electricity is low compared to other fuels. Indeed when the price of electricity is low there is no incentive to invest in heat pumps which is a key-technology to reach a significant CO<sub>2</sub> abatement. The difference in the nature of equipment diffused and in energy consumed between Grenelle scenario and

Grenelle/CO<sub>2</sub> scenario is about 15 %, which is absolutely not negligible. The amount of global effort made by households (i.e.: investment and energy bill) to reach the additional CO<sub>2</sub> target has to be multiplied approximately by 2, depending on household income and scenario.

## Conclusion

The TIMES-Households model relies on a high level of disaggregation both on the offer side and on the demand side. Household behavior is taken into account in equipment purchasing and in daily consumption. TIMES-Households model helps to provide useful insights to policy makers in evaluating impact of policies or price scenarios on the diffusion of equipment, energy consumption and household budget.

It appears that reaching a reduction of 38 % in primary energy consumption by 2020, as mandated by the Grenelle law, would imply a significant change in the nature of the equipment diffused. This effort depends on the price of energy and technologies but generally implies a strong increase in investment suggesting that it would certainly be hard to reach the Grenelle target as found by other studies [Giraudet et al 2011, Allibe 2012]. This effort would be especially significant for least well-off households as they experience a significant increase of their budget share dedicated to energy consumption. Energy efficiency measures then tend to increase inequalities between households and fuel-poverty as energy bill of the first income quintile increases. It means that policies that allow least well-off households to invest in efficient technologies and then reduce their energy bill such as subsidies have to be promoted in order to reduce potential inequalities between households. It is also interesting to note that the more competitive is electricity, the more important is the effort to be done to achieve such a reduction in primary energy consumption.

Moreover in some cases aiming at a target in energy efficiency may not be compatible with a target in CO<sub>2</sub> emissions

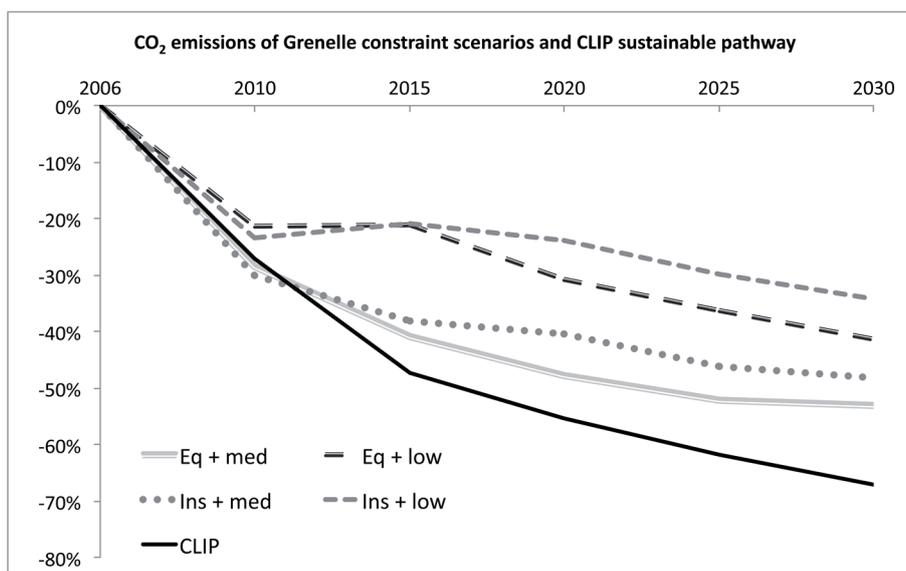


Figure 9. CO<sub>2</sub> emissions reduction of the Grenelle constraint scenarios compared to CLIP scenario.

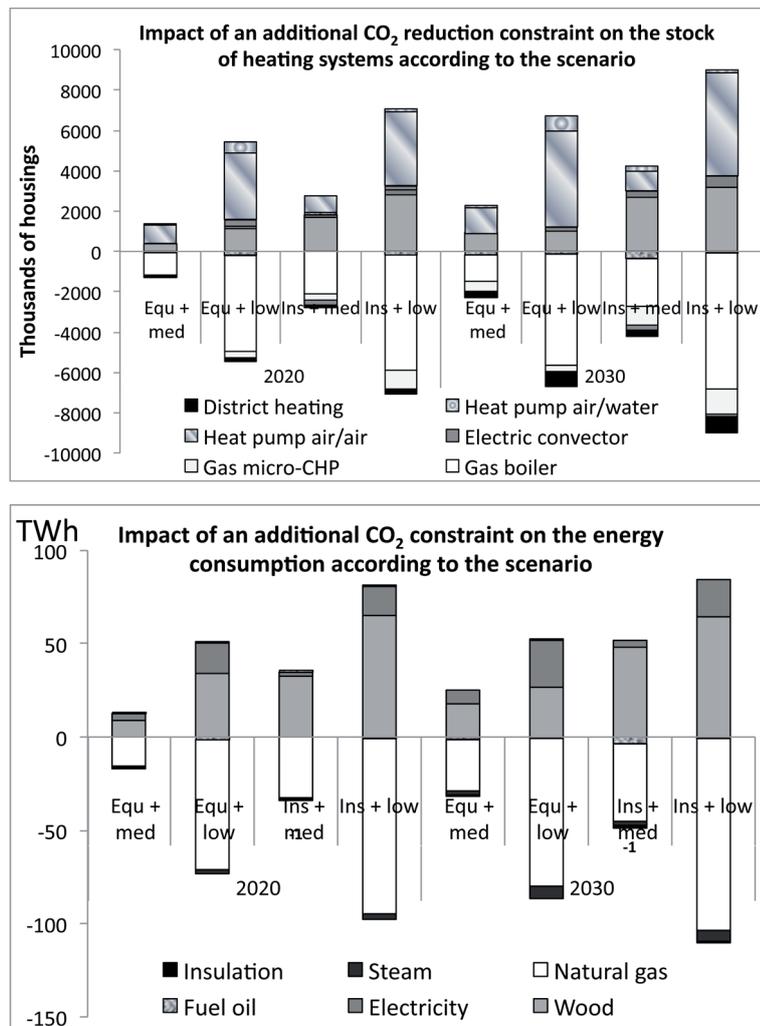


Figure 10. Impact of an additional CO<sub>2</sub> constraint on heating systems and energy consumption compared to the Grenelle scenarios.

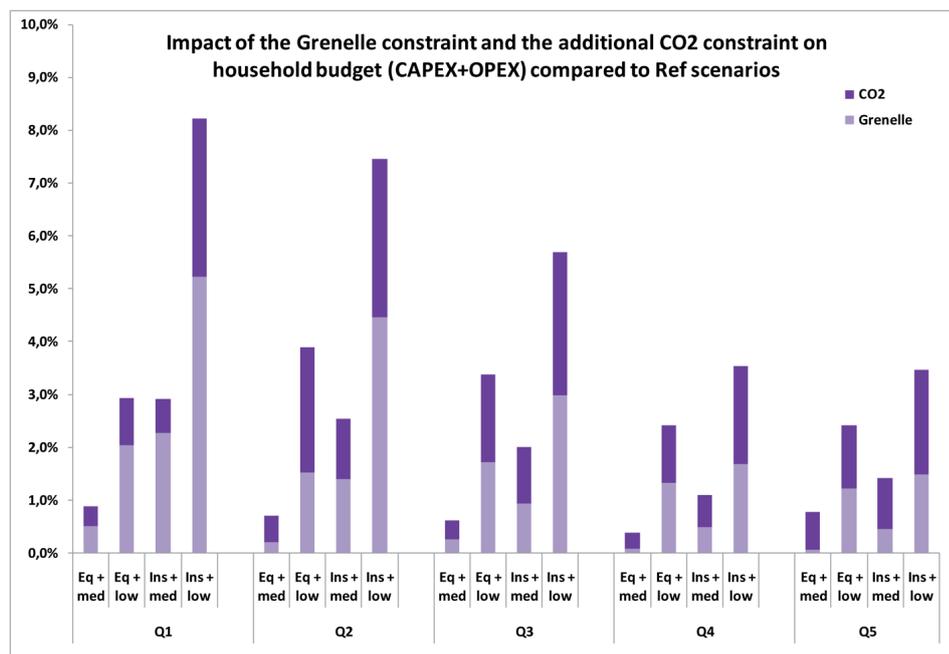


Figure 11. Impact of an additional CO<sub>2</sub> constraint on household budget compared to the impact of the Grenelle constraint.

reduction. Indeed we have seen that an additional effort may be required in order to follow a pathway coherent with both Grenelle target and “factor 4” target. The achievement of a CO<sub>2</sub> emissions reduction is mainly based on wood systems and heat pumps whereas the achievement of a primary energy consumption reduction is partly based on a switch from direct electric heating to gas boilers. This additional target implies significant additional efforts made by the least well-off households. The gap between CO<sub>2</sub> emissions target and primary energy target is increased when price of electricity and carbon content of electricity are low. It seems that specific policies aiming at helping the least well-off households to make efficient investments and reducing their energy bill are needed since Grenelle and CO<sub>2</sub> constraints lead to an increase of their energy budget and then of fuel-poverty.

European Union and France are facing many issues: fossil fuel depletion, security of supply, climate change and fuel poverty. In this context some policies that help reducing oil consumption may luckily address all of these issues at the same time, but others would not and in this complex context policy makers would certainly have to establish an order of priority when choosing targets of their energy policies.

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