Environment and energy : analysis and evaluation of public policies

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Abstract

In the context of growing concerns for climate change, the objective of this dissertation is to bring some insights on two environmental issues. The first one deals with the question of whether environmental policies are efficient enough to significantly decrease greenhouse gas emissions and energy consumption and the second one concerns the way households' well-being is affected by environmental changes.

France committed to reduce greenhouse gases emissions and energy consumption in residential sector. In a first time, we study the determinants of residential energy consumption. An in-depth understanding of energy consumption is needed to design adequate energy policies and achieve a low-carbon society. We show that to improve buildings' energy efficiency, the challenge is to induce households to undertake renovations and to adopt energy-saving equipments. This is the objective of public policies, such as tax credit or subsidies. We evaluate the impact of these measures, using a simulation model. We conclude that environmental policies are efficient because they allow decreasing energy consumption and greenhouse gas emissions. However, we point out that they are not sufficient to reach government objectives. Finally, we focus on the impact of the tax credit on households' behavior. The tax credit provides little incentive to undertake energy-saving renovations. The impact of the measure is very low compared to its cost and this is partially due to free riding.

Emerging countries are more exposed to climate disasters than developed ones. Therefore, the most important concern in emerging countries is to find a way to limit the consequences of climate change. In this context, our objective is to understand how deforestation affects population and how agents adapt to environmental degradations. More precisely, we study how deforestation, that increases fuel scarcity, affects women living in rural India. We show that fuel scarcity increases the probability for women to be involved in natural resource collection. Through this, it has a negative effect on the labor force participation, especially on family business and wage activities.

List of Abbreviations

ADEME	Agence de l'Environnement et de la Maitrise de l'Energie
AMS	American Meteorological Society
ANAH	Agence Nationale de l'Habitat
DGEMP	Direction Générale de l'Energie et des Matières Premières
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gases
HDI	Human Development Index
kWh	Kilowatt hour
kg.CO2	Kilograms carbon dioxide (CO2)
IEA	International Energy Agency
EIA	U.S. Energy Information Administration
INSEE	Institut National de la Statistique et des Etudes Economiques
IPCC	Intergovernmental Panel on Climate Change
MEDDTL	Ministry of Ecology, Energy, Sustainable Development and the Sea
Mt CO2e	Million metric tons of carbon dioxide equivalent
OPEN	Observatoire Permanent de l'amélioration ENergétique du logement
SD	Standard Deviation
UNDP	United Nations Development Programme
VAT	Value Added Tax

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Introduction

Energy consumption and greenhouse gases emissions become key concerns following increasingly alarming observations on climate change. In September 2013, the Intergovernmental Panel on Climate Change (IPCC) met in Stockholm to present its results, that harden its previous findings. Global warming is accelerating. The land and ocean surface temperature has been increasing by 0.85°C in average since 1880 and the IPCC forecasts an increase in temperature from 0.3°C to 4.8°C for this century depending on the scenario. Such an increase would have a non-negligible impact on the number of extreme climatic events. For example, 2012 was among the 10 warmest years on record. This caused several startling climatic events, such as the lowest recorded levels of Artic sea ice (97% of the Greenland ice sheet showed some forms of melt (Blunden et al., 2013)), Hurricane Sandy in United States, the heavy rain in northern Europe and eastern Australia.

First, natural disasters caused a number of human fatalities, counted in 2012 at approximately 8,800. This represents the fewest number of victims related to climatic events since at least 2002. Second, besides human fatalities, damages related to natural disasters represent a very high cost. Events that occurred in 2012 represent an economic loss of $200 billion and an insured loss for the population of $72 billion (AON Benfield, 2013). Hurricane Sandy was the costliest event of the year and accounts with the drought in U.S. for the half of economic losses. This is not an exceptional cost: 2012 was the fifth costliest year in term of economic losses since 2002. Third, all consequences of these climatic changes are not observable today. The level of sea will continue to increase following the rise of temperature, and this would increase the frequency and worsen the intensity of events such as storm and flooding. As we can observe on map 1, emerging countries are more exposed to climate disasters than developed ones. The 2011 UNDP report stresses the fact that the environmental degradations or habitat destruction could jeopardize development and increase poverty in emerging countries. In this report, the impact of climatic events on HDI is estimated, taking into account several scenarios. The ‘environmental challenge’ scenario captures the adverse effects of global warming on agricultural production, on the access to clean water and improved sanitation, and on pollution. The ‘environmental disaster’ scenario features vast deforestation and land degradation, dramatic declines in biodiversity and accelerated extreme weather events. Simulations suggest that the global HDI would be 8% lower by 2050 in the ‘environmental challenge’ scenario than in the baseline, and even 12% lower for south Asia. The ‘environmental disaster’ predicts a global HDI 15% below the baseline. Several mechanisms play a role. The same report shows that climatic events, as the droughts in Africa and the sea level rise in low-lying countries like Bangladesh, could lead to an increase of the world food price from 30 to 50%, affecting first the poorest countries.

Considering these dramatic consequences, it seems important to focus on the causes of these events. Even if there are natural climate fluctuations, the last IPCC report (2013) confirms the impact of human activities on climate change (with a 95% confidence level). Moreover, 18 research groups recently studied the causes of 12 events of exceptional intensity that occurred in 2012. They stress that human influences have an impact on some extreme weather and climate events (Peterson et al. 2013). For example in the United States, they argue that human-caused climate change plays an important role in the warm wave in the east during spring 2012. In the same way, they show that the extremely low Artic sea ice extent during summer 2012 cannot be explained by natural variability alone. Human activity increases the concentration of greenhouse gases in the atmosphere principally as a result of fossil-fuel combustion and deforestation (American Meteorological Society, 2012). In 2010, the total greenhouse gases emissions reached 47 billion tons CO2 equivalent, which represents 32.3% more than in 1990 (source: CAIT).

Environmental damages have irreversible consequences and raise the issue of responsibilities toward the most affected countries and toward future generations. These concerns are not recent. The 1987 Brundtland report (World Commission on Environment and Development, 1987) came which a global awareness about global warming challenges. One year later, the IPCC was established to assess climate change and the associated risks. Their alarming findings underline the necessity to adopt an international response strategy, which leads to the Kyoto protocol (1997). For the first time, some developed countries committed to decrease the total emissions of several greenhouse gases by 5.2% in average compared to 1990 level by 2012. However, the largest greenhouse gases emitters had not ratified the treaty. United States, whose emissions accounted for almost one-fifth of global CO2 emissions in 2008 (source: United States Environmental Protection Agency) have withdrawn from Kyoto Protocol. They justify their decision by arguing that emerging countries are not involved in the protocol, whereas their greenhouse gases emissions are growing with their economic development. Indeed, almost 30% of global $CO2$ emissions in 2008 came from China and India (source: United States Environmental Protection Agency). However, European Union pledged to cut its greenhouses gases emissions by 8% by 2012, and committed on new objectives, namely to cut emissions by 20% by 2020 compared with the 1990 level. To reach this, they have to take measures to control for their energy consumption and greenhouse gases emissions. Several environmental public policies have been introduced these last years in France and some other countries. However, challenges for emerging countries are still unclear. They have to find a way to mitigate the negative effects of global warming or to adapt to environmental changes. Even if they are the most vulnerable to climate change and projections are not optimistic, impacts for populations remain little known and environmental policies may be costly for them and therefore delay their development.

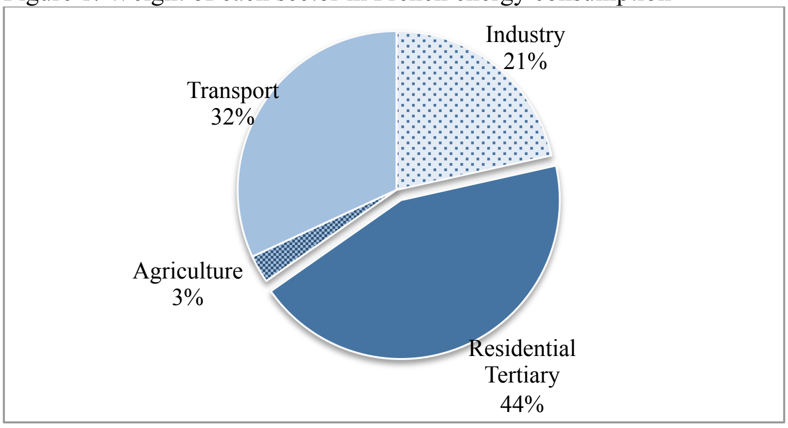
These observations lead us to wonder about the efficiency of environmental policies and about the economic impacts of climate change on emerging countries. First, stylized facts and examples presented above show that it is important to fight against global warming. Nevertheless, public measures are efficient only if individuals are sensitive to it and they represent high public cost. Active environmental policies have been introduced these last ten years and few evaluations examine their impact. Second, the impact of environmental degradations on population living in emerging countries will become a growing concern and economic consequences need to be studied. In this dissertation, we explore these issues, using data for France and India.

Environmental policies efficiency in developed countries: Evidence from France

The challenges

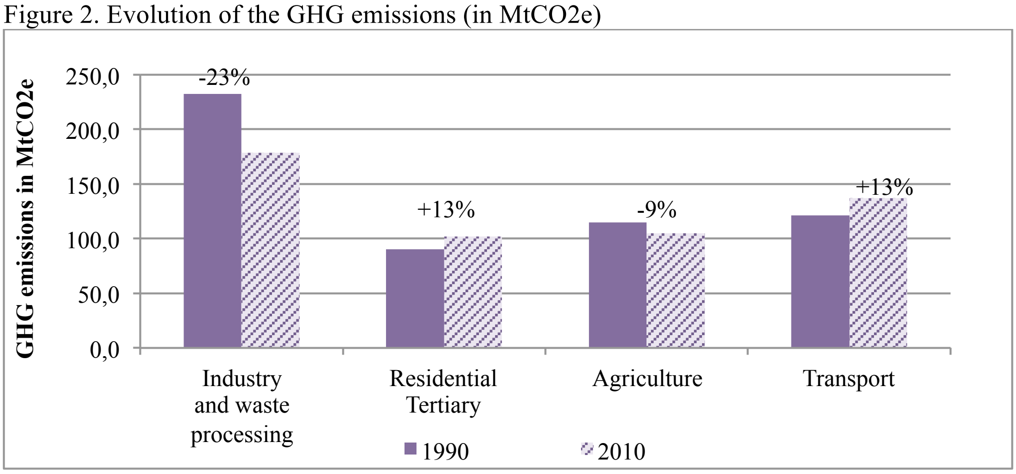
France is committed by international agreement to cut greenhouse gases emissions by 20% by 2020 and divide it by 4 by 2050 compared with 1990 level. This leads to Grenelle Act, which sets more specific objectives as reducing energy consumption in the building sector by 38% and developing renewable energies up to 23% of final energy consumption by 2020. It focuses on the building sector first because it is the primary energy consumer (figure 1) and its energy consumption increases by 18% between 1990 and 2010. Even if it is not the primary greenhouse gases emitter, the increase (of 13%) of emissions in this sector is the most important with transport between 1990 and 2010, whereas industry and agriculture have been able to reduce their emissions (figure 2). Second, the greatest energy-saving potential lies in buildings due to the improvements in efficiency of insulation or appliances (European Commission, 2011 Energy Efficiency Plan). However, huge efforts are required to achieve the objectives. In 2010, energy consumption in residential-tertiary was 68 million tons of oil equivalent and we have committed to reach 41.88 in 2020. Moreover, renewable energy only represented 6% of energy consumption in 2010 (figure 3).

Figure 1. Weight of each sector in French energy consumption



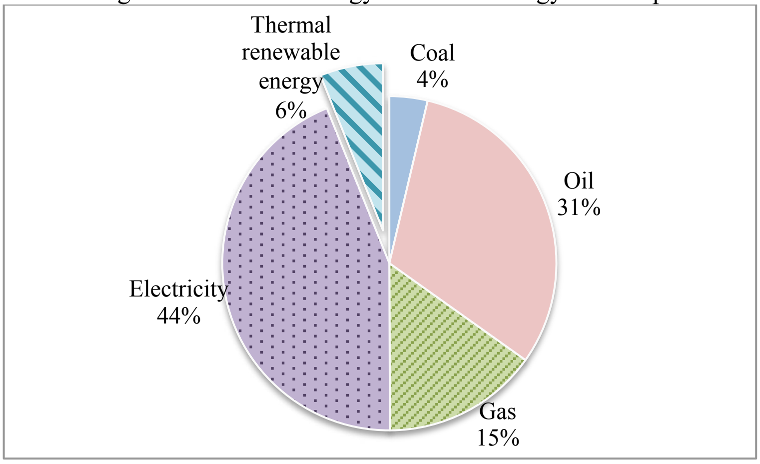
Source: INSEE

Figure 2. Evolution of the GHG emissions (in MtCO2e)



Source: INSEE

Figure 3. The weight of renewable energy in French energy consumption in 2010



Source: INSEE

The residential sector

What matters in residential energy consumption?

We focus on residential sector, which accounts for two-third of energy consumption in the building sector or for approximately one-quarter of the total energy-consumption (Odyssee, 2013). Both the growth of the population, which has led to an increase in the number and in the size of homes and the increase in electronic equipment, tend to raise energy needs. The number of housings has increased by more than one million between 2006 and 2010. New constructions are associated with low energy consumption due to insulation improvement. However the building renewal rate is lower than 1% per year (DGEMP, 2007), and this is not sufficient to significantly cut energy demand.

Consequently, it is crucial to understand the main factors driving household energy consumption to significantly decrease energy consumption in residential sector. This is the purpose of the first chapter of this dissertation. More precisely, our objective is to identify the main determinants of households energy consumption. Literature identifies several potential determinants but do not pay much attention to households' characteristics, except the income. We (1) investigate the relative ability of household sociodemographic characteristics, technical properties of the dwelling, and climatic specificities of the surrounding area to explain energy consumption per square meter; (2) identify some of the main sources of energy conservation in the French housing sector; and (3) propose an estimation of the price and income elasticities of energy consumption per square meter, that has not been done so far in the French context. We use an empirical approach and the 2006 *Enquête Logement* that is a disaggregated household-level survey data set representative of the French housing. Energy provides utility indirectly through the use of various appliances. Therefore, energy consumption must be studied conditional on a household's stock of appliances. We use a discrete-continuous decision framework, estimating first the heating system choice and then energy consumption conditional on the first choice. Results show that the intensity of energy used per square meter is almost completely determined by the technical properties of the dwelling and by the climate. The role of sociodemographic variables is particularly weak. In the short run, without large investments in insulation and new types of energy-efficient appliances, changes in energy consumption will be weak. The challenge for environmental policies is thus to induce households to undertake energy saving renovations in their housing.

Adoption of energy-saving equipment, energy paradox and policy response

Given the results of the first chapter, it seems important to understand the behavior of households facing adoption of energy-saving equipment or renovations. Taking into account only energy-saving improvements, 8.8% of residential housings have been renovated in 2010, and this represents a decrease compared to 2006 (Source: OPEN, 2011). The number of energy-saving renovations is still insufficient to have a significant impact on the level of energy consumption in the residential sector. This can be explained by the energy paradox: agents pass up very attractive opportunities to invest in highly efficient equipment that would result in significant energy savings in the future. The literature identifies several barriers to energy saving investments.

- Market failures

Market failures are one of these barriers. One may think of lack of information, of energy saving renovation supply saturation or split incentives (Golove and Eto, 1996; Brown, 2001; Boulanger, 2007).

First, individuals are often misinformed about technology, opportunities and about the return on the investment. Information can be difficult and expensive to obtain. This is for example the case as far as the energy saving following a renovation (Beillan et al. 2011; Francfort, 2009). Indeed, agents and dwellings are heterogeneous; consequently the return is specific to the investor. The return of energy saving equipment depends for example on the quality of the building: It is expected to be higher for old and very inefficient houses (Hasset and Metcalf, 1993).

Second, energy saving renovation requires special knowledge, and suppliers may not be able to meet the demand. We observe indeed a saturation of the supply in the energy saving renovation market in France (Moussaoui, 2008).

Third, there exist split incentives between owners and occupants of residential housings (Gillingham et al., 2011; Charlier, 2013). Split incentives result from bill-paying arrangements. Households that do not directly pay for their heat but have instead these costs included in their rent or condo fees opt for a higher thermal comfort and thus a higher energy-consumption. This is also the case in France when households live in collective apartment buildings, where energy consumption can be assimilated to a public good because all owners share the energy bills. In these situations, tenants have little incentive to efficiently use energy and are less prone to adopt energy efficient equipments (Maruejols and Young, 2011; Levinson and Niemann, 2004). Moreover, dwellings occupied by the owners have a higher degree of insulation and conversely (Gillingham et al., 2011). When the housing is rented, owners have less incentive to renovate because they do not benefit from energy saving following the investment (tenants do).

To overcome market imperfections, information failures in particular, several measures have been implemented. For example, the *Espaces Info-Energie* have been created. There are places where households can find all the information they need about energy consumption, renewable energies, and energy-saving renovations. It has been initiated in 2001 to alert and inform households. It now exists about 250 such places in France. Moreover, appliances are associated with an energy label, from A+ for those that consume the least amount of energy to C for the largest energy consumers (from 1999, on appliances belonging to higher energy consumer labels are no longer authorized for sale). This allows identifying the less energy consumer appliance. There are the equivalent of “Power Smart” in Canada, “Energy Star” in United States or “E2000” in Switzerland. The energy labels have been compulsory for fridge and freezers since 1995 in all European Union, and they have first been extended to other appliances and then later on houses or apartments for sale or for rent.

- Economic barriers

It exists also economic barriers such as the liquidity constraint and the restricted access to capital (Boulanger, 2007). For example, low-income households often do not have collaterals and credit institutions are reluctant to grant them loans. They faced liquidity constraint for

investment in energy saving technologies whereas energy expenditures often represent a large share of their budget. It is estimated at 15%-20% in France by Cayla et al. (2011).
For this reason, several financial measures have been introduced in France. In 2009, a zero rate bank loan can be used to fund a series of energy saving renovations. Also, subsidies are available for households (as for example subsidies from ANAH or from the regions) to reduce the cost of the investment and thus make it more affordable. In addition, a tax credit has the objective since 2005 to induce households (owners or tenants) to undertake energy-efficient renovations (e.g., insulation, changes in heating equipments) and to adopt renewable energy systems in their main housing. In the same way, the introduction of a reduced VAT for energy saving renovations with a 5.5% rate instead of 19.6% has the objective to decrease the investment cost.

- Uncertainty, irreversibility and high discount rates

By contrast, Hassett and Metcalf (1993) argue that the so-called energy paradox is in reality a optimal response to first, uncertainty about the return on investment (i.e. the energy savings following the adoption of equipment), and second, the irreversibility of the investment (as insulation for example). Indeed, the uncertainty on the evolution of energy prices leads to an uncertainty on energy-savings that will be realized following the investment. Agents have to forecast future energy prices to appraise the profitability of the investment. Moreover, once the investment is undertaken, it cannot be sold if the energy prices fall and the investment becomes unprofitable. Therefore, it is prudent for an agent to wait to get information about energy price trends.
Given uncertainty and irreversibility, agents use high implicit discount rates for energy-saving investment, i.e. the present value of future energy savings is low. A literature review that empirically estimates the implicit discount rates used for energy saving investment show that they substantially exceed the maximum discount rate that consumer would be expected to apply (using the rate of return available on investments of similar risk) (Sanstad et al., 1995). Hassett and Metcalf (1993) find that the discount rate used for energy saving investment exceeds the conventional estimate by a factor of four. Therefore, agents require a largely higher return on investment for energy saving equipment than for other kinds of investment to undertake the project.
In terms of policy implication, this finding stresses the fact that providing more information about benefits of energy saving investments is not sufficient to induce investment. Hasset and Metcalf (1993) show that increased benefits of an investment are also likely to only have a

small effect. They simulate the impact of 15% tax credit for energy saving investments and show that the effect of such a policy is dramatically attenuated because of uncertainty. Given these observations, it seems that standards could be efficient to decrease energy consumption because they have no link with the agents' perception of future energy savings following an investment. Thermal regulations for new constructions and then for renovations have been introduced in France for the first time respectively in 1974 and 2008.

Public policy efficiency vs. green paradox, free riding and rebound effect

The energy paradox leads to under-investment in energy saving equipment. Public policy intervention is then necessary to induce renovations. Public policy can lower some of these barriers and help agents to undertake energy-saving investments, in order to finally significantly reduce energy consumption and greenhouse gas emissions. In recent years, several measures have been implemented in France, (1) informative measures, with for example the presence of eco-label on appliances or bulb-light to inform consumers on the energy efficiency level of the equipment, or information campaigns to rise households sensitivity about energy-savings; (2) financial measures to induce households to adopt renewable energies or improve the housing quality; it can be zero rate bank loans, subsidies or tax credits, or reduced rate VAT; (3) and regulatory measures, such as the thermal regulation on new constructions or renovations, labels, or the requirement to indicate the energy quality of housing when it is sold or offered for rent.

One of the most famous measures is the tax credit. It allows part of the expenses of energy saving renovations to be deducted from income taxes. From 2005 to 2008, 4.2 million French households received a tax credit (Clerc and Mauroux, 2010) and this represents a significant cost: public cost reached €7.8 billion during this period and €4.2 billion during 2009–2010. However, several behaviors can undermine the effect of environmental policies.

- Free riding and spillover effects

Financial measures have to be implemented carefully, because of potential free riding. Free riders are households that obtain for example a subsidy to undertake a renovation that would have made even in the absence of public policy. Recent literature estimates the extent of the free-riding effect from 50% to 92%. Grösche and Vance (2009) use a cross-section of data from the 2005 German Residential Energy Consumption Survey to evaluate this effect. They define free riding as a situation in which a household's willingness to pay for renovations exceeds its cost under no policy action, and show that such a free riding occurs in 50% of the cases. In an original study, Grösche et al. (2009) simulate the effect of grants on renovation choices using revealed preference data on home renovations from Germany's residential sector. They find that if every eligible household had behaved rationally and applied for the grant, 92% of the program expenses would have been awarded to free riders. Malm (1996) also finds an important free riding effect. He investigates the impact of subsidies on the purchase of high-efficiency heating systems and estimates it at 89%.

However, some spillover effects can reduce free riding (Eto et al., 1995; Rosenow and Galvin, 2013). Such effects correspond to additional products being installed, as a result of the program but not through the program. Few studies focus on this point, but a recent evaluation shows that spillover effects can be substantial (NYSERDA, 2012).

- Rebound effect

The policies already presented have the objective to induce investment. However, the adoption of energy saving technologies is not necessarily followed by a reduction of energy consumption. It appears that investment in a new technology such as insulation improvement can entail a change in household behavior (e.g., increase in the temperature target), which at least partially offsets the beneficial effects of the technology. This is called the direct rebound effect (for a review see International Risk Governance Council, 2013). One explanation is that people tend to consume more energy services when it is less expensive. Therefore, the rebound effect reduces or offset the impact of environmental measures on energy consumption and greenhouse gas emissions. In a large survey, Greening et al. (2000) find that a 100% increase in energy efficiency led to an estimated rebound of 0%–50% for residential end uses. Also, Alberini et al. (2013b) examine household energy consumption in Maryland and show that the larger the subsidy obtained for the adoption of energy saving equipment, the less the electricity reduction, and this result may be explained by the rebound effect.

Moreover the rebound effect can have indirect impact (Schipper and Grubb, 2000). When energy services are less costly, households have more income and can increase the demand for other goods that require energy for production or use. Druckman et al. (2010) simulate the effect of a set of abatement actions of carbon emissions in UK, using different scenarios. On average, the indirect rebound effect is estimated at 34% of the anticipated GHG emissions reductions (this means that only two thirds of the anticipated GHG emissions reductions are likely to be achieved). These authors also show that in the best case, it may be only 12% but that in extreme cases backfire may occur. Backfire means that carbon emissions increase, instead of decreasing.

An economy-wide rebound effect may also exist and take into account a wide range of effects at the macroeconomic level. Gillingham et al. (2013) explain this effect at a worldwide level using the example of fuel standards on vehicles in the United States, which can lead to a decrease in world oil prices causing in turn an increase in oil demand in other countries. The estimates of this economy-wide rebound effect varies considerably across countries, depending on the model used (computational general equilibrium model, macroeconomic model) and on the variables considered. However, results are generally greater than 37%, with most studies finding larger rebounds or backfire (Sorrell, 2007; International Risk Governance Council, 2013). For example, Barker et al. (2007) examine the rebound effect in the UK related to energy efficiency policies between 2000 and 2010 and show that it was not large enough to prevent a significant decrease in energy consumption and greenhouse gas emissions. They estimate simultaneously the indirect and economy-wide effects using a macroeconomic model and they obtain that the rebound is around 11% on average across all sectors of the economy, i.e. the reduction in energy demand is 11% less than expected. The direct rebound effect is around 15% leading to a total rebound of 26% of the expected reduction of energy demand.

- Green paradox

Some environmental policies could become inefficient because of the existence of a green paradox (Sinn, 2008). Instead of decreasing greenhouse gas emissions, measures that aim at decreasing fossil energy demand (as tax carbon or subsidies on renewable energies) could increase pollution and accelerate climate change at least in the short run. Using a Hoteling model, Sinn (2008) shows that the introduction of a carbon tax that rises over time (note that green paradox never happens for the optimal tax path) can indeed have a negative effect. Since the tax will increase the price of the fossil energy over time, producers have incentive to extract and sell the resource immediately. Such a policy therefore accelerates environmental damages. Van der Ploeg and Withagen (2010) show that the green paradox occurs for relatively expensive but clean energy (such as solar or wind). If the government introduces subsidies on solar or wind energy, this leads to an overconsumption of oil and gas, i.e. to a more rapid depletion of these energies. In this case, the energy paradox is confirmed and it has negative effect on climate change. In contrast, there is no evidence of the energy paradox if the clean energy is sufficiently cheap relative to marginal global warming damages (as nuclear energy). In this case, it is attractive to leave fossil fuels unexploited and thus limit CO2 emissions. Grafton et al (2010) find that biofuel subsidies could lead to green paradox depending on several variables, such as the demand and supply elasticities, the expected change in the measure, the technological change in extraction and extraction cost. It seems that the green paradox can also occur when a climate policy is announced in advance and the implementation date is uncertain. Indeed, between these two dates (that of the announcement and that of the implementation) the use of fossil energy and thus the greenhouse gas emissions increase (Smulders et al. 2010).

Given all these effects that can undermine the effectiveness of environmental policies, we can wonder whether French environmental policies are sufficiently efficient to reach the ambitious objectives set by Grenelle Act. This doctoral research aims at providing insights on these issues. We evaluate these measures first at a national level using a simulation model (chapter 2) and second, we focus on one measure and observe its impact on households' behavior using an econometric approach (chapter 3).

In chapter 2, we test the impact of some existing policies (tax credit, zero rate bank loans, subsidies, and VAT) and of one potential policy (bonuses). We combine several approaches found in the literature and model energy consumption dynamics resulting from both the housing stock dynamics (including three end-uses: heating and hot water, lighting, and appliances) and the energy saving investment decisions. This study produces three major outputs: (1) an estimation of French residential energy consumptions and of GHG emissions until 2050, (2) an assessment of the impact of environmental policies compared to the public cost, and (3) proposals of different means to reach the objectives set out in the Grenelle Act. Results show that current policies are effective in the sense that they have enabled a decrease in energy consumption and in GHG emissions over recent years. A tax credit seems to be one of the most effective policy measures. However, existing policies alone will not ensure that the objectives set for 2050 will be reached. Additional public expenditures are necessary to achieve these goals.

We saw that a tax credit seems to be the most effective policies, but that this measure represents a high public cost. In chapter 3, we examine the impacts of a tax credit on the renovation rate and on the renovation expenditures. Our objective is (1) to determine whether households are sensitive to this measure or whether the tax credit simply provides additional funding for households that would have undertaken a renovation anyway (i.e. there exists free riding) (2) to investigate whether the tax credit provides the households with an incentive to invest in more expensive and more energy-efficient renovations. To do this, we use matching methods and French household-level databases: *ADEME-SOFRES Maîtrise de l'Energie* surveys from 2001 and 2008, which regroup information on energy-efficient renovations. We find that tax credit has a significant and positive effect on renovation rate and renovation expenditures. However, the effect is low, particularly compared to the public cost of the measure. Results suggest the presence of a free riding effect. Moreover, building professionals (i.e., those qualified and certified to do renovations) seem to capture a part of the earnings from the tax credit through price increases. These two effects tend to lower the impact of the measure.

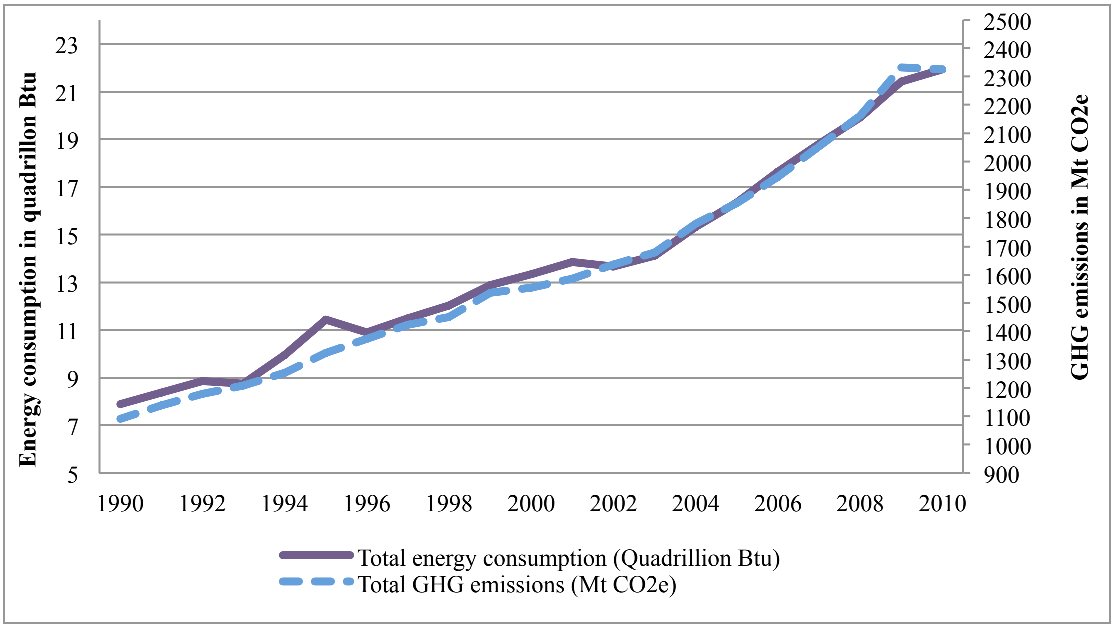
Economic impact of environmental degradations for emerging countries: Evidence from India

The challenges

In emerging countries, the most important concern is not the implementation of adequate environmental policies to decrease greenhouse gases emissions, but the challenge is to find a way to limit the consequences of climate change. Indeed, emerging countries are the most vulnerable to global warming as we can see on map 1. This map shows the climate change vulnerability index (Maplecroft, 2013). This index evaluates the exposure to climate-related natural disasters and sea-level rise, as well as the sensitivity of populations in terms of developments, natural resources, and agricultural dependency. It also considers the adaptive ability of a country's government and infrastructures to counter climate change. We can observe countries with extreme risk in red on the map and countries with high risk are in yellow. India is amongst the countries bearing extreme risk.

Emerging countries are the most exposed to environmental degradations and climatic events caused by human activity. However, greenhouse gases emissions have been increasing quickly in these countries since recent years and it is highly possible that this trend continues in the future. Indeed, India is amongst the top carbon dioxide emitters and energy consumer, after China, the United States, the European Union and Russia. Total greenhouse gas emissions increased by 113% between 1990 and 2010 (or 3.9% per year on average over the period) (figure 4). For comparison, the greenhouse gases emissions of European Union decreased by 10% over the period, and those of the United States increase by almost 9% on the whole period (source: CAIT). Moreover, India is the fourth-largest energy consumer in the world, after the United States, China and Russia. Primary energy consumption more than doubled between 1990 and 2010 (figure 4) even if per capita energy consumption remains much lower than that of developed countries (according to U.S. Energy Information Administration). Two main elements can explain this sharp increase. First, economic growth in India has been very high, reaching almost 7% per year between 2000 and 2010. Second, population growth is particularly important, with an increase of 40% between 1990 and 2010. Pressures on the environment are therefore strong and we can expect that they will get stronger with sustained growth and increasing population in the future.

Figure 4. Evolution of energy consumption in quadrillion Btu and greenhouse gases emissions in MtCO2e in India



Source: U.S. Energy Information Administration for energy consumption, CAIT data for GHG emissions

Impacts of environmental degradations

As we saw previously environmental degradations could have an impact on HDI and income advancement (UNPD, 2011) but it could also have economic consequences for the populations. Literature is not very extensive on this subject. Some literature focuses on the negative impact of air pollution, especially on health, but it showed little interest for the impact of deforestation on individuals. However, both deforestation and restrictions on the access to natural resources could affect agents. Indeed, many rural people depend on natural resources for their income (Cavendish, 2000; Kamanga et al. 2009). For example, in India, 200 million peoples are dependent on forests for livelihood (source: Indian Ministry of Environment and Forest). Individuals living in rural areas heavily rely on traditional biomass: more than 80% of rural households use traditional biomass as primary fuel for cooking, compared with only 22% of urban households (source: 2011 India census). In the meantime,

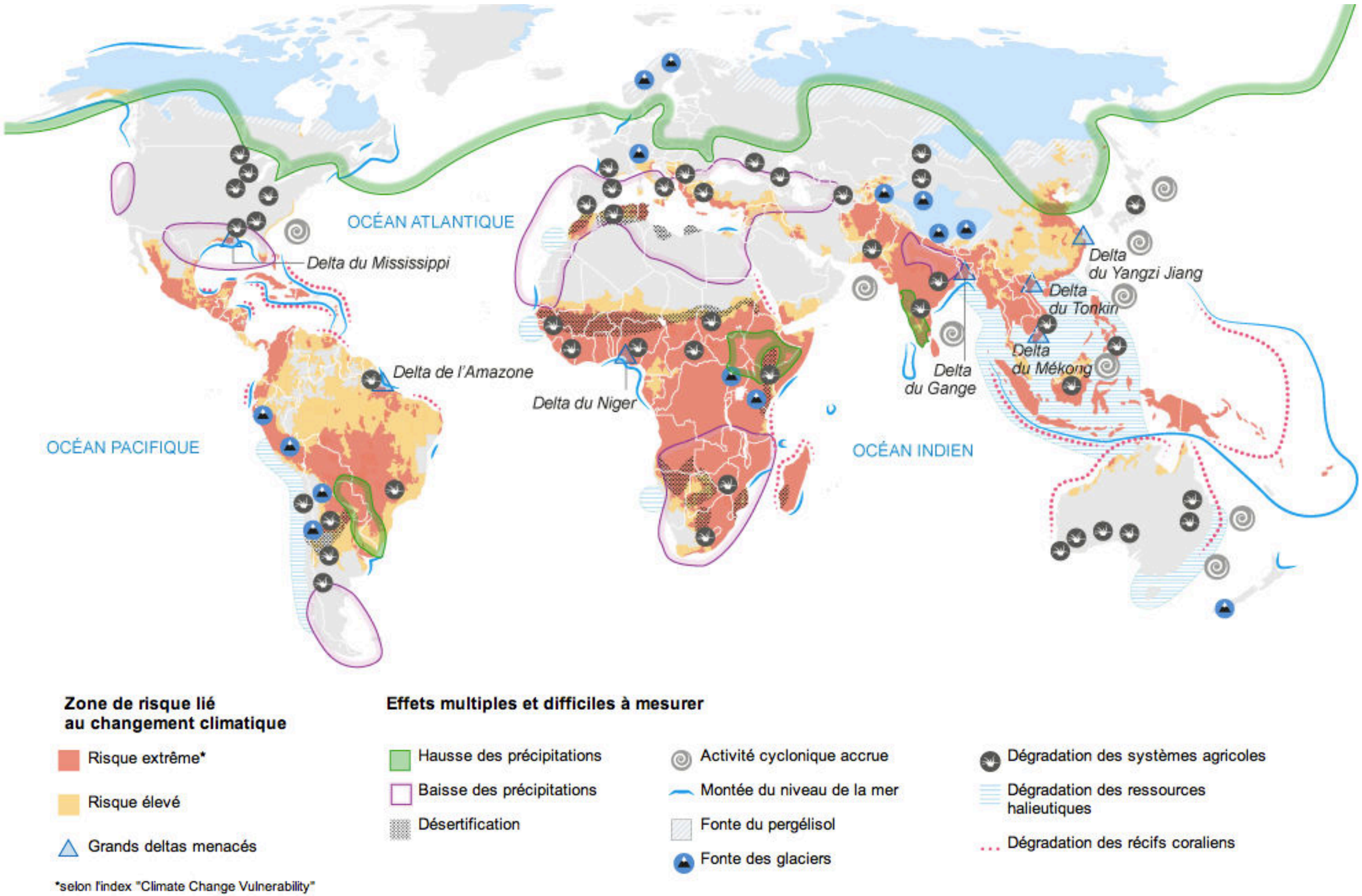
deforestation is one of the largest visible environmental degradations. India is the tenth country in the world for the size of the forest area, with about 68 million hectares (source: Global Forest Resource Assessment, 2010), but an estimated 41% of India's forest cover has been degraded to some degree in the past decades. Pressures on forest come from many sources, particularly the increase in population, the overuse of resources and the need for land. Moreover, deforestation has other dramatic consequences. It is responsible for 20% of global greenhouse gases emissions (source IPCC) and tropical deforestation in Asia, Africa and South America are the largest contributors to these emissions.
Pollution and environmental changes can also have an impact on individuals' access to labor market. Few studies focus on this link whereas it is directly related with poverty and inequalities including differences between men and women. Literature on pollution is again slightly larger than that on environmental degradations. Sala-i-Martin (2005) shows that pollution, through its impact on health, has negative effects on human capital and productivity. Indeed, poor households cannot afford to improve their health. As a result, it is more difficult for them to increase their human capital and their economic productivity. In this case, pollution may exacerbate poverty and makes it more persistent because poor households may therefore enter a vicious circle, known as a poverty trap (Dasgupta and Ray, 1986, 1987). Concerning environmental degradations as deforestation the relationship with the access to labor market is unclear. Kumar et al. (1988) show that a deterioration of the access to forest wood, measured by the time spent collecting fuel, leads to less time for productive agricultural activities for women. However, authors do not take into account a potential endogeneity of variables, therefore caution has to be taken in the interpretation of the results. In contrast, Cooke (1998b) stresses that in Nepal households allocate more time to collection activities when environmental products are more costly but the author finds no evidence that it induces women to spend less time farming.

In this doctoral dissertation we will focus on this last point and try to bring news insights on the ways environment can affect individual and how they adapt to deforestation. This is the purpose of the last chapter (chapter 4). Deforestation, by increasing fuel scarcity could have an impact on individuals. Rural households in developing countries typically heavily rely on self-collected environmental products such as fuelwood. Women are particularly concerned with natural resources collection. We aim at studying whether deforestation and fuel scarcity has both (1) a direct impact on their decision to collect natural resources and (2) an indirect effect on labor market participation through collection activities. We use a bivariate probit model that simultaneously estimates the decision to collect wood and that to participate to labor market. Using the 2004 Indian Human Development Survey, we show that fuel scarcity increases the probability for women to be involved in natural resource collection. Through this, it has a negative effect on the labor force participation, especially to family business and to wage activities. We find that this effect is more pronounced for households living above poverty line. Indeed, the income constraint is lower for them.

Four chapters compose this dissertation. We first investigate the determinants of energy consumption in France (chapter 1) and then we assess the impact of environmental public policies at a national level (chapter 2) and at a household level (chapter 3). Finally, we study the impact of deforestation on women's access to the labor market in India (chapter 4).

We hope this dissertation brings news insights on the way pollution and environmental degradations affect contemporaneous economies thanks to our research on (i) the evaluation of public environmental policies in developed countries and on (ii) the evaluation of some consequences of environmental degradation in developing countries.

Map 1. Risks related to climate change



Compilation Atlas du monde de demain, La Vie/Le Monde
Sources : PNUE ; V. Raisson, 2033, Atlas des futurs du monde, Robert Laffont, 2008 ; Maplecroft, Climate Change Vulnerability Index 2013

Chapter 1.
What matters in Residential Energy Consumption? Evidence from France[1]

Summary

Given objectives set by countries to realize energy savings and decrease greenhouse gas emissions, an understanding of the main factors driving household energy consumption is crucial for the formulation of efficient policy measures. Our objective is to identify the main determinants of households' energy consumption. The model incorporates a discrete-continuous decision framework, which allows for interactions between decisions about the heating system (the discrete choice) and decisions about the consumption of energy (the continuous choice). The results show that the intensity of energy used per square meter is almost completely determined by the technical properties of the dwelling and by the climate. The role of sociodemographic variables is particularly weak. The primary challenge for environmental policy thus is to encourage households to undertake renovations.

[1] This paper has been written in collaboration with Claire Salmon

1.1. Introduction

Following the 2009 United Nations Climate Change Conference (which was attended by major emerging countries, the United States, and Europe), several countries pledged to reduce their greenhouse gas emissions. The United States committed to decrease its greenhouse gas emissions by 17% below 2005 levels by 2020, and Europe pledged to cut it by 20% by 2020 compared with 1990. Because the residential sector is a primary energy consumer in these countries, accounting for approximately one-quarter of total energy consumption (Odyssee, 2013; International Energy Agency, 2013), an in-depth understanding of residential energy consumption is needed to design adequate energy policies and achieve a low-carbon society. Indeed, a measure will be efficient only if households are sensitive to it. Thus, the objective of this paper is to identify the main determinants of households' energy consumption.

Prior literature has explored five potential determinants: types of fuel used, energy prices, technical building properties, climates, and households characteristics. In general, however, literature has focused on one category of determinants. The most widely studied are the impact of energy prices and the technical properties of the dwelling (Baker et al., 1989; Bernard et al., 1996; Branch, 1993; Dubin and McFadden, 1984; Halvorsen and Larsen, 2001; Labandeira et al., 2006; Nesbakken, 1999, 2001; Parti and Parti, 1980). In contrast, few studies focus on households' sociodemographics characteristics (Meier and Rehdanz, 2010; Santin et al., 2009; Sardianou, 2008; Vaage, 2000). Our objective is to investigate the impact of all categories of variables commonly used in the literature on energy consumption, to explore their contributions to residential energy consumption, and to estimate the influence of household characteristics versus dwelling properties. In doing so, we hope to fill gaps in the literature on French households' energy consumption. This literature is sparse, due to the lack of data on French energy consumption. Studies using French data have focused on electric heating (Cayla et al. 2010) and on the impact of income on residential energy consumption (Cayla et al. 2011). Our objective is to gain greater insight into the determinants of energy consumption by taking into account several heating systems, including collective heating. Several environmental policies have been introduced in France to encourage households to make energy-saving investments (as a tax credit or a subsidy). We study the determinants of energy consumption to understand whether these kinds of policies are appropriate for decreasing energy consumption. This study therefore (1) investigates the relative ability of household sociodemographic characteristics, technical properties of the dwelling, and climatic specificities of the surrounding area to explain energy consumption per square meter; (2)

identifies some of the main sources of energy conservation in the French housing sector; and (3) proposes an estimation of the price elasticity and income elasticity of energy consumption per square meter, which has not been done previously in the French context. In doing so, we hope to inform the discussion of what the target of environmental policies should be.

We use the 2006 *Enquête Logement*, a disaggregated household-level survey data set, representative of the French residential sector, that provides information on household and building characteristics. It enables us to calculate the total energy consumption (kWh/m^2) for each household, which we can then use to identify its main determinants. Energy consumption provides utility indirectly through the use of various appliances. To take into account this level of specificity and to obtain unbiased results, we estimate energy consumption conditional on the heating system, using a discrete-continuous methodological framework. We find that households' sociodemographic characteristics play a weak part in explaining the amount of energy used. Energy consumption is largely determined by dwelling quality and energy prices. In particular, it appears that the replacement of collective heating systems with individual heating systems can help significantly decrease energy consumption in the residential sector. To be efficient, an environmental policy must encourage households to renovate and adopt energy-efficient equipment.

We organize the rest of the paper as follows: in section 2, we review literature on the determinants of energy consumption, then present the data in section 3. In section 4, we focus on the discrete-continuous model; in section 5, we present the results. Finally, we discuss the implications and offer some concluding remarks in section 6.

1.2. Literature

Although prior literature has explored several potential determinants of residential energy consumption (types of fuel used, prices, technical building properties, climates, and households characteristics), studies tend to focus most often on one category of determinants and on the estimate of prices and income elasticities. Little interest has been devoted to households' sociodemographic characteristics.

Furthermore, despite the focus on the impact of prices and income on energy consumption (Baker et al., 1989; Branch, 1993; Bernard et al., 1996; Dubin and McFadden, 1984; Halvorsen and Larsen, 2001; Labandeira et al., 2006; Nesbakken, 1999, 2001; Parti and Parti, 1980), there is a considerable variation in the estimates of energy price elasticities, ranging in absolute values from 0.20 to 1.14 for own-price elasticity of electricity and from 0.04 to 1.6 for own-price elasticity of natural gas. The own-price elasticity of fuel oil has rarely been estimated: Newell and Pizer's (2008) estimate in the commercial sector is particularly high, reaching 2.95 (see table 1.1). Income elasticity has been estimated at less than 0.23 (Branch, 1993), and several studies find an income elasticity lower than 0.1 (Dubin and McFadden, 1984; Nesbakken, 1999, 2001). Thus energy consumption appears weakly responsive to an increase of income (see table 1.1). Moreover, Cayla et al. (2010, 2011) are the only authors to use micro data to explore energy consumption in the French residential sector. They focus on electric heating (Cayla et al. 2010) and they stress the role of household income (Cayla et al. 2011): Households with the lowest income cannot make investments in higher-performing equipment.

With the exception of income, household characteristics have received relatively little attention. Some studies have considered the impact of age, the size of households, and the occupancy status of households. The age of the reference person and household size have been shown to have a positive impact on energy consumption, ceteris paribus (Meier and Rehdanz, 2010; Santin et al., 2009). The effect of occupancy status is, however, indeterminate. Some studies find that owners tend to consume more energy than tenants (Sardianou, 2008; Vaage, 2000), and others find the opposite result (Rehdanz; 2007) or no significant effect (Meier and Rehdanz, 2010). It is noteworthy that few studies exploit data on actual household behavior (e.g., inside temperature, use of bath vs. shower, number of hours someone is present at home, individual strategies to reduce energy costs) or preferences regarding comfort. However, Vringer et al. (2007) find no relationship between households' total energy requirement and their value patterns or perception of climate change.

Table 1.1. Estimates of income elasticities and price elasticities for energy consumption in the literature

	Price elasticity	Income elasticity
Discrete-continuous choice analysis		
Bernard, Bolduc, and Bélanger (1996). Quebec residential consumption for electricity. First step: heating equipment and instrumental variable (IV) method.		
Short-term results. Own-price elasticity of electricity	-0.67	0.14
Cross-price elasticities of: Oil	0.04	
Gas	0.08	
Dubin and McFadden (1984). United States. First step: heating and water equipment. Elasticities of household electricity demand, including portfolio shift.		
Own-price elasticity of electricity	-0.26	0.02
Cross-price elasticity of gas	0.39	
Halvorsen and Larsen (2001). Norway. Longitudinal approach. Analysis of flexibility of household electricity consumption over time. Survey of Consumer Expenditure, 1974–1994.		
Short-term electricity elasticity	-0.43	
Long-term electricity elasticity	-0.44	
Labandeira, Labeaga, and Rodriguez (2006). Spain, household micro data. Demand model for a simultaneous analysis of energy goods, IV method. Results from whole sample, uncompensated own-price elasticities of: Electricity		
Natural gas	-0.79	
LPG	-0.04	
	-0.36	
Nesbakken (2001). Norwegian micro data. Simultaneous discrete-continuous choice model (heating equipment). Short-term results.	-0.21	0.06
Nesbakken (1999). Norway. Simultaneous discrete-continuous choice model (heating equipment). Short-term results from pooled data, 1993–1995.	-0.50	0.01
Newell and Pizer (2008). U.S. commercial sector. Long-term results, from a detailed model then aggregated with fuel choice variable.		
Own-price elasticities of: Electricity	-1.14	
Natural gas	-1.60	
Fuel oil	-2.95	
District services	-0.88	
Vaage K. (2000). Norway. Household's energy consumption. First step: heating equipment. Long-term results, from a reduced model.	-1.24	
Conditional demand analysis		
Baker et. al. (1989). United Kingdom. Study household gas and electricity		
expenditures: Electricity	-0.758	0.131
Gas	-0.311	0.115
Branch (1993). United States. Study electricity consumption with a generalized least squares GLS estimator.		
Electricity	-0.20	0.23
Garbacz (1984). Estimation of the U.S. electricity consumption via two-stage least squares 2SLS.	-0.13 to -0.59	
Marginal price		
Leth-Petersen and Togeby (2001), Denmark, panel data, 1984–1995.		
Oil	-0.08	
District heating	-0.02	
Meier and Rehdanz (2010). United Kingdom, household-level panel data.		
Oil	-0.4 to -0.49	
Gas	-0.34 to -0.56	
Parti and Parti (1980). Demand for electricity for San Diego County.	-0.58	0.15
Rehdanz (2007). Germany, household-level panel. Oil	-2.03 to -1.68	
Gas	-0.63 to -0.44	

Source: Synthesis of authors

In contrast, significant attention has been paid to the impact of the technical properties of housing (insulation, year of construction, building materials, design of the building) on energy consumption. Newer buildings tend to consume less energy (Rehdanz, 2007; Santin et al., 2009; Vaage, 2000), which leads Leth-Petersen and Togeby (2001) to conclude that building regulations play a significant role in improving energy efficiency in new buildings in Denmark. Some other results do not converge. For example, Santin et al.'s (2009) study in the Netherlands shows that insulated surfaces have a negative effect on energy consumption, whereas Sardianou (2008) finds no evidence of the impact of thermal quality of buildings in Greece. This result might be due to different climates. In addition, the latter study finds no significant impact of housing type (detached or nondetached houses), whereas this is an important explanatory variable in Nesbakken (2001) and Vaage (2000), both of whom work with Norwegian data.

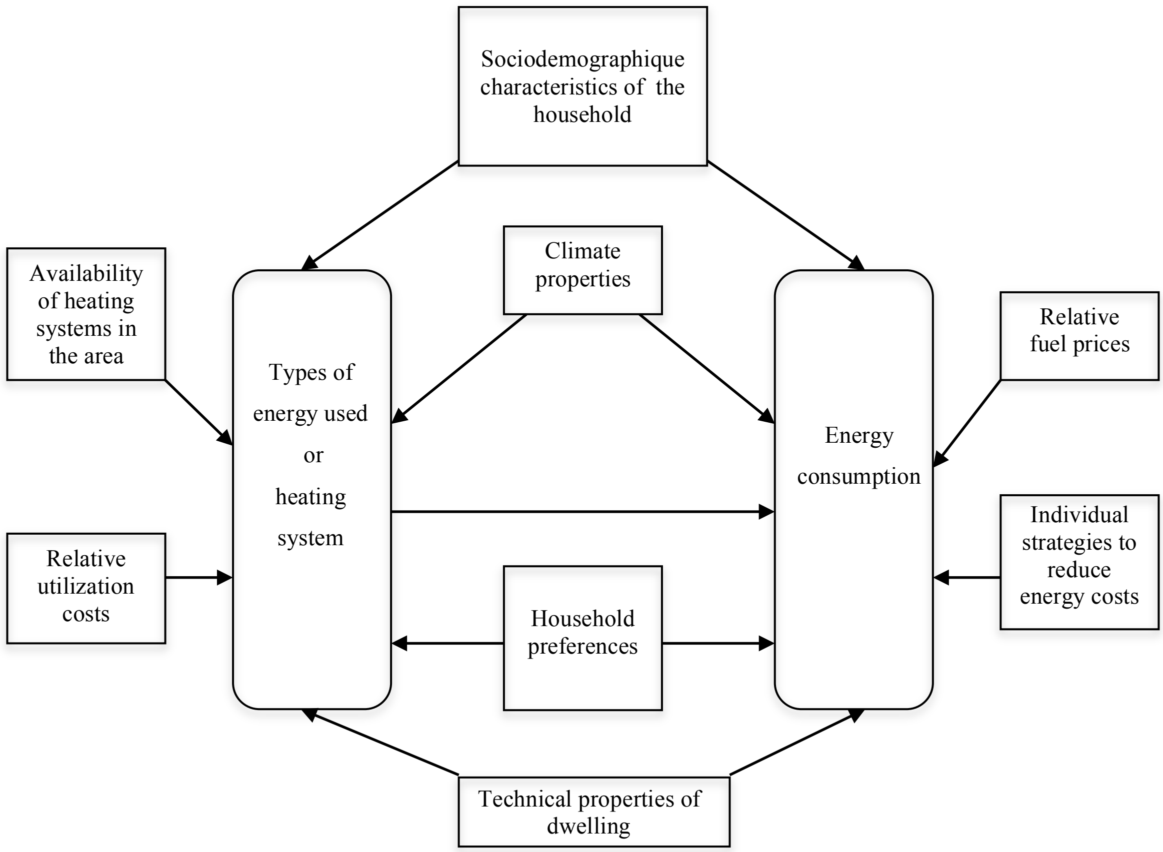
With respect to regional differences, climate data are generally taken into account in empirical studies. Models typically include average outside temperatures measured by degree/days, or dummy variables for colder or warmer regions. Climate variables have a significant impact on energy consumption and indicate that energy consumption is greater in the colder regions (Meier and Rehdanz, 2010; Nesbakken, 1999; Vaage, 2000).

Appliances and the type of fuel used also have an impact on energy consumption. Most studies only take into account the heating system (Bernard et al., 1996; Nesbakken, 1999, 2001; Vaage, 2000). For example, Dubin and McFadden (1984) consider only the space- and water-heating fuel choice, treating other appliances owned by the household as exogenous. This is not too restrictive, however, given the relatively large weight placed on heating in households' energy consumption.

Energy consumption is embedded in a complex system. Energy provides utility indirectly through the use of various appliances. In this sense, we face an endogeneity problem: To obtain unbiased results, energy consumption must be studied conditional on a household's stock of appliances. Therefore, some literature (Dubin and McFadden,1984; Nesbakken, 1999, 2001; Newell and Pizer, 2008; Vaage, 2000) has focused in a first step on the heating system itself. Choice of heating system can depend on the same variables explaining energy consumption (e.g., household and building characteristics, climate areas) and also variables such as the availability of fuel and the relative utilization costs (Braun, 2010). Using Norwegian data, Vaage (2000) shows that the probability of choosing electricity as the only fuel for heating increases with income and is more often chosen in flats and new buildings. In a second step, this literature estimates the determinant of energy consumption, taking into account results from the first step. These studies then observe the impact of the chosen heating system on energy consumption: households that only have electric heaters use far less energy than households using other heating systems (Nesbakken, 1999).

Our objective is to determine the weight of each category of variable to explain energy consumption. We summarize the main determinants of energy consumption, as analyzed in the literature, in figure 1.1.

Figure 1.1: Main determinants of heating system choice and energy consumption found in the literature



1.3. Data

Our objective is to understand the main factors that drive energy consumption. We explore both the main determinants of energy consumption per square meter and the contribution of each variable category in figure 1.1 to explain energy consumption per square meter. We use the 2006 *Enquête Logement* (INSEE), a disaggregated household-level survey data set, representative of the French residential sector. This survey provides information on 36,955 households related to their housing, heating systems, household characteristics, and geography. Although few household-level data on French energy consumption are available, information included in the *Enquête Logement* survey enables us to calculate energy consumption in terms of kWh/m^2. However, we observe only one year; therefore, we cannot control for unobserved heterogeneity. We present the variables in table 1.2.

Table 1.2. Description of variables

Variables	Vector Name	Description
Energy consumption (per m²)		Final energy consumption in kWh/m² is defined as the sum of all energy consumption for all types of fuels used for residential purposes in a dwelling (use of appliances, heating, cooling, cooking, and lighting).
Technical properties of dwelling	**DW**	
Individual house type		Dummies: attached houses, semidetached houses, detached houses
Collective dwelling characteristics		Number of dwellings in block of flats; floor
Size		Dwelling size in m²
Specificities		Dummies: roof <3m, office in the dwelling; veranda, moisture problem, cellar not converted, attic
Construction date (vintage)		Dummies: before 1948, 1949–1974, 1975–1989, 1990–2005
Insulation characteristics		Dummies: double-glazing, recent roof insulation, sufficient roof insulation, insufficient roof insulation, nonexistent roof insulation
Exposure (according to households)		Dummies: poor exposure, medium exposure, good exposure
Location		Dummies: downtown, suburb, rural town.
Climate areas	**CL**	In France, INSEE divided regions into seven different climate areas (see map 1.1 in appendix). Dummies: mountain climate, semicontinental climate, cooler oceanic climate, mixed oceanic climate, oceanic climate, mild oceanic climate, Mediterranean climate
Heating system	**HS**	Dummies: collective heating system with gas or fuel, individual system with electricity, individual system with gas, individual system with fuel
Price of energy	**P**	Average energy price: weighted average of different fuel prices; weights depending on the specific mix of fuels used by each household.
Household sociodemographic variables	**SDH**	
Demographic characteristics		Number of people in the dwelling, age of household member answering the questions in the survey
Occupancy state		Dummies: own, renter, socially subsidised housing, private rent, free-housed
Educational level of household member answering the questionnaire		Dummies: without certificate, less than baccalaureate, baccalaureate, more than baccalaureate.
Income		Monthly income per consumption unit

To conduct this study, we need to know household energy consumption in kWh/m^2. We can calculate it using energy expenditures provided by the *Enquête Logement*. This survey provides information on the total expenditure of each household across each type of fuel (regrouping expenditures for heating, cooling, lighting, and other uses of appliances) over the preceding 12 months. Combining this information with the energy prices in kWh, we can compute household energy consumption. Prices of natural gas, electricity, oil, wood, district service, and coal are not available in the survey and come from the *Ministère de l'économie, des finances et de l'industrie*. There is no regional difference in energy prices in France. However, the prices of electricity and natural gas depend on the use of the fuel (heating, cooking, water) and the size of the housing. We take these characteristics into account to determine the unit price in kWh of each type of fuel and for each household,[2] then calculate total energy consumption. This step of the work was particularly difficult and led us to eliminate a significant part of the sample, particularly households using collective heating systems. Indeed, a particularity in France is the existence of collective heating, in which several households living in the same block of flats share the same heating system. Approximately 44% of households using this type of heating system were unable to state their actual energy expenditures in the survey because their energy bill is combined with other shared charges (expenditures for the elevator, cleaning of common space, gardening, and so forth). With this interesting observation, we can deduce that approximately 7% of French households cannot properly react to any kind of price signal because they cannot calculate the real cost of their energy use. Moreover, because approximately 90% of French households use fuel oil, electricity, or natural gas, we focus our analysis on these three fuel types (see figure 1.2 in appendix). We therefore excluded households that mainly used wood, coal, or a district service for heating. Our final sample comprises 19,849 dwellings. Households using collective heating still represent a significant part of our sample (41% of flats). Weights have been applied to ensure the sample is representative. As such, the proportion of variables representing flats and houses, occupancy status, and construction period are maintained.

The average energy consumption for residential needs (heating, cooking, cooling, lighting, use of appliances) was 191.30 kWh/m² in 2006. This result falls in the range of what is commonly computed in the French residential sector (ANAH, 2008). The residential park is split into two broad categories (houses and flats). We observe that final energy consumption is significantly higher for houses than for flats: 201 kWh/m² per year for houses versus 178 kWh/m² for flats (see table 1.3).

[2] Price per kWh is €0.0645 for oil, €0.0594 on average for natural gas, and €0.1005 on average for electricity.

Table 1.3. Final energy consumption by heating system for individual houses and flats

	Houses			Flats		
	Final energy consumption (kWh/m²)		Weight in the housing park	Final energy consumption (kWh/m²)		Weight in the housing park
	Mean	SD		Mean	SD	
Individual heating						
Electricity	158.93	74.39	21.57%	146.33	77.00	14.64%
Natural gas	216.52	84.37	18.51%	194.64	89.47	10.82%
Fuel	239.33	89.89	16.49%	-	-	-
Collective heating	-	-	-	194.59	83.22	17.87%
Year of construction						
Before 1948	216.98	95.10	16.73%	183.89	88.93	11.34%
1949–1974	230.48	90.60	13.50%	193.12	84.89	18.45%
1975–1989	184.88	80.74	15.25%	160.25	79.81	7.44%
After 1990	164.76	70.65	11.20%	145.02	77.02	6.09%
Double-glazing						
With	193.73	85.64	42.78%	172.73	85.27	29.14%
Without	224.33	96.13	13.90%	189.73	86.07	14.18%
Total	**201.24**	**89.30**	**56.67%**	**178.30**	**85.90**	**43.33%**
Number of observations	11,476			8,373		

Source: 2006 *Enquête Logement* (INSEE).
Note: Weights have been applied to maintain representativeness of the sample.

These two kinds of dwellings are different, which can explain the energy consumption differential. The fuel used differs according to the dwelling type. In our sample, 38% of households living in houses use an electric heater, 33% use a natural gas heater, and 29% use an oil heater. For collective residential buildings, 34% use an electric heater, 51% use a natural gas heater, and 15% use an oil heater. It is noteworthy that households equipped with an electric heater consume significantly less energy than those heating with other fuels. The difference in energy consumption per square meter between users of electric and oil heat is particularly striking for households living in houses.

Notably, in flats, 41% of households use a collective heating system, and they register significantly higher energy consumption on average than those using an individual heating system (194.6 kWh/m^2 vs. 166.86 kWh/m^2). This can be explained by both the higher level of energy used when the energy is a public good (the incentive to reduce consumption is weak) and the difference of energy type used (mainly gas and fuel oil). With respect to the first explanation, Levinson and Niemann (2004) show using U.S. data that energy consumption is generally higher when tenants are not directly confronted with the marginal cost of their own energy use. This is the case when collective heating is not associated with individual metering or when a household cannot modulate the temperature of its own flat, which is a common situation in France in flats heated by a collective heating system. That is also the case when energy costs are included in the monthly rent. In these situations, tenants have little incentive to use energy efficiently. Maruejols and Young (2011) show that split incentives result from bill-paying arrangements. Households that do not pay directly for their heat but instead have these costs included in their rent or condo fees opt for a higher thermal comfort.

Other building characteristics differ between the two types of housing. Residential buildings, and flats in particular, are typically older structures, with a majority of the existing housing built before 1975 (53% of houses and 69% of flats). This period of construction is associated with the highest energy consumption, related to the insulation characteristics. For example, 61% of buildings built during this period were not equipped with double-glazing.

Table 1.4. Final energy consumption by households' characteristics

	Final energy consumption (kWh/m²)		% of households	
	Mean	SD	Houses	Flats
Occupancy status				
Owners	196.98	88.75	85.24	37.47
Private tenant	178.92	89.36	10.07	31.00
Socially subsidised housing[1.a]	183.34	84.80	4.69	31.53
Number of persons in the household				
1 or 2 persons	189.36	89.59	58.87	74.47
3 - 4 persons	193.98	86.20	33.97	21.07
5 persons or more	199.87	87.60	7.16	4.46
Age of reference person				
between 16 and 24 years old	176.56	91.43	0.48	2.95
between 25 and 39 years old	182.03	85.15	17.33	29.10
between 40 and 54 years old	188.14	86.26	30.37	26.85
55 years old and more	198.13	90.88	51.81	41.11
Educational level of the person of reference				
without certificate	203.54	96.48	14.96	15.99
brevet diploma or vocational training qualification	196.55	90.02	51.83	40.56
baccalaureate	182.20	81.00	11.93	13.20
baccalaureate + 2 years or more	178.53	82.21	21.27	30.25
Annual income per consumption unit				
below €5,000	192.49	92.56	13.55	22.69
between €5,000 and €10,000	195.63	93.26	23.60	22.12
between €10,000 and €15,000	194.45	88.97	23.30	18.64
more than €15,000	186.32	83.29	37.79	34.55

Source: 2006 *Enquête Logement* (INSEE).
Note: Weights have been applied to maintain the sample representative
[1.a]These dwellings are allocated according to household income levels and sociodemographic characteristics.

Moreover, the profile of households is somewhat different according to the type of housing in which they live (table 1.4). In flats, the majority of households are tenants, whereas in houses, the majority are owner-occupied; on average, this latter group consumes more energy. Households living in flats are also smaller (on average, 2 people compared with 2.5 in individual houses) and younger (the person of reference in a flat [i.e., the household member answering the questions in the survey] is, on average, 5 years younger than the person of reference in a house), and energy consumption increases with the size and the age of the household. We also observe that the intensity of energy use decreases with the level of education. In contrast, income per consumption unit seems to have no impact on energy consumption per square meter. These observations suggest that household characteristics can have an impact on the intensity of energy used. We pay particular attention to this point in the following sections

Because the characteristics of houses and flats are significantly different (e.g., distribution of heating systems and fuels), we study the determinants of energy consumption separately for these two types of housing in the rest of this study.

1.4. Method

1.4.1. Methodology issues

Techniques used to model residential energy consumption can be grouped broadly into two main categories: ‘‘top-down’’ and ‘‘bottom-up’’ models (for reviews, see Swan and Ugursal, 2009; Zagamé, 2008). The top-down approach considers the residential sector as a whole and does not address energy consumption broken down into individual uses. The bottom-up approach encompasses all models that use input data. Because we want to estimate energy consumption (in kWh/m²), we use a bottom-up approach. We face two potential problems of endogeneity: the first is related to the stock of appliances or the heating system, and the second is related to energy prices.

Energy consumption can be described as a two-step process. First, households choose their heating system or their stock of appliances. Second, they decide how much energy to consume, given the available technology (relating to the inside temperature for example). This process leads to a potential endogeneity problem regarding the stock of appliances, which we must take into account to obtain unbiased results. Literature employs two general methodological frameworks to estimate residential energy consumption: conditional demand analysis and discrete-continuous choice analysis.

The first methodology estimates energy consumption, conditional on a given stock of appliances (Baker et al., 1989; Branch, 1993; Larsen and Nesbakken, 2004). This approach was proposed by Parti and Parti (1980), who disaggregate the total household consumption for electricity into a set of component demand functions for electricity usage in 16 appliance categories. The approach has been used in several studies (Leth-Petersen and Togeby, 2001; Meier and Rehdanz, 2010; Rehdanz, 2007). However, this method has two drawbacks. It focuses only on continuous energy consumption, without taking into account possible changes in equipment stock, and it requires a data set with information on the ownership of a variety of appliances (Swan and Ugursal, 2009). The second modeling methodology uses discrete and continuous choice analysis. An assumption under this framework is that, due to its dependence on appliance use, elasticities should not be estimated exclusively on the basis of one energy equation but also in terms of the choice of fuels for heating or cooling and the stock of other appliances. It is common for the choice of appliances using energy and energy consumption to be assessed in different steps. In a first step for example, the probability of using a specific heating system may be estimated, and in a second step, energy consumption is analyzed, introducing as an explanatory variable the estimated probability of using a specific heating system. The joint discrete-continuous decision framework makes it possible to account for the interrelationship between the choice of appliances and the intensity of energy use. This two-stage model is largely used to correct for endogeneity of discrete variables (Heckman and Robb, 1985). Dubin and McFadden (1984) were the first to apply this approach to the estimation of residential energy consumption: they use U.S. household data to simultaneously model the choice of appliances and energy consumption. In turn, they avoid the potential endogeneity bias resulting from unobserved factors that influence both appliance choice and its intensity of use. This approach has since been used in several studies (Baker and Blundell, 1991; Bernard et al., 1996; Nesbakken, 1999, 2001; Newell and Pizer, 2008; Vaage, 2000). We estimate the determinants of French households' energy consumption using this latter method.

Moreover, we take into account a second potential endogeneity problem related to energy prices. One of our objectives is to estimate price elasticity. Therefore, we introduced as explanatory variable in the second step the average energy prices (calculated as the weighted average of different fuel prices, with weights depending on the specific mix of fuels used by each household). To this end, we use instrumental variables to estimate the energy consumption choice, and we choose as instruments the previous energy prices.

1.4.2. Analysis method: discrete and continuous choices model

We focus on a discrete-continuous model. In the first stage of our model, we model decisions regarding space-heating systems with a multinomial probit. This is the “heating system choice.” Due to data limitations in the 2006 *Enquête Logement*, we can only examine heating system choices, and we have to ignore appliances, light, and energy choice for cooking. However, given the considerable weight of heating expenditures in French households’ total residential energy expenditures, which is assessed at approximately 70% of total energy consumption by the French National Institute of Statistics and Economic Studies (INSEE), this restriction does not necessarily prevent our analyses from yielding relevant insights. Moreover, most papers take into account only the choice of heating system in the first step (Bernard et al., 1996; Nesbakken, 1999, 2001; Vaage, 2000). Therefore, we estimate the probability that households in the flat sector choose one of the three mutually exclusive types of heating system: (1) an individual system with electricity, (2) an individual system with gas, and (3) a collective heating system with gas or fuel. In the house sector, all households have an individual heating system, but they must choose between three types of fuel for their main heating system: (1) electricity, (2) natural gas, and (3) oil. As we observed previously, the choice of heating system (**HS**) is commonly explained by most of the variables that also explain energy consumption, namely, the technical properties of the dwelling (**DW**), the climate area (**CL**), and sociodemographic characteristics (**SDH**). In addition, some variables explain only the heating system choice. These variables are grouped in the vector **Z**. It includes the dwelling location (downtown, suburbs, rural area) to take into account the availability of fuel in the area (Braun, 2010; Nesbakken, 1999, 2001; Newell and Pizer, 2008; Vaage, 2000). City gas is not available in a rural area. It also includes a dummy equal to 1 if the flat or the house is a co-ownership. In this case, the household is not the only one to choose the heating system.

Therefore,

$$HS_{i,k} = \alpha_0 + \alpha_1' \boldsymbol{DW}_{i,k} + \alpha_2' \boldsymbol{CL}_{i,k} + \alpha_3' \boldsymbol{SDH}_{i,k} + \alpha_4' \boldsymbol{Z}_{i,k} + \mu_{i,k}.$$

Conditional on this previous choice, a household decides how much energy to consume. Therefore, in the second stage, we estimate the total energy consumption (the logarithm of the energy consumption in kWh/m²), conditional on the chosen heating system. This is the “energy consumption choice.” The joint estimation of both choices enables us to capture the potential correlation between unobservable variables in the discrete and the continuous stages.

We estimate it using a double least squares model, which enables us to correct for the endogeneity issue of energy prices.[3] In addition, two-step methods can lead to an underestimation of standard errors of the second step. We apply a bootstrap correction on the variance-covariance matrix to avoid bias in the interpretation of coefficients' significance level (Murphy and Topel, 1985).

We want to compare the role of different categories of variables in explaining energy consumption per square meter. This includes the household's sociodemographic characteristics (**SDH**), energy price (**P**), the technical properties of the dwelling (**DW**), the heating system **(HS**), and the climatic specificities of the area (**CL**). First, we estimate a complete model, taking into account all these variables. We also introduce multiplicative variables to correct for collinearity problems. This complete model estimates the logarithm of energy consumption per square meter in dwelling i belonging to housing category k (flat or house). We introduced the predicted heating system ($\hat{\mathbf{HS}}$).

(1) *Complete model:*

$$\ln(C_{i,k}) = \beta_0 + \beta_1' \boldsymbol{DW}_{i,k} + \beta_2' \boldsymbol{CL}_{i,k} + \beta_3' \widehat{\boldsymbol{HS}}_{i,k} + \beta_4 \boldsymbol{P}_{i,k} + \beta_5' \boldsymbol{SDH}_{i,k} + \varepsilon_{i,k}.$$

Second, we test three different interlocked models to assess how the five categories of variables predict the variance in energy consumption. We estimate these interlocked models to compare the predictive power of the five different categories of variables (F-test of a set of coefficient) and the goodness of fit of the reduced model (adjusted R-square). The technological model explains energy consumption by characteristics of the building (**DW**), predicted heating system ($\hat{\mathbf{HS}}$), and climate dummies (**CL**).

(2) *Technological model:*

$$\ln(C_{i,k}) = \beta_0 + \beta_1' \boldsymbol{DW}_{i,k} + \beta_2' \boldsymbol{CL}_{i,k} + \beta_3' \widehat{\boldsymbol{HS}}_{i,k} + \varepsilon_{i,k}.$$

The eco-technological model is the technological model with the average price (**P**).

(3) *Eco-technological model:*

$$\ln(C_{i,k}) = \beta_0 + \beta_1' \boldsymbol{DW}_{i,k} + \beta_2' \boldsymbol{CL}_{i,k} + \beta_3' \widehat{\boldsymbol{HS}}_{i,k} + \beta_4 \boldsymbol{P}_{i,k} + \varepsilon_{i,k}.$$

[3] We use as instruments previous energy prices. We show the validity of these instruments in appendix (table 1.10).

The sociodemographic model assesses the energy consumption by the household characteristics only (**SDH**).

(4) *Sociodemographic model*:

$$\ln(C_{i,k}) = \beta_0 + \beta_5' \boldsymbol{SDH}_{i,k} + \varepsilon_{i,k}.$$

1.5. Results

We focus on estimations on energy consumption. The results of the first step are available in appendix (tables 1.8 and 1.9). We evaluate the explanatory power of the different models presented in the previous section[4] (Santin et al., 2009) and carry out tests a set of coefficients to determine the contribution of each category of variables (households' sociodemographic characteristics, technical properties of housing, energy price, climate area, and heating system) to explain energy consumption.[5] The results are similar for flats and houses. It appears that energy consumption is almost completely determined by technology and climate. Table 1.5 shows that the complete model (model 1) explains approximately 35% of the variance of energy consumption. Technical properties of the dwelling, the type of heating system, and the climate characteristics of its location (model 2) explain 19% of the variation of energy consumption for houses and 17% for flats. It is striking to observe how the sociodemographic model (model 4) registers a low R-square, emphasizing that the influence of socioeconomic factors on energy consumption is weak compared with that of building features and climate. Income and household sociodemographic characteristics play only a weak role in explaining the variance of energy consumption (approximately 2% in houses and 4.5% in flats). In the short run, energy consumption per square meter is determined only slightly by the household itself. Santin et al. (2009) obtain a similar result in the Dutch housing context, with only 5% of variance of energy consumption explained by sociodemographic variables and by household behavior. They include variables similar to those we considered in our model (income, household size, age of respondent, occupancy status), excluding variables on educational level, but with additional information on temperature in the housing. This result illustrates that, in the short run, the possibility for a

[4] This approach gives an indication of the relative importance of different categories of variables in explaining energy consumption. However, the results must be interpreted with caution. Removing significant variables from the model can introduce a bias in the estimation.

[5] We measure the significance of a set of coefficient using a Fisher test.

given household in a given dwelling to reduce its energy consumption is extremely weak in the absence of investment in the quality of the lodging.

Table 1.5. Comparison of goodness of fit of different models (variable to explain: consumption by m² [in ln] in flats. F-test and adjusted R-squares)

Variables	**Complete model (1)**	**Technological model (2)**	**Economic and technological model (3)**	**Sociodemographic model (4)**
Results for houses				
Group 1: technical properties of dwelling **DW**	F: 90.42***	F: 66.38***	F: 79.65***	—
Group 2: climate dummies **CL**	F: 59.35***	F: 53.98***	F: 59.22***	—
Group 3: heating system **HS**	F: 13.53***	F: 47.61***	F: 28.94***	—
Group 4: price of energy **P**	F: 413.01***	—	F: 398.56***	—
Group 5: sociodemographic variables **SDH**	F: 11.53***	—	—	F: 27.74***
Adjusted R-square	0.3506	0.1965	0.3231	0.0272
Observations	11,476	11,476	11,476	11,476
Results for flats				
Group 1: technical properties of dwelling **DW**	38.67***	68.90***	83.38***	—
Group 2: climate dummies **CL**	40.10***	48.71***	54.89***	—
Group 3: heating system **HS**	3.29**	16.77***	0.19^{ns}	—
Group 4: price of energy **P**	412.51***	—	629.01***	—
Group 5: sociodemographic variables **SDH**	47.32***	—	—	40.42***
Adjusted R-square	0.3440	0.1696	0.2978	0.0450
Observations	8,373	8,373	8,373	8,373

Note: The complete list of each group of variables appears in table 1.2.

The results enable us to identify some of the main sources of energy conservation in the French housing sector. In the flats sector, there is a strong effect of collective heating on energy consumption. Buildings equipped with a central heater (either natural gas or oil) have significantly higher levels of consumption than those equipped with an individual heater (either natural gas or electricity), ceteris paribus. This is in the line of the results of Santin et al. (2009), who show that in dwellings in which heating is included in the rent, more energy is used. The installation of individual metering or the replacement of collective systems by individual heating systems could be helpful in decreasing energy consumption in collective housing blocks. In addition, energy consumption per square meter is lower in dwellings heated by electricity than in dwellings heated by fuel oil, ceteris paribus (see table 1.6 below and table 1.11 in appendix).

With regard to insulation characteristics, double-glazing reduces energy consumption on average in flats, but the effect is less pronounced in the more recently constructed segment. However, in houses, roof insulation renovations are more efficient for saving energy than the installation of double-glazing in houses. Environmental policies should target these kinds of renovations to have a significant effect on energy consumption. The impact of double-glazing is not significant for houses, ceteris paribus, except for those built between 1975 and 1989 (compared with those built before 1948). This surprising result may be due to the "rebound effect." Such an effect appears when investment in a new technology such as double-glazing can entail a change in household behavior (e.g., increase of temperature target), which at least partially offsets the beneficial effects of the technology. In a large survey, Greening et al. (2000) find that a 100% increase in energy efficiency led to an estimated rebound of 0%–50% for residential end uses.

It appears that among other technical properties, the size of the dwelling has a negative impact on energy consumption per square meter. Flats with a better exposure and more recent constructions (built after 1975) have lower energy consumption. In contrast, in houses, an unconverted cellar or attic, a veranda, or a detached house rather than an attached one tend to increase energy consumption.

Moreover, as we expected, the quantity of energy consumed is significantly lower in the areas with a warmer climate: oceanic and Mediterranean compared with mountain areas. In contrast, energy consumption is the highest in the semicontinental areas. This confirms Nesbakken's (1999) and Meier and Rehdanz's (2010) results.

Households' characteristics have received little attention in the literature, and as we observed, they play a weak part in explaining energy consumption. However, the number of household members, their income per consumption unit, their education, presence at home, occupancy status, and the age of the head of the household have a significant impact on energy consumption. Income elasticity is low (0.02) in houses and not significant in flats. In most studies, income elasticity is estimated to be less than 0.15 (see table 1.1). Energy consumption is a normal good, but it remains weakly responsive to an increase of income per consumption unit.

Table 1.6. Estimates of household energy consumption per square meter in a year - individual dwellings

Double least squares. Explained variable: household energy consumption per m² a year (in logarithm)			
Explanatory factors	**Coeff.**	**Student t boostrap correction**	
Technical properties of dwelling			
House type			
attached houses	ref		
semi detached houses	-0.0078	-0.68	
detached_houses	0.0780	7.16	***
Dwelling area			
ln dwelling area (m²)	-0.4926	-28.56	***
Specificities			
roof_less 3 meters	-0.0355	-2.36	**
office in the dwelling	0.0645	2.67	***
veranda	0.0223	2.02	**
moisture problem	-0.0020	-0.18	

cellar_not_converted	0.0556	4.88	***
attic	0.0307	4.20	***
Dwelling construction period			
construction_before 1948	ref		
Construction 1949–1974	0.0514	2.81	***
Construction 1975–1989	-0.0149	-0.52	
Construction 1990–2005	-0.0257	-0.40	
Insulation characteristics			
recent roof insulation	-0.0704	-3.55	***
adequate roof insulation	-0.0261	-1.52	
inadequate_roof_insulation	-0.0104	-0.55	
nonexistent roof insulation	ref		
recent roof insulation*construction 1975–1989	0,0429	1.54	
recent_roof_insulation*construction 1990–2005	-0,0664	-1.69	*
adequate_roof_insulation*construction 1975–1989	-0,0289	-1.36	
adequate roof insulation*construction 1990–2005	-0,0320	-0.77	
double glazing	-0.0232	-1.28	
double_glazing*construction 1949–1974	-0.0333	-1.59	
double glazing*construction 1975–1989	-0.0503	-1.97	**
double_glazing*construction 1990–2005	-0.0581	-0.92	
Dwelling exposure (according to households)			
poor exposure	ref		
medium exposure	-0.0062	-0.22	
good_exposure	-0.0059	-0.21	
Climate areas			
mountain climate	ref		
semi continental climate	0.0513	2.67	***
mild_oceanic_climate	-0.0492	-2.72	***
mixed oceanic climate	0.0065	0.35	
oceanic climate	-0.1670	-9.47	***
cooler oceanic climate	-0.1166	-5.77	***
mediterranean_climate	-0.1175	-5.83	***
Heating type			
predicted probability to choose electric heating	ref		
predicted probability to choose gas heating	0.0438	1.02	
predicted probability to choose fuel oil heating	0.2405	3.67	***
Energy price			
ln_average energy price	-0.4685	-21.15	***
Household sociodemographic characteristics			
Household demographic characteristics			
ln nb persons	0.4501	4.29	***
ln_age_ ref_person (age of household member answering the questions)	0.2016	6.21	***
ln nb persons*ln age ref person	-0.0690	-2.59	**
Household occupancy state			
owner	ref		
socially subsidised housing	-0.0386	-2.22	**
private tenant	-0.0606	-3.76	***
Educational level of household member answering the questions in the survey			
without_certificate	ref		
brevet diploma or vocational training qualification	0.0085	0.74	
baccalaureat	0.0047	0.32	
baccalaureat +2 years or more	0.0008	0.05	
Income and others characteristics			
ln annual income per consumption unit	0.0295	3.87	***
retired	-0.0011	-0.09	
unemployed	0.0174	1.10	
homemaker	0.0032	0.30	
constant	7.1658	42.46	***
Number of observations	11,476		
R^2	0.3532		

***Significant at 1%. **Significant at 5%. *Significant at 10%.

Among other sociodemographic characteristics, the age of the head of household, the number of people living in the dwelling, and the presence at home (which is captured by the presence of an office in houses and the type of employment in flats: unemployed or homemakers) increase the intensity of energy used per square meter. Education level is only significant for flats, in which more educated people consume less energy than less educated ones. In addition, the impact of occupancy status on energy consumption depends on the type of dwellings. Tenants consume more energy than homeowners in flats. In contrast, owners have a significantly higher energy consumption than tenants occupying private and subsidized housing in houses.

Households are sensitive to energy price evolution. Price elasticity in absolute value is equal to 0.46 in houses and 0.86 in flats. With cross-sectional data, this means that households facing higher average energy prices consume less energy than others. Moreover, the higher price elasticity in flats means that households living in this kind of dwelling are more responsive to the price of energy. The main policy implication of these results is that adopting a policy of building renovation or introducing supplementary taxes on energy prices could be helpful in significantly decreasing energy consumption in France. This last measure could affect primarily the poorest people and raise the issue of energy poverty, but taxes could be redistributed to fund other environmental policies as subsidies.

1.6. Conclusion

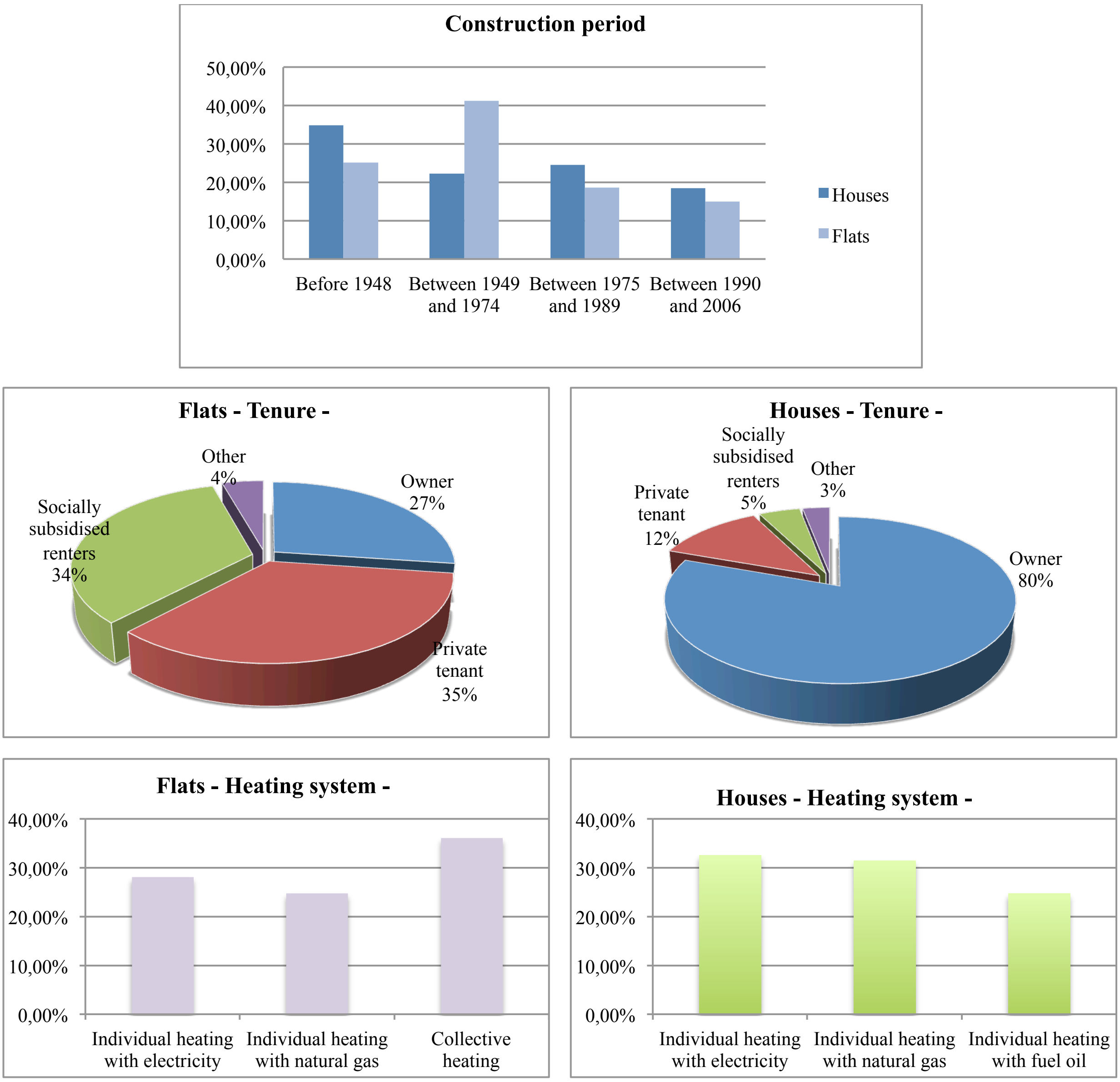
In this study, using a micro data set, we estimate the residential energy consumption of French households, conditional on their heating system. Households face a two-stage decision process when determining their energy consumption. First, they choose which energy to use for their heating system. Conditional on this first step, households then determine how much energy to use in a second step. We estimate energy consumption for two different types of dwellings: houses and flats. We compare the predictive power of four different models for each category of housing: (1) a complete model, (2) a technological model (with consumption explained by characteristics of building, heating system, and climate dummies), (3) an eco-technological model (technological model with average level of energy price), and (4) a sociodemographic model (consumption explained by household characteristics alone).

The first result of our analysis is that energy consumption is almost completely determined by the technical properties of a dwelling, the type of heating technology, and climate dummies. In the short run, without large investments in insulation and new types of energy-efficient appliances, changes in energy consumption will be weak. The second contribution is to identify some of the main sources of energy conservation. It appears that in addition to standard measures such as roof insulation and the improvement of exposure in new buildings, the replacement of collective systems with individual heating systems would improve buildings' energy efficiency. In contrast, the effect of double glazing is surprisingly ambiguous, which raises the possibility of the existence of a "rebound effect" problem. The third contribution of this study is to propose an estimation of the price elasticity and of the income elasticity of energy consumption per square meter, an issue that is not well documented in prior literature for French households. The results show that price elasticities are in the range of what is generally found in other countries. Price elasticity in absolute values reaches 0.81 in flats and 0.46 in houses; households are responsive to an increase in energy prices. In contrast, we find almost no variation of energy used per square meter with the level of household income. This result is also common in prior literature. Given these results, we conclude that the challenge for environmental policies is to encourage households to undertake renovation in their dwelling.

1.7. Appendix

1.7.1. Data

Figure 1.2. French dwelling characteristics (full sample)



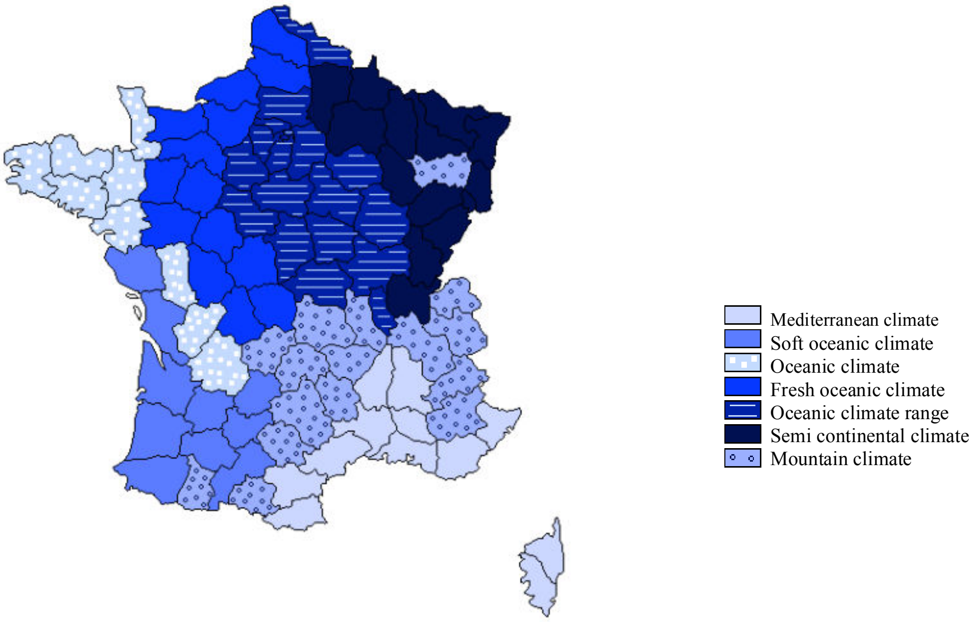
Source: 2006 *Enquête Logement* (INSEE)—results for the France

Table 1.7. Data description—the final sample

	Houses		Flats	
	Mean	**SD**	**Mean**	**SD**
House type				
gathered_houses	0.1389	0.3459		
semi_detached_houses	0.3219	0.4672		
detached_houses	0.5392	0.4985		
Flat characteristics				
public_housing			0.3699	0.4828
co_ownership	0.0689	0.2533	0.5460	0.4979
ln_nb_dwellings_in_block_of_flats			2.6910	1.0249
ln_floor			1.0340	0.6154
Dwelling characteristics				
ln_dwelling_area	4.6442	0.3280	4.1230	0.3963
roof_less_3meters	0.9380	0.2412	0.9473	0.2234
office_in_the_dwelling	0.0223	0.1477	0.0045	0.0672
veranda	0.1115	0.3147	0.0232	0.1505
moisture_problem	0.1715	0.3770	0.2885	0.4531
cellar_not_converted	0.1693	0.3750		
attic	0.5071	0.5000		
Dwelling construction period				
construction_before 1948	0.2368	0.4251	0.2463	0.4309
Construction 1949–1974	0.2375	0.4255	0.4051	0.4909
Construction 1975–1989	0.2436	0.4293	0.1710	0.3766
Construction 1990–2000	0.2822	0.4501	0.1776	0.3822
Insulation characteristics				
double_glazing	0.7744	0.4180	0.6817	0.4658
recent_roof_insulation	0.3975	0.4894		
sufficient_roof_insulation	0.4258	0.4945		
insufficient_roof_insulation	0.1129	0.3165		
nonexistent_roof_insulation	0.0638	0.2444		
Exposure (according to households)				
bad_exposure	0.0200	0.1401	0.0664	0.2490
medium_exposure	0.1245	0.3302	0.1747	0.3798
good_exposure	0.8554	0.3517	0.7589	0.4278
Location				
town	0.3486	0.4765	0.5942	0.4911
suburbs	0.4115	0.4921	0.3930	0.4885
rural_town	0.2400	0.4271	0.0128	0.1123
Climate areas				
mountain_climate	0.0566	0.2310	0.0364	0.1874
semi_continental_climate	0.0771	0.2668	0.0626	0.2422
cooler_oceanic_climate	0.1261	0.3320	0.0508	0.2195
mixed_oceanic_climate	0.2921	0.4547	0.4086	0.4916
oceanic_climate	0.1792	0.3836	0.1395	0.3465
mild_oceanic_climate	0.1163	0.3206	0.0742	0.2621
mediterranean_climate	0.1526	0.3596	0.2280	0.4196
Energy price				
ln average energyies price	1.8836	0.2361	1.9233	0.2437
price of electricity (for 100kWh)	2.2948	0.0817	2.3251	0.1136
price of gas (for 100kWh)	1.7342	0.2572	1.6670	0.2536
price of fuel oil (for 100kWh)	1.8641	0.0000	1.8641	0.0000
Demographic characteristics				
ln_person	0.9061	0.5306	0.6669	0.5625
ln_age_ref_person (age of household member)	3.9356	0.2979	3.8233	0.3501
Occupancy state				
ownership	0.8377	0.3688	0.2838	0.4509
socially subsidised housing	0.0044	0.0665	0.0140	0.1174
private_rent	0.0021	0.0457	0.0165	0.1273

Educational level of household member answering the questions in the survey				
without_certificate	0.1419	0.3489	0.2064	0.4047
less_than_baccalaureat	0.4841	0.4998	0.3917	0.4882
baccalaureat	0.1305	0.3369	0.1344	0.3411
more_than_baccalaureat	0.2436	0.4292	0.2675	0.4427
Others characteristics				
retired	0.3502	0.4771	0.2408	0.4276
unemployed	0.0626	0.2422	0.1571	0.3639
homemaker	0.1379	0.3449	0.1387	0.3456
Standard living of households				
ln_monthly_income_per_consumption_unit	9.7379	0.6138	9.4397	0.7798
ln_energy_consumption (m²)	5.1695	0.4577	5.0738	0.5066
Number of observations	11,476		8,373	

Map 1.1. Climate Areas of France



Source: INSEE

1.7.2. Heating system choice estimations

Building characteristics are somewhat different according to the type of heating system. Briefly, our estimates show that electric heat is mainly chosen by dwellings built after 1975 that are equipped with double-glazing; these dwelling are relatively small, located primarily in rural areas, and often occupied by tenants rather than their owners. Natural gas heating is generally found in towns in rather large, semidetached houses built between 1949 and 1975 that rarely are equipped with double-glazing and are owner-occupied. Fuel oil heating is found primarily in large detached houses in rural areas that were built before 1974, rarely are equipped with double-glazing, and are owner-occupied.

Table 1.8. Multinomial probit regression—houses

Discrete choice	Electricity heating			Gas heating			Fuel oil heating		
	Coeff.	Student t		Coeff.	Student t		Coeff.	Student t	
Technical properties of dwelling									
House type									
gathered_houses	ref			ref			ref		
semi_detached_houses	-0. 0146	-0.91		0.0387	2.36	**	-0.0241	-1.85	*
detached_houses	0. 0429	2.87	***	-0.1195	-7.73	***	0.0766	6.42	***
Dwelling area									
ln_dwelling_area (m²)	-0.2802	-15.22	***	0.1110	6.09	***	0.1692	12.80	***
Specificities									
co_ownership	0.0426	2.10	**	0.0295	1.41		-0.0721	-4.70	***
roof_less_3meters	-0.0015	-0.07		-0.0252	-1.16		0.0267	1.79	*
cellar_not_converted	-0.0790	-5.84	***	-0.0130	-0.91		0.0920	7.83	***
attic	-0.0302	-2.91	***	0.0041	0.38		0.0261	3.24	***
Dwelling construction period									
construction_before48	ref			ref			ref		
Construction 1949–1974	-0.1161	-7.79	***	0.0609	3.93	***	0.0552	4.64	***
Construction 1975–1989	0.3144	20.13	***	-0.1845	-12.16	***	-0.1299	-14.51	***
Construction 1990–2006	0.2057	11.62	***	-0.0500	-2.84	***	-0.1557	-15.56	***
Insulation characteristics									
double_glazing	0.1431	11.43	***	-0.0637	-4.65	***	-0.0794	-7.13	***
recent_roof_insulation	-0.0294	-1.21		0.0888	3.65	***	-0.0594	-3.63	***
adequate_roof_insulation	-0.0013	-0.06		0.0467	2.03	**	-0.0453	-2.92	***
inadequate_roof_insulation	0.0069	0.26		0.0328	1.24		-0.0397	-2.42	**
nonexistent_roof_insulation	ref			ref			ref		
Dwelling localization									
downtown	ref			ref			ref		
suburbs	0.0130	1.08		-0.0088	-0.73		-0.0042	-0.44	
rural_town	0.2042	14.29	***	-0.3951	-34.48	***	0.1909	14.80	***
Climate areas									
mountain_climate	ref			ref			ref		
semi_continental_climate	-0.1521	-6.37	***	0.1721	5.97	***	-0.0200	-1.10	
cooler_oceanic_climate	-0.0365	-1.45		0.1306	4.82	***	-0.0941	-7.15	***
mixed_oceanic_climate_range	-0.0633	-2.74	***	0.2276	9.29	***	-0.1643	-13.13	***
oceanic_climate	-0.0082	-0.33		0.0609	2.30	**	-0.0527	-3.53	***
mild_oceanic_climate	0.0344	1.28		0.0964	3.47	***	-0.1307	-11.87	***
mediterranean_climate	0.1652	6.20	***	-0.1469	-5.70	***	-0.0183	-1.07	
Household characteristics									
Households demographic									
ln_nb_persons	-0.0418	-3.49	***	0.0379	3.09	***	0.0039	0.41	
ln_age_ref_pers	-0.0632	-2.88	***	-0.0008	-0.03		0.0640	3.58	***
Household occupancy state									
ownership	ref			ref			ref		
socially subsidised housing	-0.1740	-10.26	***	0.3126	16.03	***	-0.1386	-10.18	***
private_tenant	0.1554	8.11	***	-0.0994	-5.32	***	-0.0560	-4.38	***
Rate of correct predictions	61.5%								
Number of observations	11,476								

***Significant at 1%. **Significant at 5%. * Significant at 10%.

Table 1.9. Probit multinomial—flats

Discrete choice	Individual heating						Collective heating		
	Electricity heating			Gas heating			(gas or fuel oil)		
	Coeff	Student t		Coeff	Studen		Coeff	Stud	
Technical properties of dwelling									
Number of dwelling in apartment buildings									
ln_nb_dwellings	-0.0342	-4.30	***	-0.0049	-0.67		0.0390	11.33	***
floor (ln)	-0.0166	-1.39		-0.0136	-1.26		0.0302	6.26	***
Dwelling area									
ln_dwelling_area (m²)	-0.4122	-18.86	***	0.3425	17.18	***	0.0698	6.88	***
Specificities									
public_housing	-0.3781	-25.73	***	0.1499	7.11	***	0.2282	10.71	***
co_ownership	0.0215	1.06		0.0042	0.23		-0.0257	-2.38	**
roof_less_3meters	0.0067	0.22		0.0046	0.17		-0.0113	-0.63	
Dwelling construction period									
construction_before48	ref			ref			ref		
Construction 1949–1974	-0.2674	-14.48	***	0.0104	0.56		0.2570	15.45	***
Construction 1975–1989	0.0991	4.38	***	-0.1209	-6.08	***	0.0219	1.74	*
Construction 1990–2000	0.1741	8.18	***	-0.1313	-6.62	***	-0.0428	-4.56	***
Insulation characteristics									
double_glazing	0.1446	9.10	***	-0.0918	-6.33	***	-0.0528	-7.50	***
Dwelling localization									
downtown	ref			ref			ref		
suburbs	-0.0051	-0.33		0.0003	0.02		0.0048	0.73	
rural_town	0.3732	11.59	***	-0.3296	-13.01	***	-0.0435	-2.44	**
Climate areas									
mountain_climate	ref			ref			ref		
semi_continental_climate	-0.1659	-3.44	***	0.1228	2.89	***	0.0431	1.79	*
cooler_oceanic_climate	-0.0131	-0.26		0.0045	0.10		0.0086	0.46	
mixed_oceanic_climate	0.1134	2.81	***	-0.1183	-3.34	***	0.0048	0.33	
oceanic_climate	-0.0839	-1.97	**	0.1197	3.03	***	-0.0358	-3.21	***
mild_oceanic_climate	0.1022	2.38	**	-0.0418	-1.03		-0.0603	-7.52	***
mediterranean_climate	0.2286	6.07	***	-0.1476	-4.27	***	-0.0809	-8.27	***
Household characteristics									
Households demographic characteristics									
ln_nb_persons	0.0256	1.86	*	-0.0233	-1.85	*	-0.0023	-0.43	
ln_age_ref_pers	0.0055	0.25		-0.0200	-0.99		0.0145	1.61	
Household occupancy state									
ownership	ref			ref			ref		
tenant	0.1559	8.34	***	-0.0749	-4.23	***	-0.0810	-7.99	***
Rate of correct predictions	64.9%								
Number of observations	8,373								

***Significant at 1%. **Significant at 5%. *Significant at 10%.

1.7.3. Enercy consumption estimations

Table 1.10. Tests of overidentifying restrictions

	Houses estimation	Flats estimation
Instruments	Gas city price in 1986 and 1996	Electricity price in 1986 and price of the electricity subscription
Sargan test	p-value = 0.1903	p-value =0.4900
Basmann test	p-value = 0.1912	p-value =0.4910

Table 1.11. Estimates of household energy consumption per m² (in logarithm) in a year: flats

Linear regression for flats. Continuous choice. Double least Squared.			
Explanatory factors	**Coefficient**	**Student t**	
Technical properties of the housing unit			
Collective dwelling characteristics			
nb of dwellings in blocks of flats (ln)	-0.0252	-3.92	***
floor (ln)	-0.0630	-7.47	***
Dwelling area			
ln_dwelling_area (m²)	-0.4853	-14.34	***
Specificities			
roof_less_3meters	0.0376	1.67	*
veranda	0.0131	0.39	
moisture problem	0.0412	4.06	***
Dwelling construction period			
construction 1949–1974 (ref. construction before 1948)	-0.0440	-1.49	
construction 1975–1989 (ref. construction before 1948)	-0.0472	-1.85	*
construction 1990–2005 (ref. construction before 1948)	-0.2012	-3.12	***
Insulation characteristics			
double_glazing	-0.0548	-2.67	***
double_glazing*construction 1949–1974	0.0409	1.70	*
double_glazing*construction 1975–1989	0.0309	1.05	
double_glazing*construction 1990–2005	0.1194	1.80	*
Dwelling exposure (according to households)			
medium_exposure (ref. poor exposure)	-0.0414	-1.95	*
good_exposure (ref. poor exposure)	-0.0397	-2.08	**
Climate areas			
semi_continental_climate (ref. mountain_climate)	0.0696	2.31	**
cooler_oceanic_climate (ref. mountain_climate)	-0.0233	-0.73	
mixed_oceanic_climate (ref. mountain_climate)	0.0458	1.78	*
oceanic_climate (ref. mountain_climate)	-0.2095	-7.70	***
mild_oceanic_climate (ref. mountain_climate)	-0.0494	-1.59	
mediterranean_climate (ref. mountain_climate)	-0.0482	-1.67	*
Heating System			
predicted probability to choose individual electric heating	ref		
predicted probability to choose individual gas heating	0.1262	1.92	*
predicted probability to choose collective heating (gas or fuel oil)	0.2165	2.59	**
Energy price			
ln_average energy_price	-0.8152	-19.81	***
Household sociodemographic characteristics			
Household demographic characteristics			
ln_nb_persons	0.1934	18.46	***
ln_age_ref_person (age of household member answering the questions in the survey)	0.0830	3.83	***
Household occupancy state			
rent	0.4780	3.95	***
rent*area	-0.1150	-3.97	***
socially subsidised tenant	-0.0969	-3.75	***
Educational level of household member			
without_certificate	ref		
brevet_diploma or vocational_training_qualification	-0.0267	-2.03	**
baccalaureate	-0.0381	-2.24	**
baccalaureat +2 years or more	-0.0137	-0.88	
Income and others characteristics			
ln annual income per consumption unit	0.0038	0.49	
retired	0.0058	0.37	
unemployed	0.0245	1.73	*
homemaker	0.0380	2.54	**
constant	8.3024	45.91	***
number of observations		8,373	
R^2		0.3468	

***Significant at 1%. **Significant at 5%. *Significant at 10%.

Chapter 2.
Evaluation of the impact of environmental public policy measures on energy consumption and greenhouse gas emissions in the French residential sector[6]

Summary

A cut in energy consumption by 2050 to reach 50 kWh_{pe}/m^2/year and reduce GHG emissions by 75% are important objectives of environmental policy in France. The residential sector represents a significant potential source of energy savings. In this paper, our main objective is to construct a simulation model and to evaluate the impact of environmental public policy measures. We model energy consumption and GHG emissions, the decision to invest in energy saving renovations and the dynamics of the housing stock. This study has three major outputs. First, we estimate the energy consumption and GHG emissions of the residential sector in France through 2050. Second, we study the impact of environmental public policy measures. Lastly, we propose different means to reach the objectives. The results show that while current policies are effective, they are not sufficient to reach the objectives.

[6] A version of this paper is published as: Charlier, Dorothée and Risch, Anna. "Evaluation of the Impact of Environmental Public Policy Measures on Energy Consumption and Greenhouse Gas Emissions in the French Residential Sector." *Energy Policy*, 46(0), pp. 170-84

2.1. Introduction

Energy consumption and GHG emissions are a key concern in France. French legislation known as the Grenelle 1 Act has set objectives to reduce GHG emissions by 75% by 2050 and reach 50 kWh_{pe}/m^2/year. The residential sector (with heating and hot water, lighting and appliances) consumes more energy than any other sector in France. It also has considerable potential to save energy, particularly through energy-efficient, cost-effective renovations. However, households do not invest significantly in energy saving measures even when these could save them money. The literature about this so-called energy paradox is extensive (Brown, 2001; Jaffe and Stavins, 1994; Sanstad et al., 1995; van Soest and Bulte, 2001) with most authors arguing that market imperfections are the underlying cause of the paradox. The intervention of the government, through public policy, may be a solution to these market failures. Environmental policies currently are targeting the residential sector to better exploit its energy saving potential. Several measures have been introduced in recent years, including income tax deductions, subsidies and zero rate bank loans, to encourage households to undertake energy efficient renovations. It seems important to evaluate the impact of these measures.

To our knowledge, two models of simulation study residential energy consumption and dynamics of housing stock in France. *MENFIS* and *Res-IRF* models aimed at assessing the impact of environmental policies (MEDDTL et al., 2011 and Giraudet et al., 2011). These both models segment housing on the basis of energy labels. The first one considers a very large number of renovations and finds that tax credit allows decreasing residential energy consumption by 8% between 2008 and 2010. The second one considers only important renovations, which allow housing switching to another label, but takes into account households behavior concerning demand for heating-space energy consumption as rebound effect. They show that policies improve the energy efficiency of building stock but, with the exception of carbon tax, generate a rebound effect. Our objective is to bring a complementary approach to these models. Our method is different especially in the construction of the model, and we provide additional information on the behavior of households in term of energy saving investment, including segmentation by income quintile.

Overall, the residential sector is complex due to the wide variety of housing types and diverse household behaviors. Each type of housing has different technical characteristics determined by a combination of factors, including when the building was constructed, its potential for renovation and surface area, whether the housing is individual or collective, the climate, etc.

The behavior of households also varies depending on whether they own or rent the place in which they live, their sensitivity to the environment (Levinson and Niemann, 2004), and their lifestyle (Weber and Perrels, 2000).

Previous studies have taken diverse approaches to analyzing the use of energy in the residential sector. Some focus on the dynamics of housing stock under the assumption that renovations, demolitions and constructions have a strong impact on energy demand (Sartori et al., 2008) and GHG emissions. Nemry et al. (2000) predict emissions by determining the number of square meters of Belgian housing projected to be built each year until 2020. Other studies model energy consumption. In the 21st century, on a global level, energy consumption for both heating and air conditioning will increase, although heating will do so to a lesser extent than air conditioning (Isaac and van Vuuren, 2009). This will impact GHG emissions, hence the importance of setting up and testing the effect of measures which improve energy efficiency. Shimoda et al. (2004) have developed a model to predict the level of energy consumption in Osaka and to test the effects of changes in lifestyle, efficiency of appliances, and the quality of insulation. Siller et al. (2007) show that energy consumption and GHG emissions could be reduced significantly by 2050 in Switzerland, but this would require the implementation of ambitious policies. Several studies indicate that incentives to change the source of heating energy have a strong impact on gas emissions (Jaccard et al., 1996; Kadian et al., 2007), whereas technologies that improve energy efficiency are more effective with regard to reducing energy consumption (Kadian et al., 2007). In Japan, the large scale introduction of photovoltaic panels is a key measure aiming to reduce gas emissions (Shimoda et al., 2010). Yet other studies examine the decision to invest in energy saving technologies. Amstalden et al. (2007) show that the expected energy price has a significant impact on the analysis of the profitability of energy saving investment. The introduction of environmental measures such as subsidies, taxes or income tax deduction also has an important effect. Jakob (2006) works on the marginal cost of energy-saving technologies and considers the feasibility of some investments. For uninsulated housing, it is profitable in most cases to invest in thermal insulation, especially if the homeowner anticipates high energy prices.

In this article, we have chosen to combine these approaches and model energy consumption dynamics resulting from both housing stock dynamics and energy saving investment decisions. We propose a simulation model built using a bottom-up approach. Bottom-up models calculate the energy consumption of groups of houses and then extrapolate these results to represent the nation. We extrapolate the estimated energy consumption and GHG emissions of a representative set of dwellings. The major attribute of bottom-up approach is the determination of typical end-use energy contribution and the inclusion of socioeconomic using billing data from a survey sample of households. However, with this method, assumptions of occupant behavior are made[7] (see Swan and Ugursal (2009) for a precise review of this techniques). This study produces three major outputs: (i) an estimation of French residential energy consumption and GHG emissions through 2050, (ii) an assessment of the impact of environmental policies, and (iii) proposals of different means to reach the objectives set out in the Grenelle 1 Act (referred to in the remainder of the text as the 'Grenelle I objectives'). We test the impact of existing policies (income tax deduction, zero rate bank loans, subsidies, and VAT) and one potential policy (bonuses). We also calculate the amount these policies cost for the government. The results show that current policies are effective in the sense that they have enabled a decrease of energy consumption and GHG emissions over recent years. However, they alone will not ensure that the objectives set for 2050 will be reached. Additional public investment is necessary to achieve these goals. The remainder of the paper is organized as follows: section 2 presents the current public policies in France, section 3 describes the model, section 4 presents the results, and section 5 discusses the sensitivity analysis conducted.

2.2. Public policy

In France, several environmental policies are meant to encourage households to undertake energy saving renovations. There are four principal financial supports, and households can receive them if renovations are done by building professionals. A tax deduction allows part of the expense to be deducted from their income tax. The deduction rate is a function of equipment (for example double glazing or heating system), and the portion of expenses deducted depends on the number of persons in the household. A zero rate bank loan is offered to homeowners who make several renovations or an energy-saving investment. Since 2011, it can no longer be combined with the income tax deduction. Homeowners who make renovations involving insulation or choose an efficient heating system also can receive a subsidy depending on household income. Finally, a reduced value added tax of 5.5% is applied to all types of renovations (the normal rate is 19.6%). The last policy is decided by the European Union whereas the others are decided by the French government and therefore can be modified more easily (table 2.1).

[7] For example, we consider that the heating temperature in the dwelling is 19°C or the length of occupation by day is set to.

We explain in the part 2.3.2.1 how these policies are introduced in the model.

Table 2.1. Public Policies

Measure	Description	Rate
Income tax deduction	A part of the expenses in energy saving renovation can be deducted from the household income tax (or refunded if the household pays no income tax). This concerns only a range of specific renovations and the expenses deducted is limited to a certain amount, depending on the household characteristics	15% for double glazing 25% for roof and wall insulation 25% for modernization of heating system 40% for adoption of renewable energy
VAT reduction	A reduction of the indirect tax based on consumption	5.5% (instead of 19.6%)
Zero rate bank loan	No interest on the amount of the bank loan. It concerns homeowners who make several renovations or an important energy saving investment. The amount of the loan depends on the renovation	
Subsidy	A subsidy, for homeowner, depending on household income (concerns mainly first income quintile households)	35% of renovation expense

Note: To receive these financial assistances, an household has to hire a company to make the renovations. If he decides to make the renovations itself, he cannot receive a subsidy, a VAT reduction, an income tax deduction or a zero bank loan.

2.3. Model

To simulate energy consumption and GHG emissions we use a bottom-up method. We consider that 12 types of dwellings represent the range of housing available in France. The twelve types differ depending on the type of housing (collective or individual), the main fuel source for heating and hot water (electricity, gas, oil and renewable energy), and the type of heating in flats (individual: only for one dwelling, or collective: common for the building). We assess the energy consumption for each representative dwelling. The model is dynamic: the weight of the representative dwelling in the total housing stock is affected by heating system renovations, and evolution in the number of households and their characteristics. We estimate separately for each representative dwelling the evolution of the housing stock and the energy consumption. The model is implemented in simulation software, named IODE. This platform is free and has been developed by the Belgian Federal Planning Bureau[8]. The model is constructed in two steps. First, the dynamics of the housing stock is built. Second, energy

[8] This tool takes into account all stages of construction and operation models. The features are the writing of equations and the simulation of scenarios.

consumption is modeled. In order to make the section easier to read, a list of variables is provided in table 2.5 in the appendix section.

2.3.1. Modeling the dynamics of the housing stock

The population is assumed to be exogenous and is divided into five categories of households (single, couple without children, couple with children, single-parent family and others). Each household category is characterized by a propensity to live in a defined type of housing. For each category of representative dwelling *i* the housing stock in year *t* corresponds to the housing needs of households (it is equal to the number of households living in the category). The structure of the household and the way it changes over time affect the structure of housing stock (i.e., the number of dwellings in each representative category).
To estimate housing demand through 2050, we use scenarios for the evolution of the population and of household structure provided by INSEE (French Institute of Statistics). Housing stock in year *t* in category *i* (S_{it}) thus is an endogenous variable determined by the evolution and structure of households and different households' propensity to live in particular types of housing. This variable evolves over time and has an impact on the energy demand of the housing stock. Each year, the additional housing needed corresponds to the number of new constructions (NC_{it}). The number of new constructions is equal to the difference between the stock of the current year and the stock of the previous year (S_{it-1}) plus the number of demolitions (D_{it}). The number of dwellings demolished at time t is a percentage d_{it} of housing stock of the previous year. This share is exogenous and constant over time. This approach is based on the study of Nemry et al. (2000). So, we have:

$$D_{it} = d_{it} \cdot S_{it-1} \quad (1)$$

and

$$NC_{it} = S_{it} - S_{it-1} + D_{it} \quad (2)$$

In the model, two age variables are estimated. First, we calculate the average age of the housing stock ($AGE1_{it}$). We consider that new buildings are one year old and the age of demolished housing in time *t* is the average age of housing stock from the previous year. So, we have:

$$AGE1_{it} = \frac{(1 + AGE1_{it-1}) \cdot S_{it-1} + NC_{it} - D_{it} \cdot AGE1_{it-1}}{S_{it-1} + NC_{it} - D_{it}} \quad (3)$$

We then calculate a second age, which is closer to the concept of obsolescence ($AGE2_{it}$). In this case, all renovations of type r in time t in each category i are taken into account (R_{rit}). The calculation of renovations is developed in part 2.3.2.1. We consider $AGE2_{it}$ as a proxy for housing quality. It is an endogenous variable that reflects the renovations of previous years. Renovations reduce $AGE2_{it}$ by bringing new blood into the housing stock. We calculate the modernization effect produced by renovated housing by calculating the number of kilowatts per hour saved after a renovation ($AGE2R_{rit-1}$).

$$AGE2_{it} = \frac{(1 + AGE2_{it-1}) \cdot S_{it-1} + NC_{it} - D_{it} \cdot AGE2_{it-1} + \sum_{1}^{r} R_{rit} \cdot AGE2R_{rit-1}}{(S_{it-1} + NC_{it} - D_{it} + \sum_{1}^{r} R_{rit})} \quad (4)$$

Finally, the average surface area of each representative dwelling (SA_{it}) is obtained using the average surface area of the previous year (SA_{it-1}), the surface area of the new constructions (SC_{it}) and the surface area of demolitions. Demolished surfaces are equal to the surface area of the previous year. The surface area of new construction (SC_{it}) is exogenous and increases at a constant rate of 0.46% each year. The average surface area of each representative dwelling is:

$$SA_{it} = \frac{S_{it-1} \cdot SA_{it-1} + NC_{it} \cdot SC_{it} - D_{it} \cdot SA_{it-1}}{S_{it}} \quad (5)$$

2.3.2. Modeling energy consumption and GHG emissions

The average energy consumption in kWh in primary energy (EC_t) is the sum of the energy consumption for each end-use j ($EC_{\text{END\_USE}t}$): heating and hot water (H_t), lighting (L_t) and appliances (A_t)[9].

[9] Note that in the model we do not take climate change into account. First, the change in temperature is still quite uncertain. Second, if climate becomes hotter in the next years, we expect the energy consumption due to heating system to decrease, but that due to air conditioning to increase, leading therefore to an ambiguous effect on overall energy consumption.
It is also worth noting that at present, air conditioning ownership is quite low in France (only 4% of the dwelling are equipped with air conditioning in 2006 according to ADEME). Thus, it is not included in the model.

$$EC_t = \sum_{j=1}^{3} EC_{END\_USEjt} \tag{6}$$

$$EC_{END\_USEt} = \left\{ H_t^{EC}; L_t^{EC}; A_t^{EC} \right\} \tag{7}$$

Each end-use then is a sum of the energy consumption of each of the 12 representative dwellings. The total energy consumption related to heating and hot water (H_t) is the sum of energy consumption for a representative dwelling (H_{it}) multiplied by the stock corresponding to a category (S_{it}). On the same way, the total energy consumption related to appliances (A_t) is the sum of energy consumption for a representative dwelling (A_{it}) multiplied by the stock of this category (S_{it}). Finally, the total energy consumption related to lighting (L_t) is the sum of energy consumption for a representative dwelling (L_{it}) multiplied by the stock of this category (S_{it}). The methodology is exactly the same for GHG emissions.

$$H_t = \sum_{i=1}^{12} H_{it} \cdot S_{it} \tag{8}$$

We will now present a method to calculate the total energy consumption for a representative dwelling in kWh/m^2/year (EC_{it}), which is also applied to calculate GHG emissions.

2.3.2.1. Energy consumption and GHG emissions related to heating and hot water

We determine the average energy consumption for heating and hot water for each representative dwelling (H_{it}). It is determined by renovations (R_{it}), new constructions (NC_{it}) and the average energy consumption of the previous year (H_{it-1}). Heating consumption (H_{it}) in segment *i* at time *t* in kWh$_{pe}$/m^2/year is equal to the consumption for a representative dwelling the previous year in kWh$_{pe}$/m^2/year (H_{it-1}) multiplied by housing stock without renovation plus the consumption for each renovated dwelling of type *r* (H_{rit}) multiplied by the number of renovations *r* (R_{rit}) plus the new constructions (NC_{it}) multiplied by the consumption of the latter (HC_{it}). The whole is divided by the housing stock.

We consider five types of renovation for individual dwellings (glazing insulation, wall insulation, roof insulation, equipment for heating and hot water, and the replacement of fuel by renewable energy) and an additional type for collective dwellings (the individualization of the heating system for collective buildings with collective heating)[10]. Equipment for heating and hot water and changing fuel to renewable energy are renovations that cannot be combined. Finally, we obtain 23 possible combinations in the individual sector and 35 in the collective one. We calculate for each type of renovation the associated energy saving in kWh_{pe}/m^2/year (G_{rit}). The consumption for each renovated dwelling of type r (H_{rit}) is obtained by the difference between the average consumption in the previous year (H_{it-1}) and the energy savings provided by the renovation r (G_{rit}). We therefore have:

$$H_{it} = \frac{H_{it-1}(S_{it} - R_{it}) + NC_{it} \cdot HC_{it} + \sum_{1}^{r} H_{rit} \cdot R_{rit}}{S_{it}} \tag{9}$$

$$H_{rit} = H_{it} - G_{rit} \tag{10}$$

To estimate the number of renovations (R_{rit}), we proceed in two stages following a sequential approach. First, we compute the probability that a household invests in a renovation that improves energy efficiency (PI_{rit}) and we conduct a cost-benefit analysis. Second, we assign a probability to the possibility that the co-owners in a collective building will vote in favor of the measure (PC_{rit}). In this type of housing, some renovations cannot be decided at the household level but must be decided by the community of co-owners. We then obtain the following equation for individual housing units:

$$R_{rit} = S_{it} \cdot PI_{rit} \tag{11}$$

And for collective ones:

$$R_{rit} = S_{it} \cdot PI_{rit} \cdot PC_{rit} \tag{12}$$

The probability that a household invests in an energy efficiency renovation PI_{rit} depends on a cost-benefit analysis, that is to say, discounted energy savings for renovation (G_{rit}) versus its total cost (C_{rit}) and on the household's financial constraint (FC_{it}). We shall now describe these three elements.

The energy savings (in kWh_{pe}/m^2/year (G_{rit})) equations are linear functions of the age of the housing ($AGE2_{it}$). It is cheaper to save 1 kWh when the housing unit has never been

[10] Each category of household can realize only one combination of renovations. These combinations are sequential that is to say, in a first time, the household considers the better combination (in terms of energy savings). If this renovation is not affordable, it considers the second combinations and so on. Thus, this method prevents multiple renovations of the same type in the same house.

renovated. The older the housing stock, the larger is the number and impact of possible renovations. Energy savings are estimated in kilowatt-hour of primary energy.
Therefore, before calculating energy savings in euros, we convert primary energy into final energy[11]. To avoid comparing an annual energy saving in euros to one-shot total cost, we discount the expected benefit to obtain a present value:

$$PV_{it} = \sum_{t=1}^{T_k} \frac{G_{it}}{(1+\phi)^{T_k}} \tag{13}$$

where ϕ is the market long term interest rate and T_k the average life of equipment (Source: ADEME and Tns SOFRES (2009), *Agence De l'Environnement et de la Maitrise de l'Energie*). All costs and all benefits are calculated each year. Thus, an investment that is not profitable today may become so over time, notably as the dwelling ages.
The cost of renovation depends on the price of the renovation, per square meter and potential public policies. Households may incur two types of loans: a conventional bank loan and a zero rate bank loan. They also can receive an income tax deduction and a subsidy and benefit from reduced VAT rates. However, a distinction is made between renovations carried out by a hired company and those made by households themselves. If a household decides to make the renovations itself to save the cost of hiring a company to do the work, the household will not receive the assistance (subsidies, VAT reduction, income tax deduction and zero rate bank loan) included under the public policies. The percentage of households choosing to do the renovation work themselves is different for each type of renovation and varies over time. The evolution is based on the ratio between the total cost of a measure (including the cost of hired labor) and the cost without the hired labor. The share of households engaging in renovations on their own increases with the cost of hired labor.
The maximum amount in euros that the households can invest in a home renovation, namely the financial constraint, should depend on income quintile, tenure, disposable income, saving rate, share of savings devoted to energy efficiency investments and borrowing power. Indeed, it is more difficult for a household with debts and low income to invest in an energy efficiency renovation. To determine the financial constraints for each category of dwelling, each income quintile and each year:

[11] For electricity only, it is necessary to produce 2.58 kWh/m^2/year of primary energy to obtain 1 kWh/m^2/year of final energy.

- we first multiply (i) saving rate and (ii) the share of savings rate devoted to energy efficiency investments with (iii) the disposable income,
- second, we add the debt ratio.

These variables are different depending on whether homeowners or tenants are considered.

The probability (PI_{rit}) is determined by a decision rule in three stages. This probability is calculated each year for each combination of renovations. The value of PI_{rit} is between 0 (in this case, the household does not renovate) and 1. First, we compare the cost of renovation with the household's financial constraint. If a household cannot afford the renovation, we set $PI_{rit} = 0$. In a second stage, if $PI_{rit} \neq 0$, we calculate the length of time that allows a positive return on investment. Third, depending on the duration, we assign a value to the probability PI_{rit}. The latter decreases over time. To set this probability, we take into account the average length of occupancy (5.2 years with a margin up to 7 years) and the tenure. If the household is a homeowner, the probability associated to renovation is higher. A tenant has less incentive to make an energy efficiency investment because he does not stay long enough in the dwelling to secure a return on the investment. Meanwhile, renovations increase the value of the dwelling for homeowners.

In France, there are collective dwellings (e.g., apartment buildings) with a collective heating system. One energy bill is divided among all residents of the building contingent on shares allocated when the dwelling was purchased. The cost of excess energy consumption is borne by all residents of the building. Moreover, in this type of housing, decisions are made by majority vote at owners' meetings. The energy-saving measures have a lower probability of being accepted. This is due, for example, to households living in a well-located apartment being less willing to pay for an energy-saving investment, or to households living below the roof being more interested in roof renovations than households living on the first floor. Therefore, we set a probability that the co-ownership accepts the measure in collective dwellings (PC_{it}).

2.3.2.2. *Energy consumption related to appliances*

The electricity consumption of appliances is the sum of the consumption of each dwelling in kWh_{pe}/m^2/year. We take into account eight appliance categories (e.g., refrigerator, freezer, dishwasher, washing machine, tumble dryer, oven, television and computers) and an additional consumption related to other devices (coffee maker, boiler, lawnmower …). The probability for appliance ownership is determined by the rates of household equipment, and we assume they are constant over the period. We assign an average consumption for each device in kWh_{pe}/m^2/year, which is computed according to its energy label. In France, each appliance is associated with an energy label, from A+ for those that consume the least amount of energy to D for the largest energy consumers. For computers and televisions, we count an additional energy consumption related to standby.

We set a probability that households are equipped with an appliance belonging to a specified energy label. It then is weighted with the rates of the equipment utilization and of household equipment. No data is available about the ownership of appliances with different energy labels, so we assume the number of households owning efficient energy label appliances (A and A+) is growing over time. First, this assumption is based on past trends. Second, we assume that appliances with lower energy consumption become cheaper over time and the household sensitivity concerning environment quality increases. We conduct a sensitivity analysis. It shows that the impact of a change in the repartition is not really significant.

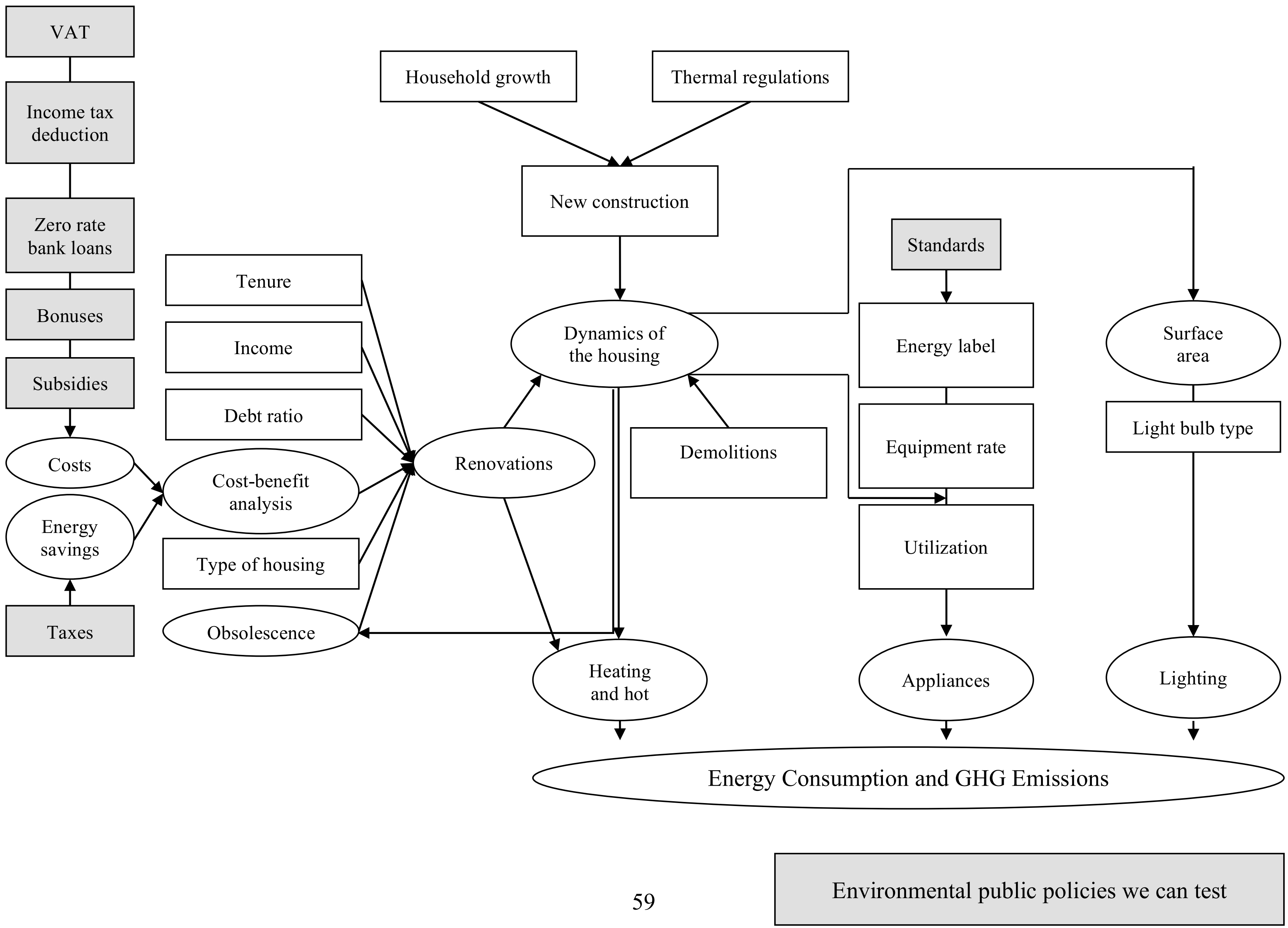
2.3.2.3. Energy consumption related to lighting

We consider that there are three kinds of light bulbs in a dwelling: halogen, standard and energy saving. To calculate the energy consumption from lighting in kWh_{pe}/m^2/year, the consumption of each type is weighted. The number of light bulbs depends on the surface area. On average, each French household owns 22 lamps in a dwelling of 110 m^2. We therefore assume that there is 0.25 bulb light by m^2 in a dwelling (source: ADEME).

The weights of different lighting technologies are set in 2006 according to the observation of ADEME (70% of standard, 5% of halogen and 25% of energy saving). Then, we assume that they change each decade: progressively, energy saving light bulbs replace standard light bulbs and the halogen stays constant over the period. This assumption is based on trends computed on the previous years.

References for the sources of data and scenarios used to construct the model are presented in table 2.6 in appendix section. The model is summarized in the following framework (figure 2.1). Endogenous variables are represented by oval.

Figure 2.1. The main determinants of energy consumption and GHG emissions in the model



2.4. Results

One of our objectives is to estimate the impact of environmental policies. To judge their effectiveness, we use two criteria. First, we assess the extent to which these policies facilitate achieving the Grenelle targets (an average energy consumption of 50 kWh_{ep}/m^2 by 2050 in the residential sector and reducing GHG emissions by 75% compared to the level of emissions in 1990). To reduce GHG emissions by 75% in the residential sector, the maximum amount of CO2 that the residential sector can emit in 2050 is 13.75 million tons. Second, we study the cost of the measures for the government. How much must the government invest to save one ton of CO2? To answer to this question, we calculate the cost of a policy and we divide it by the GHG emissions saved thanks to a policy measure. The cost for the government is estimated by comparing two scenarios: one where no policy is implemented, the second where a selected policy which we wish to examine is implemented. This allows us to take into account the impact and cost of one policy at a time. We study the impact of current environmental policies with these indicators.

To estimate the energy consumption of the housing stock until 2050, we calibrate the model using 2006 data from: (i) INSEE, *l'enquête logement* 2006, (ii) the Ministry of Ecology, Energy, Sustainable Development and the Sea and (iii) simulation software[12] which estimates energy consumption and GHG emissions on the basis of building characteristics (year of construction, surface area, thermal insulation, fuel and heating system). The energy prices depend on evolution scenarios provided by International Energy Agency.

In 2007, our results are consistent with *Agence Nationale de L'habitat*. According to the latter, energy consumption is 274 kWh_{pe}/m^2 and we obtain 283.6 kWh_{pe}/m^2. Parameters values used for calibration are summarized in appendix in table 2.7.

We now present our results. Different scenarios are tested. They are summarized in appendix in table 2.8. First, the effects of current environmental policies are tested. Second, public policies to achieve the Grenelle I goals are simulated.

2.4.1. The effects of current environmental policies

We consider a reference scenario in which public policies in 2050 are the same as in the

[12] The simulation software is named PROMODUL. This software is used to estimate energy consumption and greenhouse gases emission for each category of dwelling, using 3CL method. This is the standard method to estimate consumption and greenhouse gases emissions in France and it is used to label the dwelling. This computation method is described by French decree in September 2006. PROMODUL is an extra tool that we used just to feed the model with data.

period between 2006 and 2010 (e.g., an income tax deduction at a constant rate during the entire period, a zero rate bank loan, a subsidy, a VAT with a reduced rate of 5.5% instead of 19.6%, and households can receive several forms of financial support at the same time). Before to study the impact of public policies, quantitative results of basic variables are presented using this reference scenario.

2.4.1.1. Quantitative results of basic variables in the reference scenario

The number of dwellings increases by 50% between 2006 and 2050. Average surface area (figure 2.2) is growing over time as well as new constructions. When the housing stock shows signs of obsolescence, the number of renovations is high; however, once renovated, the quality of the housing stock increases, and households consequently have less incentive to renovate. Then, energy consumption and GHG emissions (figure 2.3) decrease over the period. The decrease is more pronounced at the beginning of the period thanks to public policies. AGE2 (meaning obsolescence) is still relatively constant over the period around 60 years.

Figure 2.2. Evolution of the average surface area in square meters

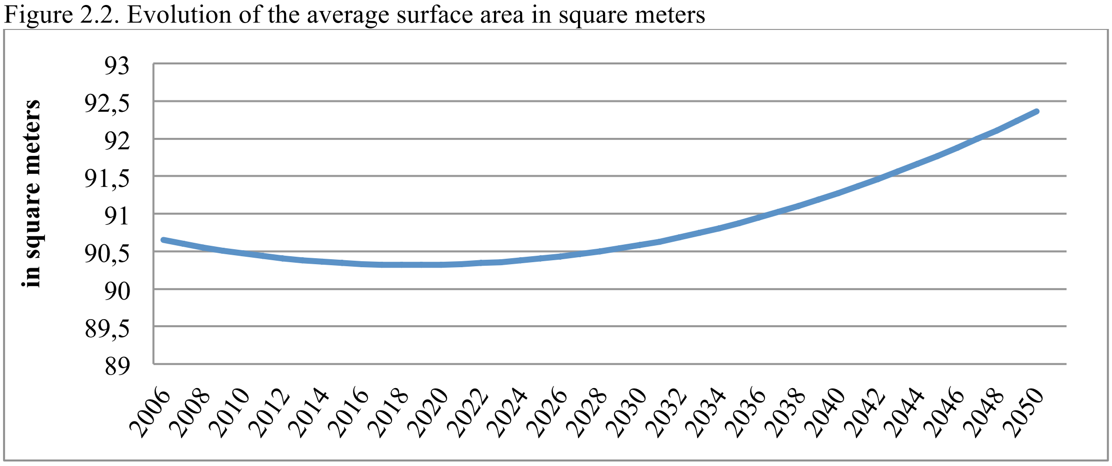
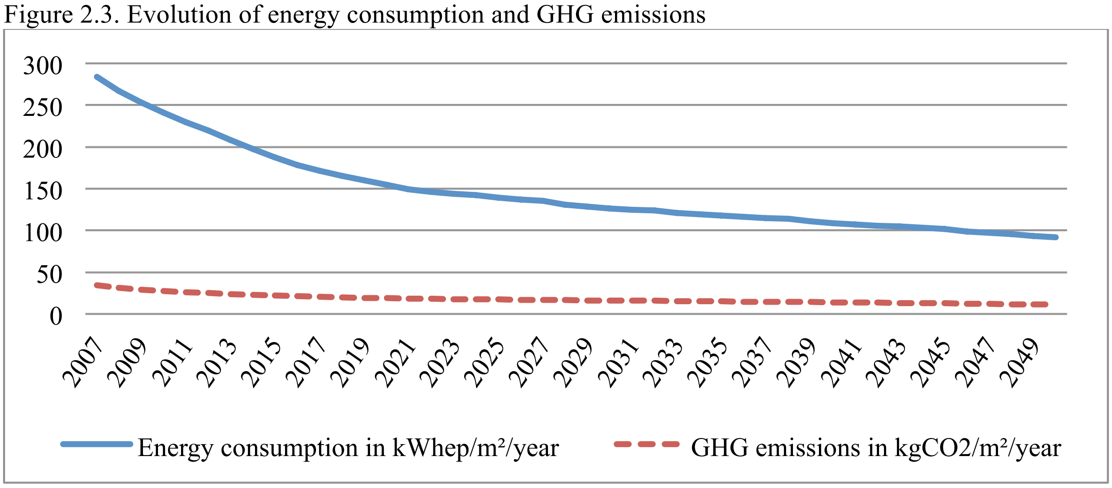
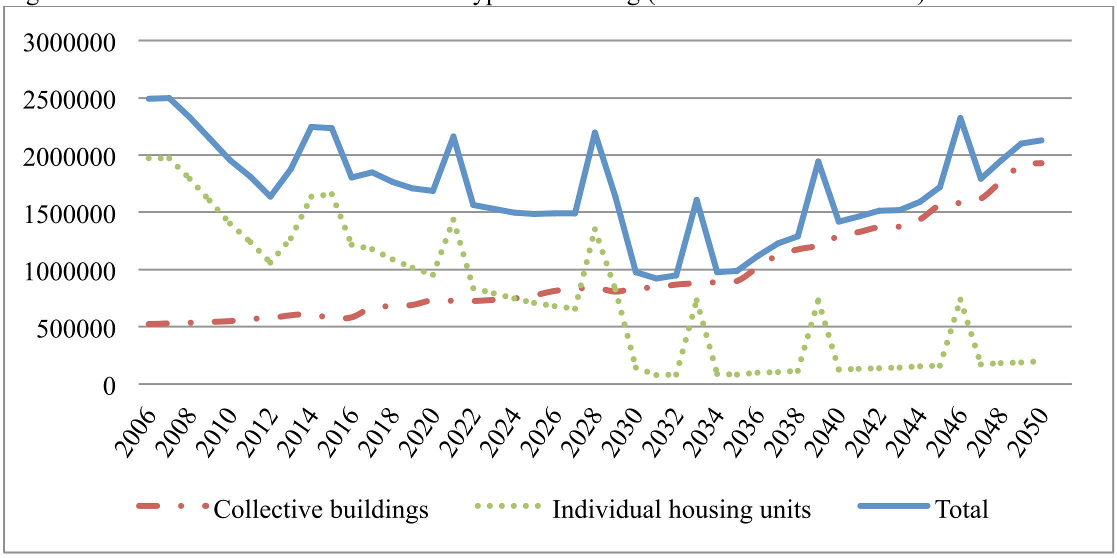


Figure 2.3. Evolution of energy consumption and GHG emissions



We note a sharp decline in renovations between 2008 and 2020 in individual housing units although they are more numerous than in collective dwellings (figure 2.4).

Figure 2.4. Number of renovations and the type of dwelling (in the reference scenario)



In the reference scenario, households prefer investing in one renovation rather than in a combination of renovations. The renovations favored are double-glazing insulation and wall and roof insulation. From 2013 on, roof insulation and heating systems changes become dominant. In general, the switch from fuel to renewable energy is very rare over the entire period (see figures 2.5 and 2.6).

Figure 2.5. Number of renovations in collective buildings by type (in the reference scenario)

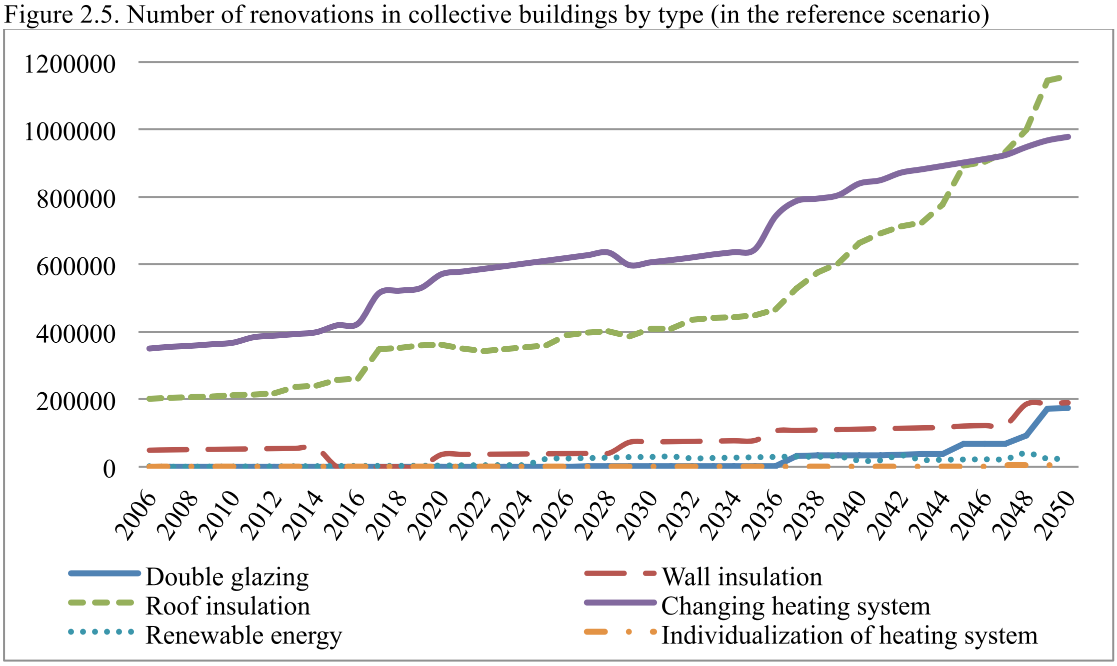
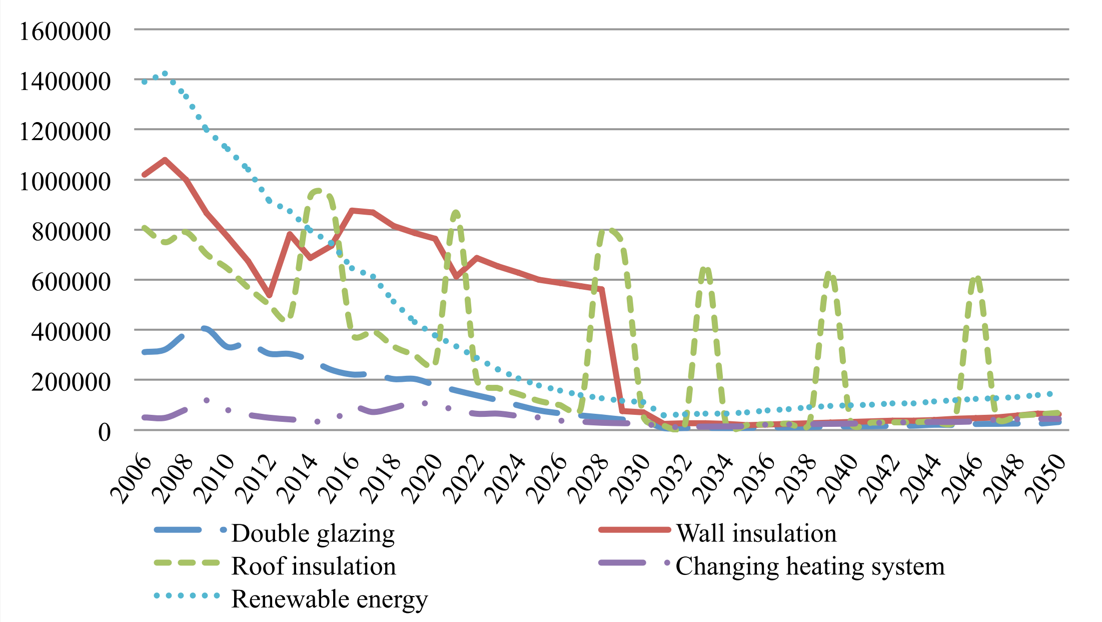


Figure 2.6. Number of renovations in individuals housing units by type (in the reference scenario)



Renovations change the structure of the housing stock (see figures 2.7 and 2.8). Indeed, the weight of each category changes over time. Renewable energy takes a more prominent place in 2050. This result is even stronger in individual housing.

Figure 2.7. Weight of each category in collective buildings (in the reference scenario)

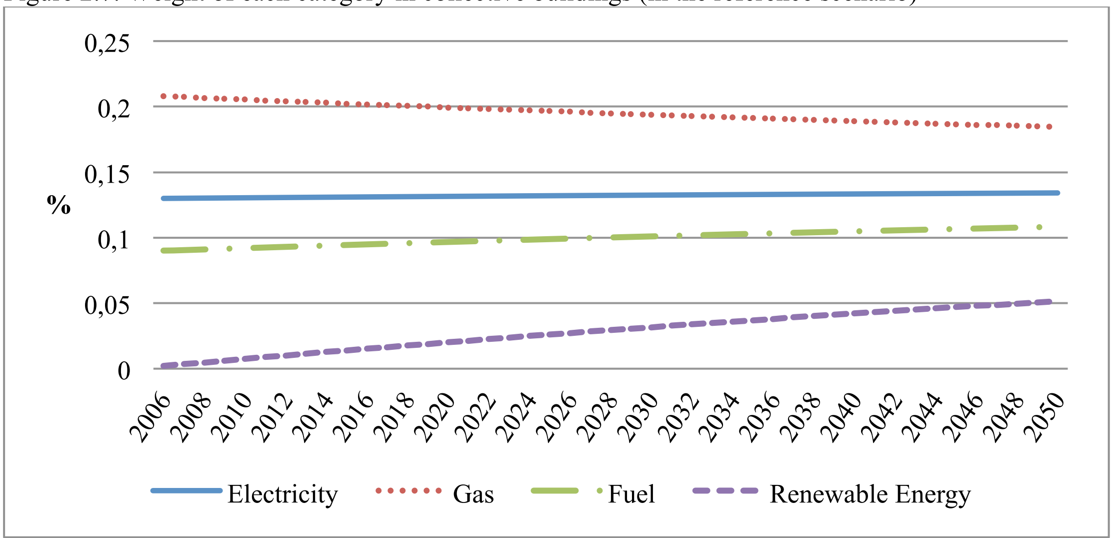
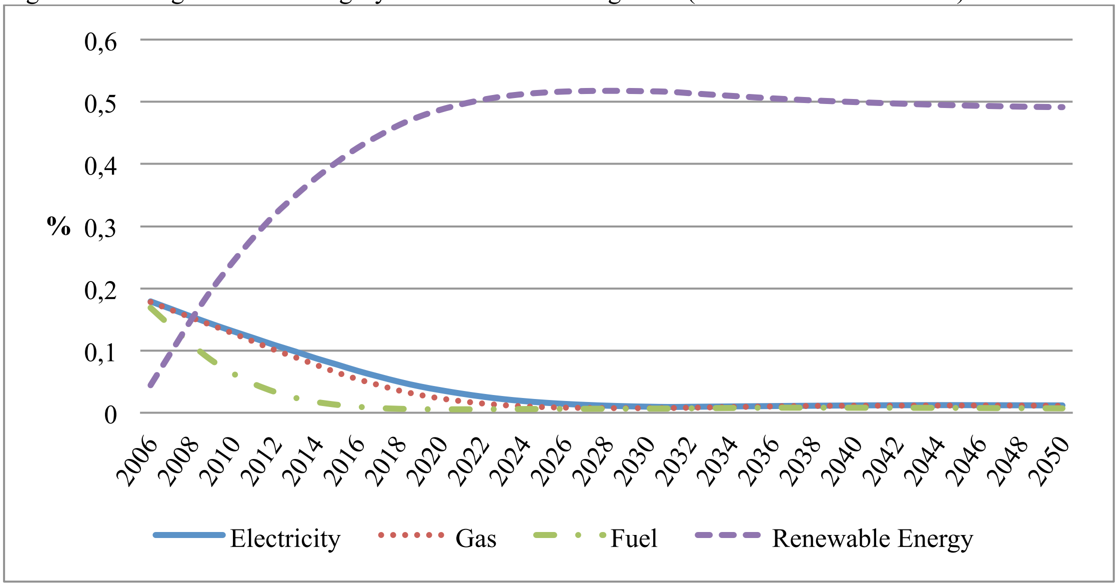


Figure 2.8. Weight of each category in individual housing units (in the reference scenario)



It is mostly the households in the fourth income quintile who invest up to 2026 (figure 2.9). Fifth quintile households already live in energy efficient housing. After 2026, the poorest households invest because investing in energy efficient measures becomes profitable: the older the housing stock, the larger the energy saving associated with renovation. In 2010, we have the following result: individuals belonging to the first quintile can afford measures costing up to 4500 euros and individuals belonging to the second quintile may finance measures costing up to 8400 euros (figure 2.10).

Figure 2.9. Number of renovations by quintile (in the reference scenario)

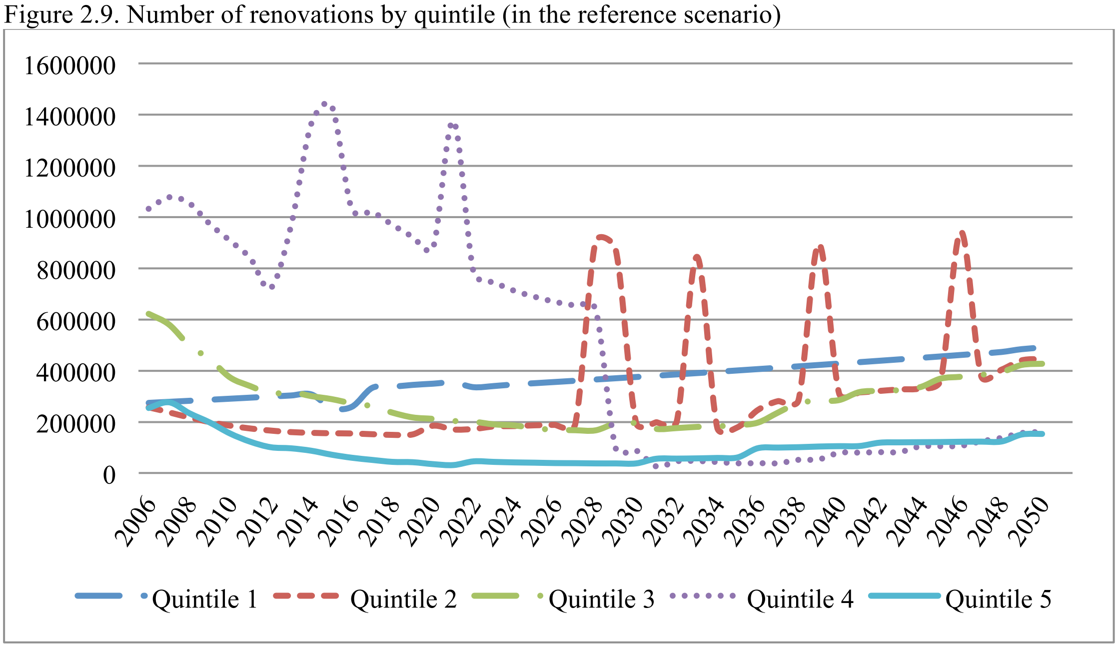
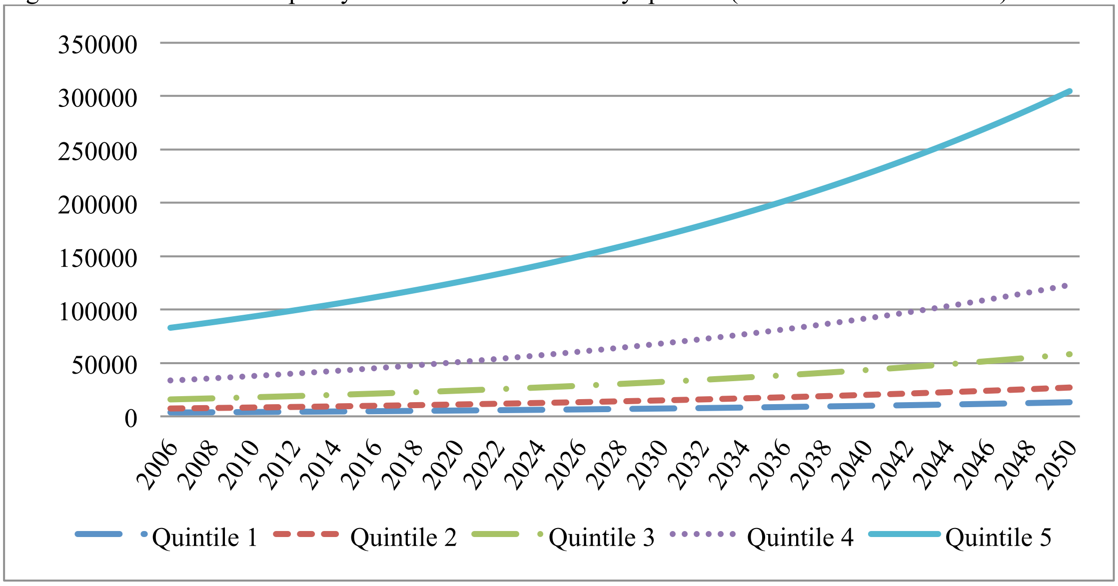


Figure 2.10. Investment capacity in euros of households by quintile (in the reference scenario)



In fact, only individuals in the fifth income quintile can finance class A renovation (i.e., < 50kWh/m^2/year), that cost between 40 000 and 60 000 euros.

2.4.1.2. The effects of current public policies

The policies are efficient. In 2010, an energy consumption of 240 kWh$_{pe}$/m^2/year and 63 millions of tons of CO2 are reached in the model. In the absence of public policy, consumption would have been 28% higher and emissions would have multiplied by 1.5. These measures remain effective in future years (compared to the reference scenario and the scenario without policy from 2011).

By comparing the discounted benefit and the cost of measures, we note that in the absence of environmental policies, very few energy-saving renovations are profitable or can be financed by households (results are summarized in table 2.2). Without public policy measures, energy consumption and GHG emissions decrease because the housing stock is showing signs of obsolescence and renovations are necessary. However, to achieve the Grenelle I objectives of energy consumption of 50 kWh$_{pe}$/m^2/year and CO2 emissions of 13.75 millions of tons by 2050, public policy measures are required. Our results are similar to those of Siller et al. (2007) for Switzerland and those from French simulation models (MEDDTL et al., 2011 and Giraudet et al., 2011), further underscoring that implementation of ambitious public policies are required to reduced significantly the energy consumption and GHG emissions by 2050. The combination of the income tax deduction and the zero rate bank loan recently was ruled out, and this decision takes us further away from the set goals. In addition, thermal regulation on new constructions is not sufficient for the objectives to be reached.

To study the effectiveness of the policies, we can estimate the extent of free-riding by calculating the ratio between the number of renovations made in the absence of policy measures and the number of renovations with policy measures. ‘‘Free riders’’ are households who would have made energy efficiency investments even in the absence of public policy. This free-ridership may undermine the effectiveness of environmental policies[13]. Comparing the sum of renovations between 2011 and 2050 without and with policies (reference scenario), free-ridership represents 40.15% of the number of renovations during the entire period. This result is consistent with the finding of Grösche and Vance (2009). In the following section, we compare public policies and propose measures to reach the Grenelle I objectives.

Table 2.2. Effects of current environmental policies

	kWh_{pe} /m² /year	Decrease compared to the current situation (situation in 2010 with current policies)	Millions of tons of CO2	Decrease compared to the current situation
Situation in 2010:				
Situation in 2010, with current policies	240.94[2.a]	-	63.01	-
Situation in 2010, if no policy had been implemented	308.45	+28%	97.36	+55%
Situation in 2050 (with different scenarios):				
Objective by 2050	*50.00*	*-79%*	*13.75*	*-78%*
Reference scenario: situation in 2050, if policies remain unchanged compared to 2010[2.b]	91.67	-62%	35.01	-44%
Situation in 2050 without any policy from 2011	124.89	-48%	46.50	-26%
Situation in 2050 if income tax deduction and zero rate bank loan are not cumulative from 2011	100.14	-58%	38.41	-39%

Note: 2.a With current policies, we obtained with simulations an average energy consumption of 240.94 kWh_{pe}/m^2 in 2010, whereas without policy the energy consumption is 28% higher and reach 308.45 kWh_{pe}/m^2.

2.b This is our reference situation: we consider that the current policies remain unchanged from 2010 until 2050, this means a VAT with a reduced rate of 5.5%, a income tax deduction, a zero rate bank loan and a subsidy and an household can receive several forms of financial support at the same time.

2.4.2. Comparison of policies

A scenario without public policy measure and a scenario with only one public policy measure are compared to evaluate the effectiveness of each measure. Using this method, only the impact of the selected public policy is studied (see figures 2.11 and 2.12). We can deduce the savings in energy consumption and GHG emissions due to public policy measures. It also

[13] For more information, the free-ridership was studied in the literature by Malm (1996) and Grösche and Vance (2009).

gives us the renovation surplus linked to the measure (figure 2.13 represents the number of renovations by public policies). Thus, we estimate the cost for the government by ton of CO2 saved with a measure. In the absence of public policy, mostly the richest households (fifth and fourth income quintiles) invest in energy-saving renovations.

Figure 2.11. Energy consumption in kWh/m²/year by type of public policies

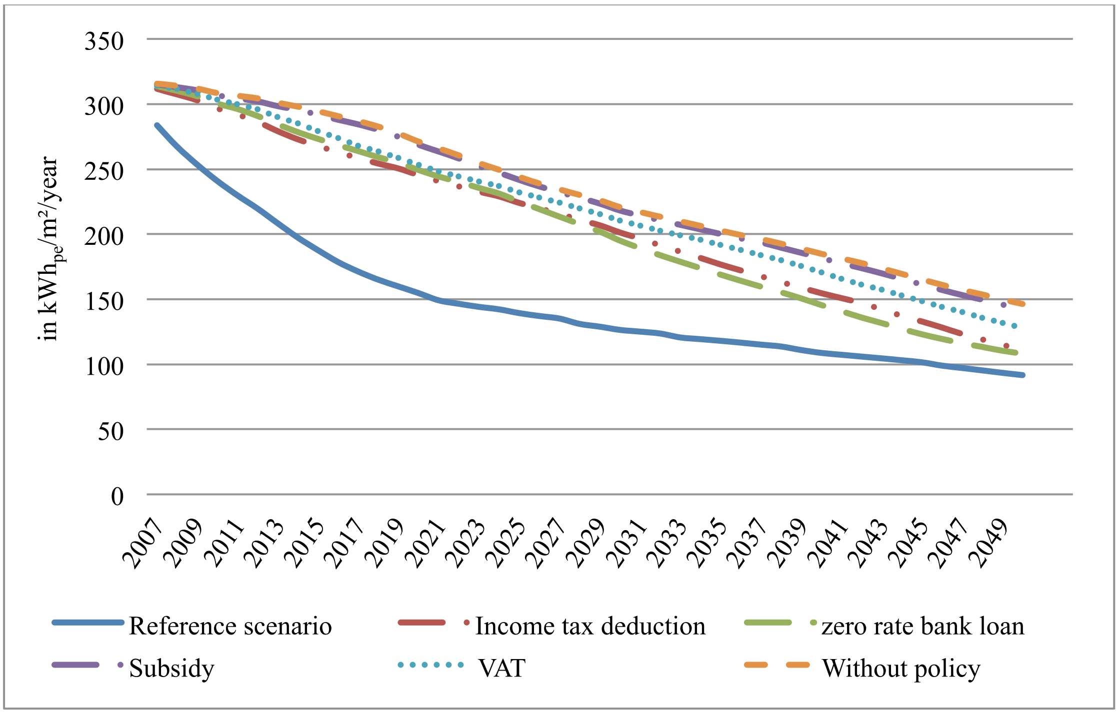


Figure 2.12. GHG emissions in KgCO2/m²/year by type of public policies

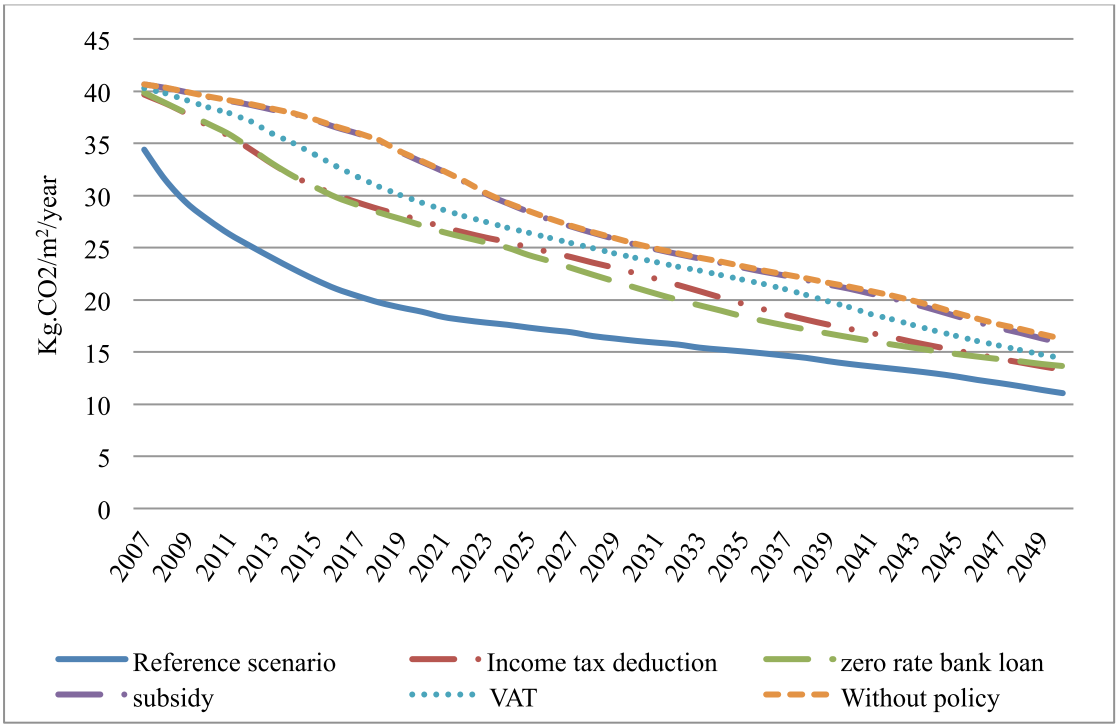
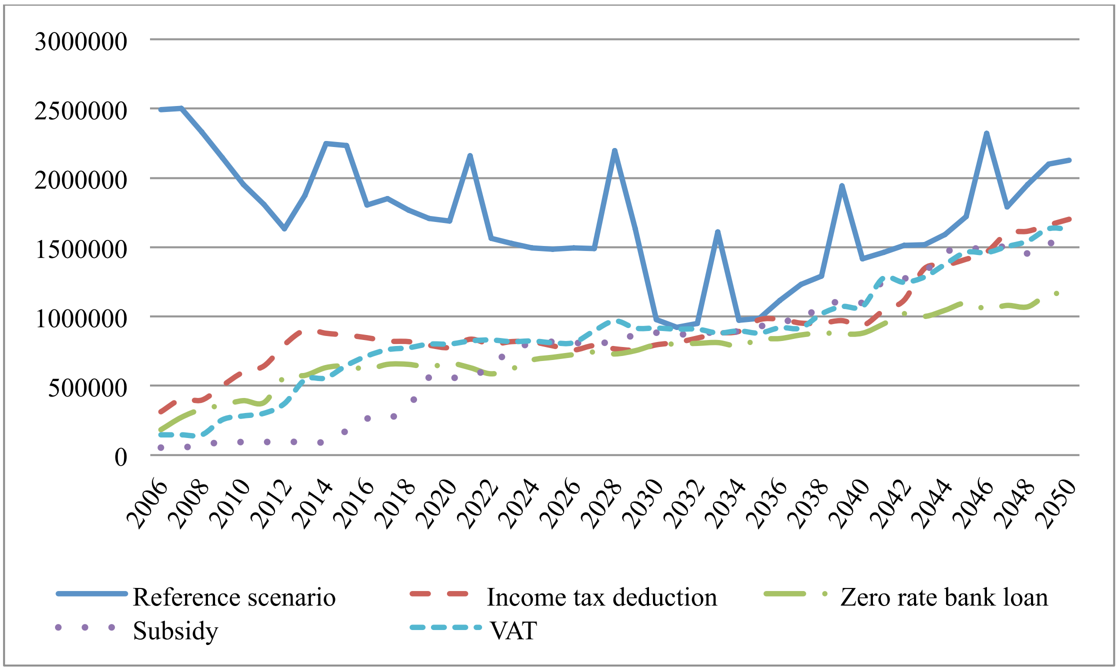
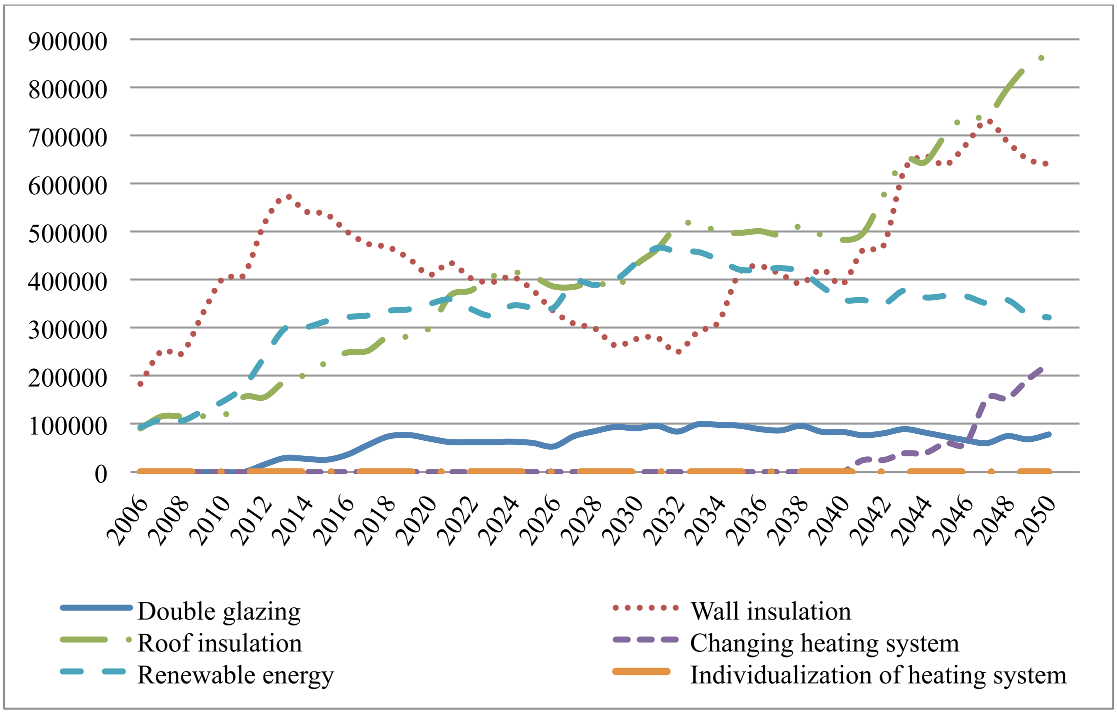


Figure 2.13. Number of renovations by public policies



The income tax deduction seems to be one of the most efficient policy measures (see table 2.3). Indeed, the scenario leading to the smallest energy and GHG emissions savings between 2006 and 2050 is the scenario without this measure. The zero rate bank loans have a similar impact on energy consumption and GHG emissions, but its cost to the government is higher. The subsidy is the least costly measure, but has not an impact. We simulate the effects of an increase of the maximum amount of renovations covered by the subsidy and an increase on applicable rates. Rates are a function of household income. At first glance, the subsidy thus does not seem to be the most effective solution. An increase in VAT encourages households to do the renovations themselves because the cost of renovations increases. In these five scenarios, households prefer to undertake roof and wall insulation renovations (figure 2.14). These renovations offer the best value for money. Regarding the cost of policy measures, the income tax deduction and zero rate bank loan are the most expensive but the most efficient.

Figure 2.14. Number of renovations by type under income tax deduction scenario



The effectiveness of a policy is stronger if it is combined with another one. A single environmental policy is not sufficient to encourage households to renovate. All measures do not have the same long-term impact on energy consumption. Subsidies concern only homeowners, while tenants often live in collective and less energy efficient dwellings. Tenants have no incentive to renovate because they do not stay long enough in a dwelling to make such an investment worth their while, and they cannot exploit the investment by selling their property. This result is consistent with Diaz-Rainey and Ashton (2009) where they show the importance of tenure in adoption decisions. In addition, households belonging to the second income quintile do not receive enough subsidies to enable them to renovate; in consequence, they hardly ever renovate. In some sense, we face a problem of energy poverty. All results presented in the following table are given compared to a scenario without public policies.

Table 2.3. Comparison of policies

	Energy consumption saved in 2050, in % compared to a scenario without policy	CO2 saved in 2050, in % compared to a scenario without policy	Cost (of shortfall) of policies in constant euro by ton of CO2 saved, between 2006 and 2050
Income tax deduction	-24 %*	-22,1 %	115 €
Zero rate bank loan	-26 %	-21 %	194 €
Subsidy	-2.7 %	-2 %	36 €
VAT	-12.6 %	-13.7 %	44 €
All policies take together	-37.4 %	-35.24 %	-

Note: *With income tax deduction only, the energy consumption in 2050 is 24% lower compared to a scenario without policy

2.4.3. Public policy measures to achieve the Grenelle I goals

In a first step, we examine whether adjustments in the public policy measures in place will allow the Grenelle I objectives to be achieved. We observe, however, that even with all of these policies, the objectives will not be reached. In a second step, we therefore introduce a new measure: bonuses.

The income tax deduction seems to be the most efficient measure. However, to achieve the objectives, the income tax deduction rate must be increased significantly. We simulate the effect of several rates from 2010, with the same rate applied to all types of renovations with the exception of individualizing heating systems, which is not currently eligible for income tax deductions. The tax-deductible amount is limited, and essentially is based on the number of persons in the household. In the calculation, the platform limits do not change. We reach 13.01 million tons of GHG emissions and 50 kWh_{pe}/m^2 in 2050 (see figures 2.15 and 2.16) with a rate of 54% (compared to the current rates of 15% for double-glazing, 25% for roof and wall insulation and modernization of the heating system, and 40% for adoption of renewable energy). This means a cost of 258 euros for the government per ton of CO2 saved (all public costs are expressed in euro 2006). The effectiveness of one euro invested by the state is less when income tax deduction rates are high. This can be explained by free-ridership because many households would have renovated even if the rate had been lower.

Figure 2.15. Energy consumption in 2050 with different income tax deduction rates

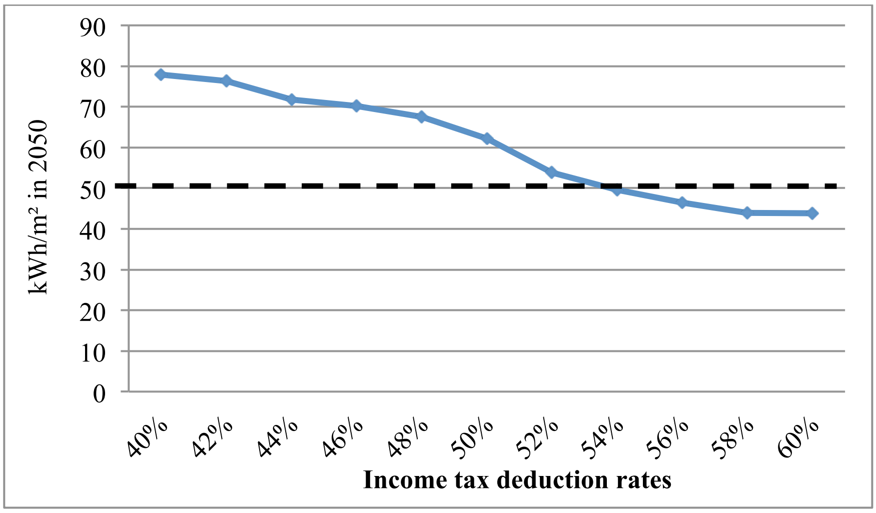
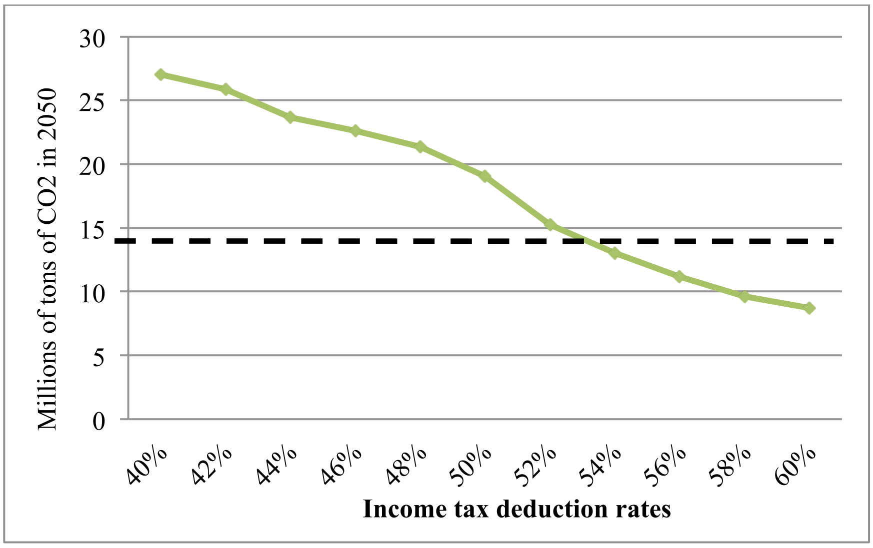


Figure 2.16. Energy consumption in 2050 with different income tax deduction rates



Another possible policy measure that we test in our model are bonuses. Bonuses are introduced in 2010, and the amount of each bonus increases at the same rate as inflation. A bonus can be linked to low income or can be made available to all households. Incentives for a specific renovation or a combination of several renovations (i.e., 2 or more) also can be introduced. Starting with a bonus for all households and applicable to all kinds of renovations, a bonus of 2900 euros per renovation (cost to the government of 255 euros per ton of CO2 saved) is required to achieve the factor 4 (see figures 2.17 and 2.18) and a bonus of 4050 euros per renovation to reach 50 kWh_{pe}/m^2 (cost to the government 257 euros per ton of CO2 saved). A bonus of 4050 euros corresponds to 1/3 of the average cost of one renovation. However, this bonus fully finances window, roof and wall insulation. Half the cost of switching to renewable energy is financed by this bonus. From 2500 euros, the impact of one euro of additional bonus diminishes (the slope of the curve is lower).

Introducing a bonus based on low income (households earning less than 9200 euros per year in 2010), we reach factor 4 with a 4100 euros bonus per renovation and 50 kWh_{pe}/m^2 with a 5100 euros bonus per renovation. The costs of these measures (see table 2.9 in appendix) to the government are respectively 441 euros per ton of CO2 saved and 435 euros per ton of CO2 saved. It is more expensive to fund a single category of households rather than all households.

A bonus also can be set to a specific type of renovation. However, it is more difficult to achieve the objectives. We consider an incentive to encourage households to change their heating systems and in particular to adopt renewable energy. A bonus of 6800 euros is necessary to reach the factor 4 (and the cost to the government is 1236 euros per ton of CO2 saved), which is higher than the price of some equipment. It is not possible to reach the objective of 50 kWh_{pe}/m^2/year by adding this type of measure to the reference scenario.

The public cost of all these different policy measures are resumed in table 2.9 in appendix.

Figure 2.17. Energy consumption in 2050 with different amount of bonuses

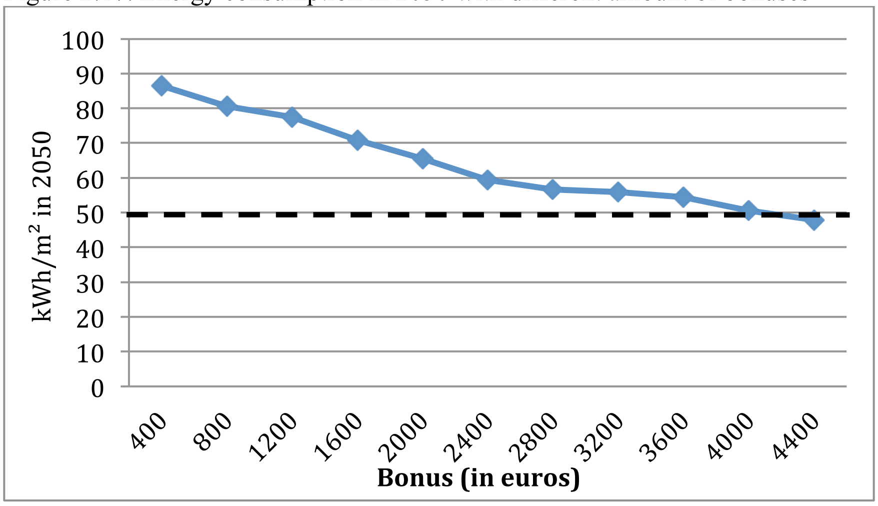
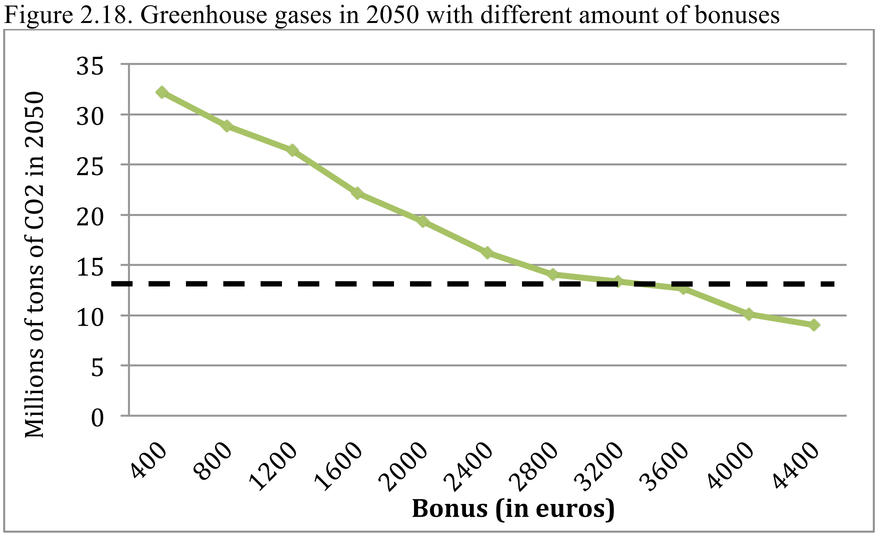


Figure 2.18. Greenhouse gases in 2050 with different amount of bonuses



2.5. Sensitivity analysis

All results presented are for the year 2050. Energy consumption is in kWh_{pe} by square meter and GHG emissions are in million of tons. Results are summarized in table 2.10 in appendix. Energy prices clearly are key variables in the model. Savings in euros associated with a renovation vary according to energy prices. A sharp increase in prices would lead the household, all things being equal, to quickly invest in energy-saving renovations. If the IEA rates are maintained, the objective of 50 kWh_{pe}/m^2/year would be reached in 2078. This result is consistent with Amstalden et al. (2007). Expecting high energy prices, efficiency investments are close to profitability even without policy support.

When the discount parameter decreases, the number of energy saving renovations increase because the net discounted profits are higher. The level of energy consumption is a decreasing function of the discount rate. The level of energy consumption also is an increasing function of homeowner share. One may intuitively deduct that the higher the homeowner share is, the higher the number of households impacted by the measure, and therefore the higher the number of renovations will be. Also, tenants currently have no incentive to renovate. In France, part of the population are tenants for life. This means that part of the population will never involve themselves with energy savings investments. However, even if the entire population became homeowners, the objectives would not be reached. The issue of renovation seems more related to a calculation of profitability than to occupational status.

Finally, the smaller the inflation rate is, the smaller will be energy consumption and GHG emissions. Indeed, a lower inflation rate reduces the cost of renovations. Energy prices increase faster than the inflation rate. The ratio between discounted savings and the cost of renovations rises. Energy saving investments become more profitable.

2.6. Conclusion

In this paper, we estimate energy consumption through 2050 and evaluate the impact of environmental policies. We construct a simulation model using a bottom-up approach. We model energy consumption and GHG emissions by taking into account decisions to invest in energy saving measures and the dynamics of the housing stock. In the model, energy consumption is divided into three end-uses: heating and hot water, lighting, and appliances.

Particular attention is paid to decisions regarding home renovations. Several environmental public policies are tested: income tax deduction with different deduction rates, subsidies, bonuses. Our results indicate that current policies are effective, but not enough to reach the Grenelle I objectives.

These conclusions may be modified as we have made numerous assumptions. Energy consumption estimates (particularly the reference consumption and the gains from renovations) are based on technical analysis. Such an estimation method does not take into account, for example, the rebound effect.[14] Moreover, in the model we consider that the thermal regulations have an immediate effect, although this may be unrealistic in reality. We also had to assume some ad-hoc evolution of the distribution of appliances across energy labels through 2050. Furthermore, energy prices are key variables in the model. The effects obtained on energy consumption and GHG emissions may be very different depending on their evolution. Finally, it is obviously impossible to take into account future technological innovations or the environmental sensitivity of households that we hope will play an important role in the future.

With these caveats in mind, we draw the following key conclusions from our analysis. First, the results show that while current policies are effective, they are not sufficient to reach the objectives. If the current public policy measures are kept without modifications, (i.e., the income tax deduction, the zero rate bank loan, VAT at 5.5% and the subsidy) energy consumption will still be $91.67kWh_{pe}/m^2$/year in 2050. In the absence of public policy between 2006 and 2010, consumption would have been 28% higher and emissions would have been multiplied by 1.5. By comparing the discounted benefit and the cost of measures, we note that in the absence of environmental policies, very few energy-saving renovations are profitable or can be financed by households. The income tax deduction seems to be one of the most efficient policy measure. The effectiveness of a policy is stronger if it is combined with another one.[15] We could reach the factor 4 with an income deduction rate of 45% for all renovation from 2011, a zero rate bank loan that can be combined with the income tax deduction over the whole period, a VAT at 5.5%, a bonus of 1000 euros for households belonging to first and second income quintiles and a bonus of 500 euros for others households. This combination is one of the possible efficient policy mix.

[14] The rebound effect appears if investment in an energy-saving technology (like double-glazing) entails a change in household behavior (increase of temperature target for instance) which offsets the beneficial effects of the technology on energy consumption.

[15] However, we can note that the redundancies of policies can lead to inefficiency. Some households benefit from several policies but they would have invested in a home renovation with only one financial support.

2.7. Appendix

2.7.1. Introduction of a carbon tax

We can also test the imapct of a carbon tax. We introduce a tax in the energy-savings equations in euros. If the government taxes energy-intensive housing, the tax will be added as a benefit for households that want to renovate (since this tax will no longer be requested after renovation).

If a carbon tax is introduced in 2010 which increases by 2% per year, the same rate as inflation, a tax of 185 euros per tons of CO2 is needed to divide emissions by 4 and a tax of 360 euros to reach the energy consumption goal of 50 kWh_{pe}/m^2 /year (figures 2.19 and 2.20). We note that the GHG emissions and energy consumption decrease sharply following the introduction of a tax (with a more pronounced effect for GHG emissions). However, beyond a tax of 150 euros, the effect of an additional euro is very low. A tax of 180 euros would earn the state 176 euros per ton of CO2 saved (292 billion euros over the period) and a tax of 360 euros would earn the state 172 euros per ton of CO2 saved (374 billion euros). The latter tax level, which would be more expensive for households, is more effective at persuading households to invest in energy-saving renovations.

Figure 2.19. Energy consumption in 2050 with a carbon tax

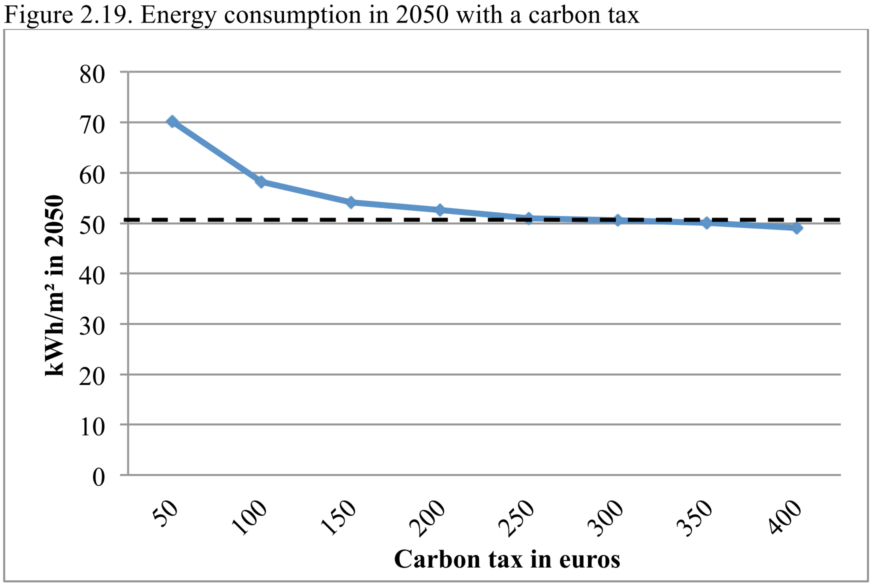
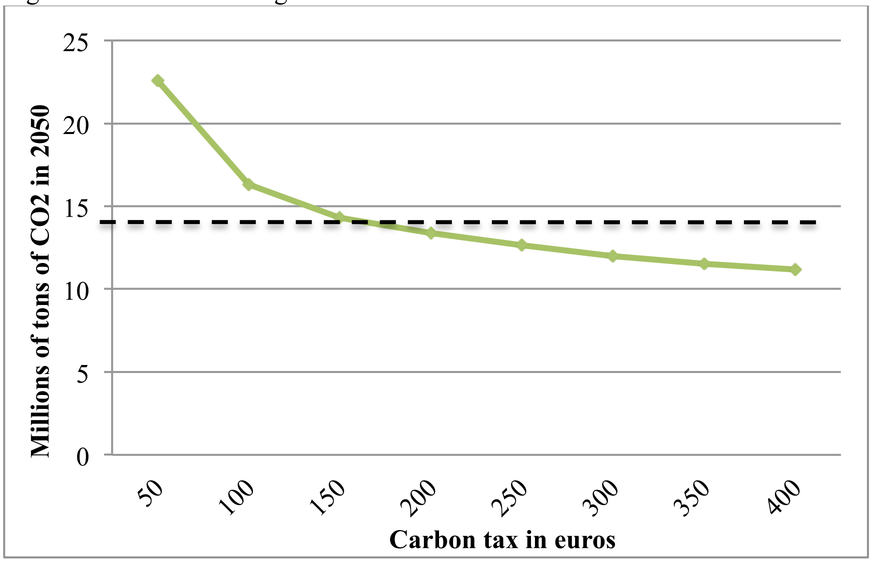


Figure 2.20. Greenhouse gases in 2050 with a carbon tax



A carbon tax is efficient on GHG emissions but it becomes costly for households when the objective is to reach $kWh_{pe}/m^2/year$. Since the taxes we tested mainly affect the poorest people (because they live in the least efficient dwellings), they are the most socially unfair measure. However, they could be redistributed to fund other environmental policies. By combining several measures, it is possible to bring the cost to the government close to zero. For example, we can reach the factor 4 with an income deduction rate of 40% and a carbon tax of 100 euros per ton of CO2. In this case, the tax will fund the income tax deduction cost. However, results with carbon tax do not take into account the effects on the whole economy and every aspect of people's lives.[16] In a such context, results with carbon tax should be taken with caution.

2.7.2. Change in the evolution of the population

We can also test the impact of a change in the evolution and the structure of the population compared to a baseline scenario. We can simulate the impact of a higher growth in the number of households (table 2.4). In scenario A, we consider that the number of households increases by 2% by year (vs. 1% in the reference scenario). In this case, new constructions

[16] Just as an example of a measure not included in the model, people could react to a carbon tax that is sufficiently high by accepting a lower indoors temperature in winter and saving energy through less heating.

increase to meet households needs. This lead to a decrease in energy consumption per square meter and in the average CO2 emissions by dwelling. However, the housing stock is more important and the total CO2 emissions is thus higher. Conversely, in scenario B, we estimate the effect of a shock of the population, which could be related to an epidemic or a war. We assume that the number of households drops to 10% in 2020. In this case, we observe the opposite effect. Given the lower number of new constructions, the energy consumption per square meters and the CO2 emissions by dwelling is slightly higher than in the reference scenario. It is indeed more tricky to decrease energy consumption and greenhouse gases emissions through renovations. In a scenario C, we simulate a change in the structure of population, i.e. we assume that the growth of couples is greater than single person households (we decrease the growth of single person households by 40 percentage points and we increase those of couples with and without children by 20 percentage points each). This leads to a decrease of the weight of collective housing in the housing stock but the impact on energy consumption is weak.

A change in the evolution of the number of households has an impact throught new constructions. It would be appropriate to combine a change of population with a hardening of thermal regulations. We assume that thermal regulation sets an energy consumption of 10 kWh_{pe}/m^2 for new constructions since 2013 and 0 kWh since 2020 (vs. respectively 50 kWh and 10 kWh in reference scenario). However, the thermal regulation will not offset the increase of total emissions following the rise of the number of households.
A change in the evolution and the composition of households will not allow reaching the objectives set by the government.

Table 2.4. Simulation with new assumptions on the evolution of the population

	Average energy consumption by kWh_{pe}/m^2 in 2050	Millions of tons of CO2	Average CO2 emissions by dwelling in kg.CO2	Weight of collective housing
Reference scenario: Rate of households growth of 1% by year	91.67	35.01	11.05	48%
Scenario A: Rate of households growth of 2% by year since 2012	79.69	47.15	9.70	51%
Scenario B: Shock on population in 2020: decrease in the number of households of 10%	93.27	31.13	11.13	47%
Scenario C: Change in the structure of population: the growth of couples is greater than single person households	91.52	34.47	10.76	42%

	Average energy consumption by kWh_{pe}/m^2 in 2050	Millions of tons of CO2	Average CO2 emissions by dwelling in kg.CO2	Weight of collective housing
Scenario D: Hardening of thermal regulations in the reference scenario	89.97	33.10	10.43	48%
Scenario E: Hardening of thermal regulation + rate of households growth of 2% by year since 2012	76.83	42.4	8.63	51%

2.7.3. Variables and data

Table 2.5. List of variables

Variables	**Definitions**
S_{it}	Housing stock in year *t* in category *i*
S_{it-1}	Housing stock in year *t*-1 in category *i*
NC_{it}	Number of new constructions in year *t* in category *i*
d_{it}	Percentage of dwellings demolished at time *t* in category *i*
D_{it}	Number of dwellings demolished at time *t* in category *i*
$AGE1_{it}$	The average age of the housing stock at time *t* in category *i*
$AGE2_{it}$	The obsolescence of the housing stock at time *t* in category *i*
R_{rit}	Renovations of type *r* at time *t* in category *i*
$AGE2R_{it}$	The number of kilowatts per hour saved after a renovation
SA_{it}	Average surface area at time *t* in category *i*
SA_{it-1}	Average surface area at time *t*-1 in category *i*
SC_{it}	Surface area of new constructions at time *t*-1 in category *i*
SD_{it}	Surface area of demolitions at time *t*-1 in category *i*
EC_t	Average energy consumption in kWh in primary energy in time *t*
$EC_{end\ uset}$	Energy consumption for each end use in kWh in primary energy in time *t*
H_t	Energy consumption for heating and hot water in kWh in primary energy in time *t*
L_t	Energy consumption for lighting in kWh in primary energy in time *t*
A_t	Energy consumption for appliances in kWh in primary energy in time *t*
H_{it}	Energy consumption for heating and hot water in kWh in primary energy in time *t* in category *i*
A_{it}	Energy consumption for appliances in kWh in primary energy in time *t* in category *i*
L_{it}	Energy consumption for lighting in kWh in primary energy in time *t* in category *i*
EC_{it}	Average energy consumption in kWh in primary energy in time *t* in category *i*
H_{it-1}	Energy consumption for heating and hot water in kWh in primary energy in time *t*-1 in category *i*
H_{rit}	Energy consumption for heating and hot water for each renovated dwelling of type *r* in kWh in primary energy in time *t* in category *i*
HC_{it}	Energy consumption of new constructions for heating and hot water in kWh in primary energy in time *t* in category *i*
G_{rit}	Energy savings for each renovated dwelling of type *r* in kWh in primary energy in time *t* in category *i*
R_{rit}	Number of renovations of type *r* in time *t* in category *i*
PI_{rit}	Probability that a household invests in a renovation *r* that improves energy efficiency in time *t* in category *i*
PC_{rit}	Probability that co-owners in collective buildings vote a renovation *r* that improves energy efficiency in time *t* in category *i*
C_{rit}	Cost of a renovation of type *r* in kWh in primary energy in time *t* in category *i*
FC_{it}	Household's financial constraint in time *t* in category *i*
PV_{it}	Present value in time *t* in category *i*
Φ	Long term interest rate
T_k	Average life of equipment *k*

Table 2.6. Main assumptions in the model

Parameters	Sources of data and assumptions
Housing Stock	A function of demographic evolution
Demolition	A constant share of the housing stock. In 2006, data come from Ministry of Ecology, Energy, Sustainable Development and the Sea (website: http://www.developpement-durable.gouv.fr/).
Renovations	Depending on obsolescence of dwelling and cost-benefits analysis.
Energy Consumption related to heating and hot water	Depending on energy consumption of new constructions (based on thermal regulations), demolitions and renovations (energy consumption are obtained using PROMODUL software and the data are available from the authors upon request. In this software, energy consumption can be calculated using 3CL method to estimate energy consumption and GHG emissions in France, and it is used to label the dwellings. This computation method is described by a French decree in November 2006).
Cost Benefit analysis	Depending on: -household financial constraint (data come from INSEE) -prices of renovations (from ADEME) -energy savings
Energy savings	Energy savings in kWh and kg_{CO2} are linear functions of $AGE2_{it}$. These functions were constructed using PROMODUL software. Energy savings in euros through the renovation depend on: -energy prices (projection of IEA) -average life of equipment (ADEME)
Energy Consumption related to appliances	Depending on: -repartition in energy label (ADEME) -utilization and equipment rate (INSEE)
Energy Consumption related to lighting	Depending on: -the number and the kind of lights bulbs (data from ADEME) -surface area (from INSEE in 2006 and then the surface area for new construction is increasing by 0.46% per year. This figure is based on the twenty previous years trend)

Table 2.7. Main values of parameters used for calibration

Parameters	2006	Annual change	Sources
Number of dwellings	26,049,046	Depending on number of households	Ministry of Ecology, Energy, Sustainable Development and the Sea
Number of new constructions	0.84% of the total housing stock	Endogenous	Ministry of Ecology, Energy, Sustainable Development and the Sea
Demolition rate	0.05%	Constant of the period	INSEE
Energy consumption for new dwelling	110 kWh/m²/year	110 kWh/m² until 2013, 50 kWh/m²/year until 2030, 10 kWh/m²/year after.	Thermal regulations, Ministry of Ecology, Energy, Sustainable Development and the Sea
Surface area (in square meter)	65 m² in collective buildings and 110 m² in individual housing	Surface area for new construction is increasing by 0.46% per year	*INSEE*
Average area per new built dwelling	66 m² in collective buildings and 110 m² in individual housing	0.46% per year	*INSEE, projection of past trend*
AGE1	60	Endogenous	*INSEE, l'enquête logement 2006*
AGE2	60	Endogenous	*INSEE, l'enquête logement 2006*
Energy prices (euros/kWh/m²)			
Gas	0.0622	3.6%	IEA
Fuel	0.0651	3.3%	IEA

Parameters	2006	Annual change	Sources
Electricity	0.091	3.1%	IEA
Interest rate of bank loan for renovation works	6.12%	Constant over the period	*INSEE*
Inflation rate	2%	2%	*OECD*
Average cost of renovations (in euros by square meter)			
double glazing	27.6	2%	*ADEME*
wall insulation	15.31	2%	*ADEME*
roof insulation	10.72	2%	*ADEME*
changing heating system	35.88	2%	*ADEME*
renewable energy	106.42	2%	*ADEME*
Average disposable income (in euros)			
Quintile 1	7274	2%	*INSEE, l'enquête logement 2006*
Quintile 2	14550	2%	*INSEE, l'enquête logement 2006*
Quintile 3	21921	2%	*INSEE, l'enquête logement 2006*
Quintile 4	31412	2%	*INSEE, l'enquête logement 2006*
Quintile 5	56260	2%	*INSEE, l'enquête logement 2006*
Homeowner share	47.8%	Constant over the period	*INSEE, l'enquête logement 2006*

Table 2.8. Scenoarios used to test public policies

Comparison of current policies			
N°	**Scenario**	**Description**	**Sources**
1	Reference Scenario	-Value added tax of 5.5% to all types of renovations (instead of 19.6%) -Zero rate bank loan -Subsidy for homeowner: 35% of renovation expense. -Income tax deduction: 15% for double glazing, 25% for roof and wall insulation, 25% for modernization of heating system and 40% for adoption of renewable energy	Current public policies in France
2	Income tax deduction	Only income tax deduction is introduced. Rates are the followings: 15% for double glazing, 25% for roof and wall insulation, 25% for modernization of heating system and 40% for adoption of renewable energy	
3	Subsidy	Only subsidy for homeowner is introduced. 35% of renovation expense.	
4	Zero rate bank loan	Only zero rate bank loans is introduced.	
5	Value added tax	Only value added tax is introduced: 5.5% instead of 19.6%	
Public policy measures to achieve the Grenelle I goals			
6	Income tax deduction	Tests of several rates from 2010	Ministry have planed to change rates.
7	Bonuses	Bonuses on low income. Different amounts of bonuses are tested.	Local level

Table 2.9. Public cost of the different policy measures

Policy measures	Public cost of policies per ton of CO_2 saved to reach 13.75 million tons (in euro 2006)	Public cost of policies per ton of CO_2 saved to reach 50 kWh_{pe}/m^2/year (in euro 2006)
Income tax deduction	258 *	258
Bonus for all renovations	255	257
Bonus for low income	441	435
Bonus to encourage renewable energies	1,236	Impossible
Measures	**Public Benefit of policy per ton of CO_2 saved to reach 13.75 million tons**	**Public Benefit of policy per ton of CO_2 saved to reach 50 kWh_{pe}/m^2/year**
Carbon tax	176	360

Note: * The public cost per ton of CO_2 saved to reach 13.75 million tons with the income tax deduction is 258 euros (euro 2006)

2.7.4. Sensitivity analysis

Table 2.10. Results of sensitivity anaylisis

	Low scenario	Ref. Scenario	High Scenario
Inflation rate	1%	2%	3%
Energy consumption*	91.76 ***	91.67	89.63
GHG emissions**	35.5	35.01	34.1
Interest rate of bank loan for renovation works	5.12%	6.12%	7.12%
Energy consumption	88.43	91.67	94.67
GHG emissions	33.2	35.01	36.8
Discounting rate	1.98%	2.98%	3.98%
Energy consumption	86.54	91.67	95.16
GHG emissions	32.9	35.01	36.7
Anticipated increase in domestic prices from 2010 by year			
Gas	2.6%	3.6%	4.6%
Energy consumption	102.07	91.67	74.91
GHG emissions	40.8	35.01	26.02
Fuel	2.3%	3.3%	4.3%
Energy consumption	94.85	91.67	82.78
GHG emissions	36.8	35.01	30.3
Electricity	2.1%	3.1%	4.1%
Energy consumption	95.08	91.67	88.41
GHG emissions	36.2	35.01	33.8
All energies	- 1 pp		+1 pp
Energy consumption	109.9	91.67	64.33
GHG emissions	43.9	35.01	20.6
Bulbs light repartition	constant over the period		only economy saving light bulbs from 2020
Energy consumption	92.73	91.67	91.37
GHG emissions	35.09	35.01	34.99
Equipment utilization of appliances		constant over the period	100% (all household have all appliances) from 2020
Energy consumption		91.67	97.05
GHG emissions		35.01	35.49
Homeowner share	-10 pp		+10 pp
Energy consumption	92.67	91.67	90.66
GHG emissions	35.5	35.01	34.5

Notes: * in kWh_{ep}/m^2/year, ** in tons of $C0_2$, ***in the case where inflation rate is equal to 1%, the average energy consumption is 91.76 kWh_{pe}/m^2/year

Chapter 3.
Environmental fiscal incentives: Effectiveness or free-riding effect? An econometric evaluation of the French energy tax credit

Summary

In several countries, fiscal incentives have been introduced to encourage households to undertake energy-efficient renovations or adopt renewable energies. Our objective is to study the sensitivity of households to fiscal measures and to determine if a tax credit is effective or if free riding undermines its effect. We examine the impacts on renovation rate and on renovation expenditures using matching methods. We use French household-level databases, which regroup information on energy-efficient renovations. A tax credit has little effect on the decision to renovate. Building professionals (i.e., those qualified and approved to do renovations) capture a part of the earnings from the tax credit, and this tends to diminish the impact of the measure. Moreover, the presence of free riding reduces the actual effect of the tax credit.

3.1. Introduction

Energy consumption and greenhouse gas emissions are key concerns. However, household energy use continues to increase in most developed countries—in the European Union, for example, by an average of 0.6% per year since 1990 (source Odyssee, 2013). The growth of the population, which has led to an increase in the number and the size of homes and an increase in electronic equipment, tends to raise energy needs. To reverse this trend, several measures (e.g., tax credits, subsidies, thermal regulations, zero-rate bank loans) have been introduced in many developed countries to encourage households to undertake energy-efficient renovations in their homes. Our objective is to evaluate the effectiveness of such a fiscal incentive, and more precisely, the impact of a French tax credit on households' behavior.

It is crucial for households to renovate their housing to significantly decrease residential energy consumption. In the 2011 Energy Efficiency Plan, the European Commission states that the greatest energy-saving potential lies in buildings due to the improvements in efficiency of insulation or appliances. Energy use is largely determined by buildings' characteristics, whereas occupants' characteristics and behavior have more negligible effects on energy consumption (Santin et al., 2009). However, households do not invest in energy-saving measures even if it is profitable in the long run. Many authors (Brown, 2001; Jaffe and Stavins, 1994; Sanstad et al., 1995; Van Soest and Bulte, 2001) refer to this phenomenon as the "energy paradox." They explain this paradox essentially as a market imperfection (i.e., uncertainty about energy prices or energy savings following a renovation and the irreversibility of the investment).

A tax credit has been implemented in France to offset such market imperfections. Since 2005, the credit has aimed to encourage households (owners or tenants) to undertake energy-efficient renovations (e.g., insulation, changes in heating equipment) and to adopt renewable energy systems in their main housing. A condition to benefit from the tax credit is that a qualified building professional must be hired to perform the renovation work.[17] This measure is very popular. From 2005 to 2008, 4.2 million French households received the tax credit (Clerc and Mauroux, 2010); this represents a significant cost for the government: the public cost reached €7.8 billion during this period and €4.2 billion during 2009–2010. Given these

[17] The tax credit allows part of the renovation expenses to be deducted from income taxes. A deduction rate of up to 50% of the equipment costs depends on the kind of renovation carried out (e.g., change in heating system, improvement of the insulation) and the equipment chosen (e.g., adoption of renewable energy). The maximum amount of expenses deducted depends on the number of people in the household (the maximum deductible expense is €8,000 for a household with one person and €16,000 for a couple).

significant expenses, it is important to assess the effectiveness of this credit to provide further guidance for policy makers. However, few studies have examined the impact of French environmental public policies.

Some simulation models evaluate the impact of environmental policies at an aggregate level (Charlier and Risch, 2012; Giraudet et al., 2011; MEDDTL et al., 2011). They conclude that a tax credit helps decrease energy consumption and greenhouse gas emissions. However, they point out that French environmental measures are not sufficient to reach government objectives, which are to cut energy consumption in the building sector by 38% by 2020 relative to 2008. Our objective here is to study in detail the sensitivity of households relative to this measure. At the household level, Mauroux (2012) uses fiscal data and a matching method to study the 2006 tax credit increase for some energy-saving renovations. However, this increase pertains to only a limited segment of households, namely, owners living for less than 3 years in housing built before 1977. This change seems effective, as 1 in 15 households that received the tax credit would not have renovated if the rate had stayed the same. Studies focusing on the French tax credit do not pay much attention to the free-riding effect. Free riders are households that would have made energy-efficiency investments even in the absence of public policy. In this paper, we focus on the introduction of the tax credit, and we try to determine if a tax credit is effective or if free riding reduces its effect.

Several articles have studied the impact of similar tax credits, and their results diverge regarding the effectiveness of such a policy. On the one hand, some studies show that a tax credit is efficient. Hasset and Metcalf (1995) measure the impact of both the U.S. federal and state tax policies on the probability of making conservation-related investments. Using a discrete choice model on panel data, they show that conservation incentive programs have a statistically significant effect on investment, after controlling for individual fixed effects. Subsidies have been introduced in Switzerland in the form of tax credits or deductions, and similar results are observed: the likelihood that homeowners undertake energy-efficient renovations increases with the size of the subsidy (Alberini et al., 2011). On the other hand, some studies obtain more mixed results. For example, the 2011 U.S. federal tax credit for home energy-efficiency renovations has encouraged only 2%–12% of homeowners in Florida to adopt energy-efficient equipment (Zhao et al., 2012). Alberini et al. (2013a) compare homeowners' behaviors before and after the 2007 implementation of a tax credit in Italy. They conclude that the tax credit had a significant and positive impact on the replacement of windows but no significant effect on the replacement of heating systems. They explain this finding by free riding.

As in the preceding example, some studies have called attention to the existence of the free-riding effect and stress that it can undermine the effectiveness of programs that subsidize the cost of renovation. Using a Tobit model on 1979 data, Dubin and Henson (1988) find no evidence that a U.S. tax credit incentivized conservation expenditures. They point out that this measure provided windfall gains to households that would have insulated their home anyway (i.e., free riding). Similarly, Pon and Alberini (2012) focus on the American Reinvestment and Recovery Act of 2009, which offers tax credits for the installation of energy-efficient investments. They find no evidence of the impact of this policy on the adoption of energy-efficient equipment or on the number of renovations. Their results suggest that this measure is not significant in convincing homeowners to replace their older, less efficient equipment with energy-efficient equipment, but it is more effective in encouraging homeowners who are already planning to replace an appliance to select the more energy-efficient product.

Recent literature has attempted to assess the extent of the free-riding effect. Estimates range from 50% to 92%. Grösche and Vance (2009) use a cross-section of data from the 2005 German Residential Energy Consumption Survey and show that free riding occurs in 50% of the cases (they define free riding as a situation in which a household's willingness to pay for renovations exceeds its cost). Grösche et al. (2009) use revealed preference data on home renovations from Germany's residential sector to simulate the effect of grants on renovation choices. They conclude that 92% of the program expenses would be awarded to free riders if every eligible household behaved rationally and applied for the grant. Malm (1996) further confirms the high extent of free riding. He investigates the impact of subsidies on the purchase of high-efficiency heating systems and estimates free riding at 89%. Free riding can go beyond the decision to invest. Alberini et al. (2013b) examine household energy consumption in four counties in Maryland and focus on the replacement of existing equipment with a newer and more energy-efficient equipment. Using a difference-in-differences approach, they show that the larger the rebate, the less the electricity reduction.

In contrast, some papers explain that free riding can be diminished by spillover effects (Eto et al., 1995; Rosenow and Galvin, 2013), which lead to additional products being installed, as result of the program but not through the program. Few studies focus on this point, but a recent evaluation shows that spillover effects can be substantial (NYSERDA, 2012). Nevertheless, literature suggests that special attention should be given to fiscal incentives that encourage energy-saving investments in the residential sector and that it is important to assess the impact of such measures. The effectiveness of such a policy remains questionable.

Thus, we study the effect of the tax credit on households' behavior. To appraise the effectiveness of the measure, we first estimate the impact of the introduction of the tax credit on the renovation rate (i.e., extensive effect). Our objective is to determine if households are sensitive to this measure or if the tax credit provides funding for households that would have undertaken a renovation anyway. Second, we assess the extent to which the tax credit increases renovation expenditures (i.e., the intensive effect). Our objective is to investigate whether the tax credit incentivizes households to invest in more expensive and more energy-efficient renovations. To do this, we use a methodology rarely put into practice in environmental economics.

As is true of any policy evaluations, we cannot observe what the renovation rate or expenditures would have been if the tax credit had not been introduced (Rubin, 1974). To overcome this problem and obtain an unbiased evaluation, we use a matching method (Heckman, Ichimura and Todd, 1997, 1998; Rubin, 1977). This methodology helps examine evaluation issues in labor economics (see, e.g., Blundell and Costa Dias, 2008; Brodaty et al., 2002; Caliendo et al., 2005; Imbens and Wooldridge, 2009; Sabatier, 2012) but has only recently been applied to environmental economics. To conduct this study, we use French data from *ADEME-SOFRES Maîtrise de l'Energie* surveys from 2001 and 2008. This source provides information on energy-saving renovations and on household and housing characteristics.

We find that, in general, the tax credit has a low impact on the decision to renovate. Two factors tend to diminish the impact of the credit and explain this result. First, through price increases, building professionals capture part of the earnings from the tax credit. Second, the results suggest the presence of free riding.

We organize the remainder of this paper as follows: in section 2, we present the data; in section 3, we discuss the method; in section 4, we present the results; and in section 5, we provide a sensitivity analysis.

3.2. Data

We use *ADEME-SOFRES Maîtrise de l'Energie* surveys from 2001 and 2008. In these databases, information is available about whether renovations took place and the type of renovations undertaken (e.g., improvement of insulation, modification of heating system, adoption of renewable energy). In addition, we find information on households' characteristics (e.g., income, occupational status, household size, age of reference person, occupancy status) and housing characteristics (type of dwelling [i.e., house or apartment], surface area, year of construction, type of heating system) as well as geographic area (climatic area, size of the urban area) and energy bills. A zero-interest bank loan was introduced in 2009. Therefore, we do not take into account databases after 2008, because we may capture the effect of the two policies and want to isolate the impact of the tax credit. Therefore, we observe energy-saving renovations four years before and four years after the introduction of the tax credit in 2005.

Each year, approximately 7,000 households are surveyed about whether they undertook energy-saving renovations. We do not observe the same households over the whole period. Because we pooled databases, we cannot take into account the temporal characteristics of the data or any change in the policy. In section 5, we pay particular attention to the way this approach affects the results.

After accounting for missing observations, our final sample comprises 41,057 households. Overall, this sample remains representative of French households and of the French housing (table 3.1). In our sample, 53.5% of households are observed after 2005 (i.e., when the tax credit was introduced).

Table 3.1. Household characteristics

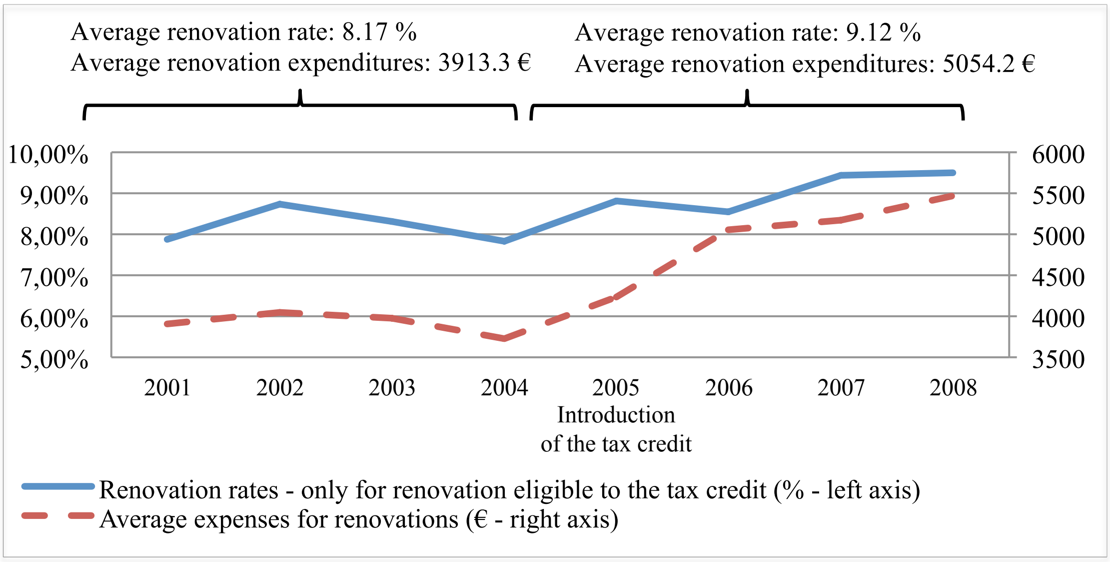
	Sample 1: Household characteristics		**Sample 2: Households that make renovations**		**Households that intend to request the tax credit**
	Before 2005	**2005 and after**	**Before 2005**	**2005 and after**	
Owners	71.7%	71.9%	96.0%	97.6%	98.3%
Income					
group 1 (the poorest)	4.6%	4.1%	1.5%	1.5%	0.9%
group 2	16.0%	14.0%	12.4%	8.4%	7.3%
group 3	13.4%	10.0%	12.7%	7.7%	7.5%
group 4	18.4%	14.4%	17.6%	13.6%	14.0%
group 5	31.1%	34.1%	35.9%	39.7%	40.4%
group 6 (the wealthiest)	16.6%	23.4%	20.0%	29.0%	29.9%
Age : less than 35 years	14.9%	14.0%	10.2%	9.9%	9.3%
1 person in the household	23.3%	25.9%	17.7%	18.7%	18.0%
2 or 3 people in the houehold	54.7%	53.0%	63.0%	61.3%	60.5%
4 people or more in the household	22.0%	21.1%	19.4%	20.1%	21.5%
Number of years spent in the housing	15.08	15.75	17.76	17.75	17.62
Environmental sensitivity					
energy-saaving bulbs	50.1%	68.2%	55.4%	73.6%	76.2%
Espaces info energie	13.0%	18.5%	17.1%	24.9%	26.2%

	Sample 1: Household characteristics		**Sample 2: Households that make renovations**		**Households that intend to request the tax credit**
	Before 2005	**2005 and after**	**Before 2005**	**2005 and after**	
Houses	66.6%	67.1%	82.2%	83.6%	84.8%
Years of construction					
before 1948	25.0%	24.9%	29.2%	29.6%	28.2%
1949–1974	31.1%	29.2%	39.6%	34.9%	36.1%
1975–1988	27.7%	26.0%	27.6%	28.7%	29.0%
after 1989	16.3%	20.0%	3.6%	6.8%	6.7%
Annual energy expenditure (m^2)	11.53	13.10	11.74	13.14	13.23
Number of observations	19,089 (46.5%)	21,968 (53.5%)	961 (42.1%)	1,319 (57.9%)	1,013 (76.8% of eligible households

Source: *ADEME-SOFRES Maîtrise de l'Energie* surveys–Final sample.
Note: In sample 2, we account only for renovations eligible for the tax credit (eligible equipment, renovation performed by a professional).

We consider only five types of energy-saving renovations eligible for the tax credit: opaque surface insulation, glazed surface insulation, installation or replacement of the boiler, adoption of renewable energy, and installation of a heating regulation or programming system. Taking into account only these renovations, we observe a renovation rate slightly higher in the four years following the introduction of the tax credit (9.12% vs. 8.17%). To benefit from the credit, households must hire a professional to do the renovation work. Thus, we study renovation expenditures, considering only those renovations performed by a qualified professional, including the cost of labor and the cost of equipment. The difference in renovation expenditures, including only households that renovate, is more significant, reaching an average of €5,054.2 after the introduction of the tax credit versus €3,913.3 before. Moreover, the renovation rate decreases in 2004 and then continually increases after 2005, except for a small decline in 2006 (see figure 3.1). We observe a similar evolution for renovation expenditures: The average amount spent for housing renovations decreased in 2004 and then has continually increased since the introduction of the tax credit.

Figure 3.1. The influence of public policies on renovations



Source: *ADEME-SOFRES Maîtrise de l'Energie* surveys – Final sample.

Considering only renovation work performed by a household itself, the renovation rate is low and constant during the period, averaging 2.2% each year (table 3.2). We do not observe a substitution effect from renovation performed by households to renovation performed by a professional. If this were the case, the impact of the tax credit would have been lower. Moreover, we do not observe a significant difference in average expenditures in renovation performed by the household itself before or after the introduction of the tax credit. The tax credit does not seem to have any effect on noneligible renovations. Therefore, there seems to be no spillover effect.

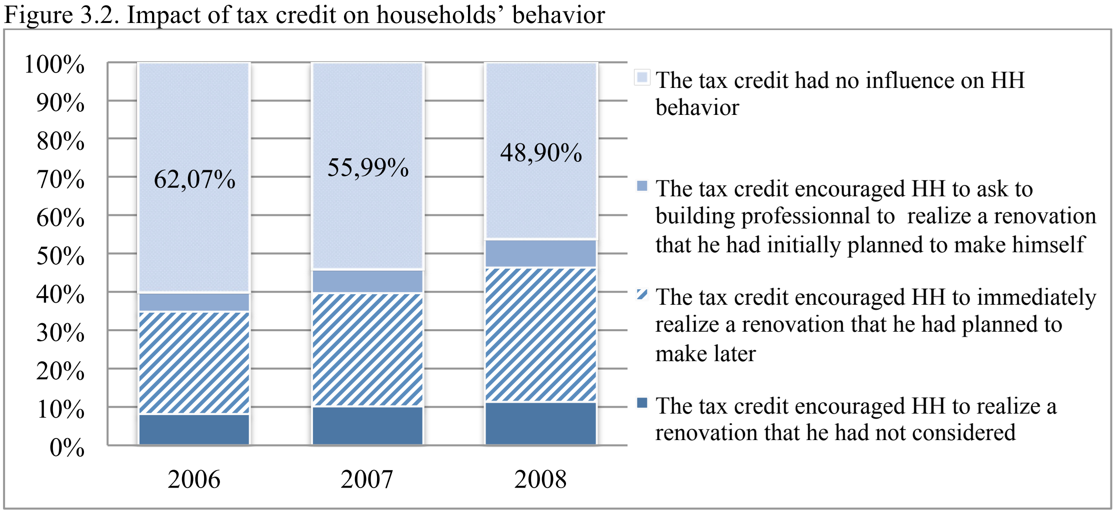
Table 3.2. Comparison renovations performed by a professional or by the household itself

	Before introduction of the tax credit	**After introduction of the tax credit**	**T-test**
Renovation rate			
Performed by building professional	6.02%	6.92%	***
Performed by households itself	2.15%	2.21%	n.s.
Renovation expenditures (including only households that renovate)			
Performed by building professional	3,750.63 €	4,906.71 €	***
Performed by households itself	1,030.45 €	963.10 €	n.s.

Source: *ADEME-SOFRES Maîtrise de l'Energie* surveys–Final sample.
Note: ***difference significant at 1%; n.s.: not significant.
We account only for equipments eligible to the tax credit.

At first glance, these observations suggest that the tax credit has a positive impact on renovation rate and on the amount spent by a household for a renovation. However, the effectiveness of fiscal measures may be mitigated by free riding. The survey provides information on the effect of the tax credit on households' behavior. Among households that received or intended to receive the tax credit, only 11% on average each year performed a renovation that they had not considered before the introduction of the measure (figure 3.2). In contrast, 55% of these households declared that the tax credit had no effect on their behavior. Thus, more than half of the households receiving the tax credit would have performed the renovation without this financial subsidy. Free riding seems to play a significant role and fall within the range of the estimates from Grösche and Vance (2009), but it is below the estimates from Malm (1996) and Grösche et al. (2009).

Figure 3.2. Impact of tax credit on households' behavior



Source: *ADEME-SOFRES Maîtrise de l'Energie* surveys–Final sample.

Households that renovate are mainly owners who live in their house, and they belong to the wealthiest income group (table 3.1). This trend is more pronounced after the introduction of the tax credit and even more pronounced among households that intend to request the tax credit. Of households that renovated before 2005, 56% belong to the two wealthiest income groups, compared with 69% after 2005. After 2005, the renovated units are slightly more recent: 35.5% are built after 1975 versus 31.2% before the introduction of the tax credit. One particularity of the tax credit is that all households can potentially benefit from this measure. However, only 76.8% of households intended to request the tax credit.

In the following section, we take our analysis a step further and assess the effectiveness of the tax credit, ceteris paribus. Our objective is to study the impact of the tax credit on the rate and expenditures of energy-saving renovations. We explore two questions: Does the tax credit encourage households to renovate? Does this measure provide an incentive for households to spend more money on energy-efficient renovations?

3.3. Methodology

3.3.1. An evaluation problem

The tax credit was introduced in 2005 ($T = 1$) to encourage households to undertake energy-saving renovations. As we noted previously, the likelihood of renovation and of requesting the tax credit were correlated with household characteristics x (e.g., income, occupancy status). Consequently, the impact of the tax credit is the difference between the renovation rate (or renovation expenditures) with the policy (y_1) and the renovation rate (or renovation expenditures) that would have been observed without the policy (y_0) (Rubin, 1974). Thus, we can express the impact of the tax credit as follows:

$$\Delta(x) = E[y_1 \,/\, T = 1, X = x] - E[y_0 \,/\, T = 1, X = x].$$

As such, the impact is unobservable because it is impossible to simultaneously observe both situations, and it is specific to each individual. We must therefore estimate what *would have happened* without the tax credit—that is, the counterfactual renovation rate (or expenditures) given by $E[y_0 \,/\, T = 1, X = x]$. We use a matching method to estimate the counterfactual situation, which involves matching each household that can benefit from the tax credit (the treated group) with a household that cannot benefit from it (the control group), with the same observable characteristics x being equal. One particularity of the tax credit is that all households have been eligible for the measure since 2005. As we mentioned previously, the stipulation of the French tax credit is that for a household to benefit from it, an energy-saving renovation must be made by a qualified building professional. This characteristic makes the tax credit a bit different from other public policies, such as employment policies, which usually target a particular segment of the population. Consequently, in our case, all households observed between 2005 and 2008 form the treated group, and we cannot identify a control group for this period. However, we need information on households that undertake energy-saving renovations and are ineligible for the tax credit. By definition, households observed between 2001 and 2004 are ineligible for the credit, and thus we consider them the control group. To derive a control group in a different time period from the treated group could lead to a problem if the tax credit has an impact on unobservable variables. The matching method must respect the conditional independence assumption (CIA), which means that households in control and treated groups must be similar not only in terms of observable characteristics but also in terms of unobservable characteristics. This assumption can hold, because our database contains a rich set of variables used to explain renovations, including sociodemographic variables, information on housing, information on energy used, and energy bills. However, in our case, it is important to pay attention to this assumption, especially because we pooled databases from 2001 to 2008. We thus cannot take into account the temporal characteristics of the data or any changes occurring during this period, for example, relative to the policy or macroeconomic index (as interest rate). We test the sensitivity of the results relative to this assumption in section 5.

The method consists of matching similar households from treated and control groups. A common way of matching households is propensity score matching (Rosenbaum and Rubin, 1983). This matching is based on a single propensity score reflecting the probability of being eligible for the tax credit (or the probability of belonging to the treated group), conditional on the observed characteristics x (Heckman, Ichimura, and Todd, 1998; Rubin, 1977). We estimate the probability of being eligible for the tax credit using a logit model. We introduce in the model variables that may explain the probability of being eligible and also the renovation decision.

First, we take into account households' sociodemographic characteristics, such as income, age, occupancy status, number of people in the household, years spent in the housing, and a proxy for environmental sensitivity. Change in income is a determinant of home improvement decisions (Cameron, 1985; Potepan, 1989), and considering this variable enables us to control for the potential change of purchasing power during the period. Regarding expenditures, Mendelsohn (1977) shows that people who have higher incomes spend more on renovation. Studies show that occupancy status also plays a role in the decision to renovate and stress that owners have a higher probability of undertaking a renovation (Diaz-Rainey and Ashton, 2009). We add the number of people in the household to control for the tax credit ceiling. The more people in the household, the higher the maximum amount of expenses that can be deducted.[18] In addition, Diaz-Rainey and Ashton (2009) show that the longer individuals live in a property, the greater the likelihood of adoption of energy-efficient measures. Moreover,

[18] As a reminder, the maximum amount of expenses deducted depends on the number of people in the household (the maximum of the expenses deducted is €8,000 for a household with one person and €16,000 for a couple).

Bogdon (1996) shows that household characteristics are important determinants of the homeowner's decision to hire someone else to do the work. We use a proxy for environmental sensitivity, assuming that households that have energy-saving bulbs (compared with standard bulbs) and know about the *Espaces Info-Energie* are more sensitive to environmental issues. The *Espaces Info-Energie* aggregates 250 places where households can find all the information they need about energy consumption, renewable energies, and energy-saving renovations. It was initiated in 2001 to alert and inform households.

Second, we introduce variables on housing characteristics, such as year of construction, type of housing (house or apartment), and surface. These variables are likely determinants of renovation decisions (e.g., Nair, Gustavsson, and Mahapatra, 2010). We consider the year of construction a proxy for insulation quality, which can have an impact on the decision to renovate. Moreover, Montgomery (1992) shows that the age of the building has a positive impact on renovation expenditures.

Third, we take into account information on energy and type of heating system. In France, some dwellings use a collective heating system. Households that use collective heating consume more energy, which might encourage them to undertake a renovation. However, changing the heating system becomes more difficult if heating is collective, because the decision must be made by all the co-owners. We also consider energy bills and a dummy equal to 1 if the heating energy price increases more than 4% in the year. We arbitrarily chose this number, which is approximately two times higher than the annual average inflation (approximately 1.8% on average over the period) and slightly higher than the average annual growth rate of the energy price index (approximately 3.5% on average over the period). The energy price information comes from the French National Institute of Statistics and Economic Studies (INSEE). It seems important to take these variables into account because of the increase of energy prices in recent years. A period of rising prices might encourage households to decrease energy consumption with energy-efficiency renovation, because households are sensitive to energy prices (Cameron, 1985). Moreover, households that believe energy cost is high are more likely to renovate (Nair, Gustavsson and Mahapatra, 2010).

Fourth, we introduce variables on geographic area, such as climatic area, and a dummy equal to 1 if the households live in a rural area. This enables us to control for regional differences.

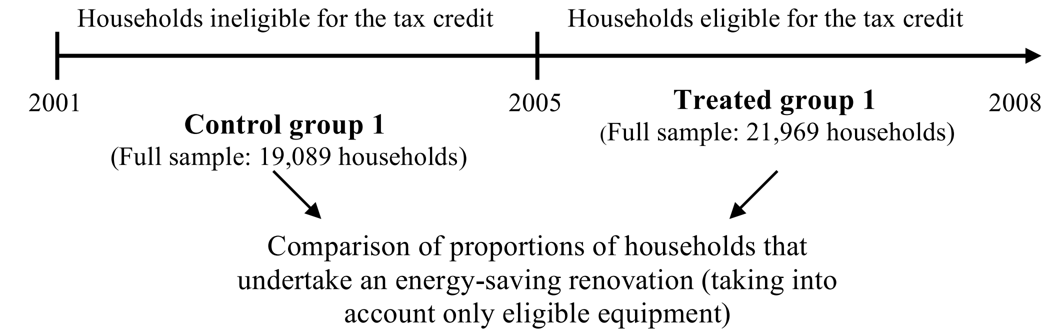
Once households are matched on the basis of their propensity score, we used what we observed for matched households to estimate the counterfactual situation and then the effect of the tax credit. For binary variables such as renovation rate, Aakvik (2001) suggests first using Mantel and Haenszel's (1959) test to draw conclusions about the significance of the results. This enables us to test the null hypothesis of no tax credit effect. It is a nonparametric test, which compares the number of people in the treated group who perform a renovation with the same expected number given that the tax credit effect is zero. If the effect is significant, the magnitude of the effect of the tax credit can be estimated as the difference between the proportions of households that undertake a renovation in the treated and control groups belonging to the matched sample (Brodaty et al., 2001). For continuous variables such as renovation expenditures, the effect of the tax credit can be estimated as the difference between the mean expenditures for the treated group and the mean expenditures for the control group in the matched sample (Rosenbaum and Rubin, 1983). This differential can be estimated using different matching estimators (e.g., nearest-neighbor estimator, stratification matching, kernel matching). We use kernel matching to estimate the impact of the measure on renovation rates. This estimator, proposed by Heckman, Ichimura, and Todd (1998), is a nonparametric estimator in which weighted averages of all ineligible households are used to construct each participant's counterfactual. Smith and Todd (2005), Heckman, Ichimura, Smith, and Todd (1998), and Heckman, Ichimura, and Todd (1997, 1998) argue for the advantages of kernel matching. It offers the most robust estimates in large samples (Heckman, Ichimura, and Todd 1997, 1998).

3.3.2. Estimation strategy

3.3.2.1. Renovation rate

To estimate the impact of the tax credit on the renovation rate (figure 3.3), we consider the entire sample and observe the energy-saving renovations, taking into account only opaque surface insulation, glazed surface insulation, installation/replacement of the boiler, adoption of renewable energy, and installation of a heating regulation or programming system. As we have noted, to benefit from the tax credit, households must hire a qualified professional to perform these renovations. The share of renovations performed by households themselves is low and constant during the period. Consequently, we chose to observe the impact of the tax credit on total renovation rate.

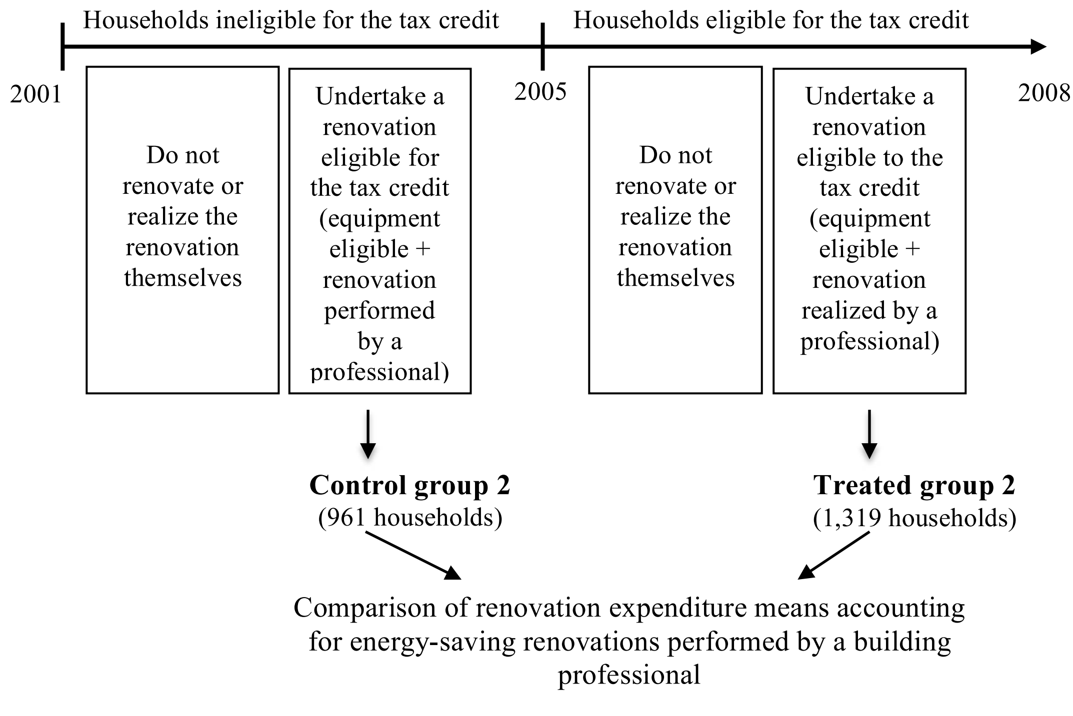
Figure 3.3. Impact of the tax credit on renovation rate—matching method



3.3.2.2. Renovation expenditures

To estimate the impact of the tax credit on renovation expenditures (figure 3.4), we consider only renovations performed by qualified professionals, including the costs of labor and of equipment.[19]

Figure 3.4. Impact of the tax credit on renovation expenditures—matching method

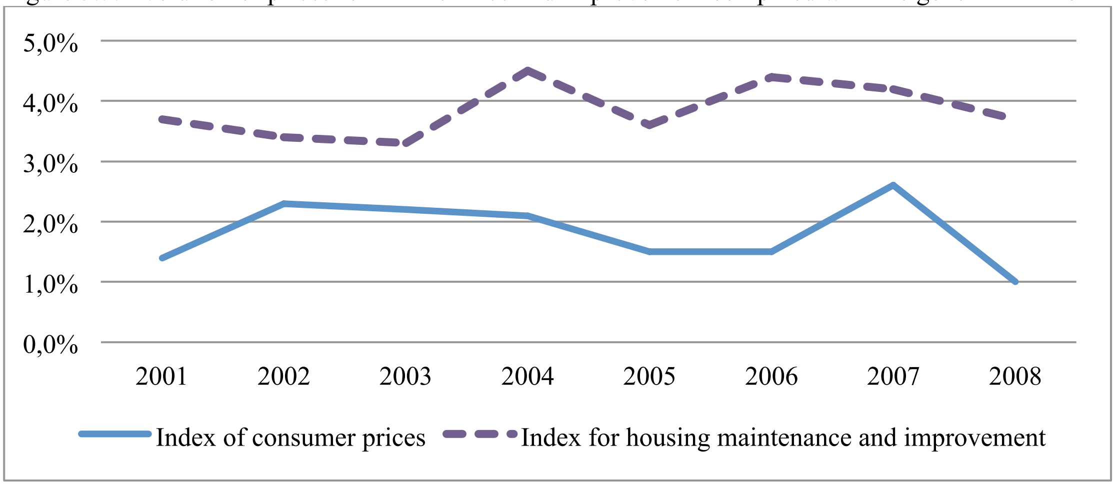


We estimate the impact of the tax credit on current prices (i.e., amounts declared by households in the survey).[20] Prior literature assumes that only households capture earnings related to the tax credit. We can identify whether households share the earnings with building

[19] We do not estimate the impact on the different types of renovation separately because of the small number of observations in the control group.
[20] We consider only the positive expenditures. In this second analysis, we do not include households that do not renovate.

professionals by taking into account the evolution of renovation costs. We use the annual price index for housing maintenance and improvements to deflate renovation expenditures and convert them into 2001 prices. This price index comes from INSEE. In figure 3.5, we observe that the prices of renovation increase more than inflation over the whole period. Thus, it is possible that building professionals take advantage of the tax credit to increase their margins. Studying the impact of the tax credit on expenditures at constant prices enables us first to identify a potential margin generated by the professional as a result of the tax credit and then determine whether households perform more important renovations after the introduction of the credit. We present the results of this analysis in the following section.

Figure 3.5. Evolution of prices for maintenance and improvement compared with the general inflation rate



Source: INSEE.

3.4. Results

3.4.1. Propensity score

We estimate the propensity score—that is, the probability of being eligible for the tax credit. We use (1) the full sample to estimate the impact of the tax credit on the renovation rate and (2) a subsample including only households that hired qualified professionals to renovate to estimate the impact of the measure on renovation expenditures (table 3.3).

In terms of results, several control variables have an impact on the probability of being eligible for the tax credit. Using energy-saving bulbs and being aware of the *Espaces Info-Energie* have significant and positive effects. This suggests that the environmental sensitivity of households has a positive impact on the probability of being eligible for the credit. As we expected given the energy price evolution over the period, the higher the energy expenditures per square meter, the higher the probability of being eligible for the tax credit.

Household composition has a significant impact as well: Having fewer than four people in the household increases the probability of eligibility. This is not surprising, given that INSEE has observed an increase in single-parent families or people living alone. Focusing only on the full sample, we note that a young age of the housing, a high housing surface area, and living in an apartment are indicative of being eligible for the tax credit. In addition, being a homeowner decreases the probability of being eligible in the full sample but increases the probability of being eligible in the subsample. This suggests that fewer households are homeowners. However, there are more owners who have renovated after 2005 than before. A tenant has less incentive to make an energy-efficiency investment because the return on the investment is lower than for an owner. The length of occupancy tends to be lower than that of an owner, and a tenant does not realize any property value increase due to renovation. In France, part of the population qualifies as “tenant for life,” and the tax credit seems insufficient to encourage them to renovate.

Moreover, in the subsample only, income, living in a house, and the year of construction of the building have no impact on the probability of being eligible. That is, the introduction of the tax credit does not encourage low-income people or households living in apartments to renovate more. Apartments are often in collective-heating buildings, and some renovations cannot be decided at the household level but must be made by the community. Thus, to agree on and then undertake renovation is more difficult. In addition, the credit does not lead to an increase in renovations for older buildings. Using the age of the building as a proxy for insulation quality, we find that renovations in less energy-efficient housing have not increased following the introduction of the tax credit. Older houses are often occupied by households in an energy poverty situation—that is, lower-income households that cannot undertake major energy-saving renovations. Given these results, the tax credit seems to fail to encourage households that are not prone to renovate, and this suggests the presence of free riding.

Table 3.3. Probability of being eligible for the tax credit

	Full sample			Households that renovate (performed by a professional only)		
	Coeff	SE		Coeff.	SE	
Households characteristics						
owners	-0.1855	0.0283	***	0.4853	0.2654	*
age of reference person less than 35 years	-0.0325	0.0332		0.0890	0.1670	
1 person in the household (ref. 4 persons or more)	0.6215	0.0744	***	0.8058	0.3771	**
2 persons in the household (ref. 4 persons or more)	0.1142	0.0683	*	0.6096	0.3103	**
3 persons in the household (ref. 4 persons or more)	0.1878	0.0858	**	0.5505	0.3661	
income group 1 (the poorest) (ref. the group 6: the wealthiest)	-0.1404	0.1118		0.3146	0.7903	
group 2	-0.4057	0.0858	***	0.3790	0.4223	
group 3	-0.5152	0.0902	***	0.0285	0.4105	
group 4	-0.5339	0.0843	***	-0.5950	0.3800	
group 5	-0.2588	0.0730	***	-0.0144	0.3085	
energy sensitivity: energy-saving bulbs	0.7706	0.0215	***	0.8093	0.0972	***
Espace info-energie	0.3270	0.0293	***	0.3407	0.1149	***
nb years spent in the housing	0.0098	0.0010	***	0.0070	0.0039	*
Building characteristics						
houses (=1 if the dwelling is a house)	-0.1466	0.0324	***	-0.0181	0.1644	
surface area in m^2	0.0014	0.0003	***	0.0018	0.0011	
year of construction (ref. after 1989) : before 1948	-0.1751	0.0811	**	-0.1473	0.6433	
1949–1974	-0.4013	0.0835	***	-0.8590	0.6500	
1975–1988	-0.1846	0.0815	**	-0.2096	0.6501	
collective heating system with fuel oil	-0.0082	0.1186		1.2167	0.6396	*
collective heating system with gas	0.5301	0.0887	***	1.7982	0.4904	***
individual heating system with electricity	0.8507	0.0644	***	1.6021	0.3016	***
individual heating system with gas	0.1914	0.0656	***	0.7405	0.2743	***
individual heating with fuel and other	ref			ref		
Energy prices information						
annual energy exenditure by m^2	0.0866	0.0095	***	0.1487	0.0652	**
energy price variation (=1 if heating energy price increase more than 4% during the year observed)	0.6525	0.0250	***	0.5198	0.1029	***
income group 1 * annual energy expenditure	-0.0346	0.0076	***	-0.0619	0.0622	
income group 2 * annual energy expenditure	-0.0184	0.0063	***	-0.1025	0.0312	***
income group 3 * annual energy expenditure	-0.0187	0.0066	***	-0.0800	0.0292	***
income group 4 * annual energy expenditure	-0.0094	0.0064		-0.0048	0.0293	
income group 5 * annual energy expenditure	-0.0027	0.0056		-0.0224	0.0237	
1 pers in the HH * annual energy expenditure	-0.0131	0.0054	**	-0.0203	0.0281	
2 pers in the HH * annual energy expenditure	-0.0058	0.0051		-0.0424	0.0235	*
3 pers in the HH * annual energy expenditure	-0.0071	0.0065		-0.0510	0.0273	*
construction before 1948 * annual energy expenditure	-0.0153	0.0065	**	-0.0456	0.0583	
construction 1949–1974 * annual energy expenditure	-0.0025	0.0067		-0.0054	0.0587	
construction 1975–1988* annual energy expenditure	-0.0145	0.0068	**	-0.0412	0.0589	
collective heating with fuel * annual energy expenditure	-0.0154	0.0077	**	-0.0682	0.0424	
collective heating with gas * annual energy expenditure	-0.0379	0.0061	***	-0.1118	0.0325	***
individual heating with electricity *annual energy expenditure	-0.0371	0.0047	***	-0.0988	0.0220	***
individual heating with gas * annual energy expenditure	-0.0078	0.0047	*	-0.0416	0.0200	**
Geographic area						
climatic area 1 (the coldest, in northeast)	-0.0834	0.0743		-0.3942	0.3505	
climatic area 2	-0.2112	0.0818	**	-0.5233	0.3807	
climatic area 3 (the warmest, in south)	ref			ref		
annual energy expenditure * climatic area 1	0.0021	0.0058		0.0453	0.0285	
annual energy expenditure * climatic area 2	0.0204	0.0066	***	0.0677	0.0312	**
rural area	0.2768	0.0285	***	-0.3157	0.1086	***
constante	-1.3565	0.1298	***	-2.3872	0.8140	***
Log-likelihood	-26,265.122			-1,402.970		
Number of observations	41,057			2,280		
Correct prediction rate	63.33%			65.09%		

Note: ***significant at 1%, **significant at 5%, *significant at 10%.

These estimations enable us to calculate the propensity scores, which we use to match households from the treated and control groups. The idea of the method is to match an eligible household with an equivalent ineligible household. The balancing assumption between characteristics of treated and control groups is valid for the full sample and the subsample. Figures 3.8 and 3.9 in the appendix show the deviation of household characteristics of the control group from those of the treated group, before and after matching. The deviation is largely reduced after matching. Moreover, to verify that the household characteristics of the treated and control groups are similar after matching, we use two indicators: the standardized percentage bias and overall explanatory power of the propensity score estimations (table 3.4). The standardized percentage bias is the percentage difference of the sample means in the treated and control groups as a percentage of the square root of the average of the sample variances in both groups (Rosenbaum and Rubin, 1983). The overall bias decreases significantly after matching. We study the overall explanatory power of the propensity score estimations using the likelihood ratio (LR) chi-square test. This test enables us to conclude that before matching, at least one of the regression coefficients in the model is not equal to zero. In contrast, all regression coefficients are simultaneously equal to zero after matching. Considering these results, we can use the matched sample to estimate the effect of the tax credit.

Table 3.4. Matching quality

	Renovation rate		**Renovation expenditures**	
	Standardized percentage bias	**LR χ^2**	**Standardized percentage bias**	**LR χ^2**
Before matching	6.4%	4,176.58 $p > \chi^2 = 0.0000$	7.2%	298.02 $p > \chi^2 = 0.000$
After matching	0.5%	41.84 $p > \chi^2 = 0.565$	1.7%	26.26 $p > \chi^2 = 0.984$

3.4.2. Impact of tax credit

3.4.2.1. Renovation rate

Our objective is to estimate the impact of the tax credit on the renovation rate. We first draw conclusions about the significance of the effect using Mantel and Haenszel's (1959) test. We calculate the this *MH* test statistic as follows:

$$MH = \frac{\left[\sum_{r=1}^{R}\left(Y_{1r} - \frac{N_{1r}Y_r}{N_r}\right)\right]^2}{\sum_{r=1}^{R}\left(\frac{N_{1r}N_{0r}Y_r(N_r - Y_r)}{N_r^2(N_r - 1)}\right)}$$

where N_r is the number of households in the stratum r, including both treated households (N_{1r}) and control households (N_{0r}), and Y_r is the number of households that renovate, including both eligible households (Y_{1r}) and ineligible households (Y_{0r}). The MH statistic follows a chi-square distribution with one degree of freedom (Aakvik, 2001). The MH test statistic is 3.41 and is significant at a 1% level. The tax credit has a significant effect on the total renovation rate.

We then estimate the magnitude of the effect of the measure on the renovation rate using the kernel-matching estimator, which enables us to assess the differential of renovation rates between similar treated and control households. The results appear in table 3.5. They confirm the significance of the impact. The effect of the tax credit is positive but very low. It increases renovations by 0.86%, ceteris paribus. This result is low compared with other reported results. Although some studies find no evidence that tax credits have an impact on the number of renovations (Pon and Alberini, 2012), other studies report a more significant impact. An increase of 10 percentage points of U.S. tax incentives leads to a 24% increase in the probability of performing energy-efficiency improvements in housing (Hassett and Metcalf, 1995). More recently, the current U.S. federal home energy-efficiency tax credit program reportedly has encouraged 2%–12% of homeowners to invest in energy-saving equipment (Zhao et al., 2012).

Table 3.5. Impact of the tax credit on renovation rate—kernel-matching estimates

	Renovation rate
Effect of the tax credit	0.0086
Standard error	(0.0031)***
Number of observations	41,057
Number in treated group	21,968

Note 1: Bootstrapped standard errors, obtained after 500 replications, appear in parentheses.
Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

This result means that between 2005 and 2008, approximately 900,000 dwellings were renovated as a result of the introduction of the tax credit (see table 3.6). There were 25.7 million main dwellings in 2005 and 26.6 million in 2008 in France (according to INSEE). We compare the public cost of the measure (i.e. the cost for the government), which is €7.8 billion over the period, with these 900,000 dwellings. The public cost reaches €8,658 per house that would not have been renovated without the tax credit. This is significant, given that the average expenditure on the period is €5,054.2 in our sample (figure 3.1). The impact of the tax credit is low compared with the public cost of the measure. This finding can be explained because 4.2 million French households received a tax credit (Clerc and Mauroux, 2010), but only 900,000 renovated specifically as a result of this credit, which indicates the presence of free riding.

Table 3.6. Number of energy-saving renovations

	2005	**2006**	**2007**	**2008**
Number of dwellings	25,743,000	26,047,000	26,353,000	26,616,000
Public cost of tax credit	€7.8 billion over the period			
Rate of energy-saving renovations in the survey	8.81%	8.55%	9.43%	9.50%
Estimation of the rate of renovations undertaken as a result of the tax credit	0.86%	0.86%	0.86%	0.86%
Estimation of the number of renovations as a result of the tax credit	221,390	224,004	226,636	228,898
	900,928 dwellings over the period			

Source: INSEE and ADEME-SOFRES Survey.

The low impact of the tax credit on the renovation rate can be related to some free riding, but it is not the sole explanation. Other factors, such as an increase of the cost of renovation, can reduce the incentive effect of the measure. Moreover, the tax credit does not really encourage households to renovate, but it can encourage households to perform more important energy-saving renovations. We explore this point in the next subsection.

3.4.2.2. Renovation expenditures

Tax credit has a significant and positive impact on the total renovation expenditures. The tax credit led to a 24.65% increase of expenditures (at current price) during the 2005–2008 period. This value is much larger than the result in Dubin and Henson (1988), who find no evidence that tax credits have an impact on renovation expenditures.

According to the working group on housing energy improvement (OPEN), the total expenditures (out of VAT) in energy-saving renovations reached €12.78 billion in 2006 and €15.10 billion in 2008. Assuming that expenditures in 2005 and 2007 were similar and knowing that 24.65% of these amounts were due to the introduction of the tax credit, we can observe that the credit led to a total expenditure of €13.42 billion during the period, of which €7.8 billion came from the government (the public cost of the measure) and the remaining €5.62 billion from households. In other words, for every €1 spent by the government, the tax credit leads households to spend an additional €0.72. The leverage of this credit is low.

The previous result does not mean that the tax credit allows households to perform more important renovations. The effect is reduced by the price increase observed during the period. If we consider constant prices, the impact is three times lower (table 3.7), down to 8.9%. In other words, the tax credit is followed by an increase in the renovation expenditures, but two-thirds of this rise is due to an increase of the prices. However, our results remain in the line with those of Pon and Alberini (2012), who show that tax incentives are not significant in encouraging households to invest in energy-saving equipment but are effective in encouraging homeowners who are already looking to replace appliances to select the more energy-efficient one.

We observe that the rise of prices for maintenance and improvement is higher than general inflation (figure 3.5). The inflation during the period following the introduction of the tax credit is lower than the period before (the index of consumer prices increases 7.4% between 2005 and 2008 and 8.5% between 2001 and 2004). In contrast, the increase of the index for housing maintenance and improvement is higher between 2005 and 2008 (15.7%) than during the preceding period (14.5%). This suggests that building professionals took advantage of the tax credit to increase their prices. Households share earnings from the tax credit with building professionals. Through price increases, the credit provides subsidies to professionals, which may partially explain the low impact of the tax credit on renovation rates.

Professionals can capture part of the earnings, given that the market of energy-saving renovations is imperfectly competitive. First, suppliers cannot meet all demand, which gives market power to these building professionals. In France, we observe a saturation of the supply in the energy-saving renovations market (Moussaoui, 2008). Second, market imperfections are also related to a lack of price transparency and a lack of information to the consumers, for example, pertaining to the energy savings as a result of a renovation (Beillan et al. 2011; Francfort, 2009).

Table 3.7. Impact of the tax credit on renovation expenditures—kernel-matching estimates

	Renovation expenditure	
	Current prices	**Constant prices**
Effect of the tax credit	0.2465	0.0890
Standard error	(0.0469)***	(0.0405)**
Number of observations	2,280	
Number in treated group	1,319	

Note 1: Bootstrapped standard errors, obtained after 500 replications, appear in parentheses.
Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

3.5. Sensitivity analysis

Matching is based on the CIA: Given the observable characteristics, the renovation rate (or expenditures) is independent of the probability of being eligible for the tax credit. This assumption is not satisfied when unobserved characteristics of the treated group differ from unobserved characteristics of the control group, and our results may be biased. In this section, we observe the sensitivity of the results to a deviation from this assumption.

The control group is on a different time period than the treated group, and we are not able to take into account time information because we pooled the database. An unobserved factor (e.g., renovation prices, households preferences) can have an impact on the decision to renovate and may change over the period. Consequently, it can differ between the treated and control groups. A sensitivity analysis enables us to appraise the extent to which the results can be altered by unobserved factors. For example, renovation price trends can affect the cost–benefit analysis of the renovation and the profitability of the investment. We observe a decrease in the renovation rate in 2004 and 2006 (figure 3.1), marking the years of the most significant increases in renovation prices (figure 3.5). However, the effect of an increase in the cost of renovation is reduced by the tax credit, because the tax deduction is a percentage of the cost of the equipment, and the higher the cost of the equipment, the larger the deduction. Moreover, even if households are sensitive to a change in renovation prices (Cameron, 1985), Charlier (2013) stresses that households are more sensitive to the gain of the renovation. Energy saving related to the investment is based on housing characteristics, and we control for these variables. Nonetheless, it seems appropriate to study the sensitivity of the results with respect to deviation from the CIA.

We use Ichino et al.'s (2007) approach. It is the appropriate approach following a nonparametric model for the outcome equation. We test the impact of an unobserved binary variable u that affects the potential outcome Y (renovation rate or renovation expenditures) and eligibility for the tax credit (T = 1). The conditional independence given the set of variables x is not valid, but this assumption holds given x and u. In other words,

$$Pr(T = 1|Y_0, Y_1, x) \neq Pr(T = 1|x)$$

and

$$Pr(T = 1|Y_0, Y_1, x, u) = Pr(T = 1|x, u),$$

where u is assumed to be binary (e.g., u = 1 if the cost–benefit analysis of the renovation is favorable to the investment, and u = 0 otherwise).

First, we must characterize the distribution of u, which depends on the choice of four parameters. In the case of a binary outcome (renovation rate), the distribution of u is defined by:

$$\Pr(u = 1|T = i, Y = j, x) = \Pr(u = 1|T = i, Y = j) \equiv P_{ij},$$

where $i, j \in \{0,1\}$, which gives the probability that $u = 1$ in each of the four groups defined by the treatment status ($i = 0$ or 1) and the outcome value ($j = 0$ or 1).

In the case of a continuous outcome (the renovation expenditures), we apply to Y a binary transformation, and we define P_{ij} as follows:

$$\Pr(u = 1|T = i, I(Y > y^*) = j) \equiv P_{ij},$$

where $i, j \in \{0,1\}$, I is the indicator function, Y is the renovation expenditures, and y^* is the mean of Y.

We can assign arbitrary values to the parameter P_{ij}. We consider the neutral confounder P_{ij} = 0.5, and then we can let u mimic the behavior of some important covariates. We choose variables that we assume to have an effect on the outcome, such as owner-occupied, income in the range of the two wealthiest groups, above-average energy expenditures per square meter, access to *Espaces Info-Energie*, and use of energy-saving bulbs. The latter two variables should influence the selection (i.e. the eligibility for the tax credit), because it seems that environmental sensitivity increased during the period.

Second, we simulate u, which is considered as any other variable and is used to estimate the propensity score and the kernel-matching estimates.

We present the results in table 3.8. The first four columns contain the probabilities P_{ij}. For each value we give at u, the next two columns present, respectively, the outcome effect (i.e., effect of u on the untreated outcome, controlling for the observables x) and the selection effect (i.e., effect of u on eligibility for the tax credit, controlling for the observables x). The two last columns provide the tax credit impact and the standard error, controlling for the observable x and the unobservable u. Here, we comment on the sensitivity analysis of the results on renovation rate. We assume that u follows the same distribution as the variable "owner." P_{11} is 0.93—that is, 93% of households that are eligible for the tax credit and renovate their housing are owners. We impose that the same percentage of eligible households that undertake renovation have a positive cost–benefit investment. In this case, we observe that u has a positive effect on the probability to renovate, given that households are ineligible for the tax credit (the outcome effect is higher than 1), but u has almost no effect on the probability of being eligible (selection effect almost equal to 1). The effect of the tax credit on the renovation rate, controlling for x and u, is close to the situation without a confounder (0.0084 vs. 0.0086), and the effect is still significant. If we consider that u has the same distribution as the "energy-saving bulbs" variable, the outcome and selection effects are both higher than 1. Therefore, u has a positive effect on the probability to renovate, given that households are ineligible for the tax credit, and a positive effect on the probability of being eligible. In this case, the impact of a tax credit is significant but lower than the situation without a confounder of 0.003 points.

Regarding renovation expenditures, the impact of the tax credit with a confounder remains significant and close to the initial situation. We obtain a larger difference when u mimics the distribution of the "energy-saving bulbs" variable. The selection effect is greater with this confounder. In this case, the effect of the tax credit increases by 0.011 points for estimations at constant prices and 0.008 points for estimations at current prices. All these simulations confirm that the measure has a significant and positive impact on renovation rate and renovation expenditures.

Table 3.8. Sensitivity analysis—impact of the tax credit on renovation expenditures

	Fraction u =1 by treatment/outcome				**Outcome effect**	**Selection effect**	**Tax credit impact**	**SE**
	P_{11}	P_{10}	P_{01}	P_{00}				
Renovation rate								
No confounder	0	0	0	0	-	-	0.0086	0.0005***
Neutral confounder	0.50	0.50	0.50	0.50	0.999	0.998	0.0086	0.00002***
Confounder like:								
Owner	0.93	0.70	0.89	0.70	3.472	1.006	0.0084	0.00027***
Energy expenditure (>50%)	0.48	0.48	0.38	0.37	1.079	1.558	0.0079	0.0001***
Income (groups 5 and 6)	0.66	0.57	0.53	0.47	1.274	1.486	0.0070	0.0003***
Espaces Info-Energie	0.25	0.18	0.16	0.13	1.308	1.526	0.0075	0.0003***
Energy-saving bulbs	0.75	0.68	0.57	0.49	1.273	2.175	0.0056	0.0016***
Renovation expenditures								
At current prices								
No confounder	0	0	0	0	-	-	0.246	0.047***
Neutral confounder	0.5	0.5	0.5	0.5	1.002	1.004	0.246	0.002***
Confounder like:								
Owner	0.98	0.97	0.97	0.95	2.113	1.796	0.243	0.004***
Energy expenditure (>50%)	0.49	0.48	0.38	0.36	1.138	1.642	0.241	0.008***
Income (groups 5 and 6)	0.72	0.64	0.58	0.54	1.178	1.761	0.240	0.009***
Espaces Info-Energie	0.26	0.24	0.15	0.19	0.746	1.640	0.253	0.007***
Energy-saving bulbs	0.74	0.74	0.54	0.57	0.892	2.317	0.254	0.013***
At constant prices								
No confounder	0	0	0	0	-	-	0.089	0.041**
Neutral confounder	0.5	0.5	0.5	0.5	1.002	0.992	0.089	0.002***
Confounder like:								
Owner	0.98	0.97	0.97	0.95	2.449	1.788	0.085	0.004***
Energy expenditure (>50%)	0.49	0.48	0.37	0.37	1.046	1.649	0.088	0.008***
Income (groups 5 and 6)	0.72	0.64	0.57	0.55	1.117	1.755	0.085	0.009***
Espaces Info-Energie	0.26	0.23	0.15	0.19	0.781	1.626	0.095	0.007***
Energy-saving bulbs	0.73	0.75	0.53	0.58	0.844	2.304	0.100	0.012***

Note 1: We use a kernel estimator to estimate the impact of the tax credit.
Note 2: ***significant at 1%; **significant at 5%; *significant at 10%.

3.6. Conclusion

In this paper, we evaluate the impact of the tax credit on renovation rate and renovation expenditures. We use French household-level databases on energy conservation from 2001 to 2008. The matching method is appropriate to study the impact of this measure, ceteris paribus.

The effectiveness of the tax credit is mixed. The measure has a significant and positive effect on renovation rate and renovation expenditures. However, the effect is low. The tax credit increases renovations by 0.86%, ceteris paribus, which is particularly low given the public cost of the measure. The impact on renovation expenditures is much higher, leading to a 24.65% increase of expenditures at current prices. However, it does not mean that a tax credit leads to more energy-efficient investments. Building professionals capture a part of earnings from the tax credit through price increases. Moreover, the results suggest the presence of free riding. The introduction of the tax credit does not seem to encourage renovation for households that are not prone to renovate in the first place (i.e., low-income households, tenants, and households living in an apartment).

It is important to rethink the way the tax credit is dispensed. First, free riding could be reduced by limiting access to the tax credit for households that would not renovate without the measure, for example, through an income ceiling. Second, it seems appropriate to increase the incentives to renovate for these same households, such as through an increase in the deduction rates. The current measure is not a sufficient incentive for these households.

3.7. Appendix

Table 3.9. Presentation of the tax credit

Beneficiaries of the tax credit	Conditions to receive the measure	Main equipment concerned	Deduction rate	Changes in the measure
-Owners and tenants (fiscally domiciled in France) -Main housing	-Energy-saving renovations -Renovation performed by a building professional	-Heating systems -Insulation materials -Renewable energies investment	From 10% to 50% depending on the kind of renovation	2006: increase of the deduction rate for some renovations 2009: decrease of the deduction rate

Figure 3.6. Distribution of propensity score—renovation rate

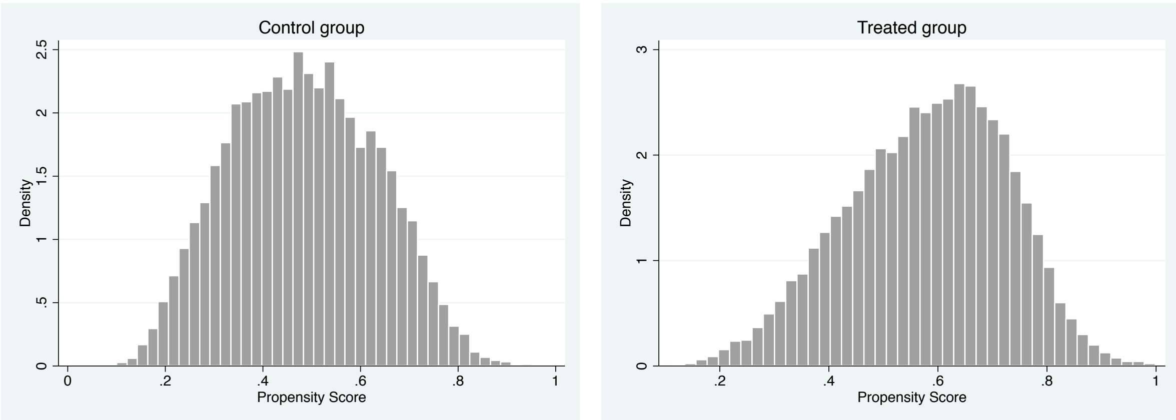


Figure 3.7. Distribution of propensity score—renovation expenditures

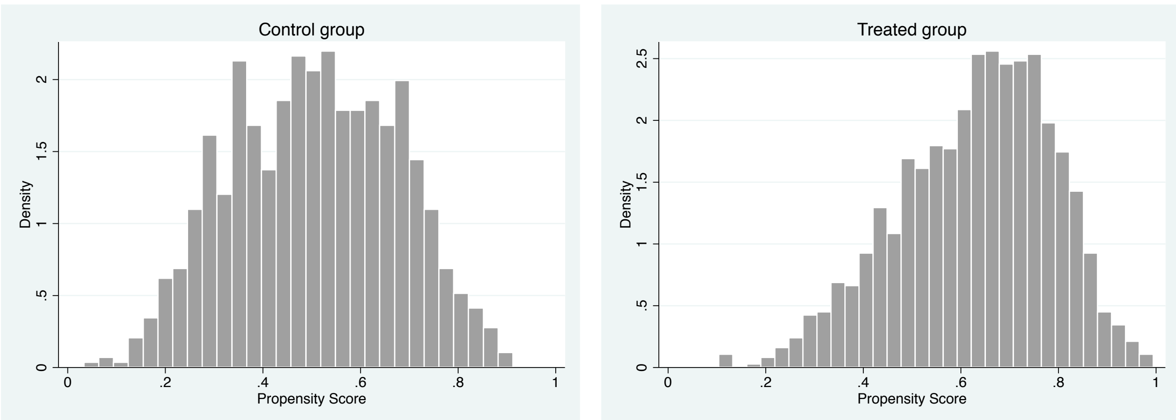


Figure 3.8. Comparison characteristics of the control group versus the treated group, before and after matching—renovate rate

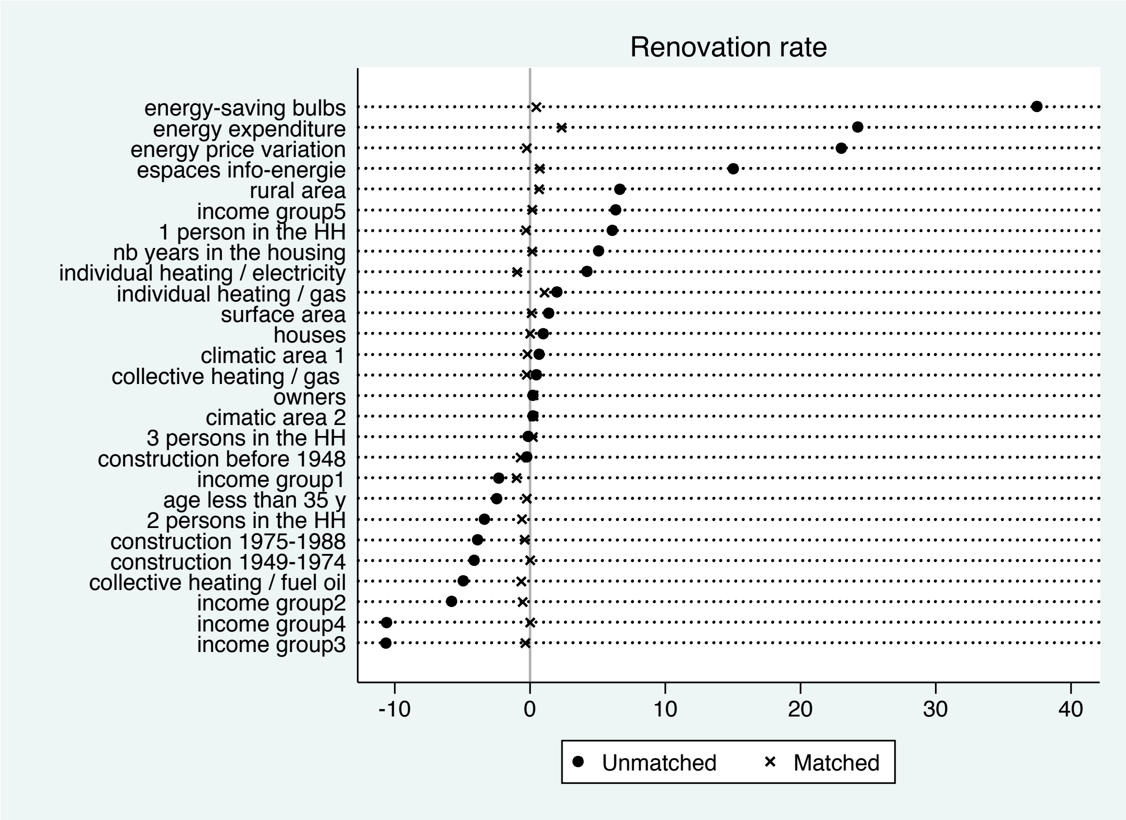
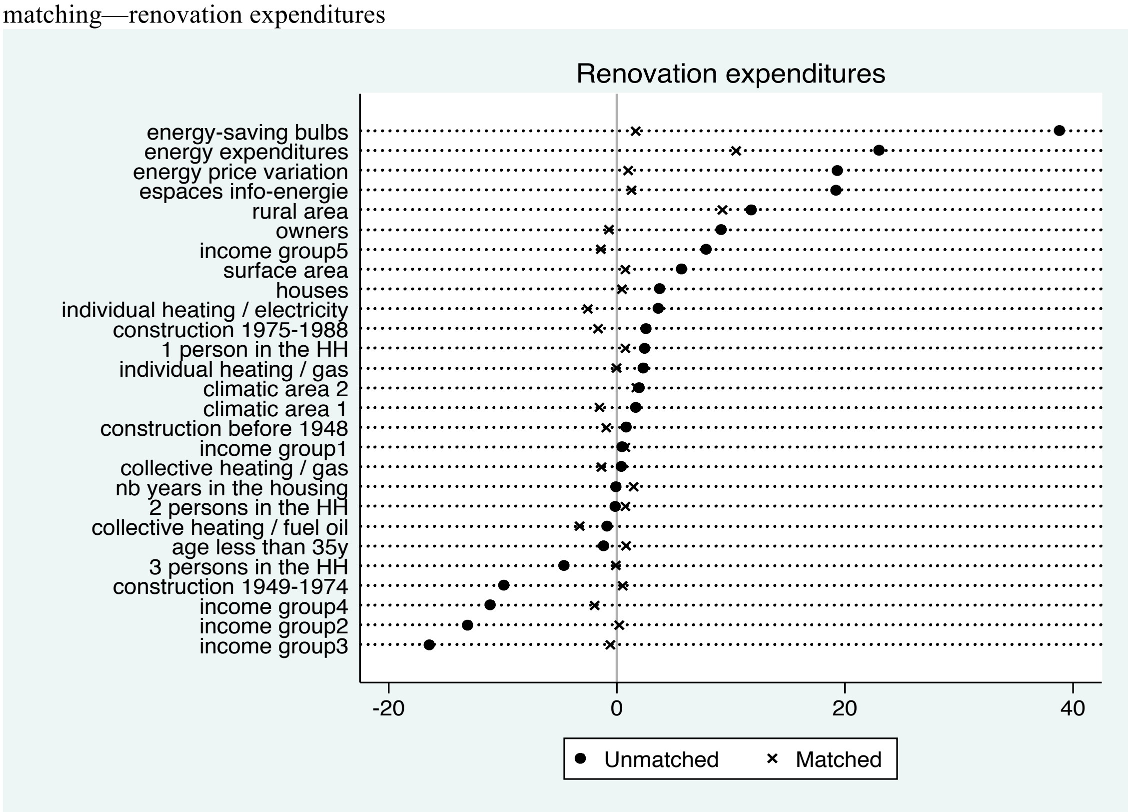


Figure 3.9. Comparison characteristics of the control group versus the treated group, before and after matching—renovation expenditures



Chapter 4.
Environmental degradations, fuel scarcity and women participation to labor market: Evidence from Rural India[21]

Summary

Environmental degradations can have adverse effects. Deforestation is for example responsible of 20% of global greenhouse gases emissions according to IPCC estimates and threatens biodiversity. However, literature on the impact of deforestation on individual is sparse. Our objective is to study how deforestation, increasing fuel scarcity, affects individuals. We focus on women, living in rural India. Using the 2004 Indian Human Development Survey, we show that fuel scarcity increases the probability for women to be involved in natural resource collection. Through this, it has a negative effect on the labor force participation, especially on family business and wage activities. We find that this effect is more pronounced for households living above poverty line. Indeed, the income constraint is lower for them.

[21] This paper has been written in collaboration with Ujjayant Chakravorty

4.1. Introduction:

In its last report, the UNDP suggests that income advancement in developing countries can be jeopardized by inaction on climate change or on habitat destruction. In this context, understanding how deforestation affects population seems important in order to determine if it may hinder economic growth. This has been little studied, literature generally focusing on the reverse relation, i.e. the impact of development on environmental degradation. We seek to identify channels by which deforestation could impact national income studying the link between environmental degradation, natural resources scarcity and women's access to labor market.

In the past ten years, the average annual net loss of forest has reached 5.2 million hectares (FAO, 2010). Deforestation is first responsible for 20% of global greenhouse gases emissions according to IPCC estimates and threatens biodiversity. Second, more than 1.6 billion people rely to varying degrees on forests for their livelihoods (FAO, 2010). Forest and environmental resources (mainly fuelwood) represent an important part of rural households' income (Cavendish, 2000; Kamanga et al. 2009). One cause of deforestation, beside the growth of the population and the natural resources overuse, is attributed to poverty. The Environmental Kuznets Curve postulates an inverted-U between per capita income and pressures on environment. Foremost, rising living standards increase environmental pressures (through the overuse of the resources) and later improve them. However empirical results vary: Koop and Tole (1999) using data for 76 developing countries between 1961 and 1992, or Nguyen Van et al. (2007) using data for 59 developing countries over 1972 and 1994 find little evidence for the existence of an environmental Kuznets curve for deforestation. Other studies find an inverted-U between per capita income and forest clearance principally in Latin America and Africa (Cropper et al., 1994; Godoy et al., 1997; Bhattarai et al., 2001).

Literature on the impact of deforestation on individuals is sparse. Deforestation can affect individuals through the decrease of fuelwood availability. When facing greater scarcity of environmental goods rural households reduce their consumption of the goods and spend more time in their collection (Cooke, 1998a). Indeed, rural households in developing countries typically rely heavily on self-collected environmental products such as fuelwood. Natural resource collection is predominantly a women activity (Kumar et al., 1988; Cooke, 1998a, 1998b; Bandyopadhyay et al., 2011) belonging to poorer as well as wealthier households. Baland et al. (2010) show that in rural Nepal poorer households collect significantly less firewood than wealthier households in the same village. This result contradicts the energy ladder model, which predicts that higher incomes induce households to switch away from traditional fuel. But it seems that households, living in rural area in particular, often have few feasible alternatives to the use of environmental products and to the use of fuelwood (Legros, 2009). Moreover, the relationship between income and fuel use is complex because social and cultural aspects are involved (Masera et al., 2000).

Our objective is to study whether deforestation and thus fuel scarcity, have an impact on labor supply through natural resource collection. A few papers examine the relationship between fuelwood collection and labor market and the link between collection and women's labor supply is not so clear. All these papers focus on Nepal because of the availability of data. Amacher et al. (1996) show that labor supply is related to the household's choice to collect or purchase fuelwood. In their study, Nepal's households living in tarai region and purchasing fuel are very responsive to an increase in fuelwood prices and labor opportunities. They can rapidly switch from purchasing fuelwood to using household time, originally dedicated for work, to replace purchased fuelwood with collected fuelwood. In contrast, collecting households do not react so quickly to a change in firewood price. Moreover, Kumar et al. (1988) show the negative impact of deforestation on women's farm labor input. A deterioration in the access to forest wood, measured by the time spent collecting fuel, leads to less time for productive agricultural activities for women, and this is not compensated by men's labor. However, authors do not take into account potential endogeneity of variables, therefore caution has to be taken in the interpretation of results. In contrast, Cooke (1998b) stresses that households allocate more time to collection activities when environmental products are more costly but finds no evidence that it leads women to spend less time farming.

In the same way as it has been done for fuelwood collection, some studies focus on the water collection and show its impact on women's activities. Ilahi and Grimard (2000) use simultaneous equations to model the choice of women living rural Pakistan between water collection, market-based activities and leisure. The distance to a water source has a positive impact on the rate of women involved in water collection and has a negative impact on the participation in income-generating activities, except for women with private water technology access who are more likely to spend time for leisure than on labor market. However, results diverge in other studies. Lokshin and Yemtsov (2005), using double differences method, show that rural water supply improvements in Georgia between 1998-2001 have a significant effect on health but not on labor supply. Also, Koolwal and Walle (2013), using across country analysis, find no evidence that improved access to water leads to greater off-farm work for women. Unlike fuel, water has no substitute and is likely to be inelastic. Therefore, households' behavior following scarcity of water or scarcity of natural resources (as fuelwood) can differ. However, these papers show that collection activities are not necessarily linked to labor market supply and can have an impact only on leisure.

Women are not the only members in the household involved in environmental goods collection (fuel and water). This is also the case for children, and children's school attendance is negatively affected by scarcity of natural resources and the increased hours of collection work that result (Ndiritu and Nyangena, 2010). To illustrate this, Nankhuni and Findeis (2004) stress that Children from the most environmentally degraded districts of central and southern Malawi are less likely to attend school.

Household can adapt to fuel scarcity adjusting fuelwood consumption, using substitutes or collecting fuelwood. Also, participation to collection of natural resources can have an impact on the participation to other activities, as leisure or labor supply. Our objective is to understand these links, focusing on the impact of environmental goods collection on labor market participation and on the role played by deforestation on individuals' choice. We focus on India. It is the tenth country in the world for its forest area with about 68 million hectares (FAO, 2010). Forest represents an important resource for people in India. 200 million peoples rely on forests for livelihood, according to Ministry of Environment and Forest. In term of fuel for example, 23 percent of population using fuelwood obtain wood from forest, and the total annual consumption of fuelwood for the country is estimated to be 216.42 million tons (Forest Survey of India report, 2011). However, an estimated 41% of India's forest cover has been degraded to some degree in the past decades. Pressure on India's forest comes from many sources, particularly the increase in the population from 390 million in 1950 to 1 billion in 2001 and the overutilization of resources. Forest is unevenly distributed in the territory: over a total of 35 states, only 6 states accounted for 50% of the forest area, whereas 8 other states accounted for less than 0.05% of the forest area. The national government is committed to conserving the forest and developing new forests. Under India's Constitution, national and state governments share jurisdiction for forestry. The national government and several states have established a network of more than 500 protected areas to preserve the country's biodiversity and natural habitats. The national forest policy sets the goal of bringing one-third of the country landmass under forest cover. This target is not reached today, but we can observe an increase in forest cover in several states these last years and the development of Joint Forest Management with the objective to develop a sustainable management of forest.

We go into details to understand which are the consequences of deforestation for women. More precisely, our objective is to study how fuelwood scarcity is involved in the relation between natural resource collection and the participation to labor market. Any measure to reduce deforestation in India has to be based on a clear understanding of household adaptation to fuelwood scarcity. We focus first on the impact of fuel scarcity on the decision to collect natural resources. We pay particular attention to the measure of fuel scarcity. It can indeed be endogenous and this issue is hardly addressed in the literature. Second, we focus on the impact of natural resource collection on labor market participation, distinguishing between the farm and wage-providing activities. Thus, we can observe the indirect impact of environment on labor market participation. We model environmental goods collection and working activity simultaneously. This allows taking into account the potential joint decision-making for the participation to both activities. We use the 2004 Indian Human Development Survey, which gives three-level information: households, individuals and village.

We obtain that environmental degradations increase the probability for women to be involved in natural resource collection. Through this, they have a negative effect on the labor force participation. We find that this effect is more pronounced for households living above the poverty line. Indeed, the income constraint is lower for them.

Section II presents the data and some statistics. Section III describes the empirical strategy and results are presented in section IV. Section V discuss the implication of results and conclude.

4.2. Data

We use the 2004-2005 Indian Human Development Survey to study the impact of deforestation on natural resource collection and labor market participation. This is a sectional and nationally representative database, which includes several levels of information: village, households and individuals. Households are interviewed in 2004 on their characteristics (household size, religion, land owned), on neighborhood (if there are conflicts in the village between people or if people get along) but also on individuals (age, education level, the working time in farm or other activities and the participation to natural resource collection). Information on poverty is available. A dichotomous variable indicates whether the household is below the poverty line. It is computed by comparing the monthly consumption per capita from the survey with the official poverty line.[22] At the village level information is provided on wages, fuel prices, isolation of the village (the distance from district headquarter, the access or not by road) and the number of people living in the village.

We use other database to complete this survey. The 2004 Indian National Service Scheme survey provides some district level information about the labor market characteristics (as the employment and unemployment rates). Moreover, information on forest cover is not available on the survey. We use 1999 and 2005 Forest Survey of India reports. Forest Survey of India reports provide regular and periodic assessment of forest cover over the country. They give us information on forest and deforestation by state and by district for almost every two years. In these both reports, the evaluation of forest cover is based on 1997 and 2004 satellite imageries, with a mapping carried out at a scale of 1:50000 and the GIS (Geographic Information System) technology is used to analyze the data. The administrative unit below the state is the district. This last one is the lowest level of disaggregation for which forest information is available. Our database, describes households living in 377 different districts. In 2004, a district registers in average 1,100 km^2 of forest cover in a total geographic area of 5,800 km^2.

We consider only women from 15 to 65 years old and living in rural area, the poorer regions. After dropping observations with missing values and taking into account only observations available in the all the databases, we have information on 18,738 women.

In 2004, forest cover in the country is estimated to be 20.6% of the total geographic area (Forest Survey of India, 2005). We note an important heterogeneity of forest cover between states and between districts (see map 4.1 in appendix). Even if the deforestation was important in the past decade (around 41% of forest cover has been degraded to some degree), the national forest policy of 1988 sets the goal of bringing one-third of the country landmass under forest cover. Recently, India has strengthened its commitment setting new objective: double the rate of restored forest cover by 2020, in order to sequester 6.35% of India's annual greenhouse gas emissions by 2020 or removing 43 million tons CO2e each year (source: Natural Resources Defense Council).

In our sample, a majority, or 53.3% of women participate to both activities: collect and labor market (table 4.1). 87.9% of women living in rural areas and aged from 15 to 65 years old are

[22] This poverty line is based on 1970s calculations of income needed to support minimal calorie consumption and has been adjusted by price indexes since then. It depends on the state and the area (urban and rural).

involved in natural resource collection, and a large part participates to labor market. As well, women in the labor market are often involved in several economic activities (work in farm and also in family business or wage activity). It is not common for women to participate to the labor market without being involved in environmental goods collection; it concerns only 5% of our sample.

Table 4.1. Repartition of the sample between both activities studied

	Labor force participation = 0	Labor force participation = 1	Total
Collect = 0	6.8%	5.3%	12.1%
Collect = 1	34.6%	53.3%	87.9%
Total	41.4%	58.6%	100%

Source: IHDS 2004 (final sample)

Almost one-fifth of the sample lives in district which have been deforested between 2002 and 2004. The participation to natural resource collection is higher in these districts. In district that lost forest cover, the percentage of women working in farm is higher than in other districts, but the percentage of women working in family business or wage activity is statistically lower (table 4.2).

The use of firewood is extremely widespread with more than 96.8% of the sample using this fuel. However, substitutes exist: almost 90% of the sample use also kerosene and 70% also electricity. We observe that only a very small share of the sample (less than 10%) purchases firewood. The remainder collects it from the household's own land or from its village.

Table 4.2. Comparison of women living in district with and without deforestation

	Districts with deforestation between 2002-2004	Districts without deforestation between 2002-2004	ttest
Participation to natural resource collection	95.2%	86.3%	***
Participation to labor market	60.9%	58.1%	***
Participation to farm activities	45.1%	39.1%	***
Participation to family business or wage activities	28.4%	32.5%	***
Poverty	27.7%	26.0%	**
Firewood use	96.5%	96.9%	ns
Firewood purchase	4.0%	10.5%	***

Source: 2004-2005 IHDS (final sample) and 2005 Forest Survey of India report
Note: *** difference significant at 1%, ns: difference non significant

In this database, several variables can be used to explain the participation to labor market and the decision to collect natural resources. First, household characteristics, as the size and composition of the household are expected to affect the decision process (Cooke, 1998b). The larger the number of persons in the household, the higher the consumption needs and this can generate an increase in the women's labor supply and in the natural resource collection needs as well. By contrast, the presence of adults' men in the family can be a substitute for women's labor. Moreover, the number of children is expected to have a negative effect on the participation of women to different activities because the children's care is generally women's responsibility. We also take into account information on religion. The objective is to capture cultural aspects that affect for example the choice of fuel (Masera et al., 2000). Finally we include a variable linked with poverty. Following an income increase, households may decide to hire to modern fuel and therefore reduce its demand and collection of fuelwood, according to the energy ladder theory. By contrast, fuel consumption increases with income and this income effect can lead to more the natural resource collection (Baland et al., 2010).

Second, variables on individual characteristics can also be taken into account to explain labor market participation and environmental goods collection: the age and the education. Education is expected to generate more labor supply. The labor force participation can be correlated to the aged because it can be a proxy for the professional experience.

Third, this database allows controlling for geographic and community effects (Koolwal and van de Walle, 2013). We take into account several variables to control for labor opportunities, as the number of households in the village, the accessibility (a dummy variable if the village is accessible by road, and the distance from the district headquarter) and the presence of public programs to promote employment schemes (as Food for Work). We also add information on conflicts between people in the village, and at the district-level, the unemployment rate and the percentage of people working in the primary sector (i.e. in agricultural and mining activities). We statistically observe that agriculture and mining activities are the most widespread.

4.3. Econometric specification

Our objective is to study whether deforestation and thus fuel scarcity, have an impact on labor supply through natural resource collection. We aim therefore at testing whether the decision to collect natural resources have an effect on labor market participation. The natural resources collection is potentially endogenous. We have to take into account this to avoid a bias in the estimation. To tackle this problem, we use a bivariate probit model (Greene, 1998) because the variable, which we suspect to be endogenous, as well as the explained variable are binary. We consider equations simultaneous model:

$$\begin{cases} y_{1i}^* = \beta_1 y_{2i} + \beta_2' X_1 + \varepsilon_i & \text{with } y_{1i} = 1 \text{ if } y_{1i}^* > 0 \text{ and } y_{1i} = 0 \text{ otherwise} \\ y_{2i}^* = \alpha_1' X_2 + \alpha_2 Z + \mu_i & \text{with } y_{2i} = 1 \text{ if } y_{2i}^* > 0 \text{ and } y_{2i} = 0 \text{ otherwise} \end{cases}$$

where:

- y_1 and y_2 represent respectively the probability of participating to the labor market and to the natural resource collection of individual i.
- X_1 and X_2 are vectors of exogeneous covariates that influence respectively y_1 and y_2. They encompass individual characteristics (age and education), household (poverty, religion, household size) and village district ones (unemployment rate).
- ε and μ are the error terms.

The correlation coefficient of error terms $\rho_{\varepsilon\mu}$ is different from zero if the participation to both activities is affected by the same unobserved characteristics. In other words, $\rho_{\varepsilon\mu} \neq 0$ would mean that there exists a significant link between the labor market equation and that of natural resource collection. In this case, the simultaneous model is appropriate and provides unbiased estimators. By contrast, if $\rho_{\varepsilon\mu} = 0$ means that the two equations are independent and can be estimated separately.

To be identified, the model requires that at least one instrumental variable according to Maddala (1983). This condition is discussed in the literature. However, it is a common practice to impose exclusion restrictions to improve identification (Jones, 2007). We include a variable Z that (i) explains the participation to natural resource collection, and (ii) does not explain the participation to labor market. A good instrument would be the wood scarcity, but it cannot easily observable. We use some proxies, discussed in literature.

Cooke (1998a) studies the impact of fuel scarcity on the time spent in collection activities and uses a shadow price for fuelwood as a relative economic cost of environmental products to a household. The shadow price is calculated by multiplying (i) the time needed for a household to collect 10 kg of fuelwood with (ii) the women's wage rate. The author finds that this variable is endogenous. In this case and without correction the results are biased. Amacher et al. use the forest area in the district to explain the supply of collected fuelwood. However, they do not take into account the potential endogeneity of forest cover. Therefore, we choose two proxies for fuel scarcity. First, we take the forest cover in the district (in km^2) in 1997, i.e. with a 7 years delayed compared with the year of the survey. The forest cover is an indicator of the resources stock and lagged variable is commonly used in the literature to tackle endogeneity issue. Second, firewood price is considered in the literature as an important variable in the decision to collect or purchase the wood (Amacher et al., 1996). The consumer market price of firewood in the village (in rupees by kg) can be another proxy for fuel scarcity. As expected the market price is higher in districts that have few forest cover and a higher pressure on the environment (table 4.3). This variable is exogenous if individuals do not have market power. Given the large size of the villages (73% of villages in the sample have more than 1,000 inhabitants) it does not seem to be a strong assumption.

Table 4.3. Fuelwood price and fuel scarcity

Districts where:	Fuelwood price (Rs / 10 kg)	ttest	Number of observations
Forest cover < 100 km^2	22.08	***	6647
Forest cover > 100 km^2 and < 500 km^2	16.92	*	6245
Forest cover > 500 km^2 and < 1500 km^2	15.72	***	5606
Forest cover > 1500 km^2	1.51	***	7611
Forest cover changes negatively between 2002 and 2004	19.61	***	5074
Forest cover does not change between 2002 and 2004	16.98	***	15598
Forest cover changes positively between 2002 and 2004	16.73	**	5437
Forest cover represents less than 5% of geographical area	27.59	***	1926
Forest cover represents more than 5% of geographical area	16.63	***	24183

Source: 2004-2005 IHDS (final sample) and 2005 Forest Survey of India report

We estimate the impact of fuel scarcity on the probability to be involved in the natural resources collection, considering these two proxies. Moreover, lagged forest cover and firewood price can legitimately be excluded from the labor market equation.

4.4. Results

Table 4.4a and 4.4b present the results and the marginal effects (marginal effects computations as well as the estimated coefficients are presented in appendix). Results concern women aged from 15 to 65 years who live in rural areas. We estimate the labor market participation and the natural resource collection on the full sample. We then estimate the impact of natural resource collection on different economic activities separately: farm activity on the one hand and family business or other activities on the other hand. As poverty has a significant impact on the women decision to participate to both activities, we study the poverty constraint by estimating the model for households below and for those above the poverty line separately.

Let us first focus on the full sample estimation (model 1a and model 1b). ρ is different from zero, that means that the errors terms from both equations y_1 and y_2 are significantly correlated. Both equations are interdependent. The bivariate probit is then the appropriate model to avoid the bias. Moreover $\rho > 0$ and this implies that unobserved characteristics affect the probabilities of participating to natural resource collection and to labor market in the same direction. For the model identification, we introduce an instrument in the natural resource collection equation. The instrument is first the lagged forest cover and second, the firewood price. These variables have a significant and positive effect on the participation to natural resource collection. Results are similar regardless the measure of fuel scarcity we use. This ensures the robustness of results. We show that fuelwood price has a positive impact on the probability to be involved in collection activities and lagged forest cover has a negative effect. This means that the scarcer the environmental resources, the higher the probability to collect to natural resource. People exploit more quickly the resources when the scarcity increases. This confirms the results of Cooke (1998a). Therefore, deforestation has a positive impact on the decision to collect fuel, ceteris paribus. The involvement in natural resource collection reduces the women's available time, and that in turn decreases the participation to labor market. Indeed, we obtain that the impact of the participation to natural resource collection on labor market supply is significant and negative. Collection decreases the probability of participating to labor market in the range of 0.26 (model 1a) and 0.19 (model 1b) percentage points. Environmental degradations are a barrier to the access of women to the labor market.

The impact of lagged forest cover (i.e. the instrument) is insignificant in the model 2a in which we focus on farm activities. It is not a good instrument in this case because agricultural activities are by nature related to forest cover. Indeed, the expansion of agricultural land is one of the main causes of deforestation. Results from this estimation should be therefore interpreted with caution because of the non-validity of the instrument.

However, estimation using fuelwood price as proxy confirms that fuel scarcity has no indirect effect on farm labor participation (model 2b). In this regression ρ is different from zero. The choices to participate to farm activities or to natural resource collection are not related. This suggests that natural resource collection has no impact on the decision to participate to farm activity. With a different methodology, estimating a cross-sectional equation for household agricultural labor using a two stage least squares approach, Cooke (1998b) finds a similar result. The participation to natural resource collection has a significant and negative impact only on the participation to family business and to wage activities.

Moreover, results show that natural resource collection and labor market participation are not interdependent for households living below the poverty line (model 4a and model 4b): ρ is also not significant. What happens is that when the income constraint is too strong, the labor supply is independent from the participation to natural resource collection. This result is confirmed by other estimations. For instance, the probability for women to both work and collect fuel increases if the household is poor. The effect of natural resource collection on labor supply is significant only for women living above the poverty line. Moreover, for poor households, the larger forest area or the higher fuelwood price, the higher the probability to collect fuel. This is the only estimation showing a positive effect of lagged forest cover.

Variables other than environmental degradations play a role in the choice of participating to the different activities. Concerning women's characteristics, the age has a positive impact on the participation to economic activities. Results reveal a specificity of India concerning the effect of education. The higher the number of school years, the lower is the probability to participate to both labor market and to natural resource collection. Several studies find a negative effect of education on labor supply in India (see for example Bordia Das and Desai, 2003). Authors explain it with cultural and structural factors. The first one indicates that women who come from families with a higher social status tend to be more educated. However, women's withdrawal from labor force would be associated with improvements in the social status of the family. Structural factors refer to the lack of appropriate employment opportunities.

We obtain that household characteristics have significant effect on the decision process. The presence of young children tends to increase the labor supply of women in farm activities. By contrast it decreases the participation to family business and wage activities. The presence of children can indeed have two opposite effects. On the one hand, children require time for care and thus reduces the time available for other activities. On the other hand, they increase consumption needs. The number of adults in the households decreases the probability to work or to collect fuel. The effect is even more pronounced with the presence of men adults. Moreover, the effect of religion is significant. It stresses the presence of cultural factors in the women's choice to participate to labor market or to collect fuel. This is in the line of literature: Cultural factors play a role in the decision of using traditional or modern fuel (Masera et al., 2000) and in the female labor force participation (Whitehead, 2011).

Job opportunities in the village have a significant impact. The employment program in the village increases the probability to participate to labor force but also on natural resource collection. By contrast, unemployment rate and the fact that the village is accessible by road have a negative effect on the probability to participate to labor market. This means that women are sensitive to labor opportunities in their village, but not outside the village.

Table 4.4a. Results with lagged forest area proxy - coefficient estimates

	Full sample (model 1a)		Full sample (model 2a)		Full sample (model 3a)		Poor households (model 4a)		Non poor households (model 1a)	
	Labor market participation	Natural resource collection	Farm activity	Natural resource collection	Family business and other activity	Natural resource collection	Labor market participation	Natural resource collection	Labor market participation	Natural resource collection
Fuel collection	-0.2624***	-	0.3058***	-	-0.2986***	-	0.0832	-	-0.3306***	-
	(0.242)		(0.237)		(0.170)		(0.482)		(0.0845)	
Lagged forest area (in log)	-	-0.0059***	-	-0.0019	-	-0.0059***	-	0.0044*	-	-0.0098***
		(0.0102)		(0.00880)		(0.0102)		(0.0214)		(0.00829)
Individual characteristics										
Age of the individual	0.0478***	0.0005	0.0356***	-0.0002	0.0325***	0.00002	0.0503***	0.0016	0.0465***	0.0001
	(0.00641)	(0.00446)	(0.00429)	(0.00422)	(0.00448)	(0.00418)	(0.00843)	(0.00966)	(0.00514)	(0.00471)
Age^2	-0.0006***	-0.00002	-0.0004***	-7.41e-06	-0.0005***	-9.98e-06	-0.0007***	-0.00002	-0.0006***	-0.00001
	(8.04e-05)	(5.57e-05)	(5.58e-05)	(5.35e-05)	(5.88e-05)	(5.29e-05)	(0.000107)	(0.000119)	(6.50e-05)	(5.96e-05)
Never attended school	ref		ref		ref		ref		ref	
School between 1-5 years	-0.0489***	-0.0121	0.0149	-0.0184**	-0.0657***	-0.0138*	0.0343	0.0064	-0.0547***	-0.0172*
	(0.0296)	(0.0396)	(0.0295)	(0.0395)	(0.0313)	(0.0392)	(0.0613)	(0.0951)	(0.0336)	(0.0432)
School between 6-10 years	-0.1194***	-0.0240***	-0.0019	-0.0329***	-0.1473***	-0.0277***	-0.0535***	-0.0026	-0.1175***	-0.0314***
	(0.0291)	(0.0406)	(0.0305)	(0.0406)	(0.0321)	(0.0398)	(0.0657)	(0.114)	(0.0320)	(0.0421)
School between 11-15 years	-0.2283***	-0.0884***	-0.0800***	-0.0983***	-0.1799***	-0.0941***	-0.0694**	-0.0227	-0.2347***	-0.1091***
	(0.0491)	(0.0610)	(0.0627)	(0.0621)	(0.0585)	(0.0610)	(0.186)	(0.255)	(0.0510)	(0.0627)
Household characteristics										
Nb of children aged 0-7	0.0018	0.0008	0.0187***	0.0012	-0.0199***	0.0004	0.0054	0.0052	-0.0001	-0.0017
	(0.0110)	(0.0194)	(0.0109)	(0.0203)	(0.0122)	(0.0197)	(0.0181)	(0.0310)	(0.0144)	(0.0225)
Nb of children aged 8-21	-0.0026	0.0001	0.0033	0.0005	-0.0111***	0.0001	-0.0073*	0.0050	-0.0006	-0.0013
	(0.00837)	(0.0159)	(0.00794)	(0.0163)	(0.00916)	(0.0160)	(0.0155)	(0.0268)	(0.0103)	(0.0170)
Nb of men aged 21-65	-0.0400***	-0.0093**	-0.0044	-0.0091**	-0.0560***	-0.0084*	-0.0271***	-0.0047	-0.0428***	-0.0128**
	(0.0152)	(0.0239)	(0.0157)	(0.0245)	(0.0173)	(0.0245)	(0.0307)	(0.0568)	(0.0174)	(0.0261)
Nb of women aged 21-65	-0.0216***	-0.0050	-0.0042	-0.0060	-0.0333***	-0.0052	-0.0562***	-0.0029	-0.0107	-0.0035
	(0.0193)	(0.0311)	(0.0193)	(0.0317)	(0.0207)	(0.0315)	(0.0366)	(0.0771)	(0.0226)	(0.0344)
Hindu	ref		ref		ref		ref		ref	
Muslim	-0.1511***	-0.0357***	-0.1163***	-0.0367***	-0.0956***	-0.0363***	-0.0594***	-0.0521**	-0.1425***	-0.0207
	(0.0456)	(0.0683)	(0.0528)	(0.0688)	(0.0511)	(0.0686)	(0.0991)	(0.140)	(0.0517)	(0.0747)
Other religion	-0.0661***	-0.0485**	-0.1031***	-0.0459**	0.0654	-0.0472**	0.0798	-0.0398	-0.0852***	-0.0626**
	(0.0720)	(0.103)	(0.0821)	(0.105)	(0.0728)	(0.104)	(0.159)	(0.281)	(0.0798)	(0.110)
Poor (=1 if HH is above poverty line)	0.0273**	0.0550***	-0.0734***	0.0553***	0.1389***	0.0574***	-	-	-	-
	(0.0331)	(0.0519)	(0.0311)	(0.0519)	(0.0295)	(0.0513)				

Village										
Nb pers in the village:										
1000 inhbts or less	ref		ref		ref		ref		ref	
1001 - 5000 inhbts	0.3111 ***	-0.0365	0.2448***	-0.0054	0.0157	-0.0439	0.2278	-0.0288	0.2829***	-0.0332
	(0.247)	(0.378)	(0.246)	(0.372)	(0.248)	(0.367)	(0.480)	(1.026)	(0.280)	(0.433)
More than 5000 inhbts	0.2157***	0.1190**	-0.0415	0.1287***	-0.1798***	0.1108**	0.0935	0.0961**	0.2456***	0.1495**
	(0.262)	(0.401)	(0.281)	(0.404)	(0.267)	(0.402)	(0.523)	(1.242)	(0.297)	(0.452)
Employment program in the village	0.0728***	0.0530***	0.0309**	0.0469***	0.0409***	0.0512***	0.1459**	0.0283	0.0709***	0.0612***
	(0.0382)	(0.0536)	(0.0405)	(0.0546)	(0.0384)	(0.0539)	(0.0833)	(0.139)	(0.0420)	(0.0576)
Accessibility by road	-0.0939***	-0.0230	-0.0630***	-0.0256*	-0.0418***	-0.0202	-0.0003**	-0.0039	-0.1039***	-0.0299
	(0.0551)	(0.0918)	(0.0552)	(0.0926)	(0.0539)	(0.0938)	(0.0987)	(0.182)	(0.0673)	(0.104)
Distance to HQ (in log)	0.0225***	0.0025	0.0249***	-0.0028	0.0202***	0.0015	0.0403***	0.0056	0.0171**	0.0013
	(0.0169)	(0.0269)	(0.0172)	(0.0280)	(0.0172)	(0.0265)	(0.0342)	(0.0703)	(0.0190)	(0.0284)
Conflict	-0.0230***	-0.0151**	0.0003	-0.0123*	-0.0190***	-0.0149**	-0.0554	-0.0036	-0.0296***	-0.0211**
	(0.0233)	(0.0363)	(0.0240)	(0.0369)	(0.0241)	(0.0367)	(0.0474)	(0.0844)	(0.0269)	(0.0398)
Daily women unskilled wage rate (in log)	0.0925***	0.0559***	0.1107***	0.0572***	-0.0940***	0.0509***	0.0687**	-0.0011	0.0775 ***	0.0782***
	(0.0490)	(0.0778)	(0.0537)	(0.0761)	(0.0505)	(0.0746)	(0.0943)	(0.208)	(0.0563)	(0.0910)
Wage x 1001 - 5000 inhbts in the village	-0.1291***	-0.0099	-0.1145***	-0.0173	-0.0035	-0.0076	-0.0683*	0.0063	-0.1282***	-0.0190
	(0.0655)	(0.101)	(0.0660)	(0.0990)	(0.0665)	(0.0977)	(0.133)	(0.280)	(0.0734)	(0.114)
Wage x more than 5000 inhbts in the village	-0.0979***	-0.0815***	-0.0879**	-0.0878***	0.0801***	-0.0766***	-0.0258	-0.0859**	-0.1048***	-0.1032***
	(0.0688)	(0.104)	(0.0781)	(0.104)	(0.0700)	(0.104)	(0.142)	(0.322)	(0.0760)	(0.116)
Unemployment rate in the district	-0.0059***	-0.0011	-0.0007	-0.0012	-0.0083***	-0.0010	-0.0111***	-0.0033*	-0.0027	0.0018
	(0.0062)	(0.0091)	(0.0063)	(0.0097)	(0.0065)	(0.0095)	(0.0139)	(0.0157)	(0.0074)	(0.0107)
% of people working in agricultural and mining activities	0.0052***	0.0007**	0.0033***	0.0005	0.0055***	0.0008**	0.0062***	0.0002	0.0047***	0.0007*
	(0.0011)	(0.0018)	(0.0011)	(0.0017)	(0.0011)	(0.0018)	(0.0020)	(0.0038)	(0.0013)	(0.0019)
Observations	18,738		18,738		18,738		4,924		13,814	
Log pseudolikelihood	-17206.13		-17902.965		-16110.931		-3754.8686		-13329.578	

Note: Robust standard errors in parentheses. Standard errors in all estimated regressions are corrected for heteroscedasticity and clustering at the households level. Several women belong to the same household and clustering allows correcting for possible bias attributed to household size. *** significant at 1%, ** significant at 5%, *significant at 10%. Marginal Effects are estimated using Greene (1998) and Baslevent and El-Hamidi (2009) formulas.

Table 4.4b. Results with firewood price area proxy - coefficient estimates

	Full sample (model 1b)		Full sample (model 2b)		Full sample (model 3b)		Poor households (model 4b)		Non poor households (model 1b)	
	Labor market participation	Natural resource collection	Farm activity	Natural resource collection	Family business and other activity	Natural resource collection	Labor market participation	Natural resource collection	Labor market participation	Natural resource collection
Fuel collection	-0.1898***	-	0.0635	-	-0.1623***	-	-0.1707	-	-0.2652***	-
	(0.219)		(0.636)		(0.174)		(0.501)		(0.185)	
Firewood price (in log)	-	0.0490***	-	0.0433***	-	0.0440***	-	0.0208*	-	0.0587***
		(0.0472)		(0.0614)		(0.0477)		(0.103)		(0.0498)
Individual characteristics										
Age of the individual	0.0478***	0.00001	0.0356***	-0.0003	0.0325***	-0.0003	0.0494***	0.0018	0.0467***	-0.0006
	(0.00511)	(0.00428)	(0.00395)	(0.00422)	(0.00442)	(0.00419)	(0.00894)	(0.00981)	(0.00614)	(0.00476)
Age^2	-0.0006***	0.00001	-0.0004***	-6.44e-06	-0.0005***	-6.88e-06	-0.0007***	-0.00002	-0.0006***	-6.67e-06
	(6.44e-05)	(5.39e-05)	(4.97e-05)	(5.33e-05)	(5.80e-05)	(5.31e-05)	(0.000115)	(0.000120)	(7.66e-05)	(6.02e-05)
Never attended school	ref		ref		ref		ref		ref	
School between 1-5 years	-0.0487 ***	-0.0146*	0.0773	-0.0165**	-0.0657***	-0.0162**	0.0672	0.0081	-0.0549***	-0.0221**
	(0.0299)	(0.0395)	(0.0316)	(0.0408)	(0.0317)	(0.0392)	(0.0611)	(0.0937)	(0.0342)	(0.0437)
School between 6-10 years	-0.1208***	-0.0287***	-0.0534	-0.0311***	-0.1487***	-0.0313***	-0.0193***	0.0012	-0.1201***	-0.0393***
	(0.0293)	(0.0401)	(0.0349)	(0.0431)	(0.0324)	(0.0399)	(0.0665)	(0.113)	(0.0325)	(0.0429)
School between 11-15 years	-0.2290***	-0.0933***	-0.0477***	-0.0949***	-0.1775***	-0.0971***	-0.0386**	-0.0197	-0.2389***	-0.1171***
	(0.0502)	(0.0613)	(0.0765)	(0.0654)	(0.0605)	(0.0617)	(0.178)	(0.260)	(0.0520)	(0.0639)
Household characteristics										
Nb of children aged 0-7	0.0014	0.0020	0.0186***	0.0017	-0.0200***	0.0017	0.0052	0.0046	-0.0011	0.0005
	(0.0109)	(0.0194)	(0.0110)	(0.0196)	(0.0122)	(0.0196)	(0.0178)	(0.0309)	(0.0141)	(0.0229)
Nb of children aged 8-21	-0.0028	0.0011	0.0034	0.0011	-0.0112***	0.0011	-0.0071	0.0042	-0.0010	0.0001
	(0.00824)	(0.0157)	(0.00821)	(0.0158)	(0.00914)	(0.0158)	(0.0155)	(0.0267)	(0.01000)	(0.0175)
Nb of men aged 21-65	-0.0401***	-0.0089**	-0.0044	-0.0086*	-0.0558***	-0.0083*	-0.0267***	-0.0028	-0.0434***	-0.0117**
	(0.0150)	(0.0243)	(0.0166)	(0.0245)	(0.0174)	(0.0247)	(0.0300)	(0.0579)	(0.0173)	(0.0268)
Nb of women aged 21-65	-0.0212***	-0.0060	-0.0044	-0.0062	-0.0330***	-0.0062	-0.0551***	-0.0047	-0.0095	-0.0055
	(0.0191)	(0.0313)	(0.0198)	(0.0318)	(0.0208)	(0.0316)	(0.0364)	(0.0759)	(0.0223)	(0.0352)
Hindu	ref		ref		ref		ref		ref	
Muslim	-0.1539***	-0.0425**	-0.0625***	-0.0417***	-0.0958***	-0.0422***	-0.0265***	-0.0556***	-0.1493***	-0.0308*
	(0.0452)	(0.0681)	(0.0531)	(0.0687)	(0.0519)	(0.0685)	(0.0949)	(0.137)	(0.0524)	(0.0751)
Other religion	-0.0626***	-0.0476**	-0.0563***	-0.0462**	0.0265	-0.0468**	0.1094	-0.0285	-0.0833***	-0.0621**
	(0.0706)	(0.103)	(0.0865)	(0.104)	(0.0728)	(0.104)	(0.172)	(0.279)	(0.0783)	(0.109)
Poor (=1 if HH is above poverty line)	0.0213**	0.0536***	0.0250***	0.0547***	0.1367***	0.0551***	-	-	-	-
	(0.0317)	(0.0518)	(0.0446)	(0.0515)	(0.0299)	(0.0513)				

Village										
Nb pers in the village:										
1000 inhbts or less	ref		ref		ref		ref		ref	
1001 - 5000 inhbts	0.3269***	-0.0321	0.2826***	-0.0232	0.0246	-0.0340	0.2450	-0.0512	0.3099 ***	-0.0282
	(0.244)	(0.380)	(0.247)	(0.384)	(0.252)	(0.374)	(0.481)	(0.980)	(0.287)	(0.435)
More than 5000 inhbts	0.2064***	0.1255***	0.1326	0.1271***	-0.1978***	0.1220**	0.1658	0.0873*	0.2418***	0.1584 ***
	(0.264)	(0.408)	(0.317)	(0.418)	(0.272)	(0.410)	(0.527)	(1.160)	(0.302)	(0.456)
Employment program in the village	0.0709***	0.0500***	0.1340***	0.0497***	0.0384***	0.0489***	0.2030***	0.0390**	0.0698***	0.0536***
	(0.0385)	(0.0533)	(0.0454)	(0.0542)	(0.0387)	(0.0539)	(0.0840)	(0.137)	(0.0426)	(0.0577)
Accessibility by road	-0.0944***	-0.0211	-0.0067***	-0.0237	-0.0400**	-0.0208	-0.0284**	-0.0041	-0.1053***	-0.0282
	(0.0557)	(0.0929)	(0.0564)	(0.0940)	(0.0550)	(0.0945)	(0.0966)	(0.181)	(0.0680)	(0.107)
Distance to HQ (in log)	0.0232***	0.0012	0.0255***	0.0001	0.0208***	0.0003	0.0393***	0.0085	0.0186***	-0.0012
	(0.0169)	(0.0261)	(0.0174)	(0.0293)	(0.0174)	(0.0261)	(0.0337)	(0.0673)	(0.0192)	(0.0284)
Conflict	-0.0227***	-0.0108	0.0629	-0.0109	-0.0184***	-0.0107	-0.0845	-0.0058	-0.0301***	-0.0131
	(0.0233)	(0.0362)	(0.0251)	(0.0365)	(0.0243)	(0.0365)	(0.0469)	(0.0828)	(0.0269)	(0.0401)
Daily women unskilled wage rate (in log)	0.0931***	0.0564***	0.1088***	0.0559***	-0.0927***	0.0538***	0.0671**	-0.0034	0.0809***	0.0778***
	(0.0498)	(0.0788)	(0.0589)	(0.0790)	(0.0518)	(0.0770)	(0.0947)	(0.201)	(0.0579)	(0.0921)
Wage x 1001 - 5000 inhbts in the village	-0.1297***	-0.0109	-0.1110***	-0.0132	-0.0048	-0.0101	-0.0684	0.0115	-0.1313***	-0.0196
	(0.0650)	(0.102)	(0.0656)	(0.102)	(0.0676)	(0.0999)	(0.133)	(0.269)	(0.0751)	(0.114)
Wage x more than 5000 inhbts in the village	-0.0968***	-0.0862***	-0.0937***	-0.0876***	0.0811***	-0.0839***	-0.0245	-0.0733**	-0.1057***	-0.1085***
	(0.0698)	(0.106)	(0.0944)	(0.108)	(0.0717)	(0.106)	(0.141)	(0.302)	(0.0780)	(0.117)
Unemployment rate in the district (in unit)	-0.0060***	-0.0010	-0.0009	-0.0010	-0.0083 ***	-0.0010	-0.0115***	-0.0034*	-0.0025	0.0016
	(0.0062)	(0.0093)	(0.0065)	(0.0097)	(0.0065)	(0.0096)	(1.365)	(1.537)	(0.731)	(1.113)
% of people working in agricultural and mining activities (in unit)	0.0052***	0.0007**	0.0033***	0.0006*	0.0055***	0.0007**	0.0062***	0.0006	0.0047***	0.0007*
	(0.0011)	(0.0017)	(0.0011)	(0.0017)	(0.0011)	(0.0018)	(0.0021)	(0.0035)	(0.0013)	(0.0019)
Observations	18,738		18,738		18,738		4,924		13,814	
Log pseudolikelihood	-17182.805		-17883.883		-16094.995		-3755.0623		-13324.01	

Note: Robust standard errors in parentheses. Standard errors in all estimated regressions are corrected for heteroscedasticity and clustering at the households level. Several women belong to the same household and clustering allows correcting for possible bias attributed to household size. *** significant at 1%, ** significant at 5%, *significant at 10%. Marginal Effects are estimated using Greene (1998) and Baslevent and El-Hamidi (2009) formulas.

4.5. Conclusion

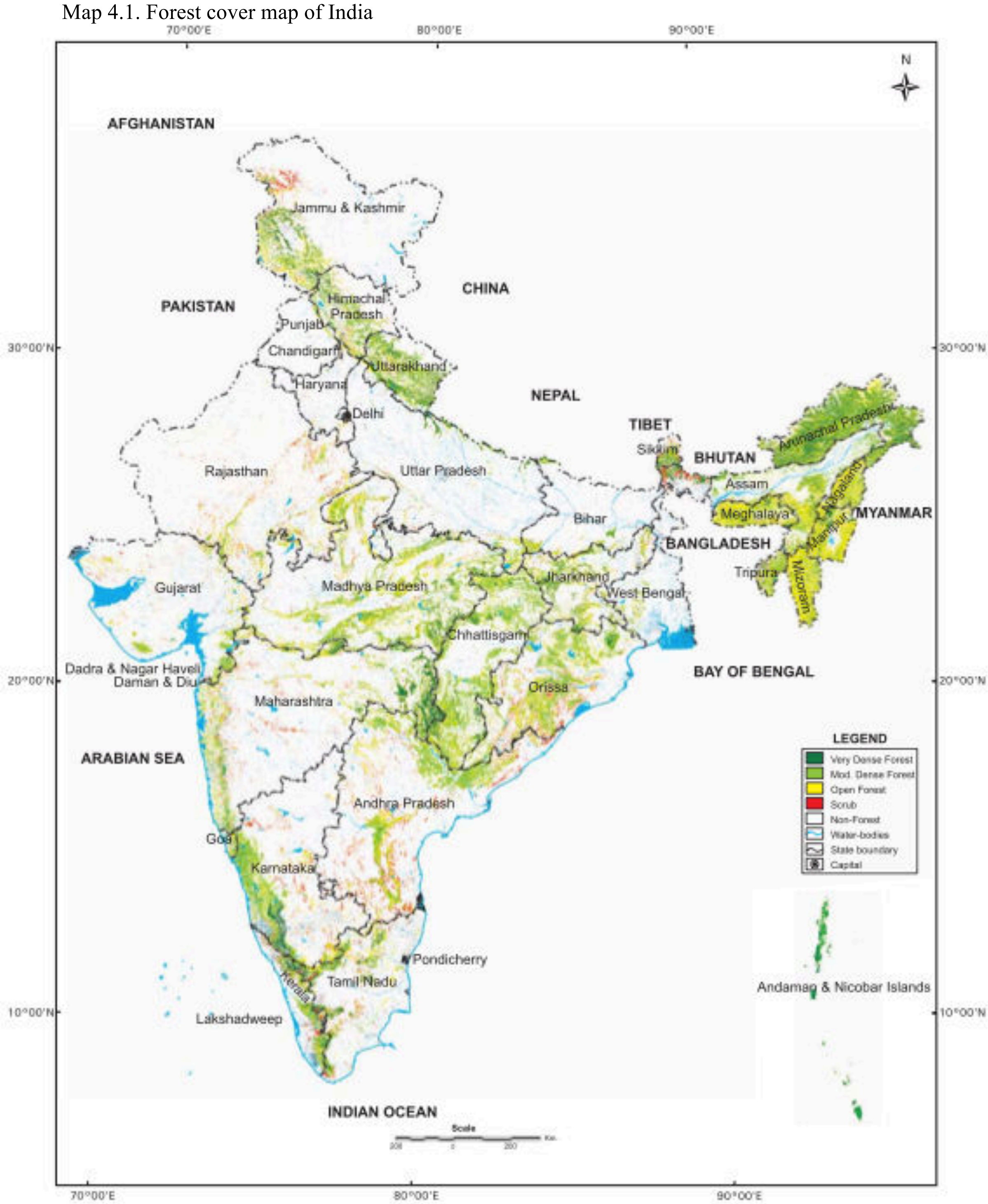
Our objectives are to understand first the relationship between natural resource collection and labor market participation, and second the role of fuel scarcity on the decision process. We focus on women aged from 15 to 65 years old who live in rural India. Forest represents an important resource for people in India especially in terms of fuel. Deforestation increases fuel scarcity has therefore an impact on people. We use two measures of fuel scarcity: lagged forest cover and firewood price. We show with a bivariate probit that fuel scarcity increases the probability that women are involved in natural resource collection. Through natural resource collection, environmental degradations are a barrier for women to access the labor market. Indeed, it decreases the probability to participate to wage activity or to family business. By contrast, there is no evidence that it has an impact on agricultural activities. We also note that households living above poverty lines are more sensitive to fuel scarcity. Indeed, Households living below the poverty line are constrained by their income. In their case fuel collection has no effect on women's choice to participate to labor market and lagged forest cover has a positive effect on the probability to collect wood.

We can conclude that environmental degradations have adverse effects on people. Our results are in the line of the UNDP observations: even developing countries must engage in the protection of environment. It would be interesting to continue this project studying the impact of fuel scarcity on children school attendance.

4.6. Appendix

4.6.1. Forest cover in India

Map 4.1. Forest cover map of India



Source: 2005 State of Forest Report

4.6.2. Marginal effects

Despite the issue of endogeneity of y_2 in the equation of y_1, the terms that enter the likelihood function for the recursive bivariate probit model are the same as those for the usual bivariate probit (Maddala, 1983). The probabilities for the model are given by:

$$\Pr(y_1 = 1, y_2 = 1) = \Phi_2(B_1 + B_2'X_1, \alpha_1'X_2, \rho),$$
$$\Pr(y_1 = 0, y_2 = 1) = \Phi_2(-B_1 - B_2'X_1, \alpha_1'X_2, -\rho),$$
$$\Pr(y_1 = 1, y_2 = 0) = \Phi_2(B_2'X_1, -\alpha_1'X_2, -\rho),$$
$$\Pr(y_1 = 0, y_2 = 0) = \Phi_2(-B_2'X_1, -\alpha_1'X_2, \rho).$$

where Φ_2 is the bivariate normal cumulative distribution function. We cannot interpret results on the basis of coefficient estimates. The vector of explanatory variables *X* appearing in the natural resource collection equation has an indirect effect (through the endogenous dummy y_2) on labor market participation, as well as a direct effect since they also appear in y_1 equation. Therefore, we compute the marginal effects at the sample means of variables, which provide the change in the probability following one unit increase in the explanatory variable. Greene (1998) proposes the definitions and formulas to calculate them in the case of $\rho = 0$, showing that the marginal effect of an explanatory variable is the sum of a direct and/or indirect effect depending on which equation(s) the variable is included in. In our case, the decisions to participate to the labor market and to collect natural resource are potentially interdependent. Therefore we can expect that ρ is different from zero, and computation of marginal effects may differ. Baslevent and El-Hamidi (2009) adapt formulas to obtain correct marginal effects.

In the case of $\rho \neq 0$, the marginal effect of a continuous explanatory variable *x* (representing for example the age of individuals), is given by:

$$\frac{\partial E(y_1|X_1, X_2, y_2)}{\partial x} = \left[\phi(\beta_1 + \beta_2'X_1)\Phi\frac{(\alpha_1'X_2 - \rho(\beta_1 + \beta_2'X_1))}{\sqrt{1-\rho^2}} + \phi(\beta_2'X_1)\Phi\frac{(-\alpha_1'X_2 + \rho(\beta_2'X_1))}{\sqrt{1-\rho^2}}\right].\beta_x + \left[\phi(\alpha_1'X_2)\Phi\frac{((\beta_1 + \beta_2'X_1) - \rho(\alpha_1'X_2))}{\sqrt{1-\rho^2}} - \phi(-\alpha_1'X_2)\Phi\frac{(\beta_2'X_1 - \rho(\alpha_1'X_2))}{\sqrt{1-\rho^2}}\right].\alpha_x$$

where α_x and β_x are the coefficients of x in both equations, ϕ and Φ are respectively the univariate normal cumulative distribution and the density function. The first part of the expression corresponds to the direct effect and the second part to the indirect effect (Greene, 1998).

Considering now the case of a binary variable q (for example a variable poor=1 if the households is below the poverty line, =0 otherwise).

$$E(y_1|X_1, X_2, y_2, q = 1) - E(y_1|X_1, X_2, y_2, q = 0)$$
$$= \left[\left(\Phi_2(\beta_1 + \beta_2{}'X_1, \alpha_1{}'X_2, \rho) + \Phi_2(\beta_2{}'X_1, -\alpha_1{}'X_2, -\rho)\right)|q = 1\right]$$
$$- \left[\left(\Phi_2(\beta_1 + \beta_2{}'X_1, \alpha_1{}'X_2, \rho) + \Phi_2(\beta_2{}'X_1, -\alpha_1{}'X_2, -\rho)\right)|q = 0\right]$$

In the case of $\rho = 0$, the marginal effect of a continuous explanatory variable *x* (representing for example the age of individuals), is given by:

$$\frac{\partial E(y_1|X_1, X_2, y_2)}{\partial x}$$
$$= [\phi(\beta_1 + \beta_2{}'X_1)\Phi((\alpha_1{}'X_2) + \phi(\beta_2{}'X_1)\Phi(-\alpha_1{}'X_2)].\beta_x$$
$$+ [\phi(\alpha_1{}'X_2)\Phi(\beta_1 + \beta_2{}'X_1) - \phi(-\alpha_1{}'X_2)\Phi(\beta_2{}'X_1)].\alpha_x$$

For a binary variable q (for example a variable poor=1 if the households is below the poverty line, =0 otherwise), the marginal effect is given by:

$$E(y_1|X_1, X_2, y_2, q = 1) - E(y_1|X_1, X_2, y_2, q = 0)$$
$$= \left[\left(\Phi(\alpha_1{}'X_2)\Phi(\beta_1 + \beta_2{}'X_1) + \Phi(-\alpha_1{}'X_2)\Phi(\beta_2{}'X_1)\right)|q = 1\right]$$
$$- \left[\left(\Phi(\alpha_1{}'X_2)\Phi(\beta_1 + \beta_2{}'X_1) + \Phi(-\alpha_1{}'X_2)\Phi(\beta_2{}'X_1)\right)|q = 0\right]$$

The calculation of the marginal effect of the binary variable y_2 does not depend of ρ and the marginal effect is:

$$E(y_1|X_1, X_2, y_2 = 1) - E(y_1|X_1, X_2, y_2 = 0) = \Phi(\beta_1 + \beta_2{}'X_1) - \Phi(\beta_2{}'X_1)$$

Finally, the marginal effects for the equation of y_2 are defined in terms of univariate normal probabilities since the expectation of y_2 only depend of X_2 and Z.

Table 4.5. Results with lagged forest area proxy - coefficient estimates

	Full sample (model 1a)		Full sample (model 2a)		Full sample (model 3a)		Poor households (model 4a)		Non poor households (model 1a)	
	Labor market participation	Natural resource collection	Farm activity	Natural resource collection	Family business and other activity	Natural resource collection	Labor market participation	Natural resource collection	Labor market participation	Natural resource collection
Fuel collection	-0.910***	-	1.021***	-	-0.949***	-	0.267	-	-1.153***	-
	(0.242)		(0.237)		(0.170)		(0.482)		(0.0845)	
Lagged forest area km^2 (log)	-	-0.0319***	-	-0.0105	-	-0.0319***	-	0.0384*	-	-0.0473***
		(0.0102)		(0.00880)		(0.0102)		(0.0214)		(0.00829)
Individual characteristics										
Age of the individual	0.135***	0.00259	0.0993***	-0.00111	0.106***	8.75e-05	0.166***	0.0140	0.121***	0.000604
	(0.00641)	(0.00446)	(0.00429)	(0.00422)	(0.00448)	(0.00418)	(0.00843)	(0.00966)	(0.00514)	(0.00471)
Age^2	-0.00177***	-8.36e-05	-0.00122***	-4.05e-05	-0.00149***	-5.44e-05	-0.00221***	-0.000176	-0.00157***	-7.02e-05
	(8.04e-05)	(5.57e-05)	(5.58e-05)	(5.35e-05)	(5.88e-05)	(5.29e-05)	(0.000107)	(0.000119)	(6.50e-05)	(5.96e-05)
Never attended school	ref		ref		ref		ref		ref	
School between 1-5 years	-0.149***	-0.0639	0.0432	-0.0966**	-0.231***	-0.0727*	-0.0976	0.0572	-0.166***	-0.0802*
	(0.0296)	(0.0396)	(0.0295)	(0.0395)	(0.0313)	(0.0392)	(0.0613)	(0.0951)	(0.0336)	(0.0432)
School between 6-10 years	-0.358***	-0.125***	-0.00551	-0.170***	-0.527***	-0.144***	-0.372***	-0.0220	-0.351***	-0.145***
	(0.0291)	(0.0406)	(0.0305)	(0.0406)	(0.0321)	(0.0398)	(0.0657)	(0.114)	(0.0320)	(0.0421)
School between 11-15 years	-0.686***	-0.392***	-0.238***	-0.430***	-0.710***	-0.414***	-0.411**	-0.172	-0.709***	-0.433***
	(0.0491)	(0.0610)	(0.0627)	(0.0621)	(0.0585)	(0.0610)	(0.186)	(0.255)	(0.0510)	(0.0627)
Household characteristics										
Nb of children aged 0-7	0.00577	0.00425	0.0507***	0.00654	-0.0647***	0.00226	0.0165	0.0448	-0.00245	-0.00802
	(0.0110)	(0.0194)	(0.0109)	(0.0203)	(0.0122)	(0.0197)	(0.0181)	(0.0310)	(0.0144)	(0.0225)
Nb of children aged 8-21	-0.00712	0.000658	0.00869	0.00279	-0.0360***	0.000501	-0.0257*	0.0430	-0.00322	-0.00620
	(0.00837)	(0.0159)	(0.00794)	(0.0163)	(0.00916)	(0.0160)	(0.0155)	(0.0268)	(0.0103)	(0.0170)
Nb of men aged 21-65	-0.123***	-0.0505**	-0.00297	-0.0495**	-0.190***	-0.0458*	-0.0887***	-0.0408	-0.128***	-0.0616**
	(0.0152)	(0.0239)	(0.0157)	(0.0245)	(0.0173)	(0.0245)	(0.0307)	(0.0568)	(0.0174)	(0.0261)
Nb of women aged 21-65	-0.0661***	-0.0272	-0.00535	-0.0329	-0.113***	-0.0282	-0.186***	-0.0248	-0.0324	-0.0168
	(0.0193)	(0.0311)	(0.0193)	(0.0317)	(0.0207)	(0.0315)	(0.0366)	(0.0771)	(0.0226)	(0.0344)
Hindu	ref		ref		ref		ref		ref	
Muslim	-0.453***	-0.177***	-0.350***	-0.182***	-0.346***	-0.180***	-0.366***	-0.356**	-0.427***	-0.0952
	(0.0456)	(0.0683)	(0.0528)	(0.0688)	(0.0511)	(0.0686)	(0.0991)	(0.140)	(0.0517)	(0.0747)
Other religion	-0.200***	-0.231**	-0.311***	-0.221**	0.0616	-0.226**	0.0743	-0.279	-0.256***	-0.263**
	(0.0720)	(0.103)	(0.0821)	(0.105)	(0.0728)	(0.104)	(0.159)	(0.281)	(0.0798)	(0.110)
Poor (=1 if HH is above poverty line)	0.0841**	0.329***	-0.216***	0.333***	0.453***	0.346***	-	-	-	-
	(0.0331)	(0.0519)	(0.0311)	(0.0519)	(0.0295)	(0.0513)				

Village										
Nb pers in the village:										
1000 inhbts or less	ref		ref		ref		ref		ref	
1001 - 5000 inhbts	1.066***	-0.201	0.793***	-0.0297	0.0539	-0.244	0.646	-0.256	0.948***	-0.162
	(0.247)	(0.378)	(0.246)	(0.372)	(0.248)	(0.367)	(0.480)	(1.026)	(0.280)	(0.433)
More than 5000 inhbts	0.770***	0.981**	-0.121	1.130***	-0.693***	0.880**	-0.174	2.594**	0.883***	1.077**
	(0.262)	(0.401)	(0.281)	(0.404)	(0.267)	(0.402)	(0.523)	(1.242)	(0.297)	(0.452)
Employment program in the village	0.221***	0.255***	0.0905**	0.230***	0.143***	0.249***	0.212**	0.214	0.214***	0.264***
	(0.0382)	(0.0536)	(0.0405)	(0.0546)	(0.0384)	(0.0539)	(0.0833)	(0.139)	(0.0420)	(0.0576)
Accessibility by road	-0.298***	-0.135	-0.182***	-0.152*	-0.140***	-0.118	-0.225**	-0.0349	-0.325***	-0.156
	(0.0551)	(0.0918)	(0.0552)	(0.0926)	(0.0539)	(0.0938)	(0.0987)	(0.182)	(0.0673)	(0.104)
Distance to HQ (in log)	0.0662***	0.0137	0.0720***	-0.0150	0.0673***	0.00812	0.132***	0.0487	0.0461**	0.00634
	(0.0169)	(0.0269)	(0.0172)	(0.0280)	(0.0172)	(0.0265)	(0.0342)	(0.0703)	(0.0190)	(0.0284)
Conflict	-0.0706***	-0.0817**	0.000939	-0.0667*	-0.0650***	-0.0806**	-0.0154	-0.0308	-0.0900***	-0.101**
	(0.0233)	(0.0363)	(0.0240)	(0.0369)	(0.0241)	(0.0367)	(0.0474)	(0.0844)	(0.0269)	(0.0398)
Daily women unskilled wage rate (in log)	0.319***	0.303***	0.249***	0.312***	-0.264***	0.277***	0.228**	-0.00932	0.305***	0.376***
	(0.0490)	(0.0778)	(0.0537)	(0.0761)	(0.0505)	(0.0746)	(0.0943)	(0.208)	(0.0563)	(0.0910)
Wage x 1001 - 5000 inhbts in the village	-0.375***	-0.0538	-0.301***	-0.0944	-0.0178	-0.0415	-0.228*	0.0545	-0.358***	-0.0917
	(0.0655)	(0.101)	(0.0660)	(0.0990)	(0.0665)	(0.0977)	(0.133)	(0.280)	(0.0734)	(0.114)
Wage x more than 5000 inhbts in the village	-0.362***	-0.443***	-0.154**	-0.479***	0.198***	-0.417***	-0.0605	-0.742**	-0.409***	-0.497***
	(0.0688)	(0.104)	(0.0781)	(0.104)	(0.0700)	(0.104)	(0.142)	(0.322)	(0.0760)	(0.116)
Unemployment rate in the district	-0.0178***	-0.0058	-0.0007	-0.0068	-0.0278***	-0.0057	-0.0359***	-0 .0288*	-0.0045	0.0086
	(0.0062)	(0.0091)	(0.0063)	(0.0097)	(0.0065)	(0.0095)	(0.0139)	(0.0157)	(0.0074)	(0.0107)
% of people working in agricultural and mining activities	0.0154***	0.0040**	0.0087***	0.0027	0.0185***	0.0042**	0.0207***	0.0015	0.0130***	0.0035*
	(0.0011)	(0.0018)	(0.0011)	(0.0017)	(0.0011)	(0.0018)	(0.0020)	(0.0038)	(0.0013)	(0.0019)
Constant	-2.310***	0.523	-4.023***	0.628*	-0.493*	0.668**	-3.906***	0.811	-1.624***	0.539
	(0.379)	(0.346)	(0.258)	(0.339)	(0.278)	(0.329)	(0.587)	(0.845)	(0.282)	(0.406)
athrho	0.732*** (0.211)		-0.433*** (0.162)		0.587*** (0.113)		-0.0181 (0.223)		1.027*** (0.113)	
Observations	18,738		18,738		18,738		4,924		13,814	
Log pseudolikelihood	-17206.13		-17902.965		-16110.931		-3754.8686		-13329.578	

Note: Robust standard errors in parentheses. Standard errors in all estimated regressions are corrected for heteroscedasticity and clustering at the households level. Several women belong to the same household and clustering allows correcting for possible bias attributed to household size. *** significant at 1%, ** significant at 5%, *significant at 10%

Table 4.6. Results with firewood price area proxy - coefficient estimates

	Full sample (model 1b)		Full sample (model 2b)		Full sample (model 3b)		Poor households (model 4b)		Non poor households (model 1b)	
	Labor market participation	Natural resource collection	Farm activity	Natural resource collection	Family business and other activity	Natural resource collection	Labor market participation	Natural resource collection	Labor market participation	Natural resource collection
Fuel collection	-0.627***	-	0.185	-	-0.525***	-	-0.631	-	-0.881***	-
	(0.219)		(0.636)		(0.174)		(0.501)		(0.185)	
Firewood price (in log)	-	0.268***	-	0.238***	-	0.242***	-	0.179*	-	0.284***
		(0.0472)		(0.0614)		(0.0477)		(0.103)		(0.0498)
Individual characteristics										
Age of the individual	0.140***	8.92e-05	0.102***	-0.00162	0.109***	-0.00142	0.164***	0.0153	0.128***	-0.00285
	(0.00511)	(0.00428)	(0.00395)	(0.00422)	(0.00442)	(0.00419)	(0.00894)	(0.00981)	(0.00614)	(0.00476)
Age^2	-0.00183***	-5.54e-05	-0.00126***	-3.53e-05	-0.00153***	-3.78e-05	-0.00218***	-0.000185	-0.00166***	-3.23e-05
	(6.44e-05)	(5.39e-05)	(4.97e-05)	(5.33e-05)	(5.80e-05)	(5.31e-05)	(0.000115)	(0.000120)	(7.66e-05)	(6.02e-05)
Never attended school	ref		ref		ref		ref		ref	
School between 1-5 years	-0.148***	-0.0772*	0.0289	-0.0871**	-0.231***	-0.0856**	-0.0888	0.0729	-0.165***	-0.103**
	(0.0299)	(0.0395)	(0.0316)	(0.0408)	(0.0317)	(0.0392)	(0.0611)	(0.0937)	(0.0342)	(0.0437)
School between 6-10 years	-0.360***	-0.149***	-0.0330	-0.161***	-0.531***	-0.163***	-0.365***	0.0105	-0.356***	-0.181***
	(0.0293)	(0.0401)	(0.0349)	(0.0431)	(0.0324)	(0.0399)	(0.0665)	(0.113)	(0.0325)	(0.0429)
School between 11-15 years	-0.684***	-0.413***	-0.334***	-0.420***	-0.700***	-0.428***	-0.430**	-0.151	-0.714***	-0.462***
	(0.0502)	(0.0613)	(0.0765)	(0.0654)	(0.0605)	(0.0617)	(0.178)	(0.260)	(0.0520)	(0.0639)
Household characteristics										
Nb of children aged 0-7	0.00556	0.0110	0.0531***	0.00914	-0.0664***	0.00952	0.0200	0.0395	-0.00243	0.00262
	(0.0109)	(0.0194)	(0.0110)	(0.0196)	(0.0122)	(0.0196)	(0.0178)	(0.0309)	(0.0141)	(0.0229)
Nb of children aged 8-21	-0.00747	0.00618	0.00965	0.00622	-0.0371***	0.00578	-0.0208	0.0361	-0.00276	0.000302
	(0.00824)	(0.0157)	(0.00821)	(0.0158)	(0.00914)	(0.0158)	(0.0155)	(0.0267)	(0.01000)	(0.0175)
Nb of men aged 21-65	-0.124***	-0.0485**	-0.0112	-0.0473*	-0.191***	-0.0456*	-0.0901***	-0.0245	-0.131***	-0.0565**
	(0.0150)	(0.0243)	(0.0166)	(0.0245)	(0.0174)	(0.0247)	(0.0300)	(0.0579)	(0.0173)	(0.0268)
Nb of women aged 21-65	-0.0666***	-0.0329	-0.0115	-0.0341	-0.114***	-0.0341	-0.185***	-0.0409	-0.0316	-0.0268
	(0.0191)	(0.0313)	(0.0198)	(0.0318)	(0.0208)	(0.0316)	(0.0364)	(0.0759)	(0.0223)	(0.0352)
Hindu	ref		ref		ref		ref		ref	
Muslim	-0.459***	-0.209***	-0.394***	-0.206***	-0.346***	-0.208***	-0.402***	-0.376***	-0.443***	-0.140*
	(0.0452)	(0.0681)	(0.0531)	(0.0687)	(0.0519)	(0.0685)	(0.0949)	(0.137)	(0.0524)	(0.0751)
Other religion	-0.189***	-0.229**	-0.376***	-0.223**	0.0891	-0.226**	0.0379	-0.210	-0.248***	-0.263**
	(0.0706)	(0.103)	(0.0865)	(0.104)	(0.0728)	(0.104)	(0.172)	(0.279)	(0.0783)	(0.109)
Poor (=1 if HH is above poverty line)	0.0654**	0.323***	-0.174***	0.331***	0.444***	0.334***	-	-	-	-
	(0.0317)	(0.0518)	(0.0446)	(0.0515)	(0.0299)	(0.0513)				

Village										
Nb pers in the village:										
1000 inhbts or less	ref		ref		ref		ref		ref	
1001 - 5000 inhbts	1.128***	-0.178	0.786***	-0.129	0.0842	-0.190	0.605	-0.460	1.050***	-0.139
	(0.244)	(0.380)	(0.247)	(0.384)	(0.252)	(0.374)	(0.481)	(0.980)	(0.287)	(0.435)
More than 5000 inhbts	0.728***	1.090***	0.110	1.119***	-0.777***	1.045**	0.0319	2.083*	0.864***	1.200***
	(0.264)	(0.408)	(0.317)	(0.418)	(0.272)	(0.410)	(0.527)	(1.160)	(0.302)	(0.456)
Employment program in the village	0.214***	0.244***	0.128***	0.244***	0.133***	0.240***	0.237***	0.282**	0.209***	0.236***
	(0.0385)	(0.0533)	(0.0454)	(0.0542)	(0.0387)	(0.0539)	(0.0840)	(0.137)	(0.0426)	(0.0577)
Accessibility by road	-0.299***	-0.124	-0.206***	-0.141	-0.134**	-0.122	-0.228**	-0.0363	-0.328***	-0.148
	(0.0557)	(0.0929)	(0.0564)	(0.0940)	(0.0550)	(0.0945)	(0.0966)	(0.181)	(0.0680)	(0.107)
Distance to HQ (in log)	0.0690***	0.00659	0.0731***	0.000511	0.0699***	0.00175	0.135***	0.0731	0.0501***	-0.00572
	(0.0169)	(0.0261)	(0.0174)	(0.0293)	(0.0174)	(0.0261)	(0.0337)	(0.0673)	(0.0192)	(0.0284)
Conflict	-0.0693***	-0.0589	-0.0105	-0.0594	-0.0628***	-0.0589	-0.0209	-0.0503	-0.0909***	-0.0633
	(0.0233)	(0.0362)	(0.0251)	(0.0365)	(0.0243)	(0.0365)	(0.0469)	(0.0828)	(0.0269)	(0.0401)
Daily women unskilled wage rate (in log)	0.313***	0.309***	0.302***	0.307***	-0.286***	0.295***	0.219**	-0.0290	0.299***	0.377***
	(0.0498)	(0.0788)	(0.0589)	(0.0790)	(0.0518)	(0.0770)	(0.0947)	(0.201)	(0.0579)	(0.0921)
Wage x 1001 - 5000 inhbts in the village	-0.388***	-0.0598	-0.315***	-0.0722	-0.0210	-0.0557	-0.219	0.0989	-0.381***	-0.0952
	(0.0650)	(0.102)	(0.0656)	(0.102)	(0.0676)	(0.0999)	(0.133)	(0.269)	(0.0751)	(0.114)
Wage x more than 5000 inhbts in the village	-0.344***	-0.472***	-0.253***	-0.481***	0.232***	-0.461***	-0.127	-0.632**	-0.398***	-0.526***
	(0.0698)	(0.106)	(0.0944)	(0.108)	(0.0717)	(0.106)	(0.141)	(0.302)	(0.0780)	(0.117)
Unemployment rate in the district	-0.0182***	-0.0053	-0.0025	-0.0053	-0.0284***	-0.0058	-0.0400***	-0.0290*	-0.0054	0.0080
	(0.0062)	(0.0093)	(0.0065)	(0.0097)	(0.0065)	(0.0096)	(0.0137)	(0.0154)	(0.0073)	(0.0111)
% of people working in agricultural and mining activities	0.0158***	0.0039**	0.0094***	0.0033*	0.0189***	0.0038**	0.0207***	0.0048	0.0137***	0.0034*
	(0.0011)	(0.0017)	(0.0011)	(0.0017)	(0.0011)	(0.0018)	(0.0021)	(0.0035)	(0.0013)	(0.0019)
Constant	-2.644***	0.149	-3.474***	0.285	-0.890***	0.279	-3.033***	0.709	-2.009***	0.127
	(0.332)	(0.354)	(0.563)	(0.358)	(0.277)	(0.339)	(0.681)	(0.841)	(0.350)	(0.418)
athrho	0.517*** (0.150)		0.0532 (0.335)		0.327*** (0.0958)		0.451 (0.290)		0.732*** (0.163)	
Observations	18,738		18,738		18,738		4,924		13,814	
Log pseudolikelihood	-17182.805		-17883.883		-16094.995		-3755.0623		-13324.01	

Note: Robust standard errors in parentheses. Standard errors in all estimated regressions are corrected for heteroscedasticity and clustering at the households level. Several women belong to the same household and clustering allows correcting for possible bias attributed to household size. *** significant at 1%, ** significant at 5%, *significant at 10%

Conclusion

In the context of growing concerns for climate change, the objective of this dissertation has been to bring some insights on two environmental issues. The first one concerns the way households' well-being is affected by environmental changes and the second one deals with the question of whether environmental policies are efficient enough to significantly decrease greenhouse gas emissions and energy consumption.

To tackle the latter issue, we have three contributions. We focused in a first chapter on the determinants of residential energy consumption in France. The residential sector is the primary energy user in the European Union or the United States; it accounts for approximately one-quarter of total energy consumption (Odyssee, 2013; International Energy Agency, 2013). Therefore, an in-depth understanding of households energy consumption is needed to design adequate energy policies and achieve a low-carbon society. The literature identifies several potential determinants but do not pay much attention to households' characteristics, except for the income. Using an econometric model and INSEE data, we show that energy consumption is almost completely determined by the technical properties of a dwelling, the type of heating technology, and climate dummies. This implies that in the short run, without large investments in insulation and new types of energy-efficient appliances, changes in energy consumption will be weak.

We evaluate the impact of environmental policies in the two following chapters using two levels of analysis, macroeconomic (in chapter 2) and microeconomic (in chapter 3). The challenge for environmental policies is to induce households to undertake energy saving renovations in their housing. This is the objective of current policies as (i) the tax credit, (ii) the 5.5% VAT, (iii) subsidies for households belonging to the first income quintile, and (iv) the zero rate bank loans. However, these measures are very expensive for the government (for instance, the public cost of the tax credit reaches €12 billions in 5 years). It seems therefore important to assess their effectiveness.

In chapter 2, we evaluate the impact of French current policies at a national level, using a simulation model. We study their impact on energy consumption, greenhouse gases emissions and on the number of renovations by 2050. All public policies exhibit some efficiency since they allow decreasing energy consumption and greenhouse gases emissions and they encourage households to renovate. Residential energy consumption per square meter would have been 28% higher in 2010 without any public policies, and greenhouse gases emissions would have been 55% higher. Their impact shows up until 2050. One of the most efficient public policies, given its impact on energy consumption and greenhouse gases emissions as well as its cost, seems to be the tax credit. In chapter 3, we analyze the effect of this measure on households' behavior, paying a particular attention to the presence of free riding. This measure has essentially an impact on renovation expenditures (with a 24.65% rise if we consider current prices). However, it allows increasing the renovation rate only slightly (by 0.89%) between 2005 and 2008. Out of these two chapters, we obtain that several effects tend to mitigate the impact of environmental measures.

First, we observe the presence of free riding. We estimate that free riders represent more that 40% of the households who renovate between 2011 and 2050 (in chapter 2). The effect is more important at the beginning of the period and it then fades over time. If we only consider the tax credit between 2005 and 2008, it encouraged 900,000 households to renovate ceteris paribus, whereas 4.2 millions benefited from this measure (according to chapter 3). It is consistent with a statistical analysis: less than 10% of households who benefit from the measure declare that they have undertaken a renovation that they did not consider before the introduction of the measure. Free riding on fiscal measure seems thus very important.

Second, public policies are not sufficient to encourage low-income households and tenants to renovate. Even if energy consumption is only weakly responsive to an increase of income per consumption unit (in chapter 1, we find that income elasticity is 0.02 in houses and is not significant in flats), income plays an important role in the decision to renovate. It is mostly the households in the fourth and fifth income quintile who invest (as we can see in chapters 2 and 3). Environmental public policy does not manage to induce poorer households investment. Moreover, we have shown in chapter 1 that buildings equipped with a collective heating (using either natural gas or oil) have significantly higher levels of consumption than those equipped with an individual heater (using either natural gas or electricity), ceteris paribus. However, in this type of housing, decisions to renovate are made by majority vote at owners' meetings. The energy-saving measures have therefore a lower probability of being undertaken. In addition, environmental measures, as tax credit, principally encourage owners-occupant to undertake renovations, and not tenants. A tenant has less incentive to make an energy efficiency investment because he does not stay long enough in the dwelling to secure a return on the investment. Meanwhile, renovations increase the value of the dwelling for homeowners.

Third, the market for energy-saving renovations is imperfectly competitive and this allows building professionals to capture part of the earnings from tax credit, through prices increase. We show in chapter 3 that the tax credit is followed by an increase in the renovation expenditures of 24.65%, but two-thirds of this rise is due to an increase of the prices.

Finally, as we obtain in chapter 1, investment in glazing insulation may not impact energy consumption. Households can decide to opt for a higher thermal comfort following the investment. This rebound effect explains that the final impact of renovations on energy consumption and greenhouse gases emissions could be zero.

These four effects reduce the impact of environmental policies. Consequently, current policies are not sufficient to achieve the objectives set by the Grenelle Act. Based on simulations in the chapter 2, we can propose several solutions to reach a 50 kWh_{ep}/m^2 average energy consumption and divide by 4 greenhouse gases emissions by 2050 compared to 1990 level. We could consider significantly increasing the tax credit up to 54% (the current rates are 15% for double-glazing, 25% for roof and wall insulation and modernization of the heating system, and 40% for renewable energy adoption) or introduce new policies such as bonuses: a bonus of €2900 per renovation would then be required to reach the objective. Finally, a possible efficient policy mix to reach the objectives would be an income deduction rate of 45% for all renovations from 2011, a zero rate bank loan that can be combined with the income tax deduction over the whole period, a 5.5% VAT, a €1000 bonus for households belonging to first and second income quintiles and a €500 bonus for others households.

However, such measures would represent a very high public cost. We therefore recommend introducing income ceilings to limit free riding and to encourage only households with low income. Moreover, public costs could be limited thanks to an additional tax on energy prices. Energy consumption is correlated with energy prices (in absolute values the price elasticity is about 0.46 in houses and 0.86 in flats). In addition, a sharp increase in prices would lead the household, all things being equal, to quickly invest in energy-saving renovations. If the energy prices trend remains as forecasted by IEA (i.e. an increase of 3.1% of electricity price, of 3.3% of fuel oil price and 3.6% of gas price), a 50 kWh_{pe}/m^2 average residential consumption will be reached in 2078. However, a tax on energy prices could affect primarily the poorest people and raise the issue of energy poverty, but note that taxes could be redistributed to reach equity objectives. Nonetheless, we can wonder about the suitability to conduct environmental policy without international coordination. Indeed, it generates high costs without the guarantee to decrease environmental damage and climatic events.

As we saw emerging countries are more exposed to climate disasters than developed ones. Therefore, the most important concern in emerging countries is to find a way to limit the consequences of climate change. In chapter 4 we explore how environment can affect people and how they adapt to environmental changes. More precisely, we try to understand the link between deforestation or fuel scarcity and the decision to collect natural resources or participate to labor market in India. Indian households are also sensitive to the evolution of the price of their main fuel, particularly those living above proverty line. In France, households adjust their consumption depending on the energy prices. In India, consequences are quite different. An increase in fuelwood price has an impact on women participation to the labor market. Prices reflect the scarcity of fuel. Higher prices encourage women to collect fuelwood themselves and that in turn reduce their probability to participate at wage activities. This means, deforestation through increase in the fuelwood scarcity affects households. This is in line with the UNPD report (2011): environmental degradations have adverse effects on people. It seems important to enhance measures to limit deforestation. It could be for example realized through an increase of protected forest area or Joint Forest Management.

Given our results, several recommendations can be formulated. To sum up, in developed countries the most important concern is the implementation of adequate environmental policies to decrease significantly greenhouse gases emissions. To achieve the objectives set in France, current policies should be strengthening. First environmental measures should provide incentives to the installation of individual metering or the replacement of collective systems by individual heating systems. Indeed, it could be helpful (i) in decreasing energy consumption in collective housing and (ii) in inducing households to renovate or improve thermal quality of their housing. The incentive to renovate in dwelling with collective heating is weak because the energy saving is shared between all co-owners.

Second, environmental policies should decrease the cost of energy-saving equipments for low-income households, introducing for example high bonuses with income ceiling. This would allows (i) decreasing significantly energy consumption because these households often live in less insulated dwellings and (ii) focusing only on households who need financial support to renovate in order to limit free riding.

Third, the impact of fiscal measure on renovation rate is low because of free riding and as we saw, financial incentives represent a high public cost. Therefore, to mitigate the negative effects related to these policies while minimizing public cost, a possible solution would be to harden the regulatory measures such as thermal regulations on new constructions. Moreover, it is more complicated to decrease the energy consumption following a renovation than directly build an energy-efficient housing.

Finally, emerging countries have to limit environmental degradations because of the negative effects on population. Deforestation is one of the largest visible environmental degradations and in this context, a better forest management, through Joint Forest Management for example, is needed.

Environmental issues raise a lot of questions. Even if we have tried to bring some insights it would be interesting to continue this research.

We plan to study energy poverty in France. According to INSEE, around 13% of households are in an energy poverty situation. This corresponds to households that have to spend more than a tenth of their income to pay their energy bills, in order to heat their home at an acceptable level. Indeed, energy expenditures represent a higher part of the income of households belonging to the firsts income quintiles. At the same time, income is a constraint for energy saving investments. However, literature on energy poverty in developed countries is sparse. The contributions could be to identify (i) which households are in a situation of energy poverty in France and (ii) the main factors leading a household to energy poverty, in order to introduce adequate and efficient measures. Fight against energy poverty could increase the well-being of these households but could also have an impact on the level of residential energy consumption. Indeed, we can expect that households in energy poverty situation live in worst insulated dwelling, and use more polluting fuels but consume less energy.

As we saw in the last chapter of this dissertation, the scarcity of a resource can have negative impacts on households, hampering the access of women to the labor market. This allows us to conclude that environmental degradations have adverse effects on people. Therefore households' access to modern energy can have a positive impact on economic growth in emerging countries, as chapter 4 and some literature on access to electricity seems show. But it can also increase pollution that in turn affects households' wealth. Future research could be to analyze the impact of energy access on development at a macro level, also considering the pollution issue. The impact of pollution to study the link between growth and access to electricity is not often considered in the literature.

To go further, an attention will be also paid to the impact of pollution regulations in India on households' productivity. Literature focuses on the impact of pollution on health. Through health effect, pollution may enhance poverty and could make it more persistent (Sala-i-Martin, 2005). Indeed, poor households cannot afford to improve their health. As a result, it is more difficult for them to increase their human capital and their economic productivity. Poor households may therefore enter a vicious circle, known as the poverty trap (Dasgupta and Ray, 1986, 1987). The rapid growth in India leads to pressure on the environment, and to a high acceleration of the pollution: the total greenhouse gas emissions increased by 113% between 1990 and 2010. However, an air regulation was adopted early in India with the 1981 Air act, which provides prevention, control and abatement of air pollution. Thereafter, an action plan has been adopted to reduce pollution in critically polluted cities. Today, 17 cities are concerned with these measures. We could study whether environmental regulation is effective enough to improve the workforce productivity and to prevent people to enter the poverty trap.

Table 5. Summary

	Main objectives	Empirical approach	Data	Main results
Chapter 1	Studies the determinants of residential energy consumption (1) Investigates the relative ability of household characteristics, technical properties of the dwelling, and climatic specificities to explain energy consumption per square meter (2) Identifies some of the main sources of energy conservation in the French housing sector (3) Proposes an estimation of the price elasticity and income elasticity of energy consumption per square meter	Discrete-continuous choice analysis	- INSEE 2006 *Enquête logement* - Data on energy prices from the *Ministère de l'économie, des finances et de l'industrie*	(1) Energy consumption is almost completely determined by technology and climate, while it is determined only slightly by the household itself (2) Strong effect of collective heating on energy consumption. Rebound effect for double-glazing in houses (3) Price elasticity in absolute value is equal to 0.46 in houses and 0.86 in flats. Income elasticity is low (0.02) in houses and not significant in flats.
Chapter 2	Evaluates environmental policies at a national level (4) Estimates the French residential energy consumption and GHG emissions until 2050 (5) Assesses the impact of environmental policies on energy consumption, GHG emissions and the number of renovations (6) Proposes different means to reach the objectives set out in the Grenelle Act	Simulation model, with a bottom-up approach. We model: - Energy consumption and GHG emissions - The decision to invest in an energy saving renovation - The housing park	- INSEE 2006 *Enquête logement* - Ministry of Ecology, Energy, Sustainable Development and the Sea, providing information on the number of housing and new constructions - Simulation software PROMODUL, used to estimate energy consumption and GHG emissions for each category of dwelling - International Energy Agency providing energy prices	(4) With current environmental policies, energy consumption will be 91.67kWh_{pe}/m^2 in 2050 (vs. an objective of 50 kWh_{pe}/m^2) (5) Policies are effective, but not enough to reach Grenelle Act objectives. Free riding exists in 40.15% of the renovations undertaken between 2011 and 2050 Tax credit is one of the most efficient policies. (6) To reach the objective, more ambitious policies are required. Proposition of policy mix: tax credit of 45% for all renovations from 2011, combined with a zero rate bank loan, a 5.5%VAT, a €1000 bonus for 1st and 2nd income quintiles households and a €500 bonus for others.

Chapter 3	Evaluates the effect of the tax credit on households' behavior (7) Determines if households are sensitive to this measure or if the tax credit provides funding for households that would have undertaken a renovation anyway (free riding) (8) Investigates whether the tax credit induces households to invest in more expensive and more energy-efficient renovations.	Matching method	*ADEME-SOFRES Maîtrise de l'Energie* surveys from 2001 and 2008	(7) A tax credit increases renovations by 0.86%, ceteris paribus. This represents 900 000 housing but 4.2 millions households received the tax credit between 2005-2008: presence of free riding. (8) The tax credit led to a 24.65% increase in expenditures (at current price). The impact is three times lower if we consider constant prices (8.9%): Building professionals capture a part of the earnings from the tax credit.
Chapter 4	Studies the impact of environmental changes on agents, more precisely the impact of deforestation and fuel scarcity on women living in rural area (9) Examines whether deforestation and fuel scarcity have a direct impact on women's decision to collect natural resources (10) Investigates whether it exists an indirect effect of fuel scarcity on women labor market participation through fuelwood collection activities	Simultaneous equations model: bivariate probit model	- 2004-2005 Indian Human Development Survey - 2004 Indian National Service Scheme - 1999 and 2005 Forest Survey of India reports	(9) The scarcer environmental resources, the higher the probability to participate to natural resource collection (10) Fuelwood collection reduces the probability of participating to labor market: environmental degradations are a barrier to the access of women to the labor market. When the income constraint is too strong, the labor supply is independent of the participation to natural resource collection.

Résumé

La consommation d'énergie et les émissions de gaz à effet de serre sont au cœur des préoccupations, suite aux observations de plus en plus alarmantes sur le changement climatique. Le GIEC (Groupe d'experts Intergouvernemental sur l'Evolution du Climat) qui s'est réunit en septembre dernier à Stockholm pour présenter ses résultats, confirment et durcit ses précédentes conclusions : le réchauffement climatique s'accélère. La température de la terre et des océans a augmenté de 0,85°C en moyenne depuis 1880 et le GIEC prévoit une hausse des températures de 0,3°C à 4,8°C d'ici 2100, en fonction de différents scénarios. Une telle augmentation aurait des effets non négligeables sur le nombre et l'intensité des évènements climatiques. Par exemple, l'année 2012 fait partie des 10 années les plus chaudes et plusieurs évènements climatiques extrêmes ont pu être recensés, tels que la fonte de la banquise qui a atteint des records, l'ouragan Sandy aux Etats-Unis ou encore les fortes pluies au nord de l'Europe et à l'est de l'Australie.

Premièrement, les désastres naturels causent un nombre important de pertes humaines (environ 8800 personnes en 2012). Deuxièmement, les dommages liés aux évènements climatiques représentent un coût économique important. Les évènements climatiques de 2012 représentent une perte économique de 200 milliards de dollars (AON Benfield, 2013). La moitié de ces pertes économiques est liée à l'ouragan Sandy, qui a causé les dommages les plus coûteux de l'année 2012, et à la sécheresse recensée aux Etats-Unis. Troisièmement, les effets du changement climatique ne sont pas tous observables aujourd'hui. Le niveau des océans va continuer à augmenter avec la hausse des températures, et cela amplifiera la fréquence et l'intensité des évènements telles que les inondations ou les tempêtes. Comme nous pouvons observer sur la carte 1, les pays émergents sont les plus exposés aux désastres climatiques. Le rapport du PNUD (Programme des Nations Unies pour le

Développement) sur le développement humain de 2011 souligne que les dégradations environnementales ou la destruction des habitats peuvent compromettre le développement et augmenter la pauvreté dans les pays émergents. Dans ce rapport, l'impact des évènements climatiques sur l'IDH (Indice de Développement Humain) est estimé, en considérant plusieurs scénarios. Le scénario « défi écologique » prend en compte les effets néfastes du réchauffement climatique sur la production agricole, l'accès à l'eau potable et la pollution. Le scénario « catastrophe climatique » considère la déforestation et la dégradation des terres, la destruction dramatique de la biodiversité et l'accélération des évènements météorologiques extrêmes. Les simulations suggèrent que l'IDH mondial serait 8% plus faible en 2050 dans le scénario « défi écologique » par rapport au scénario de référence, et même 12% plus faible pour les régions d'Asie du sud. Le scénario « catastrophe climatique » prédit un IDH mondial de 15% inférieur à celui du scénario de référence. Cela est lié à plusieurs mécanismes, par exemple la sécheresse en Afrique et l'élévation du niveau des océans vers les pays à faible altitude comme le Bangladesh pourrait mener à une augmentation du prix mondial des denrées alimentaires entre 30% et 50%, affectant en premier lieu les pays les plus pauvres.

Considérant ces conséquences dramatiques, il semble important de s'intéresser aux causes de ces évènements. Même si le climat s'explique en partie par des fluctuations naturelles, le dernier rapport du GIEC (2013) confirme l'impact des activités humaines sur le réchauffement climatique (avec un niveau de confiance de 95%). De plus, un groupe de 18 chercheurs a récemment étudié les causes de 12 évènements d'une intensité climatique exceptionnelle qui se sont produits en 2012. Ils soulignent le fait que les activités humaines ont un impact sur certains phénomènes météorologiques et climatiques extrêmes (Peterson *et al.* 2013). Par exemple, ils affirment que le changement climatique causé par l'homme a joué un rôle important dans la vague de chaleur à l'est des Etats-Unis au printemps 2012. De la même manière, ils montrent que l'étendue particulièrement faible de la banquise Arctique durant l'été 2012, ne peut pas être expliquée uniquement par la variabilité naturelle du climat. L'activité humaine augmente la concentration de gaz à effet de serre dans l'atmosphère, principalement en raison de la combustion des énergies fossiles et de la déforestation (American Meteorological Society, 2012). En 2010, les émissions de gaz à effet de serre totales ont atteint 47 milliards de tonnes équivalent C02, ce qui représentait un augmentation 32,3% par rapport à 1990 (source: CAIT, World Resources Institute's climate data explorer).

Les dommages environnementaux ont des conséquences irréversibles et soulèvent la question de la responsabilité envers les pays les plus touchés et envers les générations futures. Ces préoccupations ne sont pas récentes. Le rapport Brundtland (Commission mondiale sur l'environnement et le développement, 1987) s'est accompagné d'une prise de conscience mondiale sur les défis du réchauffement climatique. Un an après, le GIEC a été créé pour évaluer l'ampleur des changements climatiques ainsi que les risques. Leurs constats alarmants soulignent la nécessité d'adopter une stratégie d'intervention internationale, et a conduit au protocole de Kyoto en 1997. Pour la première fois, plusieurs pays développés se sont engagés à diminuer les émissions de plusieurs gaz à effet de serre de 5,2% en moyenne d'ici 2012 comparativement à leur niveau de 1990. Cependant, les plus grands émetteurs de gaz à effet de serre n'ont pas ratifié le traité. Les Etats-Unis, dont les émissions représentaient près d'un cinquième des émissions mondiales de $CO2$ en 2008 (source: United States Environmental Protection Agency) se sont retirés du protocole de Kyoto. Ils ont justifié leur décision par le fait que les pays émergents n'étaient pas impliqués dans le protocole alors que leurs émissions de gaz à effet de serre augmentent de façon importante, avec leur développement économique. En effet, en 2008, presque 30% des émissions de $CO2$ mondiales provenaient de la Chine et de l'Inde (source: United States Environmental Protection Agency). Cependant, l'Union Européenne s'est engagée à réduire ses émissions de gaz à effet de serre de 8% d'ici 2012, puis s'est fixée de nouveaux objectifs, à savoir, réduire ses émissions de 20% d'ici 2020 par rapport à 1990. Pour atteindre ces objectifs, plusieurs politiques ont été introduites ces dernières années en France et dans d'autres pays Européens.

Cependant, les défis environnementaux pour les pays émergents méritent d'être explorés. Ils doivent trouver un moyen d'atténuer les effets négatifs du réchauffement climatique ou de s'adapter aux changements environnementaux. Même si ces pays sont les plus vulnérables au changement climatique et que les projections ne sont pas très optimistes, les conséquences pour les populations restent mal connues et la mise en place de politiques environnementales peut être coûteuse et peut aussi retarder leur développement économique.

Ces observations nous montrent la nécessité de s'interroger sur l'efficacité des politiques environnementales dans les pays développés et aussi sur les impacts économiques du changement climatique pour les pays émergents. Premièrement, les faits stylisés et les exemples présentés ci-dessus montrent qu'il est important de lutter contre le réchauffement climatique. Néanmoins, les politiques publiques ne sont efficaces que si les individus sont sensibles à ces mesures et elles représentent un coût public élevé. Des politiques environnementales ont été introduites ces dix dernières années et peu d'études ont cherché à examiner leurs effets. Deuxièmement, l'impact des dégradations environnementales sur la population vivant dans les pays émergents va devenir une préoccupation croissante et les conséquences économiques doivent être étudiées. Dans cette thèse, nous explorons ces questions, en utilisant des données sur la France et sur l'Inde.

1. L'efficacité des politiques environnementales dans les pays développés : Le cas de la France

Les enjeux

La France s'est engagée par les accords internationaux à diminuer ses émissions de gaz à effet de serre de 20% d'ici 2020 et à les diviser par 4 d'ici 2050 par rapport au niveau de 1990. Cela a conduit au Grenelle de l'environnement, qui a fixé des objectifs plus spécifiques comme réduire la consommation d'énergie dans le secteur du bâtiment de 38% et d'étendre l'utilisation des énergies renouvelables pour qu'elles représentent 23% de la consommation d'énergie finale en 2020. Le Grenelle de l'environnement s'intéresse particulièrement au secteur du bâtiment puisqu'il est tout d'abord le premier consommateur d'énergie en France (figure 1 p.4). Même si ce secteur n'est pas le plus grand émetteur de gaz à effet de serre, l'augmentation (de 13%) de ses émissions est la plus importante entre 1990 et 2010, alors que les secteurs de l'industrie et de l'agriculture ont réussit à réduire leurs émissions (figure 2 p.4). Deuxièmement, le secteur du bâtiment représente un potentiel d'économie d'énergie important, notamment grâce aux améliorations en termes d'isolation ou d'efficacité énergétique des équipements (Commission Européenne, Energy Efficiency Plan 2011). Cependant, des efforts importants sont nécessaires pour atteindre les objectifs.

En 2010, la consommation d'énergie du secteur résidentiel-tertiaire était de 68 millions de tonnes équivalent pétrole et nous nous sommes engagés à atteindre un niveau de 41,88 millions en 2020. De plus, les énergies renouvelables représentaient seulement 6% de la consommation d'énergie en 2010 (figure 3 p.5).

Le secteur résidentiel

Les déterminants de la consommation énergétique

Nous nous intéressons au secteur résidentiel, qui compte pour les deux-tiers de la consommation d'énergie du secteur du bâtiment et approximativement un quart de la consommation énergétique française (Odyssee, 2013). La croissance de la population, qui a entrainé une augmentation du nombre et de la taille des logements et une hausse du taux d'équipement des ménages, a tendance à accroitre les besoins énergétiques. Le nombre de logements a augmenté de plus d'un million entre 2006 et 2010. Les nouvelles constructions sont associées à une consommation d'énergie plus faible grâce à l'amélioration de l'isolation. Cependant, le taux de renouvellement du parc de logement est inférieur à 1% par an (DGEMP, 2007), et cela n'est pas suffisant pour réduire de façon significative la demande d'énergie.

Par conséquent, il est essentiel d'identifier les principaux déterminants de la consommation d'énergie résidentielle afin de mettre en place des politiques adéquates et efficaces. Cela est l'objectif du premier chapitre de cette thèse. La littérature identifie plusieurs facteurs mais ne porte pas beaucoup d'intérêt aux caractéristiques des ménages, mis à part au revenu. Ainsi, nous souhaitons (1) étudier la capacité des caractéristiques sociodémographiques des ménages, des caractéristiques techniques du bâti, et des spécificités climatiques de la zone d'habitation, à expliquer la consommation d'énergie par mètre carré, (2) identifier les sources d'économie d'énergie principales du secteur résidentiel français, et (3) proposer une estimation des élasticités prix et revenu de la consommation d'énergie par mètre carré, ce qui n'a pas encore été fait avec des données françaises. Nous mobilisons une approche empirique et nous avons recours aux données de l'enquête logement de l'INSEE (2006). Ces données nous renseignent sur les caractéristiques des ménages, des logements et sur les énergies utilisées. L'énergie fournit de l'utilité indirectement à travers l'utilisation d'appareils électroménagers. Par conséquent, la consommation d'énergie doit être étudiée conditionnellement au stock d'équipements. Nous utilisons un modèle de choix discret et continu. Nous estimons dans un premier temps le choix du système de chauffage, puis dans un second temps la consommation d'énergie conditionnelle au premier choix. Les résultats montrent que la quantité d'énergie consommée par mètre carré est presque entièrement déterminée par les caractéristiques techniques du logement et par le climat. L'impact des variables sociodémographiques est particulièrement faible. A court terme, sans investissement important en matière de rénovations énergétiques ou d'adoption d'investissements économiseurs d'énergie, la réduction de la consommation d'énergie sera faible. Le défi pour les politiques publiques est donc d'inciter les ménages à entreprendre des rénovations énergétiques dans leur logement. Nous pouvons également noter que le chauffage collectif entraine une consommation d'énergie significativement plus importante que le chauffage individuel, *ceteris paribus*. Les politiques environnementales devraient encourager les ménages à installer des compteurs individuels ou à remplacer ce mode de chauffage par des systèmes individuels. Par contre, l'isolation du vitrage dans les maisons entraine un effet rebond. Cela signifie que les ménages préfèrent augmenter leur consommation d'énergie suite à l'installation de double vitrage (pour par exemple augmenter leur confort grâce à une température intérieure plus élevée). Par conséquent, ce type de rénovation ne permet pas de diminuer la consommation d'énergie et les émissions de gaz à effet de serre du secteur résidentiel. De plus, l'élasticité-prix estimée est, en valeur absolue, de 0,46 pour les ménages vivant dans des maisons individuelles et de 0,86 pour ceux vivant dans des appartements collectifs. En ce qui concerne l'élasticité-revenu, celle-ci est particulièrement faible. Elle est de 0,02 pour les ménages vivant dans des maisons et elle est non-significative pour ceux vivant dans des appartements. Les ménages sont donc sensibles à des variations de prix de l'énergie, mais pas à des variations de revenu.

L'adoption d'équipements économiseurs d'énergie, le paradoxe énergétique et l'intervention des politiques publiques

Compte tenu des résultats trouvés dans le premier chapitre, il semble important de comprendre le comportement des ménages face à l'adoption d'équipements économiseurs d'énergie. Si nous considérons uniquement les rénovations visant à l'amélioration de l'efficacité énergétique des logements, 8,8% des résidences ont été rénovées en 2010, ce qui représente une baisse par rapport à 2006 (Source: OPEN, 2011). Le nombre de rénovations énergétiques est encore insuffisant pour avoir un impact significatif sur la consommation d'énergie du parc de logements. Cela peut être expliqué par le paradoxe énergétique : les ménages choisissent de ne pas investir dans des équipements performants, alors que cela se traduirait par des économies d'énergie importantes. La littérature identifie plusieurs barrières aux investissements économiseurs d'énergie.

- Les défaillances de marché

Les défaillances de marché sont des barrières à ces investissements. Cela fait référence au manque d'information, à la saturation de l'offre sur le marché des rénovations énergétiques et aux incitations divergentes (Golove et Eto, 1996; Brown, 2001; Boulanger, 2007).

Premièrement, les agents sont mal informés au sujet des technologies existantes, des opportunités et de la rentabilité des investissements. L'information peut être difficile et coûteuse à obtenir. C'est par exemple le cas en ce qui concerne les économies d'énergie suite à une rénovation (Beillan *et al.* 2011; Francfort, 2009). En effet, les agents et les logements sont hétérogènes, par conséquent le retour sur investissement est spécifique à l'investisseur. La rentabilité des équipements économiseurs d'énergie dépend par exemple de la qualité du logement : les gains d'énergie devraient être plus élevés dans un logement ancien et énergétiquement inefficace (Hasset et Metcalf, 1993).

Deuxièmement, les rénovations pour l'amélioration énergétique des logements nécessitent des connaissances particulières, et les professionnels peuvent ne pas être en mesure de répondre à la demande. Nous observons en effet une saturation de l'offre sur le marché de la rénovation énergétique en France (Moussaoui, 2008).

Troisièmement, il existe des incitations divergentes entre les propriétaires et les locataires, résultant de la manière dont les dépenses énergétiques sont payées. Les ménages qui ne paient pas directement pour leur chauffage mais qui ont ces coûts inclus dans le montant de leur location ou le montant des charges collectives vont avoir tendance à opter pour un confort thermique plus élevé et donc une consommation d'énergie plus importante. C'est le cas en France pour les ménages vivant dans des immeubles collectifs avec un chauffage collectif, pour lesquels la consommation d'énergie peut être assimilée à un bien public car tous les habitants partagent la facture énergétique de l'ensemble de l'immeuble. Dans ces situations, les habitants ont peut d'incitation à utiliser l'énergie de façon efficace et sont moins enclins à adopter des équipements économes en énergie (Maruejols et Young, 2011; Levinson et Niemann, 2004). De plus, les logements occupés par des propriétaires ont un meilleur niveau d'isolation (Gillingham *et al.*, 2011). En effet, lorsque le logement est loué, les propriétaires sont moins incités à entreprendre des rénovations parce que ce sont les locataires qui bénéficient des économies d'énergie réalisées suite à l'investissement.

Pour dépasser ces défaillances de marché, notamment le manque d'information, plusieurs mesures ont été mises en place. Les Espaces Info-Energie ont été créés en 2001 pour informer les ménages. Ce sont des endroits où les ménages peuvent trouver toute l'information dont ils ont besoin concernant la consommation d'énergie, les énergies renouvelables ou encore les rénovations énergétiques. Il en existe aujourd'hui 250 en France. De plus, les équipements électroménagers se voient attribuer des étiquettes énergie allant de A+ pour les équipements les plus performants à C pour les plus grands consommateurs d'énergie (depuis 1999, les appareils électroménagers appartenant à l'étiquette énergie la plus énergivore ne sont plus autorisés à la vente). Ces étiquettes énergie sont l'équivalent des « Power Smart » au Canada, des « Energy Star » au Etats-Unis ou encore des « E2000 » en Suisse. Ces labels énergétiques sont obligatoires pour les réfrigérateurs et les congélateurs depuis 1995 dans toute l'Union Européenne, et ils ont depuis été étendus à d'autres types d'appareils, puis aux logements mis en vente et en location.

- Les barrières économiques

Il existe également des barrières économiques telles que la contrainte de liquidité et l'accès au crédit (Boulanger, 2007). Par exemple, les ménages à faibles revenus n'ont pas de garantie et les établissements de crédit sont réticents à leur accorder des prêts. Ils font face à une contrainte de liquidité pour les investissements dans les technologies économes en énergie alors que leurs dépenses énergétiques représentent souvent une large part de leur budget, estimée à 15-20% en France par Cayla *et al.* (2011).

Pour ces raisons, plusieurs mesures financières ont été introduites. En 2009, un prêt à taux zéro peut être utilisé pour financer une série de rénovations énergétiques. Des subventions sont aussi disponibles pour les ménages (comme par exemple les subventions de l'ANAH ou celles provenant des régions) afin de réduire le coût de ces investissements et de les rendre plus abordables. De plus, un crédit d'impôt a l'objectif, depuis 2005, d'encourager les ménages (propriétaires ou locataires) d'entreprendre des rénovations énergétiques (isolation ou changement du système de chauffage) et/ou d'adopter des énergies renouvelables dans leur résidence principale. De la même manière, la TVA à taux réduit de 5,5% pour les rénovations énergétiques (à la place de 19,6%) a pour objectif de diminuer le coût de l'investissement.

- Incertitude, irréversibilité et taux d'actualisation élevés

A l'inverse, Hassett et Metcalf (1993) expliquent que le soi-disant paradoxe énergétique est en réalité une réponse optimale à l'incertitude sur le retour sur l'investissement (i.e. les économies d'énergie faisant suite à la rénovation) et à l'irréversibilité de l'investissement (comme l'isolation par exemple). En effet, l'incertitude sur les prix de l'énergie mène à une incertitude sur les économies d'énergie qui seront réalisées suite à l'investissement. Les agents économiques doivent prévoir les prix futurs de l'énergie pour évaluer la rentabilité de l'investissement. De plus, une fois que l'investissement est réalisé, il ne peut pas être annulé ou vendu si les prix de l'énergie chutent et si l'investissement devient non rentable. Par conséquent, il est prudent pour un agent d'attendre afin d'obtenir de l'information sur l'évolution des prix.

Compte tenu de l'incertitude et de l'irréversibilité, les agents utilisent des taux d'actualisation implicites élevés pour les investissements économiseurs d'énergie, i.e. la valeur actualisée des économies d'énergie futures est faible. La littérature qui estime les taux d'actualisation implicites utilisés pour les investissements économiseurs d'énergie montre qu'ils dépassent largement le taux d'actualisation maximum utilisé pour d'autres types d'investissements ayant un rendement et un risque similaire (Sanstad *et al.*, 1995), par un facteur 4 d'après Hasset et Metcalf (1993). Cela signifie que les agents exigent un rendement largement supérieur pour les investissements dans les équipements économiseurs d'énergie que pour les autres types d'investissements.

En termes de politiques publiques, ces conclusions soulignent le fait que fournir davantage d'information au sujet des gains énergétiques n'est pas suffisant pour motiver l'investissement. Hasset et Metcalf (1993) montrent également que l'augmentation des gains liés à l'investissement est susceptible d'avoir qu'un faible effet. Ils simulent l'impact d'un crédit d'impôt de 15% pour les équipements économiseurs d'énergie et ils trouvent que l'effet d'une telle politique est atténué par l'incertitude. Compte tenu de ces observations, il semble que les normes pourraient être efficaces pour diminuer la consommation d'énergie parce qu'elles n'influencent pas la perception des agents sur les économies d'énergie futures liées à l'investissement. Des réglementations thermiques ont été mises en place en 1974 pour les nouvelles constructions et en 2008 pour les rénovations.

Efficacité des politiques publiques *vs.* green paradox, effet d'aubaine et effet rebond

Le paradoxe énergétique conduit à un sous-investissement dans les équipements économiseurs d'énergie. L'intervention des politiques publiques est donc nécessaire pour encourager les ménages à rénover, car elle peut atténuer quelques barrières à l'investissement et aider les agents à entreprendre des rénovations énergétiques, afin de diminuer significativement la consommation d'énergie et les émissions de gaz à effet de serre. Récemment, plusieurs mesures ont été mises en place en France, (1) des mesures informatives, avec par exemple la présence de l'étiquette énergétique sur les appareils électroménagers pour informer les consommateurs sur l'efficacité énergétique des équipements, ou des campagnes d'information afin d'accroître la sensibilité des ménages face aux économies d'énergie, (2) des mesures financières pour encourager les ménages à adopter des énergies renouvelables ou améliorer la qualité du logement comme le prêt à taux zéro, les subventions, le crédit d'impôt ou la TVA à taux réduit, (3) et des mesures réglementaires, telles que les réglementations thermiques sur les nouvelles constructions ou les rénovations, ou la nécessité d'indiquer la qualité énergétique du logement au moment de la vente ou la mise en location.

L'une des mesures les plus populaires est le crédit d'impôt. Grâce à cette politique les dépenses engendrées par les rénovations énergétiques sont en partie déduites de l'impôt sur le revenu. Entre 2005 et 2008, 4,2 millions de français ont reçu le crédit d'impôt (Clerc et Mauroux, 2010) et cela représente un coût significatif : le coût public a atteint 7,8 milliards d'euros sur cette période et 4,2 milliards d'euros en 2009 et 2010. Cependant, plusieurs comportements peuvent atténuer l'effet des politiques environnementales.

- Effet d'aubaine et effet de contagion

Les mesures financières doivent être mises en place avec prudence, en raison d'un potentiel effet d'aubaine. L'effet d'aubaine inclus les ménages qui obtiennent par exemple une subvention pour entreprendre une rénovation qu'ils auraient tout de même réalisée en l'absence de politiques publiques. La littérature récente estime l'ampleur de l'effet d'aubaine entre 50 et 92%. Grösche et Vance (2009) utilisent des données transversales issues d'une enquête sur la consommation d'énergie résidentielle en Allemagne en 2005 pour évaluer cet effet. Ils définissent l'effet d'aubaine comme une situation dans laquelle le consentement à payer des ménages pour une rénovation énergétique dépasse leur coût sans aucune action politique. Ils montrent qu'un tel effet survient dans 50% des cas. Dans une étude originale, Grösche *et al.* (2009) simulent l'effet des subventions sur la décision de rénover. Ils trouvent que si chaque ménage éligible agit de façon rationnelle et donc demande la subvention, alors l'effet d'aubaine représenterait 92% des dépenses liées au programme. Malm (1996) examine l'impact des subventions sur l'achat d'équipement de chauffage et estime que l'effet d'aubaine s'élève à 89%.
Cependant, des effets de contagion peuvent atténuer voire compenser l'effet d'aubaine (Eto *et al.*, 1995; Rosenow et Galvin, 2013). De tels effets correspondent à des technologies supplémentaires installées à la suite d'un programme, mais qui n'étaient pas couvertes par le programme. Peu d'études se concentrent sur ce point, mais une évaluation récente montre que ces effets peuvent être non négligeables (NYSERDA, 2012).

- Effet rebond

Les politiques présentées précédemment ont pour objectif d'encourager les ménages à rénover. Cependant, l'adoption d'investissements économiseurs d'énergie n'est pas nécessairement suivie d'une réduction de la consommation d'énergie. Il apparaît que l'investissement dans une nouvelle technologie telle que l'amélioration de l'isolation peut entraîner un changement dans le comportement des ménages (par exemple, une hausse de la température intérieure), ce qui peut annuler, au moins partiellement, les effets bénéfiques de l'adoption de l'équipement. Cet effet est appelé l'effet rebond (voir le International Risk Governance Council, 2013). Une explication possible est que les personnes ont tendance à consommer davantage d'énergie quand celle-ci est moins coûteuse. Par conséquent, l'effet rebond réduit ou annule l'impact des politiques environnementales sur la consommation d'énergie et les émissions de gaz à effet de serre. Dans une vaste enquête, Greening *et al*. (2000) trouvent qu'une augmentation de 100% de l'efficacité énergétique mène à un effet rebond estimé de l'ordre de 0 à 50% dans le résidentiel. De plus, Alberini *et al.* (2013b) étudient la consommation d'énergie dans une région du Maryland et montrent que plus les subventions obtenues pour l'adoption d'équipements économes en énergie sont importantes, plus les économies d'électricité sont faibles, et ce résultat peut être expliqué par un effet rebond.

De plus, l'effet rebond peut avoir un impact indirect (Schipper et Grubb, 2000). Quand l'énergie est moins coûteuse, les ménages ont un pouvoir d'achat plus important et peuvent augmenter la demande pour d'autres biens qui nécessitent de l'énergie lors de la production ou de l'utilisation. Druckman *et al.* (2010) simulent l'effet d'un ensemble de mesures visant à réduire les émissions de CO2 au Royaume-Uni, à l'aide de différents scénarios. Ils estiment que l'effet rebond indirect représente en moyenne 34% de la réduction des émissions de gaz à effet de serre attendue (cela signifie que seulement les deux tiers de la baisse espérée des émissions sont susceptibles d'être atteints). Dans le meilleur des scénarios, l'effet peut baisser à 12% mais dans le scénario extrême, les émissions augmentent au lieu de diminuer.

En prenant un large éventail d'indicateurs macroéconomiques, il est possible d'identifier l'effet rebond au niveau de l'économie. Gillingham *et al.* (2013) prennent l'exemple des normes sur les véhicules aux Etats-Unis pour expliquer cet effet rebond. Celles-ci entrainent une baisse du prix du pétrole au niveau mondial, causant alors une augmentation de la demande de pétrole dans les autres pays. L'estimation de cet effet rebond varie considérablement entre les pays, en fonction du modèle utilisé (un modèle d'équilibre général, ou macroéconomique) et des variables prises en compte. Cependant, les études trouvent généralement que cet effet d'aubaine est supérieur à 37% (Sorrell, 2007; International Risk Governance Council, 2013). Par exemple, Barker *et al.* (2007) étudient l'effet rebond lié aux politiques environnementales au Royaume-Unis, entre 2000 et 2010 et montrent qu'il n'est pas assez grand pour empêcher une diminution significative de la consommation d'énergie et des émissions de gaz à effet de serre. Ils estiment simultanément l'effet indirect et l'effet au niveau de l'économie en utilisant un modèle macroéconomique et ils obtiennent un effet rebond de 11% environ en moyenne à travers tous les secteurs de l'économie, c'est-à-dire que la réduction de la demande d'énergie est 11% plus faible que ce qui était attendu. L'effet rebond direct s'élève lui à 15%, ce qui mène à un effet rebond total de 26% de la réduction attendue de la demande d'énergie.

- Green paradox

Les politiques environnementales pourraient devenir inefficaces à cause de l'existence du green paradox (Sinn, 2008). Au lieu de diminuer les émissions de gaz à effet de serre, les politiques qui ont pour objectif de diminuer la demande d'énergies fossiles (comme la taxe carbone ou les subventions sur les énergies renouvelables) pourraient augmenter la pollution et accélérer le changement climatique, au moins sur le court terme. En utilisant un modèle de Hoteling, Sinn (2008) montre que l'introduction d'une taxe carbone qui augmente avec le temps peut en effet avoir des effets négatifs (il est à noter que le green paradox n'a jamais lieu quand on se situe sur le sentier optimal). Puisque la taxe augmentera le prix des énergies fossiles dans le temps, les producteurs ont intérêt à extraire et à vendre la ressource immédiatement. Une telle politique augmente alors les dommages environnementaux. Van der Ploeg et Withagen (2010) montrent que le green paradox se produit quand il s'agit d'énergie relativement coûteuse mais propre (comme l'énergie solaire ou éolienne). Si le gouvernement introduit des subventions sur l'énergie solaire et éolienne cela entrainera une surconsommation du pétrole et du gaz, soit une diminution plus rapide de ces énergies. Dans ce cas, le green paradox est confirmé et il provoque des effets négatifs sur le changement climatique. A l'inverse, il n'y a pas de preuve sur l'existence d'un tel paradoxe dans le cas d'une énergie propre, peu coûteuse comparé aux dommages marginaux du réchauffement climatique (comme l'énergie nucléaire). Dans ce cas, il est plus intéressant de laisser le combustible fossile inexploité et ainsi de limiter les émissions de CO2. Grafton *et al.* (2010) trouvent que les subventions sur les biocarburants pourraient menées au green paradox. Cela dépend de plusieurs variables telles que les élasticités de la demande et de l'offre, les changements attendus de la mesure, les changements technologiques concernant l'extraction et le coût de l'extraction. Il semblerait que le green paradox puisse arriver quand une politique climatique est annoncée en avance mais que la date de mise en place est incertaine. En effet, entre les deux dates (l'annonce et la mise en place), l'utilisation d'énergies fossiles et donc les émissions de gaz à effet de serre augmentent (Smulders *et al.* 2010).

Compte tenu de ces effets qui peuvent amoindrir l'efficacité des politiques environnementales, nous pouvons nous demander si les politiques françaises sont suffisamment efficaces pour atteindre les objectifs ambitieux fixés par le Grenelle de l'environnement. Ce travail doctoral vise à fournir des éclairages sur ces questions. Nous évaluons tout d'abord ces mesures au niveau national en utilisant un modèle de simulation (chapitre 2) et deuxièmement, nous nous intéressons plus particulièrement à une politique, le crédit d'impôt, et nous étudions son effet sur le comportement des ménages en utilisant une approche économétrique.

Dans le chapitre 2, nous testons l'impact de politiques existantes (le crédit d'impôt, le prêt à taux zéro, la subvention de l'ANAH et la TVA à taux réduit) et d'une politique envisageable (les bonus). Nous combinons plusieurs approches trouvées dans la littérature et nous modélisons la consommation d'énergie (en prenant en compte 3 usages : le chauffage et l'eau chaude, l'éclairage et les appareils électroménagers), résultant de la dynamique du stock de logement et des décisions d'investissement dans des équipements économiseurs d'énergie. Cette étude a trois principaux apports : (1) nous fournissons une estimation de la consommation d'énergie résidentielle et des émissions de gaz à effet de serre en France jusqu'en 2050, (2) nous évaluons l'impact de politiques environnementales comparé à leur coût public et (3) nous proposons différentes manières d'atteindre les objectifs fixés par le Grenelle de l'environnement. Les résultats montrent que les politiques actuelles sont efficaces dans le sens ou elles ont permis de diminuer la consommation et les émissions de gaz à effet de serre sur les dernières années. La consommation d'énergie du secteur résidentiel aurait été 28% plus élevée en 2010 sans l'introduction des politiques environnementales, et les émissions de gaz à effet de serre 55% plus importantes. Le crédit d'impôt semble être une des mesures les plus efficaces. Cependant, les politiques existantes ne sont pas suffisantes pour atteindre les objectifs en 2050. Des dépenses publiques supplémentaires sont nécessaires pour cela.

Nous avons vu que le crédit d'impôt semblait être une des politiques les plus efficaces, mais que cette mesure représente un coût public important. Dans le chapitre 3, nous examinons les impacts du crédit d'impôt sur le taux de rénovation et sur les dépenses de rénovation. Notre objectif est double. Premièrement nous cherchons à déterminer si les ménages sont sensibles à cette mesure ou si le crédit d'impôt fournit simplement des financements supplémentaires à des ménages qui auraient entrepris des travaux de rénovation sans la mise en place de cette mesure (c'est à dire s'il existe un effet d'aubaine). Deuxièmement, nous nous intéressons aux dépenses de rénovation et nous regardons si la politique encourage les ménages à entreprendre des rénovations énergétiques plus coûteuses et plus efficaces. Pour ce faire, nous utilisons des méthodes de matching et des données de ménages issues de l'enquête maîtrise de l'énergie de l'ADEME et de la SOFRES, de 2001 à 2008, qui regroupent des informations sur les rénovations énergétiques. Nous trouvons que le crédit d'impôt a un impact significatif et positif sur le taux de rénovation et sur les dépenses. Cette mesure a essentiellement un impact sur les dépenses de rénovation : elle permet une augmentation des dépenses de 24,65% si nous considérons des prix courant. Cependant, l'effet sur le nombre de rénovations est très faible, en particulier si nous le comparons au coût public de la politique. Le crédit d'impôt entraine une augmentation des rénovations de 0,89% entre 2005 et 2008. Les résultats suggèrent la présence d'un effet d'aubaine. En effet, 4,2 millions de ménages ont bénéficié du crédit d'impôt sur cette période mais cette mesure a incité seulement 900 000 ménages à rénover. De plus, les professionnels du bâtiment semblent capter une part des gains liés au crédit d'impôt à travers une augmentation des prix. Ces deux effets amoindrissent l'impact de la mesure.

2. L'impact économique des dégradations environnementales pour les pays émergents : Le cas de l'Inde

Les enjeux

Dans les pays émergents, la préoccupation la plus importante n'est pas la mise en place de politiques environnementales adéquates pour diminuer les émissions de gaz à effet de serre, mais l'enjeu est de trouver un moyen de limiter les conséquences du changement climatique. En effet, les pays émergents sont les plus vulnérables face au réchauffement de la planète, comme nous pouvons le voir sur la carte 1 (p.17). Cette carte montre le « climate change vulnerability index » (Maplecroft, 2013). Cet index évalue l'exposition aux catastrophes naturelles, à l'élévation du niveau de la mer, ainsi que la dépendance des populations aux ressources naturelles et à l'agriculture. Il considère également la capacité d'adaptation des gouvernements et des infrastructures à contrer le changement climatique. Nous pouvons observer les pays avec un risque extrême en rouge sur la carte, et les pays avec un risque élevé en jaune. L'Inde fait partie des pays qui supporte un risque extrême.

Les pays émergents sont les plus exposés aux dégradations environnementales et aux évènements climatiques causés par l'activité humaine. Cependant, les émissions de gaz à effet de serre ont augmenté rapidement dans ces pays ces dernières années et il est fortement possible que cette tendance continue dans le futur. En effet, l'Inde fait partie des plus gros émetteurs de dioxyde de carbone après la Chine, les Etats-Unis, l'Union Européenne et la Russie. Ses émissions totales ont augmenté de 113% entre 1990 et 2010 (ou de 3,9% par an en moyenne sur la période). Pour comparaison, les émissions de l'Union Européenne ont diminué de 10% sur l'ensemble de la période et celles des Etats-Unis ont augmenté d'environ 9% (source : CAIT). De plus, l'Inde est le quatrième plus gros consommateur d'énergie dans le monde, après les Etats-Unis, la Chine et la Russie. La consommation d'énergie primaire a plus que doublé entre 1990 et 2010 même si la consommation d'énergie par tête reste plus faible que celle des pays développés (selon l'U.S. Energy Information Administration). Deux éléments peuvent expliquer cette forte hausse. Premièrement, la croissance économique en Inde a été très élevée, atteignant presque 7% par an entre 2000 et 2010. Deuxièmement, la croissance de la population est particulièrement importante, avec une augmentation de 40% entre 1990 et 2010. Les pressions sur l'environnement sont donc fortes et nous pouvons penser qu'elles deviendront plus importantes encore avec la croissance économique soutenue et l'augmentation de la population dans le futur.

L'impact des dégradations environnementales sur la population

Comme nous l'avons vu précédemment, les dégradations environnementales peuvent avoir un impact sur l'IDH et sur le revenu (PNUD, 2011) mais elles peuvent également avoir des conséquences économiques pour les populations. La littérature sur le sujet n'est pas très étendue. Elle s'intéresse notamment aux effets négatifs de la pollution de l'air, sur la santé par exemple, mais elle s'intéresse moins aux effets de la déforestation sur les agents économiques. Cependant, la déforestation et l'accès restreint aux ressources naturelles pourraient affecter les ménages. En effet, les ressources naturelles représentent une part non négligeable du revenu des ménages ruraux (Cavendish, 2000; Kamanga *et al.* 2009). Par exemple, en Inde, 200 millions de personnes sont dépendantes des forêts comme moyens de subsistance (source: Indian Ministry of Environment and Forest). Les individus vivant dans les zones rurales dépendent fortement du bois : plus de 80% des ménages ruraux utilisent de la biomasse traditionnelle comme source principale de combustible pour la cuisson, contre seulement 22% des ménages urbains (source : 2011 India census). La déforestation est en même temps une des plus grandes dégradations environnementales visibles. L'Inde est le dixième pays dans le monde en terme de couverture forestière, avec environ 68 millions d'hectares de forêts (source : Global Forest Resource Assessment, 2010), mais environ 41% de la couverture forestière a été dégradée au cours des dernières décennies. L'accroissement de la population, la sur-utilisation des ressources et le besoin de terres sont les principales causes de la déforestation. Et les conséquences peuvent être dramatique : la déforestation est responsable de 20% des émissions de gaz à effet de serre mondiale (source : GIEC) et la déforestation tropicale en Asie, Afrique et Amérique du Sud contribue en grande partie à ces émissions.

La pollution et les changements environnementaux peuvent aussi avoir un impact sur l'accès des individus au marché du travail. Peu d'études s'intéressent à cette relation alors que l'accès au marché du travail est directement lié à des questions de pauvreté et d'inégalités, notamment en termes de différences hommes et femmes. Sala-i-Martin (2005) montre que la pollution, à travers ses impacts sur la santé, a des effets négatifs sur le capital humain et la productivité. En effet, les ménages pauvres n'ont pas les moyens d'améliorer leur santé. Par conséquent, il est plus difficile pour eux d'augmenter leur capital humain et leur productivité économique. Dans ce cas, la pollution peut exacerber la pauvreté et la rendre plus persistante. Les ménages les plus pauvres entre donc dans un cercle vicieux, connu sous le nom de trappe à pauvreté (Dasgupta et Ray, 1986, 1987). Concernant les dégradations environnementales comme la déforestation, le lien avec la participation au marché du travail est mal connu. Kumar *et al.* (1988) montrent que la détérioration de l'accès au bois, mesurée par le temps passé à ramasser du combustible, conduit les femmes à consacrer moins de temps aux activités agricoles productives. Cependant, les auteurs ne prennent pas en compte le potentiel problème d'endogénéité des variables, donc l'interprétation des résultats doit être réalisée avec précaution. A l'inverse, Cooke (1998b) souligne qu'au Népal les ménages allouent plus de temps à des activités de collecte quand les produits environnementaux sont plus coûteux, mais ne trouve cependant aucune relation entre la collecte et le temps que les femmes consacrent à l'agriculture.

Dans ce travail doctoral, nous nous concentrons sur ce dernier point et essayons d'apporter quelques éclairages sur la manière dont l'environnement peut affecter les agents et comment ils s'adaptent à la déforestation. C'est l'objectif du dernier chapitre (chapitre 4). La déforestation, en augmentant la rareté du bois pourrait avoir un impact sur les agents. Dans les pays émergents, les ménages ruraux dépendent généralement fortement des produits environnementaux collectés tels que le bois. Les femmes sont les plus concernées par la collecte de ressources naturelles. Nous cherchons à voir si la déforestation et la pénurie de combustible ont à la fois un impact direct sur la décision de collecter des ressources naturelles et un effet indirect sur la participation au marché du travail à travers les activités de collecte. Nous utilisons un probit bivarié pour estimer simultanément la décision de collecter du bois et la probabilité de participer au marché du travail. Les données sont issues de l'Indian Human Development Survey de 2004. Nous montrons que la rareté du combustible augmente la probabilité que les femmes soient impliquées dans la collecte de combustible. À travers cela, elle a un effet négatif sur la participation au marché du travail, particulièrement en ce qui concerne les activités salariales. Nous trouvons que cet effet est plus prononcé pour les ménages vivant au-dessus du seuil de pauvreté et cela s'explique par le fait que la contrainte de revenu est plus faible pour eux.

Cette thèse se compose donc de quatre chapitres. Nous étudions tout d'abord les déterminants de la consommation d'énergie en France (chapitre 1) et ensuite nous évaluons l'impact des politiques environnementales au niveau national (chapitre 2) et sur le comportement des ménages (chapitre 3). Finalement, nous étudions l'impact de la déforestation sur l'accès des femmes au marché du travail en Inde (chapitre 4). Nous espérons que ce travail doctoral apporte quelques éclairages nouveaux sur la manière dont la pollution et les dégradations environnementales affectent les économies contemporaines grâce à notre recherche sur (1) l'évaluation des politiques publiques dans les pays développés et sur (2) l'évaluation de l'impact des dégradations environnementales dans les pays émergents. La partie suivante synthétise les principaux résultats et apports de cette thèse.

3. Principaux apports de ce travail doctoral

Nous avons mis en évidence plusieurs éléments susceptibles de diminuer l'impact des politiques environnementales. Premièrement, nous observons la présence d'un effet d'aubaine. Il représente plus de 40% des ménages qui rénovent entre 2011 et 2050 si nous prenons en compte toutes les politiques environnementales (chapitre 2). Cet effet est plus important en début de période puis il s'estompe au fil du temps. Si nous considérons uniquement le crédit d'impôt entre 2005 et 2008 l'effet d'aubaine atteint 79% (chapitre 3). En effet, sur cette période le crédit d'impôt a encouragé 900 000 ménages à rénover, toutes choses égales par ailleurs, alors que 4,2 millions de ménages ont bénéficié de cette mesure. L'effet d'aubaine semble donc être particulièrement important pour les mesures fiscales.

Deuxièmement, les politiques publiques ne sont pas suffisantes pour encourager les ménages à faible revenu ainsi que les locataires à rénover. Même si la consommation d'énergie réagit faiblement à une augmentation du revenu par unité de consommation (dans le chapitre 1, nous trouvons une élasticité-revenu de 0,02 pour les ménages vivant dans des maisons et non significative pour ceux vivant dans des appartements), le revenu joue un rôle important dans la décision de rénover. Ce sont principalement les ménages appartenant aux quatrième et cinquième quintiles de revenus qui investissent (comme nous le voyons dans le chapitre 2 et 3). Les politiques publiques ne parviennent pas à inciter les ménages à faibles revenus à rénover. De plus, nous avons montré dans le chapitre 1 que les appartements équipés d'un chauffage collectif (utilisant du gaz naturel ou du fuel) consomment significativement plus d'énergie que ceux équipés d'un chauffage individuel (utilisant du gaz naturel ou de l'électricité) toutes choses égales par ailleurs. Cependant, dans ce type de logement, la décision de rénover est prise à la majorité des copropriétaires. Les équipements économiseurs d'énergie ont donc une probabilité plus faible d'être adoptés. De plus, les politiques environnementales, telles que le crédit d'impôt, incite principalement les propriétaires occupants à rénover, et n'a pas de réel impact sur les locataires. Un locataire a moins d'incitation à réaliser des investissements économiseurs d'énergie puisqu'il ne reste pas assez longtemps dans son logement pour s'assurer des retours sur investissement. Alors qu'à l'inverse, les rénovations augmentent la valeur du logement pour les propriétaires.

Troisièmement, le marché des rénovations énergétiques est imparfaitement compétitif et cela permet aux professionnels du bâtiment de capter une partie des bénéfices du crédit d'impôt, à travers une augmentation des prix. Nous montrons dans le chapitre 3 que le crédit d'impôt a entrainé une augmentation des dépenses de rénovation de 24,65% mais les deux-tiers de cette augmentation sont liés à une augmentation des prix.

Pour finir, nous constatons dans le chapitre 1, que les investissements dans l'isolation du vitrage peuvent ne pas avoir d'impact sur la consommation d'énergie. Les ménages peuvent décider d'opter pour un plus haut niveau de confort et donc une température intérieure plus élevée suite à l'investissement. Cet effet rebond signifie que l'impact des rénovations sur les émissions de gaz à effet de serre et la consommation d'énergie pourrait être nul.

Ces quatre effets réduisent donc l'impact des politiques environnementales. Par conséquent, les politiques actuelles ne sont pas suffisantes pour atteindre les objectifs fixés par le Grenelle de l'environnement. Grâce aux simulations réalisées dans le chapitre 2, nous sommes en mesure de proposer des solutions pour atteindre une consommation moyenne de 50 kWh_{ep}/m^2 et diviser par 4 les émissions de gaz à effet de serre d'ici 2050, par rapport à leur niveau de 1990. Nous pourrions envisager d'augmenter significativement les taux de crédit d'impôt jusqu'à 54% (les taux actuels sont de 15% pour le double-vitrage, 25% pour l'isolation du toit et des murs et la modernisation du système de chauffage, et 40% pour l'adoption d'énergies renouvelables) ou d'introduire de nouvelles politiques telles que les bonus : un bonus de 2900 € par rénovation pourrait permettre d'atteindre les objectifs. Finalement, une combinaison de plusieurs politiques pourrait également être efficace : il serait possible d'atteindre les objectifs en 2050 avec un taux de crédit d'impôt de 45% pour toutes les rénovations dès 2011, combiné à un prêt à taux zéro, une TVA à 5,5%, un bonus

de 1000€ pour les ménages appartenant aux premier et second quintiles de revenus et un bonus de 500€ pour les autres ménages.
Cependant, de telles mesures représentent un coût public élevé. C'est pourquoi nous recommandons d'introduire un plafond de revenu pour limiter l'effet d'aubaine et ainsi cibler uniquement les ménages à faibles revenus. De plus, le coût public pourrait être limité grâce à la mise en place de taxes supplémentaires sur les prix de l'énergie. La consommation d'énergie est corrélée aux prix des énergies (en valeur absolue, l'élasticité-prix est de 0,46 pour les maisons et de 0,86 pour les appartements). De plus, une forte augmentation des prix inciterait les ménages à investir rapidement dans des rénovations énergétiques, toutes choses égales par ailleurs. Si l'évolution des prix de l'énergie reste telle qu'elle est prévue par l'Agence Internationale de l'Energie (c'est à dire une hausse annuelle des prix de 3,1% pour l'électricité, de 3,3% pour le fuel et de 3,6% pour le gaz), nous pourrions atteindre une consommation moyenne du parc de logements résidentiels de 50 kWh_{ep}/m^2 en 2078. Cependant, une taxe sur les prix de l'énergie affecterait principalement les personnes les plus pauvres et soulèverait la question de la précarité énergétique, mais une taxe peut également être redistribuée pour atteindre un objectif d'équité. Finalement, nous pouvons nous questionner sur la pertinence de mener une politique environnementale sans une coordination internationale. En effet, cela génère des coûts importants sans la garantie de diminuer les dommages environnementaux et les évènements climatiques.

Comme nous l'avons vu, les pays émergents sont plus exposés aux catastrophes climatiques que les pays développés. Donc, leur principale préoccupation est de trouver un moyen de limiter les conséquences du changement climatique. Dans le chapitre 4, nous étudions la manière dont l'environnement peut affecter les agents et comment ils s'adaptent aux changements environnementaux. Plus précisément, nous essayons de comprendre le lien entre la déforestation ou la rareté du bois et la décision de collecter des ressources naturelles ou de participer au marché du travail. En Inde, les ménages sont également sensibles à l'évolution du prix des combustibles, en particulier ceux vivant au-dessus du seuil de pauvreté. En France, les ménages ajustent leur consommation d'énergie en fonction des prix. En Inde, les effets sont quelques peu différents. Une augmentation du prix du bois a un impact sur la participation des femmes au marché du travail. Les prix reflètent la rareté de la ressource. Des prix plus élevés incitent les femmes à collecter du bois elles-mêmes et cela réduit leurs probabilités de participer à des activités salariales. Cela signifie que la déforestation, en augmentant la rareté du bois, affecte les ménages. Ces résultats sont dans la lignée du rapport sur le développement humain du PNUD (2011) : les dégradations environnementales ont des effets néfastes sur les ménages. Il semble donc important d'améliorer les politiques qui visent à limiter la déforestation. Cela pourrait par exemple être réalisé à travers la protection des zones forestières ou par le biais des Joint Forest Management.

Etant donné nos résultats, plusieurs recommandations peuvent être formulées. Pour résumer, dans les pays développés la préoccupation la plus importante est la mise en place de politiques environnementales adéquates pour diminuer significativement les émissions de gaz à effet de serre. Pour atteindre cet objectif en France, les politiques actuelles doivent être renforcées. Premièrement les politiques environnementales devraient inciter les ménages vivant en appartement à remplacer les systèmes de chauffages collectifs par des chauffages individuels ou à installer des compteurs individuels. En effet, cela permettrait (i) de diminuer la consommation d'énergie dans les logements collectifs et (ii) d'inciter les ménages à rénover ou améliorer la qualité thermique de leur logement. L'incitation à rénover est faible pour un ménage vivant dans un appartement équipé d'un chauffage collectif puisque les économies d'énergie sont partagées entre tous les copropriétaires.

Deuxièmement, les politiques environnementales devraient diminuer le coût des équipements économiseurs d'énergie pour les ménages à faibles revenus, en introduisant par exemple des bonus importants, réservés à ces ménages par le biais de plafonds de revenus. Cela permettrait (i) de diminuer significativement la consommation d'énergie puisque ces ménages vivent souvent dans les logements les moins bien isolés et (ii) de s'intéresser seulement aux ménages qui ont besoin d'aide financière pour rénover dans le but de limiter l'effet d'aubaine.

Troisièmement, l'impact des mesures fiscales sur le nombre de rénovations est faible à cause de l'effet d'aubaine et, comme nous l'avons vu, les incitations financières représentent un coût public important. Donc, pour atténuer les effets négatifs liés à ces politiques tout en minimisant le coût public, une des possibilités serait de durcir les mesures réglementaires telles que les réglementations thermiques sur les nouvelles constructions. De plus, il est plus compliqué de diminuer la consommation d'énergie

grâce aux rénovations plutôt que directement construire un bâtiment basse consommation.
Finalement, les pays émergents doivent limiter les dégradations environnementales compte tenu de l'effet négatif sur les population. La déforestation est la plus grande dégradation environnementale visible et, dans ce contexte, une meilleure gestion des forêts, à travers par exemple les Joint Forest Management, est nécessaire.

Les questions environnementales soulèvent plusieurs questions. Même si nous avons essayé d'amener quelques éclairages, il serait intéressant de continuer ces recherches.

4. Perspectives

Suite à ce travail doctoral, nous prévoyons de nous intéresser aux questions de précarité énergétique en France. Selon l'INSEE, environ 13% des ménages sont dans une situation de précarité énergétique. Cela correspond à des ménages qui consacrent plus d'un dixième de leur revenu à des dépenses énergétiques, afin de chauffer leur logement à un niveau acceptable. En effet, les dépenses énergétiques représentent une part élevée du revenu des ménages appartenant aux premiers quintiles de revenus. Dans le même temps, le revenu peut limiter les investissements économiseurs d'énergie. Cependant, peu d'études s'intéressent à la précarité énergétique dans les pays développés. Nos contributions pourraient être d'identifier les principaux facteurs menant un ménage à la précarité énergétique, dans le but de mettre en place des mesures adéquates et efficaces pour lutter contre ce phénomène. De telles politiques pourraient augmenter le bien être de ces ménages et pourraient également avoir un impact sur la consommation d'énergie du secteur résidentiel. En effet, nous nous attendons à ce que les ménages qui sont en situation de précarité énergétique vivent dans les logements les moins bien isolés et émettent plus de gaz à effet de serre.

Comme nous l'avons vu dans le dernier chapitre de cette thèse, la rareté des ressources naturelles telles que le bois, peut avoir des effets négatifs sur les ménages, en entravant l'accès des femmes au marché du travail. Par conséquent, l'accès des ménages à des combustibles modernes pourrait avoir un impact positif sur la croissance économique dans les pays émergents, comme le chapitre 4 et la littérature sur l'accès à l'électricité semble le montrer. Mais cela pourrait également augmenter la pollution, qui à son tour affecterait le bien être des ménages. Nous pourrions dans des travaux futurs, analyser l'impact de l'accès aux énergies modernes sur le développement à un niveau macroéconomique, en considérant également les effets liés à la pollution.

Pour aller plus loin, pour pouvons également nous intéresser à l'impact des réglementations limitant la pollution en Inde sur la productivité des ménages. La littérature s'intéresse à l'impact de la pollution sur la santé. A travers cet effet, la pollution peut accroitre la pauvreté et la rendre plus persistante (Sala-i-Martin, 2005). En effet, les ménages pauvres n'ont pas les moyens d'améliorer leur santé. Par conséquent, cela est plus difficile pour eux d'augmenter leur capital humain et leur productivité économique. Les ménages pauvres peuvent donc entrer dans un cercle vicieux connu sous le nom de trappe à pauvreté (Dasgupta et Ray, 1986, 1987). La croissance rapide en Inde a créé des pressions sur l'environnement et a accéléré la pollution : les émissions de gaz à effet de serre ont augmenté de 113% entre 1990 et 2010. Cependant, des réglementations sur la pollution de l'air ont été adoptées dès 1981. Des actions ont été mises en place pour réduire la pollution dans les villes très polluées et 17 villes sont aujourd'hui concernées par ces mesures. Nous pourrions étudier l'impact de ces réglementations afin de voir si elles sont suffisamment efficaces pour améliorer la productivité des travailleurs et empêcher les ménages d'entrer dans la trappe à pauvreté.

Tableau - Résumé

	Objectifs	Approche	Données	Résultats
Chapitre 1	Etudier les déterminants de la consommation d'énergie résidentielle: (11) Analyser le poids relatif des caractéristiques des ménages, du bâti et des spécificités climatiques pour expliquer la consommation d'énergie par mètre carré (12) Identifier les sources principales d'économie d'énergie dans le secteur résidentiel français (13) Proposer une estimation des élasticités prix et revenu de la consommation d'énergie par mètre carré	Modèle à choix discret et continu	- INSEE Enquête logement de 2006 - Données sur les prix de l'énergie issues du Ministère de l'économie, des finances et de l'industrie	(11) La consommation d'énergie est presque entièrement déterminée par les caractéristiques techniques du bâti et le climat, alors que les caractéristiques des ménages ont un impact très faible sur le niveau de la consommation d'énergie. *(12)* Le chauffage collectif augmente la consommation de façon importante *ceteris paribus* Nous constatons la présence d'un effet rebond sur le double-vitrage dans les maisons. (13) L'élasticité-prix est égale en valeur absolue à 0,46 pour les ménages vivant dans des maisons et 0,86 pour ceux vivant dans des appartements L'élasticité-revenu est faible (0,02) pour les ménages vivant dans des maisons et non significative pour ceux vivant dans des appartements.
Chapitre 2	Evaluer les politiques environnementales au niveau national (14) Estimer la consommation d'énergie et les émissions de gaz à effet de serre du secteur résidentiel en France jusqu'en 2050 (15) Evaluer l'impact des politiques environnementales sur la consommation d'énergie, les émissions de gaz à effet de serre et le nombre de rénovations (16) Proposer des solutions pour atteindre les objectifs fixés par le Grenelle de l'environnement	Modèle de simulation, avec une approche bottom-up. Nous modélisons : - La consommation d'énergie est les émissions de GES - La décision d'investir dans des rénovations énergétiques - Le parc de logement	- INSEE Enquête logement 2006 - Ministère de l'écologie, de l'énergie, du développement durable et de la mer, pour des informations sur le nombre de logements et de nouvelles constructions - Logiciel de simulation PROMODUL, utilisé pour estimer la consommation d'énergie et les émissions de GES pour chaque catégorie de logements - L'Agence Internationale de l'Energie pour les prix de l'énergie	(14) Avec les politiques actuelles, la consommation d'énergie moyenne sera de 91,67 kWh_{ep}/m^2 en 2050 (l'objectif étant de 50 kWh_{ep}/m^2). (15) Les politiques sont efficaces mais pas assez pour atteindre les objectifs du Grenelle de l'environnement L'effet d'aubaine représente 40,15% des rénovations entreprises entre 2011 et 2050. Le crédit d'impôt est une des politiques les plus efficaces. (16) Pour atteindre les objectifs, il est nécessaire de mettre en place des politiques plus ambitieuses. Une combinaison de plusieurs politiques peut être envisagée : un crédit d'impôt de 45% pour toutes les rénovations dès 2011, combiné avec un prêt à taux zéro, une TVA à taux réduit de 5,5%, un bonus de 1000€ pour les ménages appartenant au 1er et 2ème quintiles de revenus et un bonus de 500€ pour les autres.

Chapitre 3	Evaluer l'effet du crédit d'impôt sur le comportement des ménages (17) Déterminer si les ménages sont sensibles à cette politique ou si le crédit d'impôt fournit un financement aux ménages qui auraient tout de même rénové sans politique (effet d'aubaine) (18) Analyser l'impact de cette mesure sur le montant des rénovations pour voir si le crédit d'impôt permet aux ménages d'investir dans des rénovations énergétiques plus coûteuses mais plus efficaces	Méthode d'appariement	ADEME-SOFRES enquête Maîtrise de l'Energie de 2001 à 2008	*(17)* Le crédit d'impôt permet d'augmenter le nombre de rénovations de 0,86%, *ceteris paribus*. Cela représente 900 000 rénovations, mais 4,2 millions de ménages ont reçu le crédit d'impôt entre 2005-2008 : présence d'un effet d'aubaine. (18) Le crédit d'impôt a permis d'augmenter les dépenses de rénovation (à prix courant) de 24,65%. L'effet est 3 fois plus faible si nous considérons des prix constants (8,9%) : Les professionnels du bâtiment captent une partie des gains du crédit d'impôt.
Chapitre 4	Etudier l'impact des changements environnementaux sur les agents, plus précisément l'impact de la déforestation et de la rareté du bois sur les femmes vivant en zones rurales : (19) Etudier l'impact de la déforestation et de la rareté de bois sur la décision des femmes de collecter cette ressource (20) Chercher à savoir s'il existe un effet indirect de la pénurie de bois sur la participation des femmes au marché du travail, à travers la collecte de ressources naturelles	Modèle d'équations simultanées : probit bivarié	- *Indian Human Development Survey* 2004-2005 - *Indian National Service Scheme* 2004 - *Forest Survey of India reports* 1999 et 2005	(19) Plus la ressource est rare, plus la probabilité que les femmes participent à la collecte de ressources naturelles est importante. (20) La collecte de bois diminue la probabilité de participer au marché du travail : les dégradations environnementales sont une barrière à l'accès des femmes au marché du travail. Quand la contrainte de revenu est trop forte, l'offre de travail est indépendante de la probabilité de collecter des ressources naturelles.

Bibliography

Aakvik A., 2001, Bounding a matching estimator: The case of a Norwegian training program, Oxford bulletin of economics and statistics.

ADEME and Tns SOFRES, 2009, Maitrise de l'énergie, Bilan 2009 - Phase 1 - Attitudes et comportements des particuliers, Note de Synthèse.

Alberini A., S. Banfi, C. Ramseier, 2011, Energy efficiency investments in the home: Swiss homeowners and expectations about future energy prices, Working paper Centre for Energy Policy and Economics.

Alberini A., A. Bigano, M. Boeri, 2013a, Looking for free-riding: Energy efficiency incentives and Italian homeowners, Working paper Fondazione Eni Enrico Mattei.

Alberini A., W. Gans, C. Towe, 2013b, Energy efficiency incentives: Do they work for heating and cooling equipment? Evidence from Maryland homeowners, Working paper presented at the 2012 Empirical Methods in Energy Economics annual meeting, Berlin.

Amacher, G., W. Hyde, K. R. Kanel, 1996, Household fuelwood demand and supply in Nepal's tarai and mid-hills: Choice between cash outlays and labour opportunity, World Development, 24(11): 1725-1736

American Meteorological Society, 2012, Climate Change, An information Statement of the American Meterological Society

Amstalden, R. W., M. Kost, C. Nathani, D. M. Imboden, 2007, Economic potential of energy-efficient retrofitting in the Swiss residential building sector: The effects of policy instruments and energy price expectations, Energy Policy 35, 1819–1829.

ANAH, 2008, Modélisation des performances énergétiques du parc de logements : Etat énergétique du parc en 2008, Rapport détaillé, étude réalisée par J. Marchal sous la tutelle d'E. Lagandre.

AON Benfield, 2013, Annual global climate and catastrophe report: Impact forecasting 2012, Report

Baker, P., R. Blundell, J. Micklewright, 1989, Modelling household energy expenditures using micro-data, Economic Journal 99(397): 720-738.

Baker, P., R. Blundell, 1991, The microeconometric approach to modeling energy demand: Some results for UK households, Oxford Review of Economic Policy 7(2), 54–76.

Baland J. M., P. Bardhan, S. Das, D. Mookherjee and R. Sarkar, 2010, The Environmental Impact of Poverty: Evidence from Firewood Collection in Rural Nepal, Economic Development and Cultural Change, Chicago Journal

Bandyopadhyay S., P. Shyamsundar, A. Baccine, 2011, Forests, biomass use and poverty in Malawi, Ecological Economics

Barker T., P. Ekins, T. Foxon, 2007, The macro-economic rebound effect and the UK economy, Energy Policy 35

Beillan V., E. Battaglini, A. Goater, A. Huber, I. Mayer, R. Trotignon, 2011, Barriers and drivers to energy-efficient renovation in the residential sector: Empirical findings from five European countries, ECEEE Report.

Bernard J. Th., D. Bolduc, D. Bélanger, 1996, Quebec residential electricity demand: A micro-econometric approach, Canadian Journal of Economics, XXIX (1), 92-113.

Bhattarai M., M. Hammig, 2001, Institutions and the Environmental Kuznets Curve for Deforestation: A cross-country Analysis for Latin America, Africa and Asia, World Development 29(6): 995-1010

Blundell R., M. Costa Dias, 2008, Alternative approaches to evaluation in empirical microeconomics, IZA Discussion Paper No. 3800.

Blunden J., D.S. Arndt, 2013, State of the climate in 2012, Bulletin of the American Meteorological Society 94(8), Special supplement to the

Bogdon A.S., 1996, Homeowner renovation and repair: The decision to hire someone else to do the project, Journal of housing economics

Bordia M. D., S. Desai, 2003, Why are Educated Women Less Likely to be Employed in India?, Social Protection Discussion Paper No. 313, Washington DC: The World Bank.

Boulanger P. M., 2007, Les Barrières à L'efficacité Energétique, Reflets et perspectives de la vie Economique, Tome XLVI, pp. 49-62.

Branch E. R., 1993, Short run income elasticity of demand for residential electricity using consumer expenditure survey data, The Energy Journal, 14(4), 227-236.

Braun F. G., 2010, Determinants of households' space heating type: A discrete choice analysis for German households, Energy Policy 38.

Brodaty T., B. Crépon, D. Fougère, 2001, Using matching estimators to evaluate alternative youth employment programs: Evidence from France, 1986-1988, Econometric Evaluation of Labour Market Policies, ZEW Economic studies 13.

Brodaty T., B. Crépon, D. Fougère, 2002, Do long-term unemployed workers benefit from active labor market programs? Evidence from France 1986-1998, mimeo.

Brown M. A., 2001, Market failures and barriers as a basis for clean energy policies, Energy Policy 29, 1197–1207.

Caliendo M., R. Hujer and S. L. Thomsen, 2005, The employment effects of job creation schemes in Germany: A microeconometric evaluation, IZA Discussion Paper No.1512.

Cameron T. R., 1985, A nested logit model of energy conservation activity by owners of existing single family dwellings, The review of Economics and Statistics.

Cavendish W., 2000, Empirical Regularities in the Poverty-Environmental Relationship of Rural Households: Evidence from Zimbabwe, World Development 28(11): 1979-2003

Cayla J. M., B. Allibe, M. H. Laurent, 2010, From practices to behaviors: Estimating the impact of household behavior on space heating energy consumption, ACEEE Summer Study Proceedings on Energy Efficiency in Buildings.

Cayla J. M., N. Maizi, C. Marchand, 2011, The role of income in energy consumption behaviour: Evidence from French households data, Energy Policy.

Charlier D., A. Risch, 2012, Evaluation of the impact of environmental public policy measures on energy consumption and greenhouse gas emissions in the French residential sector, Energy Policy 46.

Charlier D., 2013, Energy saving adoption in the residential sector an empirical analysis, Working paper IREGE.

Clerc M., A. Mauroux, 2010, Le recours au crédit d'impôt en faveur du développement durable, INSEE première No.1316.

Cooke P.A., 1998a, Intra-household labor allocation responses to environmental good scarcity: A case study from the hills of Nepal, Economic Development and Cultural Change 46(4): 807–830

Cooke P.A., 1998b, The effect of environmental good scarcity own-farm labor allocation: The case of agricultural households in rural Nepal, Environment and Development Economics 3: 443–469

Crépon B., N. Jacquemet, 2010, Econométrie: Méthode et applications, Editions De Boeck Université.

Cropper M., C. Griffiths, 1994, The interaction of population growth and environmental quality, American Economic Review 82:250–254

Dasgupta P., D. Ray, 1986, Inequality as a Determinant of Malnutrition and Unemployment: Theory, Economic Journal 96:1011-1034.

Diaz-Rainey I., J. K. Ashton, 2009, Domestic energy efficiency measures adopter heterogeneity and policies to induce diffusion, Working paper SSRN.

Druckman, A., M. Chitnis, S. Sorrell, T. Jackson, 2011, Missing carbon reductions? Exploring rebound and backfire effects in UK households, Energy Policy 39: 3572–3581.

Dubin J. A., S. E. Henson, 1988, The distributional effects of the federal energy tax act, Resources and Energy 10.

Dubin, J. A., D. L. McFadden, 1984, An econometric analysis of residential electric appliance holdings and consumption, Econometrica 52(2): 345-362.

Eto J., S. Kito, L. Shown, R. Sonnenblick, 1995, Where did the money go? The cost and performance of the largest commercial sector DSM programs, Lawrence Berkeley National Laboratory, Berkeley.

European Commission, 2011, Energy Efficiency Plan 2011, Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

FAO, 2010, Global Forest Resources assessment 2010 – Main report, FAO Forestry Paper No.163

FAO, 2012, State of the World’s Forests 2012, FAO Forestry paper

Forest Survey of India, 2011, India State of Forest Report, FSI

Forest Survey of India, 2005, India State of Forest Report, FSI

Francfort I., 2009, Interviews with stakeholders: Understanding their perceptions of the barriers and drivers concerning domestic energy use, energy-efficiency appliances and system mobility, Barenergy Report.

Garbacz C., 1984, Residential electricity demand: a suggested appliance stock equation, The Energy Journal 5 (2): 150-154.

Gillingham, K., M. Harding, and D. Rapson, 2012, Split Incentives in Household Energy Consumption, The Energy Journal 33(2): 37-62.

Giraudet, L.-G., C. Guivarch, P. Quirion, 2011, Comparing and combining energy saving policies: Will proposed residential sector policies meet French official targets?, The Energy Journal, 32(SI1): 213-242

Godoy R., K. O'Neill, S. Groff, P. Kostishack, A. Cubas, J. Demmer, K. McSweeney, J. Overman, D. Wilkie, N. Brokaw, M. Martínez, 1997, Household determinants of deforestation by Amerindians in Honduras, World Development 25(6): 977-987

Golove W. H., J. H. Eto, 1996, Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency, Energy & Environment Division - Lawrence Berkeley National Laboratory.

Grafton R. Q., T. Kompas, N. V. Long, 2010, Biofuels subsidies and the green paradox, Working Paper CESifo No.2960, Munich.

Greene W. H., 1998, Gender Economics Courses in Liberal Arts Colleges: Further Results, The Journal of Economic Education 29(4): 291–300

Greening L. A., D. L. Greene, C. Difiglio, 2000, Energy efficiency and consumption - The rebound effect - A survey, Energy Policy.

Grösche P., C. Vance, 2009, Willingness to pay for energy conservation and free-ridership on subsidization: Evidence from Germany, The Energy Journal.

Grösche P., C.M. Schmidt, C. Vance, 2009, Identifying free-riding in energy-conservation programs using revealed preference data, Working paper SSRN.

Halvorsen B., B. Larsen, 2001, The Flexibility of Household Electricity Demand over Time, Resource and Energy Economics 23: 1-18.

Hasset K., E. G. Metcalf, 1995, Energy tax credits and residential conservation investment: Evidence from panel data, Journal of Public Economics 57.

Hassett K. A., Metcalf G. E., 1993, Energy Conservation Investment: Do Consumers Discount the Future Correctly?, Energy Policy, 21(6):710-16

Heckman J., H. Ichimura, P. Todd, 1997, Matching as an econometric evaluation estimator: Evidence from evaluating a job training program, Review of Economic Studies 64.

Heckman J., H. Ichimura, P. Todd, 1998, Matching as an econometric evaluation estimator, Review of Economic Studies 65: 261-294.

Heckman, J., R. Robb, 1985, Alternative methods for evaluating the impact of interventions: An overview, Journal of Econometrics 30(1-2): 239-267.

Ichino A., F. Mealli., T. Nannicini, 2008, From temporary help jobs to permanent employment: What can we learn from matching estimators and their sensitivity? Journal of Applied Econometrics.

Ilahi N., F. Grimard, 2000, Public Infrastructure and Private Costs: Water Supply and Time Allocation of Women in Rural Pakistan, Economic Development and Cultural Change 49(1): 45-75.

Imbens G. W., J. M. Wooldridge, 2009, Recent developments in the econometrics of program evaluation, Journal of Economic Literature 47:1.

International Energy Agency, 2013, World Energy Outlook, IEA report.

International risk governance council, 2013, The rebound effect: Implications of consumer behavior for robust energy policies, A review of the literature on the rebound effect in energy efficiency and report from expert workshops

IPCC, 2013, Climate change 2013: The physical Science Basis, Full report

Isaac M., D. P. Vuuren van, 2009, Modelling global residential sector energy demand for heating and air conditioning in the context of climate change, Energy Policy 37: 507–521.

Jaccard M., A. Bailie, J. Nyboer, 1996, CO2 Emission reduction costs in the residential sector: Behavioral parameters in a bottom-up simulation model. The Energy Journal 17: 107–134.

Jaffe A. B., R. N. Stavins, 1994, Energy-efficiency investments and public policy, The Energy Journal 15: 43–65.

Jakob M., 2006, Marginal costs and co-benefits of energy efficiency investments: The case of the Swiss residential sector, Energy Policy 34: 172–187.

Jones A., 2007, Applied Econometrics for Health Economics, Radcliffe Publishing Ltd, 2nd edition.

Kadian R., R. P. Dahiya, H. P. Garg, 2007, Energy-related emissions and mitigation opportunities from the household sector in Delhi, Energy Policy 35: 6195–6211.

Kamanga P., P. Vedeld, E. Sjaastad, 2009, Forest incomes and rural livelihoods in Chiradzulu district, Malawi, Ecological Economics

Khandker S., G. Koolwal, H. Samad, 2010, Handbook on impact evaluation: Quantitative methods and practices, The World Bank.

Koolwal G., D. Walle van de., 2013, Access to Water, Women's Work, and Child Outcomes, Economic Development and Cultural Change 61(2): 369–405.

Koop G., L. Tole, 1999, Is there an environmental Kuznets curve for deforestation?, Journal of Development Economics 58

Kumar S., D. Hotchkiss, 1988, Consequences of deforestation for women's time allocation, agricultural production, and nutrition in hill areas of Nepal, Research Report No. 69 (Washington, DC: International Food Policy Research Institute, 1988).

Labandeira X., J. M. Labeaga, M. Rodriguez, 2006, A residential energy demand system for Spain, The Energy Journal 27(2): 87-111.

Larsen B. M, R. Nesbakken, 2004, Household electricity end-use consumption: results from econometric and engineering models, Energy Economics 26(2): 179-200.

Legros G., I. Havet, B. Nigel and S. Bonjour, 2009, The energy access situation in developing countries, A review focusing on the least developed countries and Sub-Saharan Africa, World Health Organization

Leth-Petersen S., M. Togeby, 2001, Demand for space heating in apartment blocks: measuring effects of policy measures aiming at reducing energy consumption, Energy Economics

Levinson, A., S. Niemann, 2004, Energy use by apartment tenants when landlords pay for utilities, Resource and Energy Economics 26(51).

Lokshin M., R. Yemtsov, 2005, Has Rural Infrastructure Rehabilitation in Georgia Helped the Poor?, The World Bank Economic Review 19(2): 311-333.

Maddala G. S. (1983), Limited-Dependent and Qualitative Variables in Economics, New York: Cambridge University Press

Malm E., 1996, An action-based estimate of the free-rider fraction in electric utility DSM programs, The Energy Journal 17.

Mantel N., W. Haenszel, 1959, Statistical aspects of the analysis of data from retrospective studies of disease, Journal of National Cancer Institute.

Maruejols, L., D. Young, 2011, Split incentives and energy efficiency in Canadian multi-family dwellings, Energy Policy.

Masera O., B. Saatkamp, D. Kammen, 2000, From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model, World Development 28(12): 2083-2103

Mauroux A., 2012, Le crédit d'impôt dédié au développement durable: une évaluation économétrique, document de travail INSEE, Direction des Etudes et Synthèses Economiques.

MEDDTL, MINEFI, MBCPFP, ADEME, 2011, Synthèse de l'évaluation du crédit d'impôt développement durable.

Meier, H., K. Rehdanz, 2010, Determinants of space heating expenditures in Great Britain, Energy Economics.

Mendelsohn R., 1977, Empirical evidence on home improvements, Journal of urban economics.

Montgomery C., 1992, Explaining homes improvement in the context of household investment in residential housing, Journal of urban economics.

Moussaoui I., 2008, Appliances: shifting for renewable, refurbishment, purchase and use, Barenergy Report.

Murphy, K., R. Topel, 1985, Estimation and inference in two-step econometric models, Journal of Business and Economic Statistics 4, 370-379.

Nair G., L. Gustavsson, K. Mahapatra, 2010, Factors influencing energy efficiency investments in existing Swedish residential buildings, Energy Policy.

Nankhuni F. J., J. L. Findeis, 2004, Natural resource collection work and children's schooling in Malawi, Agricultural Economic 31: 123–134.

Ndiritu S. W., W. Nyangena, 2010, Environmental goods collection and children's schooling: Evidence from Kenya, Working Paper Environment for Development

Nemry, F., J. Theunis, T. Bréchet, P. Lopez, 2000, Réduction des émissions de gaz à effet de serre et flux de matières, Rapport final aux Services Fédéraux des Affaires Scientifiques, Techniques et Culturelles (SSTC), Institut pour un Développement Durable, asbl.

Nesbakken R., 1999, Price sensitivity of residential energy consumption in Norway, Energy Economics 21(6): 493-515.

Nesbakken R., 2001, Energy consumption for space heating: a discrete-continuous approach, Scandinavian Journal of Economics 103(1): 165-184.

Newell R. G., W. A Pizer, 2008, Carbon mitigation costs for the commercial building sector: Discrete-continuous choice analysis of multifuel energy demand, Resource and Energy Economics 30(4), 527-539.

Nguyen Van P., T. Azomahou, 2007, Nonlinearities and heterogeneity in environmental quality: An empirical analysis of deforestation. Journal of Development Economics 84

NYSERDA, 2012, New York's System Benefits Charge programs evaluation and status report, NYSERDA Final Report

Odyssee, 2013, Energy efficiency trends in the EU – Synthesis, Odyssee publication.

Parti M., C. Parti, 1980, The total and appliance-specific conditional demand for electricity in the household sector, Bell Journal of Economics, 309-21.

Peterson T.C., M.P. Hoerling, P.A. Stott, S.C. Herring, 2013, Explaining extreme events of 2012 from a climate perspective, Bulletin of the American Meteorological Society 94(9), special supplement

Ploeg F. van der, C. Withagen, 2012, Is There Really a Green Paradox?, Journal of Environmental Economics and Management 64

Pon S., A. Alberini, 2012, What are the effects of energy efficiency incentives? Evidence from the U.S. Consumer Expenditure Survey, Working paper presented at the International Association for Energy Economics.

Potepan M. J., 1989, Interest Rates, Income, and Home Improvement Decisions, Journal of Urban Economics

Rehdanz K. 2007. Determinants of residential space heating expenditures in Germany, Energy Economics 29.

Rosenbaum P.R., D.B. Rubin, 1983, The central role of propensity score in observational studies for causal effect, Biometrika 70.

Rosenow J., R. Galvin, 2013, Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK, Energy and Buildings 62.

Rubin D.B., 1974, Estimating causal effects of treatments in randomized and nonrandomized studies, Journal of Educational Psychology 66.

Rubin D.B., 1977, Assignment to treatment group on the basis of a covariate, Journal of Educational Statistics 2.

Sabatier M., 2012, Does productivity decline after promotion? The case of French Academia, Oxford Bulletin of Economics and Statistics 4.

Sala-i-Martin X, 2005, Health and economic growth: Findings and policy implications, MIT Press, Cambridge.

Sanstad A.H., C. Blumstein, S.E. Stoft, 1995, How high are option values in energy-efficiency investments? Energy Policy 23: 739–743.

Santin O. G., L. Itard, H. Visscher, 2009, The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy and Buildings.

Sardianou E. 2008. Estimating space heating determinants: An analysis of Greek households, Energy and Buildings 40.

Sartori, I., H. V. Bergsdal, D. B. Muller, H. Brattebø, 2008, Towards modelling of construction, renovation and demolition activities: Norway’s dwelling stock, 1900–2100. Building Research and Information 36: 412–425.

Schipper, L. G., M. Grubb, 2000, On the rebound? Feedback between energy intensities and energy uses in IEA countries, Energy Policy 28 (5-6): 367-388.

Shimoda Y., T. Fujii, T. Morikawa, M. Mizuno, 2004, Residential end-use energy simulation at city scale, Building and Environment 39: 959–967.

Shimoda Y., Y. Yamaguchi, T. Okamura, A. Taniguchi, Y. Yamaguchi, 2010, Prediction of GHG reduction potential in Japanese residential sector by residential energy end-use model, Applied Energy 87: 1944-1952.

Siller T., M. Kost, D. Imboden, 2007, Long-term energy savings and GHG emission reductions in the Swiss residential sector, Energy Policy 35: 529–539.

Sinn H. W., 2008, Public policies against global warming, International Tax and Public Finance 15 (4): 360-394

Smith J. A., P. E. Todd, 2005, Does matching overcome LaLonde's critique of nonexperimental estimators?, Journal of Econometrics 125.

Smulders S., Y. Tsur, A. Zemel, 2010, Uncertain climate policy and the Green Paradox, Discussion Paper

Soest D. P. van, E. H. Bulte, 2001, Does the energy-efficiency paradox exist? Technological progress and uncertainty, Environmental and Resource Economics 18: 101–112.

Sorrell S., 2007, The rebound effect: An assessment of evidence for economy-wide energy savings from improved energy efficiency, UK Energy Research Centre report

Swan L.G., I Ugursal, 2009, Modelling of end-use energy consumption in the residential sector: a review of modelling techniques, Renewable and Sustainable Energy Reviews 13: 1819–1835.

UNDP, 2011, Sustainability and Equity: A better Future for All, Human Development Report

Vaage K, 2000, Heating technology and energy use: A discrete/continuous choice approach to Norwegian household energy demand, Energy Economics 22(6): 649-666.

Vringer K., T. A. K. Blok, 2007, Household energy requirement and value patterns, Energy Policy 35: 553–566.

Weber C., A. Perrels, 2000, Modelling lifestyle effects on energy demand and related emissions, Energy Policy 28: 549–566.

Whitehead K. A., 2011, Women in the Workforce: How Cultural Factors Affect Labor Supply, University of Tennessee Honors Thesis Projects.

World bank, 2006, Unlocking Opportunities for Forest-Dependent People in India – Main report, Document of World Bank

World Commission on Environment and Development, 1987, Our common Future, Report (Brundtland report)

Zagamé P., 2008, Modèles de l'énergie et nouvelles théories du progrès technique, Communication au Conseil Français de l'Energie.

Zhao T., L. Bell, W. Horner, J. Sulik, J. Zhang, 2012, Consumer responses towards home energy financial incentives: a survey-based study, Energy Policy 47.

Abstract:

In the context of growing concerns for climate change, the objective of this dissertation is to bring some insights on two environmental issues. The first one deals with the question of whether environmental policies are efficient enough to significantly decrease greenhouse gases emissions and energy consumption and the second one concerns the way households' well-being is affected by environmental changes.
France committed to reduce greenhouse gases emissions and energy consumption in residential sector. In a first time, we study the determinants of residential energy consumption in France. An in-depth understanding of energy consumption is needed to design adequate energy policies and achieve a low-carbon society. We show that to improve buildings' energy efficiency, the challenge is to induce households to undertake renovations and to adopt energy-saving equipments. This is the objective of public policies, such as tax credit or subsidies. We evaluate in a second time the impact of these measures, using a simulation model. The results show that while current policies are effective, they are not sufficient to reach the objectives. Finally, we focus on the impact of the tax credit on households' behavior. The impact of the measure on renovation rate is very low compared to its cost and this is partially due to free riding. Emerging countries are more exposed to climate disasters than developed ones. Therefore, the most important concern in emerging countries is to find a way to limit the consequences of climate change. In this context, our objective is to understand how deforestation, that increases fuel scarcity, affects population. We focus on women, living in rural India. We show that fuel scarcity increases the probability for women to be involved in natural resource collection. Through this, it has a negative effect on the labor force participation, especially on family business and wage activities.

Keywords: Public policies evaluation, environment, energy

Résumé:
Le changement climatique est devenu une préoccupation majeure. L'objectif de cette thèse est d'apporter quelques éclairages sur les questions environnementales actuelles. Premièrement, nous nous interrogeons sur l'efficacité des politiques environnementales. Deuxièmement, nous nous intéressons à la manière dont le bien être des ménages peut être affecté par les dégradations environnementales.
La France s'est engagée à réduire les émissions de gaz à effet de serre et la consommation d'énergie dans le secteur résidentiel. Nous étudions dans un premier chapitre les déterminants de la consommation d'énergie résidentielle, afin d'identifier les politiques les plus efficaces pour améliorer l'efficacité énergétique dans ce secteur. Nous montrons que l'enjeu est d'inciter les ménages à entreprendre des travaux de rénovation. C'est l'objectif de politiques telles que le crédit d'impôt développement durable ou les subventions. Dans un second chapitre, nous évaluons l'impact de ces mesures à l'aide d'un modèle de simulation. Les résultats montrent que si les politiques actuelles sont efficaces, elles ne sont pas suffisantes pour atteindre les objectifs fixés. Enfin, nous nous concentrons dans un troisième chapitre sur l'impact du crédit d'impôt sur le comportement des ménages. Cette mesure incite peu les ménages à réaliser des rénovations, et ceci s'explique en partie par un effet d'aubaine. Les pays émergents sont les plus exposés aux catastrophes climatiques. Nous cherchons à voir dans un quatrième chapitre comment les dégradations environnementales affectent les ménages. La déforestation augmente la rareté des ressources naturelles telles que le bois. Cela accroît la probabilité que les femmes soient impliquées dans la collecte des ressources naturelles et par ce biais, diminue leur participation au marché du travail.

Mots-clés: Evaluation des politiques publiques, environnement, énergie