MARGINAL ABATEMENT COST CURVE FOR CO_2 EMISSIONS IN THE MULTY-FAMILY HOUSING SECTOR WITHOUT OR WITH ENERGY EFFICIENY BARRIERS

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Abstract:
First aim of this article is to estimate the CO_2 emissions cuts available in a given building stock. According to our methodology based on a sharp segmentation of the park and a close estimate of refurbishment actions' price and impact on the energy consumption we were able to assess the Marginal Abatement Cost Curve of CO_2 emissions reduction for multi-family building stock in the local area of Grenoble. CO_2 emissions from this stock can be reduced by 72% with casual refurbishment actions. The potential decrease in annual CO_2 emissions reaches300 000 tons. Surprisingly, 92% of the potential decrease is hold by actions that are profitable for a purely rational inhabitant.
Based on those results the second aim of this article is therefore to understand the barriers that prevent housing from implementing refurbishment actions. A case study based on 40 multi-family housings points out liquidity constraints, poor share of homeowners, decision-making in co-ownership and inconvenience as the four main barriers. To integrate those barriers to our model we reduced inhabitants' time horizon and add a fix cost to each refurbishment action. If a reduction in inhabitants' time horizon is not sufficient to explain the poor rate of refurbishment actions observed in the area adding a fix cost of € 15 000 per building is enough to explain them.

Keywords: thermal rehabilitation, local climate plan, barriers to energy efficiency, Marginal Abatement Cost Curve

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INTRODUCTION

Since the implementation of the first measures for energy saving and climate preservation, the building's energy efficiency is becoming a core issue in the climate and energy policy orientations, at the worldwide, European, national or local level. Indeed, this sector represents a large potential for energy savings and CO_2 emissions in the perspective of the implementation of cost effective measures (Price *et al*, 1998, OECD, 2003, De la Rue du Can and Price, 2007, Levine *et al.*, 2007, Ürge-Vorsatz and Novikova, 2008, IEA 2008).

The European Union set up three major directives during the last twenty years aiming at encouraging the Member States to apply minimal requirements on energy performance for the new and existing buildings. The Member States transposed these directives in national law by setting up action plans in order to achieve reducing targets in energy consumptions and GHG emissions.

In France, within the framework of environmental regulation (called the "Grenelle for environment"), a "Grenelle Building Plan" was created with the goal to cut down by 38% the energy consumption to 2020 in existing buildings and by 50% the GHG emission to 2050. It aims in particular at Renovating 400,000 housings each year from 2013 to 2020.

In this context, the forecasting models at national level provide key elements for reaching goals such as the "Grenelle Building Plan" ones (Traisnel *et al*., 2010) as they allow analyzing/testing the public incentives (Giraudet *et al*., 2011). However, the mobilization of local authorities on the energy savings issue in housing is getting stronger (Bailey 2007, Wheeler, 2008). The built up area, which get involved in the Territorial Climate Plan implementation, also enclosed the Grenelle targets regarding this sector in their area. To reach this targets, they use their competences (Housing, town planning etc) to move their territory toward energy efficiency and also provide incentives (financial and non-financial) (IAE-OCDE, 2005, Mckinsey 2008, Criqui *et al*. 2010). Indeed, the mobilization of local authorities on this issue is fundamental because the localization and the context in which buildings were built play a role on there energy efficiency.

That is why our work aims at assessing, at a territory scale, with a bottom-up approach, the environmental and economic impact of technical solutions for rehabilitation and at evaluating the cost of reduction of CO_2 volume. We focus on CO_2 because in the household building sector, this gas represents almost the whole of direct emission of GHG. We produce a marginal abatement cost curve that shows a lot of cost-effective thermal refurbishment measures.

We deal also with the issue of barriers to energy efficiency, in going by an empirical study of multi-family buildings in Grenoble area. We modify our initials assumptions to take into account the two mains barriers identified in this study and produce a new abatement cost curve.

In a first section (§ 0, p.3), we present the main criteria to carry out a relevant segmentation in order to study, from a technical point of view, the building refurbishment, i.e. the type of housing (multifamily apartments), the year of building's construction and the energy source used for the heating system. The criteria selected to carry out a segmentation of the park determine the business as usual scenario of the energy consumption and CO_2 emissions of the existing housing.

In a second section (§ 0, p.5), we come back on the principal technical solutions currently available to reduce building energy consumptions. We observe, for a standard case, the impact of these various solutions on energy consumption and CO_2 emissions.

In a third section (§ 0, p.7), we show the economic impact of these various solutions by analyzing their profitability, through indicators such as payback period, net present value and cost of an avoided CO_2ton. These estimates allow treating on a hierarchical basis the solutions according to their technico-economic effectiveness.

In the fourth and last section (§ 0, p.10), we deal with the issue of the barriers to energy efficiency, by identifying them, starting from an empirical study. We observe then the impact of the modification of the assumptions concerning present preference of the households (by reducing the payback time) on the profitability and on the cost of the CO_2 avoided of the technical solutions.

THE SEGMENTATION OF THE HOUSING PARK

We deal only with multifamily apartments and we hold two main criteria: the year of construction of the buildings and the energy source used for the heating system. We also take into account climatic data, characteristic of the studied zone.

The building's age

The date of construction makes possible to provide key information on materials used for the construction and the thermal characteristics of the building (Table). The delimitation of each period can be done according to:

- Great historical periods marking the urban history such as the Revolution, wars, the Thirty Glorious Years (i.e. the French economic welfare between 1945 and 1975), the oil crisis, etc.
- Modifications of urban policy such as the policy of the post-war period, the stop of the construction of towers blocks etc
- Changes of constructions regulation and standards which followed since 1975.

Period of construction	Context	Building materials	Energy performances
Before 1945	Period "Haussmannienne", no thermal regulation (RT)	Depend on the areas (local materials) Mainly stone and brick	Weak
1945-1974	Post-war period, lot of construction. no RT	Thin walls, in concrete without insulation, no double glazing	Very weak
1975-1981	Oil crisis which induces the 1st RT (1974)	Emergence of prefabricated systems, beginning of walls insulation, ventilation system etc.	Weak_average
1982-1999	2nd RT (1982)	Smaller buildings, generalization of double glazing and wall insulation, beginning of materials certification, beginning of old building's refurbishment	Average
After 2000	3rd and 4th RT (2000 and 2005), (RT 2012 forthcoming).	Reinforcement of wall insulation, reduction of heating needs, increase of the equipments' energy performances ; creation of new labels for buildings' certification	strong

Table 1: *Thermal characteristics of the buildings per period of construction*

The information provided by the last census of the French national institute of statistic and economics studies (INSEE), makes possible to carry out a segmentation of the housing stock on the Grenoble area according to the period of buildings construction. It appears that among the 166,311 housing in this area (including 82% of multifamily apartments), 101,744 housings (61%) were built before 1975 and 76,553 (46%) between 1945 and 1975 (information collected by Enerdata, in the framework of ITEAC project).

The large part of old housings, built with materials and techniques used between 1945 and 1974, shows an important potential for energy savings on this territory.

Heating system

The energy source (gas, fuel, heating network, electricity) and the mode used for heating (central or individual) have an impact on energy consumption. The gap between energy consumption generated by gas and the one generated by electricity is explained mainly by the fact they are expressed in primary energy (ep) which includes the energy lost between the energy production and the supply of energy in the buildings (energy actually used by consumption). The conversion factor from final energy to primary energy is 1 for all fuels (here, fuel and natural gas) and 2.58 for electricity, in order to take into account the output of electricity production and transmission. This factor of 2.58 corresponds to an international convention. It aims to compare energy consumptions according to the various sources used. In France, a controversy exists about this factor because electricity is produced mainly with nuclear power plants (between 70% and 90%) and with hydroelectricity and this factor is thus suspected not to reflect reality by exaggerating the losses related to the production and transport. However when demand peak occurs, the production is done starting from fossil energy (either in France by historical producer EDF, or in another country like Germany which exports it in France). By convention, we preserve this factor of 2.58 and tackle the question of the energy consumption of the residences in primary energy by preoccupations with coherence with the thermal regulation.

Expressed in final energy, the residences heated with electricity are less energy consuming than those heated with other energetic sources. We chose to express consumption in primary energy because the electricity production and transmission are directly related to the demand. On the other hand, expressed in CO_2 emitted, emissions are more “favorable” to electricity, at least in France, because of the large share of the nuclear power in the electrical production.

Assessment of consumption by segment: example of the Grenoble area

In crossing energy consumption by segments resulting from theoretical simulation, with the number of multifamily apartments per segment in the Grenoble area we can (i) estimate energy consumptions and the total CO_2 emissions of the multifamily housing park and (ii) identify the segments which represent the main potential of reductions.

On the figure above, it clearly appears that the buildings from 1945 to 1974 produce the most significant share of energy consumptions and CO_2 emissions.

This is explained on the one hand because this segment represents the largest number of housing in this area but also because, as we explained in section 1, building from this period have bad thermal characteristics and thus large energy loss.

But, the high share of building built in this period (46 % of the total park of multifamily apartments) can’t by itself explain the 63% of CO_2 emissions. Indeed the gap between CO_2 emissions (63%) and energy consumption (56%) is explained by the energetic mix in each period. For instance, the buildings build before 1945 are more heated with electricity (approximately 43%) than those of 1945-1974 (approximately 14%) which are mainly heated with gas (57%).

The segmentation per construction and heating energy mode enables us to draw a representation of multifamily park and to identify the segments on which it is necessary to first operate for

thermal refurbishment. It appears that buildings built between 1945 and 1974 are those on which it is most relevant to act because they have a large potential of reduction.
The determination of the energy consumptions and CO_2 emissions and the identification of the segments which have an important potential for reduction are only the starting point of our study. The final objective of this part is to evaluate the economic impact and environmental various technical solutions.

TECHNICAL SOLUTIONS FOR THERMAL RENOVATION

A broad panel of current technologies exists to carry out energy savings allowing smaller energy consumption than standard practice (Novikova, 2010). These technologies relate to various solutions such as insulation (of walls, roofs, floors etc), improvement of heating system performance, ventilation system. Technical solutions identified here only deal with the reduction of heating consumption. Moreover, we chose “ambitious” measures because of the long lifespan of the equipment in the building, and when heavy work is undertaken (like external wall insulation or boiler replacement), it is unlikely that they are reiterated quickly. This works are called “no regret measures” because it is more efficient to implement them in one time and if retrofit measures are coupled with general refurbishment, it represents a win-win opportunity (Petersdorff *et al*., 2004)

Insulation
The energy losses due to bad walls and windows insulation affect the thermal characteristics of building. If the shares vary according to the date of construction, the main loosing area is often the same: walls, windows and joineries.

- External walls Insulation: it is still poorly developed in France (Orselli, 2008). However, the restoration of the external wall is the good opportunity to add insulation (the repair of the sealing must be carried out every 20 years. This operation can be the occasion to complete work with thermal insulation). Unlike interior insulation, it makes possible to treat a greater number of thermal bridges, without provoking a lost of living space and without decreasing the building inertia. It involves also less nuisances for the occupant during the works and protects the walls against climatic risks. Several techniques of insulation exist, the main one being the installation of an insulating material covered with a coating. The insulators can be alveolar plastics or mineral wool. The effectiveness of the insulation depends on thermal resistance (R) of material used.
- Roofs insulation: they are subjected to the climatic variations (such as thermal freezing, rain, shocks etc.) which deteriorate the roofing and the tightness. The roof thermal losses account for 9 to 11%. The roofs insulation has an important potential for energy saving and its implementation is less heavy than wall insulation. It allows to reduce energy consumption and to improve comfort for the inhabitants in the top floor.
- Low floors insulation: floor lead to losses from 5 to 7% for the independent buildings and up to 9% for the joint buildings. For the apartments located at the ground floor, the floor insulation is a source of energy savings and comfort improvement. It is possible to insulate over or under the concrete flagstone. The choice of one or the other technique will depend on the accessibility of the lower part of the flagstone.

- Windows: thermal losses coming from windows can represent up to 50% of the total thermal losses of a building. In housing, window has several functionalities: it allows improving air quality by natural ventilation and it offers a natural lighting and source of heat by the recovery of thermal contributions of the sun. To reduce the losses, it is possible either to improve existing windows, or to entirely change them. First solution is possible if original joineries are still in good condition. The second solution is recommended when original windows are in bad conditions. The replacement can be done either by preserving the door frame, or by replacing the complete door frame. Joineries can be out of wood, PVC or metal. PVC framing is most widespread because it resists the bad weather and does not require maintenance unlike joineries in wood. Metal fixed frame (aluminum) is generally reserved for large surfaces windows.

The heating system

According to the French thermal regulation for existing building (RT ex 2005), the electric radiators installed or replaced must be controlled by a powerful integrated electronic device, with at least four operating process (comfort, reduced, no-freezing, stop) and must have timer if they have other functions (blower, towels warmer etc). The standard convectors present very high electricity consumptions. Electrics radiators (with radiant source of energy) offer more homogeneous with low consumption. When the change of radiator is done at the same time or after the insulation of the building, the power necessary will be lower.

Regulation and programming allow regulated heating temperature according to external conditions and free energy contributions. A powerful electric radiator, equipped with a thermostat, can reduce from 5 to 15% the energy consumption compared to an old convector without thermostat.

For the boilers (individual or collective system), considerable progresses were made during the last years. They offer a better output and thus allow reducing energy consumptions. The two principal innovations for boiler are:

- Low temperature boilers: they have an output from 80 to 90%. They allow carrying out 12 to 15% of profits compared to traditional ones,
- Condensing boilers: they reach an output higher than the low temperature boilers thanks to the recovery of the after-heat contained in the steam of the gases combustion which are evacuated by the chimney. They make it possible to carry out from 15 to 20% of profits compared to a traditional boiler. By condensing the steam of combustion gases, they recover energy, allowing a reduction in the fuels needs. Because of their low level of CO_2 and nitrogen oxides, these boilers are also less emitting in GHG.

Ventilation system

The improvement of the ventilation system must be taken into account as soon as people want to optimize the energy performances of the ventilation system (it is a measurement of full-fledged energy saving, because air renewal generates a reducing in energy losses of around 30%), but also as soon as the thermal insulation of housing is improved (in complement of the insulation). Thus, the mechanical ventilation (MV) becomes essential to control air flows necessary to the sanitary arrangements for households.

A system of MV makes it possible to removal the inside air of the buildings while controlling the necessary flow. The air is introduced in frontage, circulates in the buildings then is included in the wet parts (kitchen, bathroom) before being rejected.

With heat recovery ventilation, the extraction and the air intake are mechanized and controlled. With heat exchanger, 90% of the evacuated hot air calories can be potentially recovered. But this technique is less cost effective than MV, because it requires more maintenance and has an electric consumption 2.5 times superior.

The Table 2 sums up the technical solutions that we integrate in our model for assessing reduction potential.

Solutions	Effectiveness	Example of technique
Wall insulation	R = 5	Polystyrene plates (15 cm, λ = 0.03)
Roof insulation	R = 5	Polyurethane plates (14 cm, λ = 0.028)
Floor insulation	R = 2,6	Glass wool (10 cm, λ = 0.039)
Windows	Uw = 1.2	Double glazing, high quality joint, PVC framings
Electric radiator	High efficiency	News radiators with integrated thermostat
boiler	High efficiency	Condensing boilers
Ventilation system	Controlling flow	Mechanical ventilation

Table 2: *Technical solutions used in the model*

We choose these main options for our assessment, but several others solutions exist (technological and non-technological), that will be integrate in our research.

ASSESSMENT OF THE TECHNICAL-ECONOMIC REDUCTION POTENTIAL

Methodology and assumptions

The aim of this section is to assess the marginal abatement cost of CO_2 emissions in the multi-family building stock in a given area (the Grenoble area) according to the cost of the CO_2 ton. The main target is to identify the refurbishment actions considering the price of the CO_2ton which make the investment profitable for society.

For every type of technical solution described in the previous section we calculate the Net Present Value (NPV) with a discount rate of 4%. This rate is used by governmental organizations to assess the efficiency of public investments since 2005 (revision of the actualization rate of public investments, chaired by Daniel Lebègue, Commissariat Général au Plan, January, the 21st 2005). We assume an increase of energy prices of 3% a year (this increase rate corresponds to the projection of IAE in 2008 and is usually used in forecasting models).

The assumption about the technical solutions' life time is based professional building field. We assumed that equipments –heating and ventilation systems- have to be changed after twenty years and the other refurbishment works have a life period of forty years.

Price of refurbishment works are based on a professional database used in building sector (the *Batiprix* database), enlightened with our expertise. We decided to assess the price of refurbishment works on marginal costs instead of total cost for wall and roof insulation. This means that we only took into account the cost of insulator equipment and not the cost of front refurbishment or roof waterproofing. For the other kind of work the cost of the full operation is taken.

To assess the impact of refurbishment actions on the energy bill we used thermal simulation software ("BAO Promodul tertiaire et collectif"), requiring an exhaustive description of the building. This software provides two different ways to evaluate the energy consumption. The first one is the calculus process used in the French regulation (called "TH-c-ex") and the second one, called below the behavioral calculus process, is closer to the German PHPP calculus process. To get more consistent results and to have elements of comparison between those two processes we made the estimation with both of them. After assessment, we chose to use the behavioral calculus process, because the results are closer to the real consumptions according to the developer of the thermal program and empirical verification. Results using THC-ex are not presented in this paper but were done to validate the results presented below.

To describe the buildings we chose between an isolated and an adjacent configuration. We decided to consider every building to be all adjacent both because buildings in the area studied are predominantly adjacent and because it tends to offset the overestimation of refurbishment actions stemming from the additive assumption described in point 0 (p.8).

Besides we assess the CO_2 emission cuts stemming from the refurbishment work over the life period. Based on the spare amount of CO_2 we then evaluate the price of the CO_2 ton that nullify the NPV. This price indicates the cost of CO_2 ton that would make the investment cost effective. For example a cost of CO_2 ton of €48 indicates that a household will not implement the refurbishment measures unless he is forced to pay a fictive tax of at least €48 for every ton of CO_2 they produce.
At this point we have, for every type of refurbishment work in every segment of building, the volume and the cost of CO_2 ton avoided that make the refurbishment work profitable.
In crossing this assessment with INSEE data presented in point 0 (p.4), we can calculate the marginal abatement cost for each segment and classify the different refurbishment work and their global impact according to the price of ton of CO_2 in order to build Marginal Abatement Cost Curve (MACC).
In order to take into account different refurbishment packages, i.e. the combination of various refurbishment actions on the same building, we tested two different hypotheses, one additive and the other cumulative:

- The additive hypothesis assumes that the effects of refurbishment actions are identical in all refurbishment packages. For example, if wall insulation reduces energy consumption by 20% and roof insulation reduces energy consumption by 10% the package would reduce energy consumption by 20% + 10% = 30%.
- The cumulative hypothesis assumes that the relative impact of a refurbishment action remains constant. For example, if wall insulation reduces energy consumption by 20% and roof insulation reduces energy consumption by 10% the cumulative effect would reduce the consumption by 1 – (1-20%)*(1-10%) = 28%.

We tested both assumptions on a couple of cases and finally opted for the additive assumption as it was closer to the software results for the whole package, although the impact was slightly overestimated. The additive assumption is closer than the cumulative one as some refurbishment actions have a synergetic effect. For example, the implementation of a sophisticated controlled mechanical ventilation system is useless if there are high air leakages by the windows. Mechanical ventilation and window change are therefore working in synergy. And if the complete insulation of the building is made the power of the heating system can be lowered.

Results
According to our model, the overall CO_2 emissions of multi-family housings' heating system in an urban area reach the level of 40,414 tons each year. To control our assessment, we compare the initial overall CO_2 emissions stemming from our model to a previous estimate made by the center which made the emission inventory in this area (In Grenoble urban area an inventory of energy consumption and CO_2 emission is conduct by ASCOPARG. This kind of inventory is conducted in almost all urban areas in France). With an estimated level of emissions of 370,000 tons each year for collective housings' heating system emission our results are closed to this estimation.
This level of emissions corresponds to a level of energy consumption of 2,469 GWh of primary energy, about 229 kWh per net floor area square meter.

Figure 1 presents the marginal abatement cost curve taking into account energy gains over the entire life of refurbishment actions.

As we also took into account energy consumption for domestic hot water in collective housings with individual gas boiler, the overall CO_2 emissions are a bit higher than in the previous part. Indeed, annual CO_2 emissions level including domestic hot water in collective housings with individual gas boiler reaches 447,254 tons.

The implementation of all refurbishment actions taken into account can reduce annual CO_2 emissions in the multi-family building sector by 300,000 tons. If we focus on heating system emissions, the potential cutbacks reach 290,000 tons, representing 72% of CO_2. The curve can be broken into three distinct parts:

- The first 20% of CO_2 potential cutbacks have a carbon price below €-200s
- The 72% followed lies in the €[-200; 0] range
- The last 8% have a positive price.

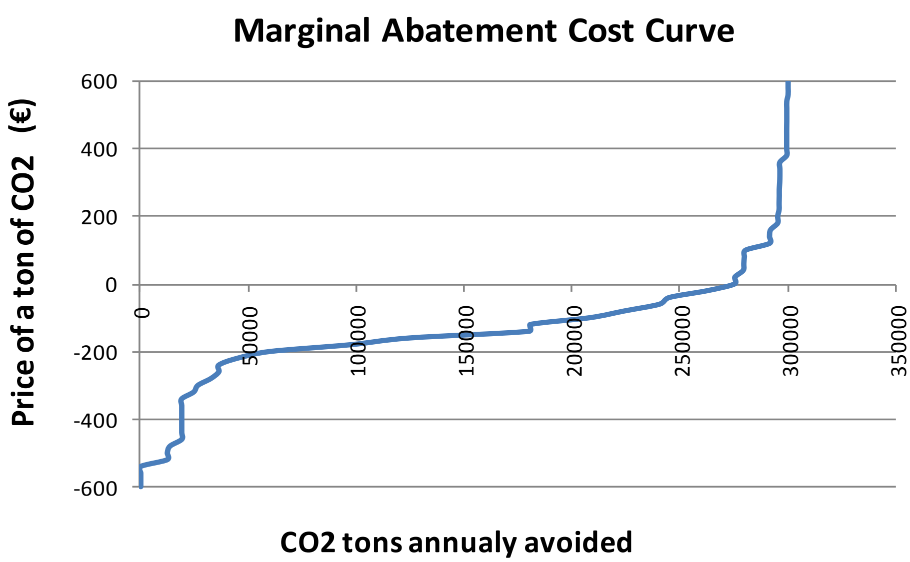

Figure 1: *Marginal abatement cost curve with life cycle analysis*

The reduction potential is different according to the period of construction and the technical solutions:

- Potential CO_2 cutbacks vary greatly with the period of construction: 1945-1975 buildings account for 59%; ante – 1945 buildings account for 27% and post 1975 buildings only account for 11%. As shown on the **Error! Reference source not found.**, the MACC is highly sensitive to the cost of the CO_2ton when its price varies between €-200 and €-20. 48 of the 115 actions are profitable on this price range. Besides, those actions stand for 68% of the potential CO_2 emissions cutback. Multi-family apartments built between 1945 and 1974 account for 44% of total collective housings in the urban area but stand for 60% of the potential of CO_2 reductions. Ante-1975 multi-family housings represent 68% of the overall housings but account for almost 87% of the potential CO_2 cutbacks. Those buildings should clearly be the heart of a low carbon refurbishment plan.
- Refurbishment actions taken into account also have different potentialities. Equipments renewal or installations stand for almost half of the potential, with change of boiler accounting for 26% of the CO_2 decrease and the ventilation system accounting for 20%. Insulation accounts for the other half of the potential, divided between wall insulation -24%-, window replacement -14%, roof insulation -9% and floor insulation -7%. Roof insulation does not account for a large share of potential reduction because of French regulations forced to isolate the roof since 1974. The impact of equipments might be overestimated as some collective buildings might have already replaced their boilers and

as the impact of ventilation system is very difficult to assess. Impact of floor insulation might as well be overestimated as we assume this action to be possible in every situation.

Finally we find four main categories of buildings after our assessment of cost effective measures: untouched (14%), poorly refurbished (i.e. with one or two actions (23%)), well refurbished (i.e. between three and five actions (47%)) and totally refurbished (16%).

The cost of those actions is M€1,793. This gives an average price of CO_2 ton avoided of €3,900.

Implication for energy policy

In France, the 2009 “Grenelle” legislation as the Grenoble Climate Plan, stands that CO_2 emissions in existing buildings have to be cut by 50% until 2050. According to the results presented in Figure 1, this goal should be achieved with a negative carbon cost of -€156 per ton.

Looking closer at refurbishment actions with the national target provides a different perspective concerning their distribution and impact.

At this cost of the CO_2 ton for ante – 1975 buildings stands for 93% of the CO_2 cutbacks, divided almost equally between the ante – 1945 and the 1945 – 1975 periods. Ante 1945 buildings now account for 48% of the potential while they only account for 27% of the overall CO_2 potential decrease, while the impact of buildings built in the 1945-1975 period is lowered.

The price of reaching the policy target is about €375,000,000. This gives a global price of the CO_2 ton avoided of about €2,150 euro. In integrating the reduction of energy bill, the weighted price of the CO_2 ton is -€227.

The main result of this graph is that 92% of CO_2 cutbacks are due to refurbishment measures with negative CO_2 cost, which means that those actions are actually profitable for society and should be naturally implemented. Therefore there are huge lacks in our model, especially in the description of the inhabitant behavior, we can wonder why those refurbishment actions have not in fact been implemented for the overwhelming majority. Understanding those lacks will be the aim of the last part of our article.

ENERGY EFFICIENCY BARRIERS

In spite of many opportunities to reduce energy consumption and CO_2 emissions at low cost, energy efficiency actions are realized at a slower rate than expected (Novikova, 2010). This is due to various barriers such as technological, informational, market-based and behavioral (as bounded rationality) characteristics (Jaffe and Stavins, 1994, Golove and Eto, 1996, de T’Seclaes, 2007, Gillingham *et al.,* 2008).

A case study: a Policy for thermal rehabilitation of 40 multifamily building in Grenoble

A thermal rehabilitation plan in a district of Grenoble was launched by the city. Among the whole technical solutions suggested, all were profitable maximum in 20 years. Moreover, in addition to the national aids (tax credit, loan without discount rate), the city brought a help in order to reduce the payback period. However, among the 43 buildings which had to make a renovation (for aesthetic reasons), which could receive financial aids and which received an energy survey financed by the city, only 22 decided to do energy efficiency works and only 2 did ambitious works (replace the boiler, walls insulation, installation of ventilation system). The others undertook between 1 and 3 operations.

This shows that even if some barriers are reduced, some of household do not invest in energy efficiency.

We carried out interviews with the agents charged to contact the households and to incite them to carry out refurbishment works, the syndics who represent 150 households and some households. From these talks, we identified the following barriers:

- Liquidity constraints: the households do not have the possibility of releasing the funds necessary for work or, when they have savings, they prefer to preserve them for other uses. This shows that the households associate works to an opportunity. Among the owners, the greatest part of them is represented either by old people or by young first-time buyers. According to the syndics, liquidity constraint is the main barrier to invest.
- The weak share of homeowners: for the buildings we studied, less than 50% of the household are owners of their housing. This element strongly reduces the will for an owner to complete work because it is not him which will recover energy saving.
- The decision-making in co-ownership: the decision to complete works, in the case of the condominiums needs a vote in general assembly. This step requires time, implication and negotiations of the whole owners which can cause discouragement. Besides some actions, e.g. roof or floor insulation, have different impacts depending on the location of the flat inside the building. Splitting the cost can be very difficult in some assemblies.
- The inconvenience of the works: this barrier depends on the kind of works, but a part of respondents pointed it out.

The difficulty is to estimate the cost of these barriers in order to determine their impact on the potential and to see how the public authority can face them.

News assumptions and perspectives

The results we presented in the previous section are obtained by assuming no other cost than refurbishment actions and with long term anticipation. This is the reason why the main part of refurbishment actions is implemented with a negative CO_2 price.

To take into account barriers like lack of information, short term view or liquidity constraints, we tested two new assumptions.

First, we reduce the decision maker's time horizon. Reducing the time horizon is a way to account for inhabitant's short term vision but it can also be the consequence of other transaction costs. This modification is equal to an increasing of discount rate. Indeed, we increase the consumer discount rate to reduce the payback period. From a social perspective a low discount rate must be used to identify the economic potential, but from a household perspective, this rate can represent the more or less "short-sightedness" (Frederick *et al*. 2002).

We find a new marginal abatement cost curve with a five year horizon in the inhabitant estimation of the NPV (Figure 2).

Even with a five year time horizon, 43% of the CO_2 potential cutbacks should be implemented with negative cost, but potential decreases with highly CO_2 price sensitive between –100 and 0. 15% of the potential cutbacks have a price below -€100 and only 6% have a price below -€140.

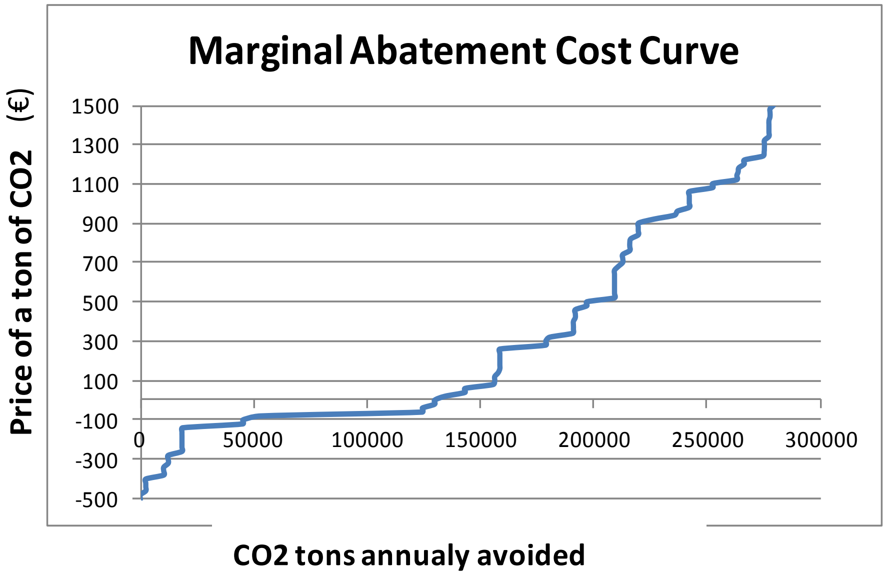

Figure 2: *Marginal abatement cost curve with a five year horizon*

Second, to take into account the inconvenience of such refurbishment actions we added a fix cost to all actions. In our model the fix cost for the building is the same for every type of action, although inconveniences stemming from refurbishment works can vary greatly. In fact, the aim of this part is to assess the sensitivity of the MACC to the fix cost rather than trying to properly estimate those costs.

With a fix cost for the building of €15 000 per action – being €1 071 for ante 1945 buildings and €536 for the rest of them- only 3% of CO_2 cuts are profitable for the inhabitants with a five years' time horizon. The MACC is therefore highly sensitive to the existence of a fix cost. On the contrary, with a fix cost of €20 000 per action for a whole building 75% of CO_2 cuts remains profitable.

A public action targeting the lengthening of inhabitants' time horizon should therefore be very efficient for the barriers that could be model by a fix cost. With the five year horizon and with a fix cost of €15 000 per action, any actions nullifying this cost would lead to an annual decrease in CO_2 emissions of 130 000 tons.

CONCLUSION AND OPPORTUNITIES FOR FURTHER RESEARCH

The methodology developed to estimate initial CO_2 emissions and potential decrease can be implemented for other building stock and should be used by any authority involved in a Territorial Climate Plan.

The first part confirms that the building sector holds a vast potential of CO_2 emissions cuts and that a large part of this potential should be reachable with no expenses from public authorities.

The originality and the main contribution of this article are to bring elements to develop a methodology to understand why those refurbishment actions are not implemented in the real world. The shortening of inhabitants' horizon or the introduction of a fix cost reflecting the inconveniences stemming from refurbishment actions are the two options explored in this paper but other barriers could be questioned in a later work. In particular, liquidity constraint and fix cost dependent from the type or the number of actions are possible assumptions to test. Besides, another development of this work could be the calibration of those barriers based on case study results.

Finally, the households support their decision to invest in energy efficiency measures on a discriminating criteria (improvement of comfort, reduction of noisy, improvement of the inside air quality etc) which decreased the only weight of economic criterion. In such a context, the use of cost effective analysis is relevant to include/understand the policy guidelines and particularly the choice of incentive tools, but it can be interesting to couple it with a multicriteria analysis in order to better comprehend the gap between the theoretical results and the choices of households.

LITTERATURE

Bailey, J., *Lessons from the pioneers: tackling global warming at the local level*, institute for local self-reliance, pp 1-17. 2007.

Criqui, P., Menanteau, P., Avner, P. (2010). In Carassus, J. Duplessis, B. (eds.). *Economie et développement urbain durable*. Paris : Presses Mines ParisTech, pp. 19-39.

De la Rue du Can, S., Price, L., *Sectoral trends in global energy use and greenhouse gas emissions*, Energy policy 36, pp. 1386-1403, 2008.

Frederick, S., Loewenstein, G., O'Donoghue, T., *Time discounting and time preference: a critical review*, Journal of Economic Litterature, Vol. XL, June, p. 351-401, 2002.

Gillingham, K., Newell, R.G., Palmer, K., *Energy Efficiency Economics and Policy*, Discussion Paper, Resources for the future, 2009.

Giraudet, G., Guivarch, C., Quirion, P., *Eploring the potential for energy conservation in French households through hybrid modeling*, Working Papers No 26-2011, Centre International de Recherches sur l'Environnement et le Développement (CIRED), 2011.

Golove, W., Eto, J., *Market Barriers to Energy Efficiency: A critical reappraisal of the Rationale for Public Policies to Promote Energy Efficiency*, LBL-38059 UC-1322, 1996.

Harvey, L.D., *Reducing energy use in the building sector: measures, costs and examples*, Energy Efficiency, p139-163, 2009.

IEA (International Energy Agency), *World Energy Outlook*, International Energy Agency, Paris, 2008.

International Energy Agency (IEA)/ OCDE, *Act Locally, Trade Globally*, 2005.

Intergovernmental Panel of Climate Change (IPCC), *Fourth Assessment Report*, New York, Cambridge University press, 2007.

Jaffe, A.B, Stavins, R.N., *The Energy-Efficiency gap. What does it mean?*, Energy Policy 22 pp. 804-810, 1994.

McKinsey&Company, *Sustainable Urban Infrastructure, London edition – a view to 2025*, research sponsored by Siemens, 2008.

Novikovan A., *Methodologies for Assessment of Building's Energy Efficiency and Conservation: A Policy-Maker View*, Discussion Papers 1086, DIW Berlin, 2010.

OCDE, *Environmentally Sustainable Buildings: Challenges and Policies*. 196 p, 2003.

Orselli, J. *Economie et substitution d'énergie dans les bâtiments*, Conseil général des ponts et Chaussées, rapport n°004831-01 pour le ministère de l'Ecologie, du développement et de l'Aménagement durables , 2008.

Petersdorff, C., Boermans, T., Joosen, S., Kolack, I., Jakubowska, B., Scharte, M., Stobbe, O., Harnisch, J., *Cost effective Climate Protection in the Building Stock of the New EU Member States Beyond the EU Energy Performance of Building Directive*. Germany: Ecofys, 2005.

Price, L., Michaelis, E., Worrell M. Khrushch, M., *Sectoral trends and driving forces of global energy use and greenhouse gas emissions*, Mitigation and Adaptation Strategies for Global Change 3, pp. 263–319, 1998.

T'Serclaes, Ph., *Financing Energy Efficiency home. Existing policy responses ton financial barriers*. Paris: OCDE/IEA, 2007.

Traisnel, J-P., Joliton, D., Laurent, M-H., Caffiaux, S., Mazzenga, A., *Habitat Facteur 4. Etude d'une réduction des émissions de CO2 liées au confort thermique dans l'habitat à l'horizon 2050*, Les cahiers du Club d'Ingénierie Prospective Energie et Environnement, n°20. Novembre 2010. 104 p., 2010.

UNEP (United Nations Environment Program), *Buildings and Climate Change. Status, Challenges and opportunities*, 2007

Ürge-Vorsatz, D., Novikova, A., *Potentials and costs of carbon dioxide mitigation in the world's buildings*, Energy Policy 36, no. 2, pp. 642-661., 2008.

Wheeler, S, *State and Municipal Climate Change Plans: The First Generation*, Journal of the American Planning Association, 74:4, 481 – 496, 2008.