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Decarbonization of the Belgian residential buildings sector: how to deal with energy poverty?

Author: Louise Aeby

Thesis Director: Vincent Van Steenberghe

Thesis Reader: Jean Hindriks

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Université catholique de Louvain - Economics School of Louvain - Place Montesquieu 3, 1348 Louvain-La-Neuve
Université de Namur – Economics School of Namur – Rempart de la Vierge 8, 5000 Namur

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List of abbreviations and acronyms

C	CO_2	Carbon Dioxyde
	CO_2e	Carbon Dioxyde Equivalent
	CPAS	Centre Public d'Action Sociale (i.e. Public Social Welfare Centers)
	CPI	Consumer Price Index
	CREG	Commission for Electricity and Gas Regulation
E	EC	European Commission
	EPB	Energy Performance of Buildings
	EPBD	Energy Performance of Buildings Directive
	EPEE	European fuel Poverty and Energy Efficiency
	EPOV	European Union Energy Poverty Observatory
	ETS	Emission Trading Schemes
	EU	European Union
F	FEBEG	Federation of Belgian Electricity and Gas Enterprises
	FPS	Federal Public Service
G	GABC	Global Alliance for Buildings and Construction
	GHG	Greenhouse gas
H	HBS	Households Budget Survey
	hEP	Hidden energy poverty
I	IPCC	Intergovernmental Panel on Climate Change
L	LPG	Liquid petroleum gas
M	MDG	Millennium Development Goal
	mEP	Measured energy poverty
O	OECD	Organization of Economic Cooperation and Development
P	pEP	Perceived energy poverty
	PPS SI	Public Planning Social Service Integration

S	SDG	Sustainable Development Goal
	SPSO	Social Public Service Obligations
U	UK	United Kingdom
	UN	United Nations
V	VAT	Value Added Tax

Introduction

Climate change has become one of this Millennium's greatest challenges. In October 2018, the IPCC issued its special report on the impacts of a global warming of 1.5°C above preindustrial levels and greenhouse gases (IPCC, 2018). According to this report, global warming has already reached 1°C above preindustrial levels and is increasing by around 0.2°C every decade (IPCC, 2018). This means that by 2060 we would have reached 2°C of global warming and most certainly, irreversible consequences. It has now become imperative to take the right measures in order to mitigate climate change.

In 2015, the Paris Agreement was signed by 196 parties (EC, 2018a). The contracting parties agreed on the following objectives:

- "Holding the increase in global average temperature well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
- Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas (GHG) emissions development, in a manner that does not threaten food production; and
- Making finance flows consistent with a pathway towards low GHG emissions and climate-resilient development" (Paris Agreement, 2015).

In order to reach these objectives, the World's carbon emissions must have decreased by 100% by 2050 to stay below a temperature of 1.5°C or by 2070 to stay below 2°C (IPCC, 2018).

In this context, the European Commission (EC) has presented its strategy aimed at decreasing GHG emissions up to zero by 2050 (EC, 2018a). Belgium, as a European Union (EU) Member State, has also committed to decrease its GHG emissions by 80% to 95% of 1990 levels by 2050 (FPS Health, 2018). To do this, federal and regional governments will have or have already started to implement decarbonization policies in the different sectors of the economy.

This thesis will focus on one specific sector*: the residential buildings sector*, for two reasons. First, together with the transport sector, the residential sector is one that directly affects households. Hence, acceptability of new policies is ambiguous. Secondly, the buildings sector is one of the most carbon- and energy-intensive sector worldwide and in Belgium (FPS Health, 2018; FPS Economy, 2019a). Consequently, it is very likely to be subject to decarbonization policies in the near future.

Decarbonizing the Belgian residential sector requires two main levers. Firstly, performing mass renovation of buildings through insulation. Secondly, investing in energy efficient carbon-free heating systems. For instance, heating pumps. These two actions, which will be called "low-carbon levers/alternatives" in the rest of this thesis, will have to be performed by households. In order to induce them to invest in low-carbon alternatives, policymakers can use carbon-pricing policy instruments such as carbon taxes.

Households are key actors in the residential buildings sector's decarbonization. On the one hand, they are required to invest in low-carbon alternatives (i.e. insulation and carbon-free heating systems). On the other hand, if a carbon tax is implemented, energy prices are expected to rise in the short and medium term. Moreover, decarbonization levers and policies are often said to have a *distributive impact* on households (Markannen and Anger-Kraavi, 2019). In fact, they weigh more heavily on low-income households than on high-income households (Murray and Rivers, 2015). Primarily, because poor households have limited resources that prevent them from investing in low-carbon alternatives and from being able to face energy price increases due to carbon-pricing instruments. Subsequently, poor households will face increasing difficulties in accessing energy. A notion of poverty that directly explains these difficulties is "energy poverty". If decarbonization of the residential buildings sector is likely to increase energy poverty in Belgium, it will make the acceptability of new decarbonization measures and policies much more difficult.

This thesis aims to answer the following research question: *from a policy point of view, how to deal with energy poverty in the context of the decarbonization of the Belgian residential buildings sector?*

In order to answer this question, this thesis is divided in two parts. The first part explains *how* the decarbonization of Belgium's residential buildings sector will potentially increase energy poverty. To do so, Chapter 1 and Chapter 2 will primarily describe the two underlying issues of the research question individually: (1) the decarbonization challenge faced by the Belgian residential buildings sector and (2) the concept of energy poverty. These first two chapters allow to give a panoramic overview to better understand the context of the research question. Then, Chapter 3 will link these two issues to describe exactly how the residential buildings sector's decarbonization could lead to an increase in energy poverty.

The second part of this thesis analyzes how to design and implement complementary policies that allow to prevent an intensification of the energy poverty issue in Belgium. Chapter 4 will focus more specifically on complementary policies to decarbonization actions concerning low-carbon investments (i.e. insulation and heating systems). Chapter 5 will analyze the impact of the implementation of a carbon tax in Belgium on poor households and the ways in which these impacts can be alleviated through complementary policies. Finally, this thesis ends with a concluding section that aims to provide a clear answer to the research question.

The methodology that was used in this paper is the following. The first three chapters consist of a large literature review using data retrieved in the literature and in the Belgian Households Budget Survey (HBS) of 2016.

HBS 2016 was used in this thesis for two reasons. Firstly, it contains substantial information on the characteristics of Belgian households (age, occupation, family composition, housing, income). This will help to distinguish the characteristics of vulnerable households. Secondly, the survey asks questions related to households' energy consumption (energy sources and systems used) for different uses (space heating, water heating, cooking, space cooling) as well as households' spending for energy. These data will be used to understand energy consumption of Belgian households and to design policies that will support vulnerable households through decarbonization in the best possible way. To obtain the database, a request was made to Statistics Belgium. The data was received at an individual level and treated to obtain aggregated results. More information on the database is given in Chapter 3 because it will mostly be used in chapters 3, 4 and 5.

The methodology adopted in Chapter 4 is an economic analysis of the barriers that prevent households from investing in low-carbon alternatives. In Chapter 5, an econometric analysis of the determinants of households' energy consumption is made to provide criteria on which a compensation mechanism that will mitigate the impact of a carbon tax could be based. Both analysis are based on HBS 2016.

Part I: How could decarbonization increase energy poverty?

Chapter 1: Decarbonization challenge

In order to decrease the speed of global warming, each country must lower its level of CO_2 emissions. This involves the use of different actions and policy instruments that will drive the world towards a zero-carbon economy. Decarbonization is a challenge because it implies both changes in production and in consumption behaviors. This chapter introduces the decarbonization challenge today's Belgian *residential buildings sector* is facing.

The chapter is structured as follows. First, it introduces the two levers through which the decarbonization of the residential buildings sector can be achieved. Second, it describes the policy instruments that can be used by governments to provide incentives to reduce carbon emissions. Last, it will zoom into the case of Belgium: (1) explaining the main features of the Belgian residential buildings sector and (2) describing the different decarbonization policies which already exist or could be implemented in a near future in Belgium. This second point allows to understand how Belgian governments introduce low-carbon levers into their policy programs and the current debate about a potential carbon tax as a policy instrument.

1.1. LEVERS FOR A ZERO-CARBON RESIDENTIAL BUILDINGS SECTOR

Large-scale decarbonization can be achieved through two main actions: (1) a decrease in overall energy consumption and (2) a transition towards a carbon-free energy mix (Timmons et al., 2016; FPS Health, 2018; FPS Economy, 2019a). For the residential buildings sector, this implies the use of two levers. On the one hand, countries need to engage in mass energy renovations in order to decrease energy consumption. Buildings' renovation mainly implies improved insulation of the envelope (FPS Health, 2018). It allows to increase their energy performance which leads to large reductions in energy consumption. On the other hand, a transition towards a carbon-free energy mix in the residential buildings sector can mainly be accomplished by investing in heating systems using renewable resources. Space heating is the final use for which most energy is consumed by households, followed by water heating (GABC, 2018).

1.1.1. Mass energy renovation

Decarbonizing the residential buildings sector implies to take measures to decrease overall energy consumption. The World's residential sector is both very carbon- and energy-intensive. In 2017, it accounted for 39% of global GHG emissions and 36% of the global final energy consumption (GABC, 2018). In order to decrease energy consumption, the speed and quality of buildings renovations must significantly increase. Many studies have shown the great potential of an energy efficient buildings stock (Georges et al., 2012; Allouhi et al., 2015; Economidou et al., 2011). It does not only have positive impacts on the environment, but it also provides multiple benefits to society such as higher standards of living, better health, poverty mitigation, improved productivity and increases in employment (GABC, 2018).

The older the buildings, the less energy-efficient they are. At the EU level, the buildings stock is quite ancient. According to the EU Building Stock Observatory (2019), most of the EU's buildings have been built before 1990. It is the case for almost 80% of European buildings. Unless they have been renovated, older buildings are likely to consume much more energy than newer buildings. A report of the European Commission (2019b) insists on the fact that around 75% of the EU buildings stock is energy inefficient and that renovation rates are very low. Only 0.4% to 1.2% of the buildings are renovated every year (EC, 2019c).

More and more regulations targeting the improvement of energy performance and the renovation of buildings stocks are issued. According to the GABC report (2018), 69 countries have already implemented building energy codes and standards setting minimum efficiency requirements for buildings. In the EU, for example, a key directive regarding the energy consumption of buildings was introduced for the first time in 2002. This directive is called the Energy Performance of Buildings Directive (EPBD) (Economidou et al., 2011). It requires EU Member States to strengthen their buildings regulation and introduce energy performance of buildings labels (EC, 2019c). Since its introduction in 2002, the EPBD was revised twice in 2010 and in 2018 (Directive 2018/844/EU, 2018).

1.1.2. Carbon-free heating systems

The second lever that allows the decarbonization of an economy is the investment in the transition towards a carbon-free energy mix (Timmons et al., 2016; FPS Health, 2018). For the residential buildings sector, investing in carbon-free heating systems is the key (Georges et al., 2012). As mentioned before, space and water heating account for the greatest share of GHG emissions in the residential buildings sector. Indeed, it represented around 80% of the sector's total emissions in 2017 (GABC, 2018). Besides, still more than 55% of global energy consumed in the sector was supplied by fossil fuels in 2017 (GABC, 2018). Consequently, decarbonizing heat could highly contribute to the reduction of GHG emissions in the buildings sector.

Carbon-free heating systems include heating pumps and solar thermal technologies. Both make it possible to obtain enough heat from renewable energy sources for space heating and/or water heating (Georges et al., 2012; Timmons et al., 2016).

1.2. LOW-CARBON POLICY INSTRUMENTS

Decarbonization can also be achieved by implementing economic policy instruments that are aimed at reducing demand for carbon emissions (World Bank Group, 2018). These include norms, removal of fossil fuel subsidies and carbon pricing instruments such as Emissions Trading Schemes (ETS) and carbon taxes (Roman P., personal communication, March 2019). All these instruments provide incentives to reduce carbon consumption.

Since this thesis aims to discuss the distributive impacts of decarbonization on households, only one of the above-mentioned instruments will be presented into more detail in this section. *Carbon taxes* have a direct impact on households because they increase fossil fuel prices for end-users (Roman P., personal communication, March 2019). After the implementation of such a tax, households will see their energy bills increase. Consequently, the most vulnerable households are expected to suffer from carbon taxes. Other instruments such as norms, Emissions Trading Schemes of removal of fossil fuel subsidies affect mainly firms, and not end-users directly.

1.2.1. What are carbon taxes?

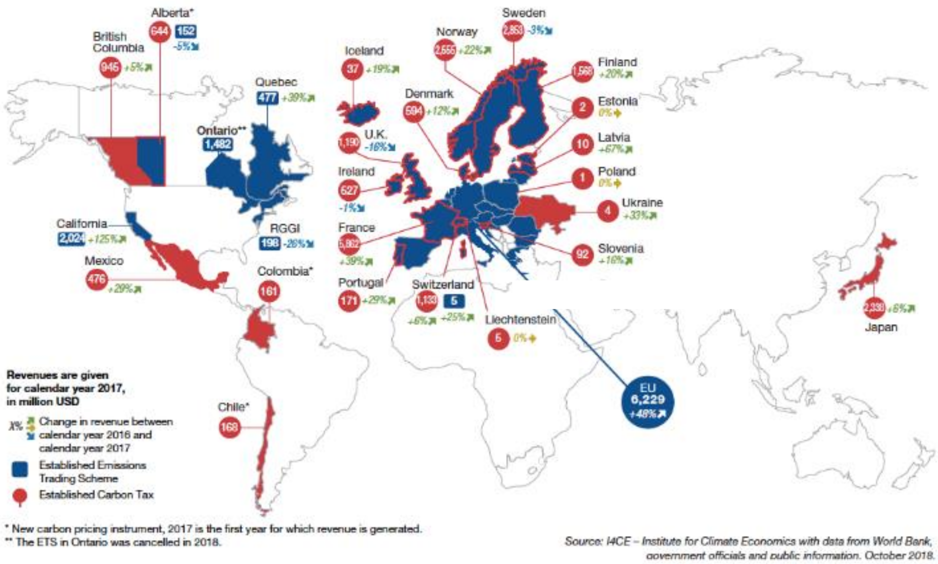
Carbon taxes are one of the two main carbon pricing instruments, the other being ETS[1] (Métivier and Postic, 2018). Carbon pricing instruments are defined by the World Bank as *the initiatives that put an explicit price on greenhouse gas emissions* (World Bank Group, 2018). Carbon pricing instruments are already in place in many areas of the globe, more precisely in 45 countries and 25 cities, states and subnational regions (Métivier and Postic, 2018; World Bank Group, 2018).

Carbon taxes were introduced by the British economist Arthur Pigou in 1920 (Roman P., personal communication, March 2019). It is based on the "Polluter Pays Principle" according to which the polluting party should pay for the damages caused to the environment (EC, 2012). In this way, the negative externality (i.e. pollution) is internalized by the polluting party.

Finland was the first country to implement a carbon tax in 1990 (Bavbek, 2016). At the time, the tax covered the use of transport fuels, coal and natural gas in the heating, electricity generation and transport sectors. Today, it is not the only country to have implemented a carbon tax anymore. Figure 1.1 below shows countries that have already introduced or scheduled a carbon tax. Sometimes, in addition to the ETS put in place. The World Bank's data (2019) confirms that 24 countries and 3 regions are currently subject to carbon taxation policies.

[1] Emission Trading Schemes (ETS) are carbon markets in which firms receive a quota of carbon they can emit and can exchange these emission allowances among each other (Decker, 2014). Since ETS only involves firms and not households, they won't be discussed in this paper.

Figure 1.1 – Carbon pricing instruments around the world



Source: I4CE – Institute for Climate Economics

1.2.2. Carbon tax revenues

One of the greatest concerns of the implementation of carbon taxes is the way in which its revenues are used. In 2017, worldwide revenues generated by carbon pricing instruments equaled a total of 26 billion € (Métivier and Postic, 2018). Figure 1.1 also shows the revenues carbon pricing instruments have generated. Most actors agree on the principle of "budget neutrality" meaning that all revenues must be returned to the carbon tax contributors in some way. Three most common uses of carbon tax revenues have been observed in countries already having a carbon tax (FPS Health, 2018; Criqui et al., 2018):

- Tax shifts (i.e. reduction in other taxes such as income taxes, labor taxes…)
- Direct redistributions/compensations (i.e. to all or certain types of households)
- Financing of public/private investment needed for the transition

Tax shift

Tax shifts were observed in Northern countries like Finland, Sweden or Denmark where the burden of the carbon tax was compensated by a decrease in other taxes weighing on households (Elbeze & Perthuis, 2011; World Bank Group, 2017).

Direct redistributions/compensations

The current "trend" is using carbon tax revenues to compensate households. Compensation can take different forms. The preferred compensation is through direct lump-sum transfers to households. In France, households below a certain level of income receive annual energy vouchers financed by carbon tax revenues (FPS Health, 2018). In other countries, all households are compensated. For example, in Switzerland where households receive a lump-sum transfer through the health insurance system (World Bank Group, 2017). Or in British Columbia where all households receive quarterly payments. In this region, payments are reduced by 2% of households' net income for households above a certain income threshold (World Bank Group, 2017). This allows to differentiate poor households from others in the compensation system.

Financing public/private investment needed for the transition

A share of carbon tax revenues can also be used to finance low-carbon investments. In Ireland and Switzerland, renovation programs which support households in investing in energy efficiency are financed by the carbon tax (FPS Health, 2018).

1.3. MAIN FEATURES OF THE BELGIAN RESIDENTIAL BUILDINGS SECTOR

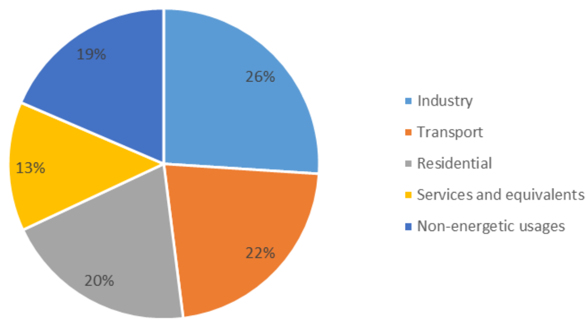
Up to now, the decarbonization of the residential buildings sector at a global level was considered. In order to respond to this thesis' research question, it is useful to better understand the current situation of the *Belgian residential buildings sector*. This section will provide a clearer picture of this specific sector. Unless stated otherwise, data used in this section comes from HBS 2016.

1.3.1. A carbon- and energy intensive sector

As it was already mentioned above, the residential buildings sector is both carbon- and energy-intensive. In 2016, the Belgian buildings sector represented almost 20% of the country's total CO_2 emissions (FPS Health, 2018). It was the second greatest emitting sector after the transport sector which accounted for 22% of Belgium's emissions. The residential sector emits almost three times more than the non-residential buildings sector, 14% and 5% of Belgium's emissions in 2016, respectively (FPS Health, 2018).

In 2017, the sector accounted for 20% of total energy consumption (Figure 1.2) in Belgium (FPS Economy, 2019a). Of this energy consumption, 73% came from fossil fuels (i.e. natural gas, fuel oil, coal and liquid petroleum gas (LPG)) which are the main cause of CO_2 emission (FPS Economy, 2019a; Timmons et al., 2016).

Figure 1.2 – Final energy consumption per sector in Belgium in 2017

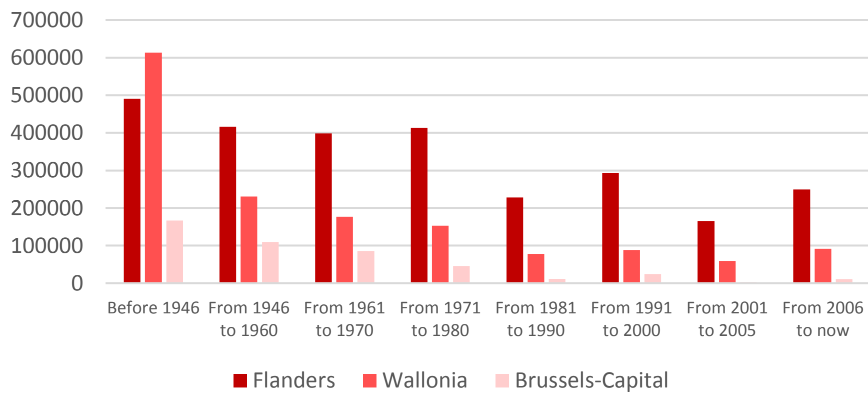


Source: FPS Economy – Energy Key data 2019

1.3.2. An old residential buildings stock

Alike the European buildings stock, the Belgian residential buildings stock is quite old. Only one fourth of residential buildings have been built after 1985 which is the year of introduction of the first Belgian thermal regulation in the Walloon region (Nolay, 2007). This means that a substantial share of buildings (i.e. all buildings older than 1985 and not yet renovated) is energy inefficient and need to be renovated. Figure 1.3 shows the number of residential buildings per age of construction in each region for the year 2016. The Flemish buildings stock is the most recent. Around 65% of Flemish dwellings have been built before 1980 compared to 80% and 90% in Wallonia and Brussels-Capital, respectively. In Wallonia, most buildings originate from before World War II.

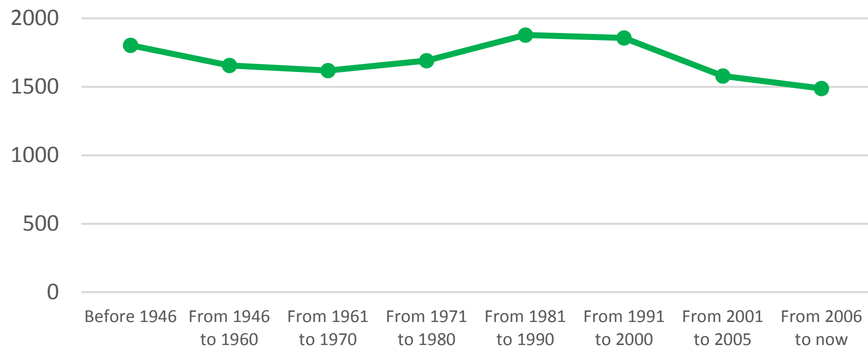
Figure 1.3 – Number of residential buildings per age of housing in each region in 2016



Source: HBS 2016

In principle, older housing consumes more energy than newer one. However, as it can be seen in Figure 1.4, total average energy bills of Belgian households do not really decrease with the age of housing. From the 1980s to the 2000s, buildings have higher energy bills. This is quite unexpected since energy bills should have decreased with the introduction of regulations on energy performance of buildings.

Figure 1.4 – Average total annual energy bill (in €) per age of housing in 2016



Source: HBS 2016

One potential explanation for this phenomenon is that during this period people started to build bigger housing. HBS 2016 data showed that a lot of detached houses were built from the 1980s to the 2000s. Before that, data shows there was a preference for terraced and semi-detached houses which should consume less energy in theory. Other factors might also explain this peak in energy consumption, but it wasn't further investigated in this thesis.

The old age of housing demonstrates the urgent need for renovation. Very few data exist on renovation rates in Belgium, but the three regions have published or are working on their strategic plans for renovations. This means that, in the next years, Belgian governments will start to implement energy performance standards and measures in order to increase renovation rates. As a result, households living in energy inefficient housing will have to invest in low-carbon alternatives for their housing to comply with new standards.

1.4. EXISTING AND POTENTIAL POLICIES REGARDING DECARBONIZATION IN THE BELGIAN RESIDENTIAL BUILDINGS SECTOR

The three regional governments have published or are currently working on the creation of renovation strategies for their buildings sector (FPS Health, 2018). In this context, regional governments have also introduced different mechanisms aimed at providing households with incentives to invest in energy efficiency of both, buildings and heating systems. Finally, each region had to introduce the EPBD to comply with European regulation. Table 1.1 in Appendix A summarizes existing policies regarding decarbonization of the Belgian residential sector.

Furthermore, there is an ongoing debate about the potential implementation of a carbon tax in Belgium. This section will provide some general insight on how the carbon tax could be implemented and how it will affect the Belgian residential sector.

1.4.1. Brussels-Capital

Renovation strategy

The region of Brussels-Capital will publish its final "Renovation Strategy" in 2021 (Brussels Environment, 2018b). The draft was published in 2018. The Renovation Strategy is being developed based on three axes: (1) increasing the renovation rate, (2) improving the quality of renovations and (3) a rational use of energy in the buildings sector (Brussels Environment, 2018b).

Incentives for investing in energy efficiency

The region of Brussels-Capital has issued several incentives for energy efficiency investment of residential buildings. These incentives include energy bonuses and "green" loans. Energy bonuses were launched in 2004 but were subject to major restructuring in 2016 in order to respond to the objectives of the Covenant of Mayors[2] (Fremault, 2015). These bonuses are granted to any household who engages in energy efficient housing measures and applies for the energy bonus (Brussels Environment, 2019a). Brussels has made a special budget available for energy bonuses. For 2019, the region of Brussels has a budget of 18 million € (Brussels Environment, 2019a). The performance of energy bonuses is quite satisfying (Brussels Environment, 2018a). In 2017, 67% of renovations' benefits went to housing occupants (i.e. not only owners). Moreover, it allowed an energy reduction of 63.21 GWh which equals the yearly consumption of around 5000 Brussels households (Brussels Environment, 2018a).

Green loans were introduced in the context of the Covenant of Mayors (Brussels Environment, 2010). They allow households to access loans at a rate of 0% to 2% to finance their housing renovation costs. Green loans can go up to 25 000 € (Brussels Environment, 2019b).

1.4.2. Wallonia

Renovation strategy

In 2014, the government of Wallonia issued a long-term strategy for energy renovations of buildings (Government of Wallonia, 2017a). Every three years, the strategy is being reviewed and

[2] In 2009, the government of Brussels-Capital has signed the European "Covenant of Mayors for Climate and Energy" in which it commits to reduce Brussels' carbon emissions by 30% in 2025 (Brussels Environment, 2010).

updated. It is built upon three main objectives: (1) improve comfort and health of inhabitants, (2) reduce environmental impacts of the buildings stock and (3) decrease energy dependence of the region (Government of Wallonia, 2017a). For the residential buildings sector, the Walloon region aims to have an average Energy Performance of Buildings (EPB) of label A for the whole housing stock by 2050. The priority is set on the renovation of the least energy performing buildings (Government of Wallonia, 2017a). Finally, the region wants to increase the renovation rate from 1% to 3% per year.

Incentives for investing in energy efficiency

Together with its long-term strategy for energy renovation of buildings, the government has installed a new regime concerning support for increasing buildings' energy performance and renovation (Government of Wallonia, 2018). Like the region of Brussels-Capital, Wallonia also issues energy bonuses and green loans to incentivize people to engage in energy efficiency investments (Government of Wallonia, 2019a). Energy bonuses are attributed based on household's revenues. Concerning green loans, there are two categories of loans available: Ecopack for energy savings investments (e.g. buying a heating pump) and Renopack for renovations (Government of Wallonia, 2017c). Both are offered at a rate of 0% and can go up to 30 000 €.

1.4.3. Flanders

Renovation strategy

In Flanders, the strategy concerning the renovation of the residential buildings stock has been introduced in the Renovation Pact of 2014 (FPS Health, 2018). The Renovation Pact is an action plan designed to increase the rate of renovation of Flemish housing by 2050 (Vlaamse Overheid, 2019a). More specifically, it aims to increase the energy performance of residential buildings by 75% and decrease the sector's GHG emissions by 80% in 2050 (FPS Health, 2018).

In recent years, Flanders has undergone a process of renovation of its social housing. Around 73% of these housing were renovated (i.e. double glazing, insulated roof and energy efficient heating systems) in 2016 compared to 52% in 2010. The Flemish region has made great progress in terms of renovations (Vlaamse Maatschappij vor Sociaal Wonen, 2017).

Incentives for investing in energy efficiency

The Flemish government also grants green loans to support households' investments in their dwellings. They can go up to 15 000 €. Any household engaging in any energy efficiency measure can apply for these loans. Energy efficiency measures range from insulation to low-carbon heating systems and energy audits.

1.4.4. Energy Performance of Buildings Directive

In addition to the different renovation strategies, the three regional governments have put in place the EPBD. In each region, any owner who sells or rents a housing must issue an energy performance certification (Brussels Environment, 2019f; Government of Wallonia, 2019b; Vlaamse Overheid, 2019b). This allows to send a signal about the energy efficiency of the rented/sold building to tenants/buyers. Also, when engaging in new constructions or old buildings renovations energy performance requirement must be respected (Brussels Environment, 2019e).

1.4.5. Potential implementation of a carbon tax in Belgium

In Belgium, only 37% of GHG emissions are regulated via the EU ETS (FPS Health, 2018). The rest of Belgian GHG emissions (63%) are not yet regulated. The main sectors which are not part of the ETS system, called “non-ETS sectors”, are the following: transport, buildings, industry, agriculture, waste and fluorinated gases (FPS Health, 2018). Therefore, if the government was to implement a carbon tax in Belgium, the residential buildings sector would be one of the targeted sectors. As a complementary measure to mass renovations and energy efficiency investments, the implementation of a carbon tax in the Belgian buildings sector is likely to facilitate the transition towards a carbon-free economy.

The final report of the Belgian National Debate on Carbon Pricing (2018) discusses the various impacts of the implementation of a carbon tax in Belgium. It presents three carbon price trajectory options which are summarized in Table 1.2 below.

Table 1.2 – Carbon price trajectory options (in $€_{2020}/tCO_2e$)

	2020	**2030**	**2050**
A	10	40	100
B	10	70	190
C	10	100	280

Note: These different carbon price trajectories represent the different possible levels of a carbon tax if it is introduced in Belgium. It shows three options of carbon taxes for the years 2020, 2030 and 2050.

Source: Belgian Debate on Carbon Pricing – Final report (2018)

Depending on the chosen trajectory, a carbon tax will have different effects on the buildings sector. First, it will have an impact on energy bills (FPS Health, 2018). In the short run (2020), heating fuel oil and gas prices are likely to increase between 3% and 5%. In the long run (2030-2050), heating fuel oil and gas prices will rise even further. Using the carbon price trajectory "B" leads to a 25% increase in energy prices. However, even with such an increase in prices, average energy bills will be reduced by two in 2050 thanks to the reduction in energy consumption. Secondly, the implementation of a carbon tax in the Belgian buildings sector will generate huge carbon revenues (FPS Health, 2018). Revenues will amount 210 million € in 2020 and 939 million € in 2030. This could help finance major investments required for the renovation and electrification of the buildings stock. Finally, it could potentially have a positive effect on the profitability of required investments[3] in the buildings stock (FPS Health, 2018).

1.5. CONCLUDING REMARKS ON DECARBONIZATION

This section has deepened the different implications of a transition towards a zero-carbon residential sector in Belgium. Firstly, it implies both mass renovation through insulation and investment in energy efficiency of heating systems. The Belgian residential buildings stock is quite old so renovation rates must increase if we expect to reach Belgian objectives. In this context, regional governments have or are working the issuance of their long-term renovation strategies. Since, these strategies potentially imply a strengthening of buildings' energy performance regulations, households will be required to invest in low-carbon levers of the residential buildings sector to comply with new regulation. Secondly, low-carbon levers can be complemented with a carbon tax. Although not yet implemented in Belgium, the debate is currently in progress. If introduced, households will face energy bill increases in the short and medium term.

As already mentioned before, introducing decarbonization levers and policy instrument in the residential buildings sector will directly involve households. Hence, it can have consequences on the acceptability of the implementation. Chapter 3 explains how decarbonization policies could lead to an increase in "energy poverty". Energy poverty is a concept that is often used to describe the difficulty of household to get access to energy. To better grasp the distributive impact of decarbonization, it is necessary to first understand the main features of energy poverty. Chapter 2 is dedicated to that.

[3] This issue is discussed further in Chapter 4.

Chapter 2: Energy poverty

Energy poverty currently exists independently of actions aimed at mitigating climate change. It concerns households' difficulties to access energy. To better apprehend how decarbonization could become a threat to energy poverty of households, it is important to understand energy poverty itself. This second chapter aims at (1) defining energy poverty both internationally and in Belgium, (2) explaining its causes and consequences and (3) giving an overview of the existing policies addressing the fundamental causes of energy poverty at different government levels in Belgium.

2.1. DEFINITIONS

First, it is essential to distinguish between two kinds of "energy poverties": energy poverty in developing countries and energy poverty in developed countries. In developing countries, energy poverty is due to the absence of distribution networks and/or the underdevelopment of energy infrastructures (Aviles, 2013). Access to electricity and modern fuels[4] is an important issue (Legros et al., 2009). In developed countries, energy poverty refers to when households cannot afford energy due to income constraints or high energy prices (Aviles, 2013). In this paper, the focus is set on energy poverty in developed countries.

2.1.1. "Is energy a basic human right?"

There is a whole debate around the question of whether energy should be considered as a human right and become a universal service. Proponents state that "living without energy makes daily tasks that we take for granted impossible or extremely difficult" (Scheinder Electric, 2015). The right to an access to energy is not yet considered as a human right (Huybrechs et al., 2011). However, increasing progress is made towards the integration of energy access in international and European conventions.

At the international level, the Universal Declaration of Human Rights does not mention energy as one of the elements needed to have an adequate standard of living (Universal Declaration of Human Rights, 1948). Neither does the International Covenant on Economic, Social and Cultural Rights of 1966 (International Covenant on Economic, Social and Cultural Rights, 1966). In the year 2000, members of the UN agreed on eight Millennium Development Goals (MDGs) which were intended to serve basic human rights for individuals across the globe (UN Millennium

[4] According to the World Health Organization (2009), modern fuels refer to electricity, liquid fuels (e.g. kerosene) and gaseous fuels (e.g. LPG and natural gas). It excludes traditional fuels such as coal or biomass.

Development Goals, 2019). These goals had to be achieved by 2015. Although not directly included in the goals, energy access was considered as an essential element for the achievement of the MDGs (Legros et al., 2009). Succeeding the MDGs, the UN established the Sustainable Development Goals (SDGs) in 2015 (Sachs, 2012). The seventeen SDGs must be reached by 2030. The seventh goal of the SDGs "affordable and clean energy for all" is directly aimed at providing universal access to energy (UN Sustainable Development Goals, 2019). In this context, the former UN Secretary-General, Ban Ki-moon launched a project called "Sustainable Energy for All" (Ki-moon, 2012). This initiative responds to three objectives (Ki-moon, 2012):

- "Ensuring universal access to modern energy services;
- Doubling the share of renewable energy in the global energy mix; and
- Doubling the global rate of improvement in energy efficiency"

In a speech he gave at the Center for Global Development in 2012, Ban Ki-moon said that "energy is the golden thread that connects economic growth, social equity and environmental sustainability". Hence, ending energy poverty is of key importance (Ki-moon, 2012).

Also, in the European treaties, very little attention is paid to energy poverty (Aviles, 2013). The European Convention for the Protection of Human Rights and Fundamental Freedoms ignores the right to energy (European Convention on Human Rights, 1950). According to Aviles (2013), the Charter of Fundamental Rights of the European Union which protects political, social and economic rights for EU's citizens does not guarantee the access to energy services either. Article 36 of the Charter says the following:

"*The Union recognizes and respects access to services of general economic interest*[5] *as provided for in national laws and practices, in accordance with the Treaty establishing the European Community, in order to promote the social and territorial cohesion of the Union*" (Charter of Fundamental Rights of the EU, 2000).

Aviles (2013) builds his argument on the first sentence which provides that the EU *recognizes and respects*, but which does not identify energy access as a general principle of the European law. Consequently, it only means that the EU cannot take any action that would impede energy access provided by Member States to their people (Aviles, 2013). A great step towards the establishment of universal access to energy in the EU is the Third Energy Package established in 2009 (European Parliament, 2018). This package includes two directives concerning common rules for the internal electricity and natural gas markets; Directive 2009/72/EC and Directive 2009/73/EC. These directives intend to improve the efficiency of these markets' functioning (Directive 2009/72/EC, 2009; Directive 2009/73/EC, 2009). Both include an article on Public Service Obligations and Customer Protection (Article 3) which stipulates that Member State should ensure universal service of electricity and natural gas in a transparent and non-discriminatory way (Directive 2009/72/EC, 2009; Directive 2009/73/EC, 2009). Member States must pay particular attention to

[5] Services of general economic interest refer to "public utility services which are carried out by providers in return for payment" (EC, 2019a). These include energy suppliers.

vulnerable households. A further step at the European level is the introduction in 2016 of the Clean Energy Package that will be adopted in early 2019 (EC, 2016; EC, 2019b). In this latest Energy Package, the European Commission establishes eight legislative acts[6] which will help improve European energy markets (EC, 2019b). Again, a share of the package is dedicated to the fight against energy poverty, the protection of European consumers and the provision of universal access to energy (EC, 2016).

In Belgium, human rights are specified in Article 23 of the Belgian Constitution (Belgian Constitution, 2017). This article does not directly include the right to energy. Nonetheless, the question arises whether energy wouldn't be an essential element to the "right to a decent accommodation" and consequently, be indirectly embraced in the Belgian Constitution (Huybrechs et al., 2011; Moons, 2016). Several propositions have been introduced in the Belgian Senate to revise Article 23 in order to add the right to energy (Moons, 2016). However, it has not (yet) been accepted.

Even though energy is not officially recognized as a human right in international and European treaties, much work is done at both level in order to provide universal access to energy and recognize energy poverty.

2.1.2. Fuel poverty

There is no consensus on the definition of energy poverty around the world and within the EU. Over the years, many authors have worked to define the concept of energy poverty.

One of the pioneers in the definition of energy poverty is the UK with the concept of "fuel poverty". According to the Warm Homes and Energy Conservation Act (2000), *"a person is considered as living in fuel poverty if he is a member of a household living on a lower income in a home which cannot be kept warm at reasonable cost"*. More precisely, a fuel poor household spends more than 10% of its income on heating fuels (Nolay, 2007). In 2001, following the introduction of this definition, the UK's government created a strategy aimed at eliminating fuel poverty in the country. This strategy is known as the UK Fuel Poverty Strategy and consisted of two phases (BERR, 2008). In the first one, the target was set on "vulnerable" households. These include; people over 60 years old, ill and disabled people and families with infants. The objective of this first phase was to eradicate fuel poverty for vulnerable households by 2010, which failed (Huybrecks, Meyer & Vranken, 2011). In the second phase, the priority was being set on eliminating energy poverty for "non-vulnerable" households also by 2016 (BERR, 2001). The target of the current UK Fuel Poverty Strategy set in 2015 is to improve energy efficiency of fuel poor homes by 2030 (UK Government, 2015).

[6] The most relevant legislative acts in the present discussion will be conversed in the next section.

At the European level, a project called "European fuel Poverty and Energy Efficiency" (EPEE) was initiated in 2007 in order to increase knowledge and understanding of fuel poverty and to provide remedies to this issue in the EU (EPEE Consortium, 2009). The definition of fuel poverty according to the EPEE is slightly different than the UK's. In fact, due to dissimilarities in climate, heating methods and income across European Member States, the UK's definition does not seem to apply perfectly to other countries (Nolay, 2007). The EPEE defines fuel poverty as a "*household's difficulty, sometimes even inability, to adequately heat its dwelling at a fair, income indexed price"* (EPEE Consortium, 2009). This definition provides a basis for Member states who should revise it to fit their own national conditions (EPEE Consortium, 2009).

2.1.3. Towards a broader concept: "energy poverty"

These definitions of "fuel poverty" are rather narrow in the sense that their main focus is set on space heating. However, households are also likely to spend a significant amount of their income on other final uses such as water heating, lighting, electrical appliances, cooking and even, on space cooling (mostly in Southern countries)[7] (Eurostat, 2019). In Belgium, for example, 26%[8] of the residential sector's total energy consumption is used for the above-mentioned final uses in 2017 (FPS Economy, 2019b). Therefore, the term "energy poverty" may be more appropriate. Again, there is no single definition of the term that is globally accepted.

In a 2015 report commissioned by the European Commission, energy poverty was defined as "*a situation where individuals are not able to adequately heat or provide necessary energy services in their homes at affordable cost"* (Pye et al., 2015). In this report, the authors make seven final recommendations about energy poverty. The sixth recommendation is to establish an "Energy Poverty Observatory" aimed at improving transparency and helping Member States in the design of policies targeting energy poverty (Pye et al., 2015). In December 2016, the European Commission commenced a 40 month's project called "the EU Energy Poverty Observatory" (EPOV). The EPOV describes energy poverty as "*a distinct form of poverty arising from a combination of several factors: high energy expenditures, low households' incomes, inefficient buildings and appliances and specific household energy needs"* (EPOV, 2019a)[9]. The EPOV also mentions that the definition of energy poverty discussed in Pye et al.'s report should be shaped to fit different situations thanks to indicators such as climate, housing quality, economy and the structure of energy costs of a country (EPOV, 2019b).

[7] Household energy consumption is limited to energy consumption occurring in the dwellings. Therefore, energy uses such as transport are excluded (Eurostat, 2019).
[8] The rest (74%) is used for space heating (FPS Economy, 2019b).
[9] Each of these factors are discussed into more details in Section 2.2.

2.1.4. Energy poverty in Belgium

According to Grevisse and Delvaux (2017), the notion of energy poverty became popular in Belgium after the liberalization of gas and electricity markets in 2007 (and in 2004 in Flanders). Although the liberalization of markets was supposed to decrease energy prices and increase the choice for consumers, it didn't have the expected effects. The number of actors present on the energy markets multiplied which led to an increasing complexity of choices and information (Huybrechs et al., 2011; Grevisse and Delvaux, 2017). Consequently, neither access to energy was improved, nor energy prices were lower (Huybrechs et al., 2011; Grevisse and Delvaux, 2017).

Following the recommendations of the EPOV, each EU Member State is invited to create its own definition of energy poverty considering country specific parameters. In Belgium, researchers have worked towards finding a commonly accepted definition of energy poverty. The economists, Huybrechs, Meyer and Vranken (2011), define it as follows: "*energy poverty refers to a situation in which a person or household encounters particular difficulties to satisfy basic needs related to housing"*. In this definition, basic needs may refer to space heating, lighting, functioning of electrical appliances and telecommunication services. To satisfy these needs, households must have access to these energy services at a reasonable cost (Huybrechs et al., 2011).

In 2018, the King Baudouin Foundation published the fourth edition of the Energy Poverty Barometer. In this report, the authors Delbeke and Meyer (2018) desccribe three indicators of energy poverty in Belgium. These different indicators can be used to assess the different kinds of energy poverty that exist in the country.

- The first indicator is called "measured energy poverty" (mEP). It includes all households that devote a significant amount of their income to energy expenditures. This amount is considered as "too high" in proportion to their income[10]. The mEP measures *the extent of poverty*. In other words, the proportion of energy poor households.
- The second indicator, "hidden energy poverty" (hEP), is the inverse of mEP. It refers to households opting to limit their energy consumption to a level below a threshold considered as acceptable for living comfortably. It measures *the depth of poverty*[11].
- Whereas these two indicators are quite objective, the last indicator is considered as a more subjective indicator. The "perceived energy poverty" (pEP) gives the number of households that consider having insufficient money to heat their homes correctly.

In 2016, 14.5% of Belgians were considered in mEP, 4.3% in hEP and 4.9% in pEP (Delbeke and Meyer, 2018). These percentages have stayed relatively constant since 2009.

[10] The threshold is computed as twice the median ratio between the necessary energy expenditure and total Belgian people's income in the year of reference (Delbeke and Meyer, 2018).
[11] It is computed measuring the gap (in €) between hEP households and the threshold.

2.2. CAUSES OF ENERGY POVERTY

Most authors agree on three main causes of energy poverty: low incomes, the context of dwellings and energy prices (Nolay, 2007; Grevisse and Brynart, 2011; Huybrechs, Meyer and Vranken, 2011; Pye et al., 2015).

Some studies also point out additional causes. Huybrechs, Meyer and Vranken (2011) identify several socio-cultural factors as being at the origin of energy poverty. Some of which will be discussed in this section.

2.2.1. Low incomes

According to the EPEE project (2007), being on a low income is the cause that gives the highest chance for a household to live in energy poverty. The lower the income, the less a household can consume. However, there remain some basic needs that a household must satisfy, and energy is one of them. Heating, lighting, cooking, heating water; all these energy needs are essential to keep an adequate standard of living.

With this in mind, the following question arises: isn't energy poverty just a matter of general poverty? To answer this question, it is important to first define poverty. Poverty can be defined in many ways, using a range of indicators. In Belgium, three different indicators are usually used to define poverty: monetary poverty risk, material deprivation and households with low work intensity (StatBel, 2018a). If someone meets one or more of these indicators, then he/she is considered "being at risk of poverty or social exclusion".

Monetary poverty

Monetary poverty risk is determined by the number of people whose income is below the poverty threshold (Service de lutte contre la pauvreté, la précarité et l'exclusion sociale, 2018). As stated by Foster (1998) "*a person is identified as poor if its resources fall short of the poverty threshold*". In general, there are two different ways to compute the poverty threshold: in absolute or in relative terms. The absolute threshold is set at a fixed level of income (Foster, 1998). It makes it easier to compare poverty across countries. For example, the International Poverty Line is set at 1.90$/day/person (World Bank Group, 2015). The relative threshold, on the other hand, depends more on the standard of living of the whole population (Foster, 1998). For example, all people who have an income that is 50% below the average household income are poor. Therefore, it is likely to change with economic growth of a country. In Belgium, the relative poverty threshold is mainly used. It is set at 60% of the median disposable income which equals at 1 139

€/month/person or 2 392 €/month/households with 2 adults and 2 children[12] (StatBel, 2018b). This means that all people earning below this amount are considered as being "at risk of poverty". In 2017, this represented 15,9% of the Belgian population (StatBel, 2018b). This percentage is very close to the percentage of people in mEP which is not surprising as people living on low incomes are more likely to spend a great proportion of their income on energy bills.

Material deprivation

The second indicator is material deprivation defined by the OECD (2007) as "*the inability for individuals or households to afford those consumption goods and activities that are typical in a society at a given point in time, irrespective of people's preferences with respect to these items"*. Each country has its own list of consumption goods and activities considered as essential to society. When a person/household cannot afford a certain number of elements from the list, they are considered as being at risk of poverty or social exclusion. In Belgium, two of these goods and activities relate to energy: payment of energy bills and adequate heating (StatBel, 2018b). In 2017, material deprivation concerned 5.1% of Belgians.

Low work intensity

The last indicator is "households with low work intensity". According to StatBel (2018a), "*these households are those where adults (aged 18 to 59, excluding students) have worked on average less than one fifth of the time during the reference year"*. In Belgium, 13.5% of the population was living in a household with low work intensity in 2017. This last indicator may seem less relevant in the discussion of energy poverty. As a matter of fact, it does not especially mean that a household lives on a low income (Service de lutte contre la pauvreté, la précarité et l'exclusion sociale, 2018). Still, people living in a household with low work intensity might, for instance, have unstable jobs which could make them more vulnerable to sudden unemployment. As a result, their income is uncertain, and they could face energy poverty in an undefined future.

Is energy poverty a matter of general poverty?

In most views, poverty and energy poverty are inseparable (Grevisse and Brynart, 2011; Grevisse and Delvaux, 2017). The three definitions of poverty have shown that poverty is mostly an issue of income constraints which often results in difficulties to afford certain goods and activities. In this way, energy poverty could be considered as a type of poverty because poor households with low incomes will be much more vulnerable to changes in energy prices or to the energy

[12] Computed as follows: [2.1*1 139 €/month = 2 392 €/month] in which 2.1 is a family factor called the "OECD equivalence scale" (i.e. with weights of 1 for the head of the household, 0.5 for the second adult and each person aged 14 years and older, 0.3 for each children younger than 14 years old) (StatBel, 2018b).

inefficiency of their dwelling (Huyberchs, Meyer and Vranken, 2011). Consequently, affording energy is more difficult for poor households.

2.2.2. Dwellings

As stated above, the "context of the dwelling" plays a significant role in energy poverty (Grevisse and Brynart, 2011). Two important factors will be discussed here: the low energy performance of dwellings and the households' tenure status.

Low energy performance of dwellings

The low energy performance of dwellings is characterized by several factors: the absence of central heating systems, humidity and defective insulation of windows, roofs and walls (Nolay, 2007). These factors are very likely to increase the energy bills of households living in energy inefficient housing. However, there exists an "energy efficiency gap" which can be defined as "*the reluctance of consumers to invest in energy efficient technologies even if such investments are cost-effective"* (Uilhein & Eder, 2009; Gerarden, Newell and Stavins, 2015).

The energy efficiency gap in the residential sector can be explained by the existence of different barriers. The main barrier is the moral hazard problem of "split incentives" between tenants and owners (Economidou & Bertoldi, 2015). This problem arises when tenants are responsible for paying energy bills. If buildings are not energy efficient, tenants end up paying huge energy bills. However, owners do not have any incentives to renovate or replace inefficient equipment in the dwellings as the deriving benefits do not accrue to them directly (Economidou & Bertoldi, 2015). The HBS 2016 data shows that one third of Belgian residential buildings are not occupied by their owner which nurtures the problem of split incentives in the country. This issue is particularly at stake in Brussels because the share of tenants is even greater.

Another barrier to the renovation of buildings is the problem of financing renovation (Uilhein & Eder, 2009; Allouhi et al., 2015). Poor households don't have the financial resources to engage in energy efficiency investments. Although these investments are usually economical in the long run, the initial costs of replacing heating systems, windows, roofs or walls are significant and incurred at one point in time (Uilhein & Eder, 2009).

Finally, many households are simply not aware of energy efficiency and the different existing opportunities to reduce energy consumption (Uilhein & Eder, 2009; Allouhi et al., 2015). This lack of knowledge may lead them to choose energy inefficient systems and poor technologies (Uilhein & Eder, 2009).

Tenure status

Households' tenure status is a key aspect to consider when trying to address energy poverty. In fact, energy poverty also depends on whether the household is an owner, a tenant or even a tenant living in a social housing (Grevisse and Brynart, 2011). Tenants are more likely to be affected by poverty and thus energy poverty, than owners. In Belgium, 36.4% of people considered at risk of poverty or social exclusion are tenants while only 8.8% are owners (StatBel, 2018b).

According to Pye and Dobbins (2015), it is very important to keep this in mind when designing policies. For instance, larger scale building retrofit public policies will mostly benefit tenants living in social housing because their owner is the State (Pye and Dobbins, 2015). According to the HBS 2016 data, 21% of tenants were living in social housing in Belgium in 2016. Another example is the issuance of bonuses aimed at stimulating renovation. These will probably not affect tenants directly. However, it will incentivize owners to invest energy efficient measures. Depending on the households' tenure status, they will be affected differently by implemented measures.

2.2.3. Energy prices

The rise in energy prices also has a significant impact on energy poverty (Nolay, 2007). Poor households often do not have an extra margin to account for sudden increases in energy prices. In Belgium, energy bills have been rising in the recent years, especially due to the increase in the price of electricity following the increase in VAT from 6% to 21% (FPS Economy, 2019a; Government of Wallonia, 2018). In a study about energy poverty and energy prices conducted by a series of authors from the FPS Economy in 2015, data shows that the rise in energy price was greater than inflation from 2005 to 2013[13]. While the increase in the Consumer Price Index[14] (CPI) was 19.6%, the increase in consumption prices of energy products equaled 44.2% (Bonnard et al., 2015). As a result, income rose by less than the rise in energy prices.

If energy prices rise together with income, there should not be any issue. However, when energy prices rise to reflect resource scarcity or the implementation of a new policy regarding energy prices it can negatively affect a great proportion of households. Mainly, the most vulnerable ones. Reactions of households facing expensive energy bills are various (Grevisse and Delvaux, 2017). While some go into debts, others prefer to drastically decrease their energy consumption or continue to consume energy in the same way at the expense of other goods and services (food, health care…).

[13] No more recent data was found.
[14] Used to measure inflation.

2.2.4. Other socio-economic causes

In addition to low income, poor quality of dwellings and high energy prices, other factors can drive a household into energy poverty.

The level of education plays a big role in the determination of people's economic situation. People with low levels of education are more likely to be unemployed. In 2017, 17.4% of people with basic education were unemployed in the EU (Worldbank, 2019). This is more than 10% higher than people with higher education. Unemployment can quickly drive households into poverty as they earn very low incomes. Moreover, low levels of education also lead to low levels of alphabetization (Huybrechs et al., 2011). This makes it difficult for some households to read and understand energy bills. Consequently, households might not always make the best choices when it comes to picking energy suppliers.

Another cause of energy poverty is the lack of information available to consumers. Huybrechs et al. (2011) identify a series of problems associated with incomplete information between consumers and suppliers. Among them are included: errors in energy bills, complex energy bills which are difficult to understand, difficulties to contact suppliers, inefficient call centers, difficulties to access the market for indebted clients.

2.3. CONSEQUENCES OF ENERGY POVERTY

Energy poverty can have various consequences on households. The major consequences relate to health and economic insecurity. Moreover, energy poverty can also have a great impact on society through higher public expenditure for health as well as the degradation of buildings.

2.3.1. Health

Health issues among energy poor households can take different forms; higher mortality rates, poor physical and mental health. As poor quality of housing leads to more humidity and cold, energy poor households are more vulnerable to illnesses and diseases.

There is a clear relationship between energy poverty and mortality. A concept called "excess winter mortality" shows that there is a rise in the number of deaths during winter due to colder temperatures (Healy, 2003; Altanis et al., 2008). Households living in uninsulated houses or having troubles to pay their energy bills are more affected by colder periods. It has been demonstrated that countries with the poorest housing have the highest excess winter mortality (Healy, 2003). Studies also have shown that vulnerable people, that is; children, elderly and people with disabilities or long-term illnesses, are the most affected by excess winter mortality (Altanis et al., 2008).

Energy poverty also has an impact on physical and mental health. A study conducted by Thomson, Snell and Bouzarovski (2017) shows that energy poor people in Europe are more likely to report poor health and emotional well-being than non-energy poor people. Physical health issues can take the form of minor illnesses (e.g. colds, flu) or rheumatic, cardiovascular and respiratory diseases (Marmot Review Team, 2011). Whereas, mental health issues are anxiety, stress and depression associated with living in poor housing conditions (Marmot Review Team, 2011).

2.3.2. Economic insecurity

Energy poverty leads to economic insecurity of households. On the one hand, households who have difficulties to pay their energy bills often accumulate debts (Nolay, 2007; Grevisse and Delvaux, 2017). According to Eurostat (2019), 7% of households in the EU had arrears of payment on their utility bills in 2017. In Belgium, this was the case for 4% of households. Energy indebtedness is most likely among families of single parents with dependent children (Eurostat, 2019).

On the other hand, high energy bills arising from high prices and low performance of dwellings can lead to lower disposable income for other expenses (Nolay, 2007). These expenses may include food, transport, leisure activities, unexpected financial expenses, etc… In turn, households are more likely to face material deprivation[15].

2.3.3. Public expenditures

A higher rate of energy poverty in a country can have a serious impact on public expenditures regarding health and environmental matters. According to the EPEE (2007), by tackling energy poverty much can be saved in terms of public expenditure for health. A study conducted in the context of the EPEE says that for every 100 € spent on combating energy poverty, 42 € are saved in health costs and 58 € are saved in fighting against the effects of climate change (Nolay, 2007).

2.3.4. Degradation of buildings

Since energy poor households do not have the resources to engage in renovations, the quality of buildings slowly degrades. When housings are not appropriately heated, humidity can arise

[15] One of the three indicators according to which a person is considered being "at risk of poverty or social exclusion".

(Huybrechs et al., 2011). Furthermore, old and inefficient equipment may raise questions about the security of buildings. For example, defective electrical systems increase the risk of fire (Nolay, 2007).

2.4. EXISTING POLICIES DEALING WITH ENERGY POVERTY IN BELGIUM

More and more, energy poverty becomes a central issue that is subject to its specific policies. In the discussion about the distributive impact of decarbonization, it is essential to know what is already in place to mitigate energy poverty in Belgium and whether these policies are compatible with decarbonization levers and policies. This section will give an overview of the different policies that have been implemented in Belgium.

In Belgium, energy policies are implemented at two levels: the federal level and the regional level (FPS Health, 2019). Since the regionalization of Belgium in 1980, different competencies have been divided among the federal government and the three regional governments (FPS Economy, 2019c). However, all of them have introduced policies and measures that try to address energy poverty in different ways. Table 2.1 in Appendix A provides a summary of all existing policies at the federal and regional levels.

2.4.1. Protected consumers

Before looking at each government's policies individually, it is necessary to understand the notion of "protected consumers". Following the liberalization of energy markets in 2007, a series of rules called Social Public Service Obligations (SPSO) designed to ensure the protection of consumers were implemented by the Commission for Electricity and Gas Regulation (CREG) both at the federal and regional levels (CREG, 2011; Huybrechs et al., 2011). The notion of "protected consumers" was introduced in order to enable energy access to vulnerable consumers. The objectives of SPSOs are to limit indebtedness of vulnerable consumers in terms of energy bills and to support them in their energy consumption management (CREG, 2011). The federal government is responsible for giving preferential tariffs to protected consumers whereas the regional governments handle defaults of payments through Public Social Welfare Centers [16] and the attribution of energy bonuses and loans (Huybrechs et al., 2011). The list of criteria defining protected consumers differs between regions and the federal government. The four different lists are shown in Table 2.2 in Appendix A.

[16] CPAS in French.

2.4.2. Federal level

The federal government treats all matters related to Belgian people's general interest (FPS Belgium, 2019). It addresses energy poverty in different ways: by engaging in the fight against general poverty; by controlling energy prices and by issuing special energy tariffs for protected consumers.

Fighting poverty

Since social security is a matter of general interest, the federal government has taken the lead in the fight against poverty in Belgium. In 2003, a federal public service, called the Public Planning Service Social Integration (PPS SI), designed to work on social integration and anti-poverty policy was created (PPS Social Integration, 2019). Since the 4th of July 2008, the PPS SI has been issuing strategic plans to fight against poverty in Belgium (PPS Social Integration, 2008). The current and third strategic plan covers the period from 2016 to 2019 (PPS Social Integration, 2016).

This plan includes six objectives: ensure social protection; fight against child poverty; social and professional reintegration; fight against homelessness; ensure access and quality of health services; make public services accessible to all. The first of these six objectives "social protection" intends to work towards an increase in the minimum income and in overall salaries (PPS Social Integration, 2016). It also dedicates a special attention to energy and water (PPS Social Integration, 2016). It aims to ensure and facilitate access to energy services and water for all through the restructuring of social energy funds and through the improvement of existing social tariffs for energy.

Energy prices: control and special tariffs

Another set of federal policies addressing energy poverty concerns the price of energy. In its competencies, the federal government is responsible for the implementation of policies regarding energy tariffs and final energy prices (FPS Economy, 2019c). In this context, the federal government offers three different measures which facilitate energy access for vulnerable households.

The first one is a social tariff for natural gas and/or electricity for protected consumers (SPFd). The level of the social tariff is determined twice a year by the CREG based on energy prices and costs (FEBEG, 2019). In Belgium, social tariffs for natural gas and electricity can be obtained by protected consumers in order to help them pay their energy bills (FPS Economy, 2019a). According to the FEBEG (2019), 451.000 households benefit from social tariffs for electricity and 272.000 households for natural gas in Belgium. That is 9.3% and 9.7% of Belgian clients, respectively.

The second measure is a system of installment payments for heating fuel oil (FPS Economy, 2019e). This allows for households to pay in several times but still for their heating fuel oil to be delivered.

The last measure is the provision of a “Social Heating Fund” (FPS Economy, 2019f). Together with the CPASs and the petroleum sector, the federal government created the Social Heating Fund in 2004 (FPS Economy, 2019f). The Fund is aimed at helping people with financial difficulties to pay their heating bills. Three categories of people can benefit from this financial help: people with physical disabilities, people with low revenues and indebted people (Fond Social Chauffage, 2019). The Belgian National Debate on Carbon Pricing (2018) report estimates the beneficiaries of the Social Heating Fund to amount approximately 90 000 households in 2016.

2.4.3. Brussels-Capital

The state of energy poverty in the Brussels-Capital region is as follows: a mEP of 13.4%, a hEP of 9.2% and a pEP of 8.5% in 2016 (Delbeke and Meyer, 2018). The government of Brussels-Capital tries to address energy poverty through to the reduction of poverty, the issuance of renovation loans and subsidies targeting vulnerable households and the treatment of energy bills default payments.

Fighting poverty

Based on the decree of July 20th 2006, the different authorities of the Brussels-Capital region (i.e. the regional government and the three communities’ governments) are entitled to establish every two year a Social Barometer that assesses poverty in Brussels and to issue plans of action to eradicate poverty (Observatoire de la Santé et du Social de Bruxelles-Capitale, 2018b).

The current plan of action covers the period from 2014 until 2019. Although energy poverty is not directly tackled in this plan of action, one of the plan’s engagements consists of fighting against indebtedness. Energy bills are considered as being one of the main causes of indebtedness and the number of people having arears of payment on energy continues to increase in Brussels (Observatoire de la Santé et du Social de Bruxelles-Capitale, 2018b). Consequently, an increased access to debt mediation services might indirectly help energy poor households.

The 14th edition of Brussels’ Social Barometer (2018a) presents a series of facts about poverty in the region. The share of people being at risk of poverty or social exclusion is much higher than in the other two regions. In 2016, 39% of Brussels’ population was considered being at risk of poverty or social exclusion compared to 14% and 27% in Flanders and Wallonia, respectively. Being an urban region, Brussels has the highest rate of tenancy in Belgium, 60% in 2016 compared to 34% in Wallonia and 29% in Flanders. The combination of high rates of poverty, high rates of tenancy and high rents implies a great demand for social housing in Brussels (Observatoire de la Santé et du Social de Bruxelles-Capitale, 2018a). In 2016, 36 117 over 39 586 social housing available were actually rented in Brussels, the rest being in renovation or simply not occupied. However, still 48 804 households were on the waiting list for a social housing which means that 57% of the demand is not satisfied (Observatoire de la Santé et du Social de Bruxelles-Capitale, 2018a). Social housing is offered by the Public Service Real Estate Companies (Brussels Logement, 2019).

Targeting vulnerable households in renovation policies

The new energy bonus regime of 2016[17] mostly intended to reach vulnerable households and tenants which are both less likely to engage in energy efficiency investments. Therefore, since 2016, energy bonuses are granted based on households' revenues (Brussels Environment, 2019a). The performance evaluation of targeted energy bonuses shows that households with lower revenues received higher amounts for their investments in 2018. This means that granting energy bonuses based on revenues worked well (Brussels Environment, 2018b).

Vulnerable households can also have access to green loans at a lower rate than other households. Indeed, green loans of 0% to 2% are accessible to finance housing renovation costs (Brussels Environment, 2019b).

Energy bills default payment

Wallonia has a strict procedure in place regarding energy default payments. In case of default payments, energy suppliers can install power limiters for electricity (except if electricity is used as a heating source) but not for natural gas (Huybrechs et al., 2011). This allows for consumers to still be delivered for a limited amount for 60 days. During this period, energy suppliers must come up with a plan of payment for the consumer. If the client still can't pay after this period, he can make a request at his CPAS for becoming a protected consumer. Protected consumers are supplied by network distributors (GRD) at the social tariff (Huybrechs et al., 2011).

2.4.4. Wallonia

The mEP in Wallonia is almost twice as high as the mEPs of the other two regions: 20.4% in 2016. However, it has a lower hEP and a pEP than the Brussels-Capital region: 3.9% and 7.2% respectively (Delbeke and Meyer, 2018). In Wallonia also, the government has taken measures targeting energy poverty.

[17] See section 1.4.

Fighting poverty

In 2015, the regional government adopted its first plan to fight against poverty (Government of Wallonia, 2018). The main objective of this plan was to tackle all expenditures incurred by households that may have a direct effect on inequalities and poverty: housing, food, energy, water, health, family policies, mobility, tourism, digital, access to rights (Government of Wallonia, 2017b). Tackling these expenditures helps to fight against poverty on a daily basis.

The second and current plan covers the period from 2017 until 2019. Two sections of the plan deserve a closer look in the discussion of energy poverty in Wallonia: housing and energy.

According to the second plan of fight against poverty (2018), Wallonia is characterized by high inequalities concerning access to housing. Only 10.3 % of unemployed people and 2.8% of families with single parent are owners even though they represent 16.2% and 11.6% of the population, respectively. The increase in rents in Wallonia goes side by side with the increase in demand for social housing. Rents in the private housing sector are almost twice as high as in the public housing sector (Government of Wallonia, 2018). The regional government is responsible for around 103 996 social housings (Société Wallonne du logement. 2018). In 2017, 96 660 households were living in a social housing, that represented around 6% of the population. The system of social housing distribution has proven to be quite administrative and inflexible (Government of Wallonia, 2018). Moreover, over the last 20 years it has attracted a very homogeneous population which led to a concentration of social problems that might have kept people from overcoming poverty. Therefore, the second plan of fight against poverty intends to reform the current system of social housing to make it more accessible and to guarantee heterogeneous population (Government of Wallonia, 2018).

Targeting vulnerable households in renovation policies

In 1993, the government of Wallonia launched a project called “MeBaR” which is aimed at helping low income households to invest in housing renovations enhancing a more rational use of energy (Government of Wallonia, 2019c). Households can receive up to 1365 € but they can apply several times for the subsidy. In the context of its strategy to fight against poverty, the regional government intends to recalculate the amount of the subsidy (Government of Wallonia, 2018).

As it was mentioned above, the second plan of fight against poverty also includes a section on energy. The plan aims to improve the overall quality and energy performance of the housing stock through the reinforcement of regional support (Government of Wallonia, 2018). The government of Wallonia really considers energy as being a great cause of poverty. Therefore, in the context of its long-term strategy for energy renovation of buildings[18], the region has decided to grant energy

[18] See section 1.4.

bonuses based on households' revenue and offer green loans at a rate of 0% (Government of Wallonia, 2019a).

Energy bills default payment

Walloon consumers are also subject to default payment procedures in the context of SPSOs. However, the procedure slightly defers from Brussels-Capital (Huybrechs et al., 2011). In case of default payment of consumers, suppliers can ask energy network distributors to place a budget counter which is a system in which energy is prepaid by the client (ORES, 2019). The latter can manage its energy budget without being constraint to a power limiter. Non-protected consumers will continue to be supplied by their suppliers while protected consumers will be "dropped" to energy network distributors at the social tariff (Huybrechs et al., 2011).

2.4.5. Flanders

The Flemish region has the lowest energy poverty indicators of all three regions. In 2016, it had a mEP of 11.4%, a hEP of 2.9% and a pEP of 2.4%. According to Delbeke and Meyer (2018), the Flemish region is characterized by higher levels of income, smaller and attached housing and a warmer climate (on average) than the other regions. Therefore, energy poverty is less likely.

Fighting poverty

Like the other regions, Flemish region responses to the first cause of energy poverty by engaging in the fight against overall poverty. On July 3rd 2015, the regional government accepted the Flemish Plan of action to fight against poverty. The plan covers the period from 2015 to 2019 and tries to respond to the "Pact 2020" objectives[19] for poverty. Consequently, the Flemish Plan presents concrete policy actions that the government will put in place in order to reduce poverty.

Another way in which Flanders fights against poverty is by providing social housing to low income households. In 2016, 153 900 social housing were made available for needy households which was around 3000 more than in 2014 (Vlaamse Maatschappij voor Sociaal Wonen, 2017).

Fighting energy poverty

In 2015, the regional government also intended to establish an action plan exclusively dedicated to energy poverty (Vlaamse Overheid, 2015). The Flemish energy poverty program was

[19] According to the Pact 2020, the number of people at risk of poverty or social exclusion in Flanders must be "low" compared to the EU27 best performing country by 2020 (Vlaamse Overheid, 2016).

implemented in 2016 (Vlaamse Regering, 2016). It was developed in the context of the Renovation Pact of 2014[20]. One of the concrete actions outlined in the Renovation Pact was the Flemish energy poverty program (Vlaamse Overheid, 2019a). The latter contains a list of 34 policy actions which can be divided into two ranges of measures (Vlaamse Regering, 2018). One addressing energy bills default payments and a second targetting vulnerable households in renovation policies.

Energy bills default payment

The first series of actions' objective is to optimize the existing protection of protected consumers against energy closure. Since 1996, the Flemish government has installed measures aimed at protecting people's rights to energy (Bartiaux et al., 2015). These measures ensure access to energy as well as the retention of gas and electricity supply for protected consumers.

Flemish energy suppliers are also subject to SPSOs in cases of energy bills default payments and access to energy (Bartiaux et al., 2015). In case of default payments, consumers (regardless if they are protected or not) are dropped to energy network distributors (Huybrechs et al., 2011). If consumers don't pay energy network distributors either, the latter can install a budget counter like in Wallonia. The main difference between protected and non-protected consumers who are supplied by energy network distributors in Flanders is the price paid. Protected consumers benefit from the social tariff while non-protected consumers must pay the maximum price for "dropped" clients (Huybrechs et al., 2011).

Targeting vulnerable households in renovation policies

The second range of measures serves the purpose of increasing energy efficiency as a response to energy poverty. Different groups of vulnerable consumers are targeted in these measures (Vlaamse Regering, 2018). These policies widen the opportunities of vulnerable consumers in terms of energy scans, policies regarding the private housing market (roof and wall insulation), energy loans at low interest rates, renovation subsidies, etc…. (Bartiaux et al., 2015; Vlaamse Regering, 2016).

2.5. CONCLUDING REMARKS ON ENERGY POVERTY

Closely related to poverty, energy poverty is caused by a combination of three elements: low income, dwellings (i.e. poor energy performance and tenure status) and high energy prices. Energy poverty can have serious consequences on households and on society. Therefore, Belgian governments have increasingly engaged in the implementation of policies that are aimed at

[20] See section 1.4.

addressing this issue. However, these policies do not seem to be efficient in addressing energy poverty yet. Delbeke and Meyer (2018) show that mEP, hEP and pEP have all stayed relatively constant since 2009. This means that energy poverty is still an important issue in Belgium.

As already mentioned, decarbonization is very likely to have a negative impact on energy poverty. Since existing policies do not seem to sufficiently mitigate energy poverty, they will surely not prevent an increase in energy poverty following the implementation of decarbonization policies. Therefore, complementary policies directly aimed at addressing energy poverty in the specific context of decarbonization would be necessary.

Chapter 3: Distributive impact of decarbonization policies in residential buildings sector

In the previous chapters, decarbonization and energy poverty were addressed separately. Here, the link between both concepts will be discussed. Indeed, implementing any measure or instrument that is aimed at decarbonizing the residential buildings sector will directly involve households. Often, these policies have what is called a "distributive impact" on households. This means that low income households are much more affected by these policies than high income households (Murray and Rivers, 2015; Markannen and Anger-Kraavi, 2019). Besides, the causes of energy poverty are likely to be amplified by decarbonization policies. In the short and medium-term, this leads to an increase in energy poverty. This chapter will discuss this issue but first, it presents HBS 2016 which is the database that will be used in the analyses of the rest of this thesis.

3.1. METHODOLOGY AND DATABASE

3.1.1. Belgian Household Budget Survey 2016

HBS is a survey that is conducted every two years by the Belgian statistical office (StatBel). The last survey was conducted in 2018 but data has not yet been made available. Therefore, HBS data of 2016 was used in this paper.

The sample contains 4 490 households (531 Brussels households, 2 175 Flemish households and 1 784 Walloon households) which represent 10 782 people in total. HBS is a 45 minutes interview complemented by a statement in which the household must keep track of all expenses it has incurred for 1 month. Most questions about households' energy consumption were added in 2016.

The HBS sample is drawn from the Labor Force Survey (LFS) samples. The latter are drawn from a sample frame that is derived from the national register of the population. The response rate to HBS equals to about 9.1% of the contacted households is 2016. In order to consider potential sample errors, the statistician in charge of HBS recommended the presence of at least 10 respondents per answer for it to be representative of the population.

3.1.2. Sampling weights

Each household has been given a weight in order to account for a certain number of real Belgian households. These weights allow to duplicate the number of observations in the sample to match real population. This means that –together– the 4 490 respondents represent the 4 852 487 Belgian households of 2016.

Weights have been computed based on households' characteristics to be found in the national register. They also account for certain sampling design adjustments and mistakes. For example, for the fact that German municipalities were eliminated from LFS samples.

3.1.3. Income classes classification

In order to classify households per income deciles/quartiles, the concept of "equivalized disposable income" was used in this paper. This measure of households' disposable income helps considering differences in size and composition of a household (Statbel, 2018a). It is computed using the OECD equivalence scale which gives a weight to all household members.

These weights are called "consumption units":

- 1 for the head of the household/first adult
- 0.5 for the other adults and all other members above 14 years old included
- 0.3 for all children aged under 14 years old

The equivalence scale, or consumption units, is/are then multiplied with the household's disposable income (i.e. after tax and other deductions) to obtain its *equivalized disposable income.*

3.1.4. Water bill estimation

Some of the households interviewed in HBS have difficulties to estimate the amounts they pay for gas, electricity and water separately. Thus, 1 524 households in the HBS of 2016 report a combined amount for two or three of these elements. However, in this study only households' spending for energy is needed, not for water.

To estimate the water bill of households, a method presented by Xavier May (2013) in his study about energy poverty of old households was used. May estimates the water bill of Belgian households by means of the following regression:

$$\begin{aligned} Water\ bill = & -2.021 + 14.9\ consumption\ units - 3.392\ brussels \\ & + 1.855\ flanders + 3.087\ washing\ machine \end{aligned} \tag{3.1}$$

where the variable *consumption units* represents the OECD equivalence scale explained earlier; *brussels* and *flanders* are binary variables equal to 1 if the household live in the region, 0 if it does not and *washing machine* is a binary variable equal to 1 if the household owns a washing machine, 0 if it does not (May, 2013).

Estimated water bills are then subtracted from reported combined amounts. Resulting amounts give exactly what households spend for electricity, gas and water separately. Finally, all households having a negative energy bill, an energy bill of 0 or an energy bill that is higher than their income were removed from the sample. Consequently, the sample decreases from 4 491 to 4 361 households. In this new sample, still 1 434 households report a combined amount for gas and electricity. However, no method for further separation was found.

3.2. POTENTIAL IMPACT OF DECARBONIZATION LEVERS AND POLICIES

As seen earlier in Chapter 1, there are two main axes through which decarbonization of the Belgian residential buildings sector can be achieved. On the one hand, low-carbon levers which require investments: either in renovation of buildings through insulation and/or in energy efficiency of heating systems. On the other hand, carbon taxes as an instrument to decrease demand for carbon in the residential buildings sector. Both can have "distributive impacts" on households.

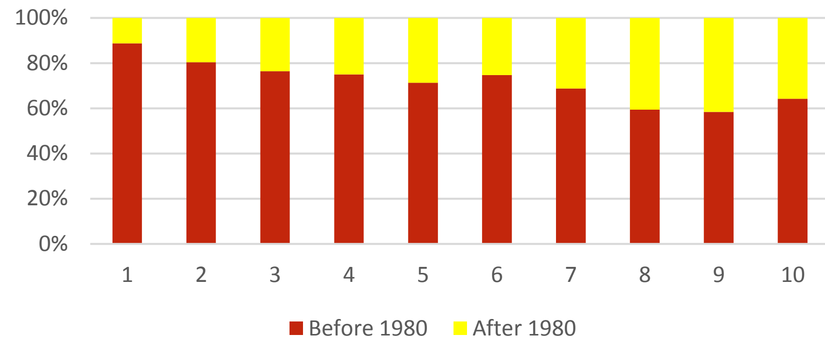
3.1.5. Potential distributive impact of low-carbon levers

In a situation[21] in which low-carbon investments are not profitable (i.e. costs are not covered by savings in energy efficiency) and/or households cannot borrow at very low rates to finance their investments, low-carbon levers can have a distributive impact on poor households.

Since poor households do not have enough margin to invest in energy efficiency, they will be more affected by the implementation of policies regarding low-carbon investments. For example, in Belgium poorer households live in older housing. Figure 3.1 below shows the age of housing per income decile in 2016. Almost 90% of the first income decile lives in a house that was built before 1980, compared to around 65% of the last income decile. Consequently, poorer household will be the first to suffer from renovation policies in Belgium.

[21] This situation is further discussed in Chapter 4.

<u>Figure 3.1 – Age of housing per income decile in 2016</u>



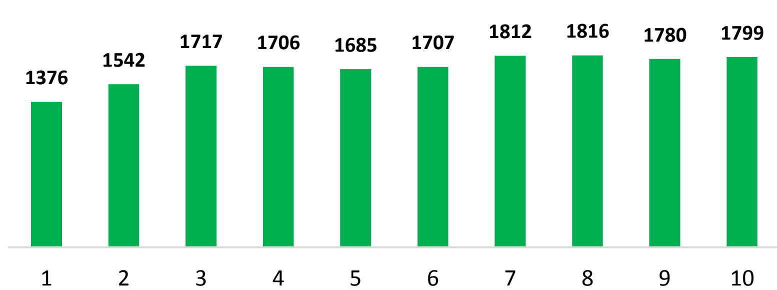
Source: HBS 2016

According to Eyckmans (2017), there is a distributive impact to imposing energy efficiency standards. On the one hand, poor households live in low energy performing housing which means they will have to invest in renovation and new heating systems. On the other hand, such standards are very likely to drive the prices of rent and buildings up (Eyckmans, 2017). If great acceptability of such reforms is expected, policymakers should accompany renovation policies with measures that specifically target poor households and offer them support in this transition.

3.1.6. Potential distributive impact of carbon taxes

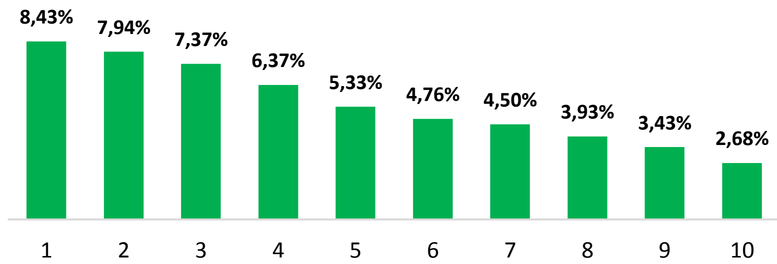
Carbon taxes can also have a distributive effect. It is one of the claims of the French "Gilets Jaunes" movement that started at the end of 2018 (Criqui et al., 2018). Two reasons explain the potential distributive impact of carbon taxes. First, data shows that even though low income deciles consume less energy, energy expenses represent a higher percentage of their income than higher income deciles. This is shown in Figure 3.2 and 3.3 below. The same pattern can be observed for carbon taxes. Although poor households pay lower carbon contributions, they represent a greater proportion of their income than richer households (Valenduc, 2017). In conclusion, lower income deciles are more affected by the tax.

<u>Figure 3.2 – Average total annual energy bill (in €/household) per income decile 2016</u>



Source: HBS 2016

Figure 3.3 – Average total annual energy bill in % of income per income decile in 2016



Source: HBS 2016

Another reason that explains the potential distributive impact of carbon taxes relates to the differences between households in their dependency to fossil fuels (Criqui et al., 2018). Living in older and potentially less energy efficient housing, poorer households consume more energy than they would have in more performing dwellings.

3.2. DECARBONIZATION AND THE CAUSES OF ENERGY POVERTY

Decarbonization policies and measures implemented in the residential buildings sector are likely to amplify the three fundamental causes of energy poverty. This would result in an increase in energy poverty.

Firstly, as it was shown in the previous section poorer households live in less energy performing housing. Therefore, they will be the most affected by policies regarding renovation. Moreover, tenants are also among the poorest households which makes the tenure status also a factor that influences the impact of policies.

Secondly, the decarbonization of the Belgian residential buildings sector is likely to provoke a sudden increase in energy prices. On the one hand, the introduction of a carbon tax will make petroleum products and natural gas more expensive. On the other hand, with the transition towards renewable energies, households will mainly have to switch to electricity to replace non-renewable energies (EC, 2018b). According to the European Commission's 2050 strategy, the share of electricity in final energy demand will be twice as high in 2050. As electricity prices have been rising in the recent years and are higher than those of fossil fuels, some households will most probably suffer from this switch. It is important to note that both effects should only arise in the short and medium-term since both carbon taxes and the transition towards renewable energies should decrease energy consumption in the long run.

Thirdly, both investments in energy efficiency and rises in energy prices are likely to constraint households' income in the short and medium-term. Since income is a determinant of poverty and in turn, energy poverty, decarbonization constitutes a threat for both. However, in the long-term better energy performance of dwellings and lower energy consumption should result in lower energy bills for all households.

3.3. CONCLUDING REMARKS ON SOCIAL COSTS OF DECARBONIZATION

In conclusion, as it stands and if no particular measures are taken, decarbonization levers as well as the different policies that could be implemented in the context of the decarbonization of the Belgian residential buildings sector could have a distributive impact on households. Indeed, decarbonization could increase energy poverty and impoverish vulnerable households. Nonetheless, these effects are only expected to happen in the short- and medium-term as decarbonization policies should increase energy efficiency and decrease energy consumption and energy bills in the long run. Therefore, in the short and medium-term, any decarbonization measure should be complemented with sufficiently mitigating policies to prevent regressive impacts to arise (Markannen and Anger-Kraavi, 2019).

Part II: Policies dealing with an increase in energy poverty

Chapter 4: Low-carbon levers and energy poverty

The next two chapters analyze how to complement decarbonization levers and policies with specific support policies targeting energy poverty. This chapter will focus on low-carbon levers (i.e. renovation through insulation and energy efficiency of heating systems) whereas the next chapter will focus on the implementation of a carbon tax in Belgium.

Concerning low-carbon investments in the residential sector, Chapter 2 has shown that there are three main barriers that prevent households to do so. These barriers relate to the second cause of energy poverty (i.e. the context of dwellings): (1) the split incentives issue, (2) the lack of resources to finance investments and (3) the lack of awareness about energy efficiency. Each of these barriers can be addressed to prevent an increase in energy poverty. This chapter discusses the first two barriers for the Belgian residential buildings sector by analyzing HBS 2016 data. The lack of awareness is not further addressed in this paper. However, it could be interesting to dig deeper into this issue in future work to study whether poor people are less likely to be educated about energy efficiency.

4.1. SPLIT INCENTIVES ISSUE

The split incentives issue is likely to be quite important in Belgium due to the high proportion of tenants across the country. As a reminder, the moral hazard issue of split incentives issue arises when tenants' and owners' motivations do not align. In other words, owners do not have any incentives to renovate their rented goods because derived benefits do not accrue to them directly. In consequence, rented buildings have low energy performance and tenants pay higher energy bills than they should. This section discusses the split incentives problem in Belgium and how it mainly affects the poorest income deciles.

4.1.1. A profile of Belgian tenants

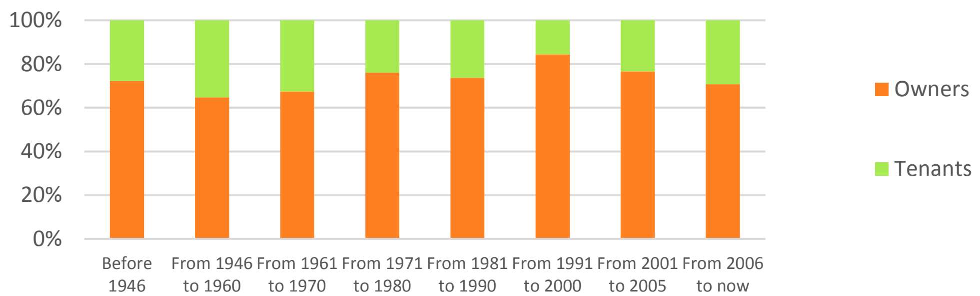
One third of Belgians are tenants. According to HBS 2016, this represents approximately 1.33 million households. This means that around 30% of the population does not live in a place they own. Consequently, they are more likely to face the split incentives problem. This issue is particularly present in the region of Brussels-Capital because more than 50% of the population are tenants, compared to below 30% in the other two regions.

Rented housing

Most tenants live in apartments whereas most owners live in houses. Roughly 85% of owners live in houses compared to only 38% of tenants. The most common types of housing for tenants are apartments in a 3 to 9 dwellings building. Since all dwellings in a building are not always owned by the same owner, it increases even more the split incentives problem because the decision to renovate the building must be taken by a group of individual owners.

Unexpectedly, rented buildings are not very much older than owned buildings. On Figure 4.1, the share of tenants and owners per construction age of buildings can be observed. The proportion of tenants does not decrease with the construction age of buildings. However, still a bit more tenants (76%) than owners (70%) live in dwellings that were built before 1980[22] but this difference is quite small.

Figure 4.1 – Share of tenants and owners per construction age of buildings in 2016



Source: HBS 2016

Energy bills and income

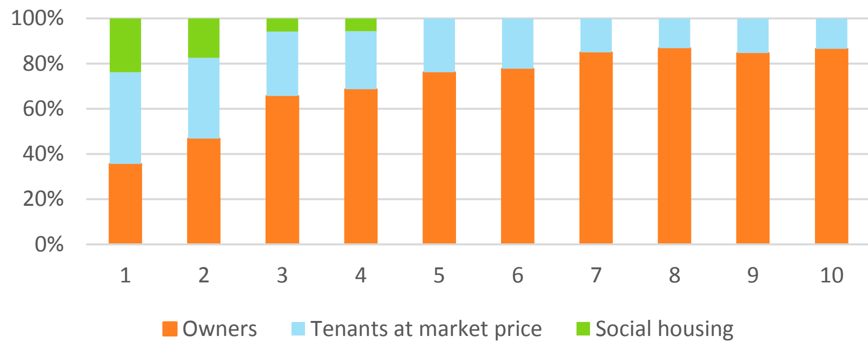
Three reasons explain why owners' average annual energy bills are higher than those of tenants. Firstly, apartments consume less than houses. As seen above, most tenants live in apartments. Secondly, tenant households are also smaller. Almost 50% of tenants are singles while it is the case of less than 30% of owners. Finally, a higher share of tenants use gas as a principal heating source which is cheaper than oil. This is potentially due to more efficient returns of gas boilers.

Although tenants' energy bills are lower, they represent a slightly higher share of their income (5.5% for tenants and 5% for owners). In fact, households are poorer. The average equivalized disposable income is 1650 €/household/month and 2225 €/household/month for tenants and owners, respectively. Figure 4.2 shows the share of tenants and owners per income deciles. Clearly, the share of tenants is decreasing with the level of income. In the two first income deciles, more

[22] 1985 is the year of first thermal regulations in Belgium. Buildings built before are likely to be energy inefficient.

than 50% of the population are tenants. Since tenants are more vulnerable, they are more likely to experience difficulties in paying their energy bills.

Figure 4.2 – Share of tenants (in social housing or not) and owners per income decile in 2016



Source: HBS 2016

Social housing

An important proportion of tenants live social housing. According to HBS 2016, around 20% of tenants were paying a rent below the market price in 2016 because they lived in social housing.

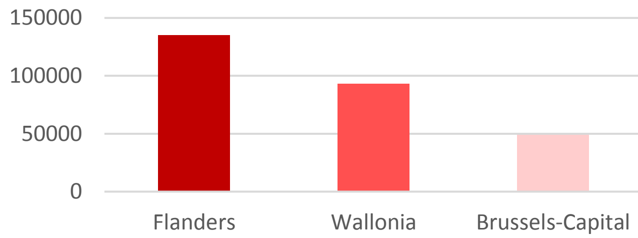
This has some implications for the split incentives issue. Since the owner of social housing is the State, one fifth of tenants should not be confronted with the split incentives problem. Figure 4.2 also shows that all these tenants come from the first four income deciles. Therefore, resolving the split incentives issue in Belgium should not be enough for preventing energy poverty.

4.1.2. Public budget for social housing renovation

In Belgium, regional governments are responsible for social housing. Figure 4.3 shows the number of households living in social housing per region[23]. Even though Flanders has the highest number of people living in social housing, it represents only 5% of its population compared to 6% and 10% for Wallonia and Brussels.

[23] It doesn't exactly match with the data that originates directly from the regions presented in section 2.4.3 but it is quite close. Social housing in Flanders and Wallonia were a little overestimated by the HBS 2016 while it was underestimated for Brussels-Capital.

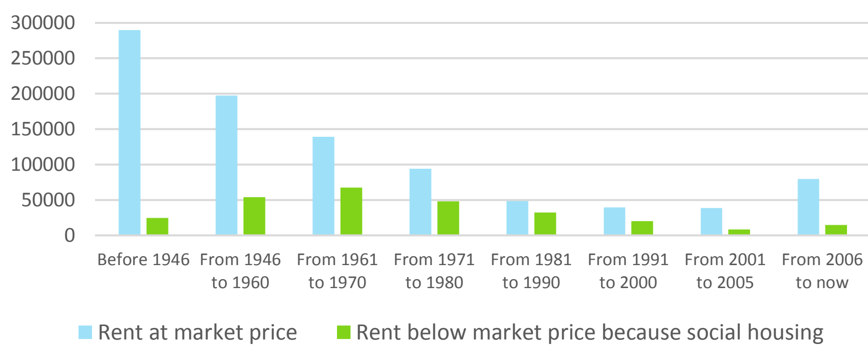
Figure 4.3 – Number of households living in a social housing per region in 2016



Source: HBS 2016

As it can be observed on Figure 4.4, social housing is quite old compared to other rented buildings. From the 1950s to the 1970s, there was a great period of social housing construction in Belgium (Dessouroux & Romainville, 2010; Government of Wallonia, 2019d). After World War II, the proportion of poor people increased and so did the need for social housing. At that time, there were no regulations on the energy performance of buildings yet. Therefore, it is very likely that social housing built during this period (and before) are energy inefficient.

Figure 4.4 – Number of tenants per age of housing and type of rent in 2016



Source: HBS 2016

Since social housing are publicly owned, the state is responsible for financing the renovation of all social housing. HBS 2016 data allows to compute how many social housings were built before the implementation of the first thermal regulation in Belgium. Consequently, it is be possible to estimate a budget for each region needed to be made available in order to renovate social housing.

Computing a public budget for social housing renovation

In order to get an idea of the budget's magnitude, an approximate amount that would be needed to engage in major renovations[24] of the Belgian social housing buildings stocks was estimated[25]. A policy report of the European Commission (2015) about energy renovation of buildings has estimated the average cost of residential buildings' renovation. According to this report, energy renovation costs[26] can range between 200 €/m^2 and 500 €/m^2 depending on the depth of renovations. Major renovations would cost approximately 300 €/m^2 (Saheb et al., 2015). It uses an average of 100 m^2 for houses and 75 m^2 for apartments.

Assuming all social housing built before 1980 would need major renovations and all built after 1980 would not, an approximate budget 5 billion € would be needed. More precisely, 2.3 billion € in Flanders, 2 billion € in Wallonia and 700 million € in Brussels-Capital (Table 4.1). It should be noted that Flanders has already highly renovated its social housing stock. In Chapter 1, we have seen that more than 70% of Flemish social housing stock had already undergone major renovation in 2016[27]. This means that the above-estimated budget is probably overestimated for Flanders. Decreasing the Flemish budget by 70% results in a total budget of 675 million €.

If all buildings must be renovated by 2050, this leaves 30 years to the three regions to renovate their social housing stock. A yearly budget of 22 million €, 70 million € and 25 million € would be needed for Flemish, Walloon and Brussels' social housing, respectively. This gives an idea of the approximate amount each region can spend in order to prevent an increase in energy poverty for around 6% of the Belgian population.

Table 4.1 – Approximate budget for social housing renovation

	Total budget	**Total budget** *(corrected for Flanders)*	**Yearly budget**
Belgium	5.026.042.433 €	3.451.913.842 €	115.063.795 €
Flanders	2.248.755.129 €	674.626.539 €	22.487.551 €
Wallonia	2.032.938.880 €	2.032.938.880 €	67.764.629 €
Brussels-Capital	744.348.423 €	744.348.423 €	24.811.614 €

Note: The amounts represent total and yearly budgets needed to renovate the whole Belgian social housing buildings stock. In the second column, the Flemish budget was lowered to reflect social housing renovations the regional government already has undergone.

Source : HBS 2016, own calculations, European Commission

[24] Major renovations are defined by Article 2 of the Energy Performance of Buildings Directive as "renovations where the total cost of the renovation relating to the envelope or its systems is higher than 25% of the value of the building, or more than 25% of the surface of the building envelope undergoes renovation" (Zebra2020, 2019).

[25] Calculations estimated in this subsection are approximate and based on publicly available data. More precise computations would be necessary in order to use the results in public policies.

[26] No specific data for social housing renovation costs was found.

[27] No data on renovation of social housing for the two other regions was found.

4.1.3. How to solve the split incentives issue?

The remaining 80% of tenants are still likely to be confronted with the split incentives issue. Split incentives can be solved by implementing policies that (1) provide incentives to owners to invest in the buildings they rent and (2) provide financial support to tenants who would like to engage in energy efficiency investments.

Incentives for owners

Policies that provide incentives to owners to engage in renovation and energy efficiency investments include: minimum energy performance requirements and financial incentives (Economidou & Bertoldi, 2015). In Belgium, minimum energy performance requirement has already been implemented through the implementation of the EPBD in each region[28]. Moreover, Flanders has a regulation concerning minimum requirement for roof insulation of rented buildings (Vlaamse Regering, 2014).

Financial incentives for renovating rented buildings have not yet been used in Belgium. Lessons learned from other countries provide a few examples of how financial incentives can be used to solve split incentives. For instance, in Italy when energy interventions yield at least 50% savings, landlords can use 60% of the savings as a pay-back for the investment and the remaining 40% goes to tenants (Economidou, 2014). Another type of financial incentive for owners are energy efficiency grants. Many countries plan to make or have made available a budget for owners who want to invest in energy efficiency measures. Green loans and subsidies that are issued by Belgian regions are a form of energy efficiency grants. However, there is no clear evidence that owners also use these to renovate their rented buildings.

Financial support for tenants

Green loans and subsidies directly targeting tenants and vulnerable households such as those issued by the region of Brussels-Capital are examples of financial support for tenants.

Abroad, the most common policy reflecting financial support for tenants is on-bill financing. It is a mechanism in which investments are refunded through the energy bill (Economidou & Bertoldi, 2015; Mundaca and Kloke, 2018). The energy supplier is the one responsible for paying the upfront cost of the investment. Afterwards, energy suppliers receive a compensation that equal the energy savings achieved thanks to the energy efficiency investment. This allows for tenants to keep peying the same amount of energy bills and to finance renovation of their housing. This policy was for the first time implemented in the UK through the "Green Deal" in 2013.

[28] See section 1.4.

What could be implemented in Belgium?

In order to solve the split incentives problem in Belgium, the following recommendations could be made. First, even though regional governments have introduced the EPBD, only Flanders has gone further with energy performance requirements for rented buildings, specifically. The three regions could, for instance, strengthen (1) standards required for EPB certificates of rented buildings and (2) compliance controls. Secondly, green loans and subsidies currently issued by the three regional governments are mainly destined to owners who want to renovate their own housing. Belgian governments could take example on the Italian mechanism used to address split incentives. In this way, Belgian owners would receive part of the energy savings from low-carbon investments which would provide them with a motivation to renovate their rented buildings. Finally, it is possible to imagine the implementation of an on-bill financing mechanism in Belgium that would be financed by network distributors which are already in charge of supplying protected consumers[29].

4.2. LACK OF FINANCIAL RESOURCES FOR OWNERS

In the previous section, energy poverty of owners was not considered. However, Figure 4.2 shows that roughly 50% of the three poorest income deciles are owners. What usually prevents owners from investing in energy efficiency of their own housing is their lack of financial resources. If energy efficiency investments are profitable and households can borrow at very low rates, the lack of financial resources should not be an issue. A low-carbon investment can be considered as profitable when the savings from lowered energy bills can recover the cost of the investment (FPS Health, 2018). However, a study conducted for the Belgian National Debate on Carbon Pricing (2018) shows that low-carbon investments (i.e. building's energy renovation and heating pumps) are not always profitable. Consequently, households could potentially loose a share of the amount they invested. In this case, owners' lack of financial resources plays a role.

This section first briefly explains the situations in which low-carbon investments could not be profitable. Then, it analyses the three first income deciles into more details to know who should be provided with support for low-carbon investments when these are not profitable.

4.2.1. Profitability of low-carbon investments

Low-carbon investments (i.e. renovation through insulation and energy efficiency of heating systems) are often presented as providing many benefits to households. Both investments in insulation and heating pumps should decrease the average energy bill of households. Proponents

[29] See section 2.4.

of such investments show that even though these investments require high upfront payments, households will have lower energy bills. Still, according to the report of the Belgian National Debate on Carbon Pricing (2018) low-carbon investments are not always profitable.

Building energy renovation

According to the report (2018), savings from lowered energy bills following an investment in energy renovation of buildings do not always allow to completely recover the cost of the investment. The profitability of the investment depends on energy prices, on households' behavior in terms of energy consumption, on the lifetime of the investment….

One way to improve the profitability of low-carbon investment is the implementation of a carbon tax (FPS Health, 2018). With a carbon tax, households using fossil fuels will find their investment to be more profitable.

Heating pumps

The report shows that energy bills of heating with the most efficient heat pump are lower than those of heating with fossil fuels. Nonetheless, low-carbon investments in heating pumps are not profitable for less efficient heating pump. Again, the report shows that the implementation of a carbon tax in Belgium could make investments profitable for all types of heating pumps.

This is important to note in the discussion about energy poverty in the context of decarbonization because if poor households invest in a heating pump, they will probably not be able to afford the most efficient heating pump. As a result, their investment is less likely be profitable.

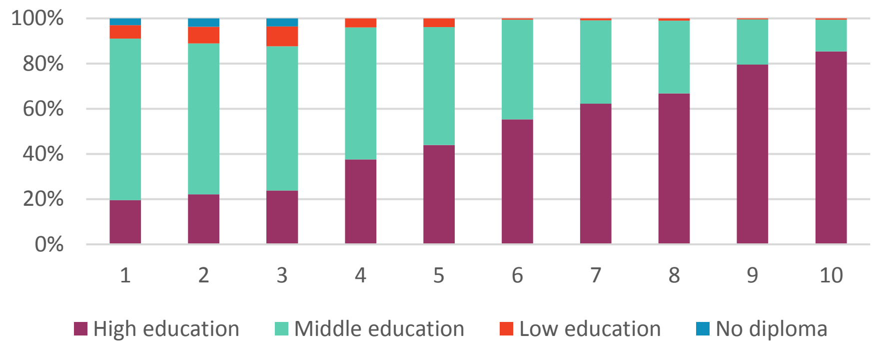
4.2.2. The poorest income deciles

Poor Belgian households' characteristics

According to HBS 2016, lower income deciles are mostly composed of isolated families, that is defined as singles and single-parent families. On the contrary, higher income deciles include more couples with and without kids. Old couples are part of middle-income classes. As a result, poor households are more likely to live in apartments than rich households. However, still 50% of the first income's population live in a house. This share increases with income.

Additionally, lower income deciles are less educated. Figure 4.5 shows the highest level of education per household in each income classes for 2016. High education refers to a university/higher education diploma, middle education refers to a high-school diploma and low education refers to a middle-school diploma. In the three first income classes, more than 75% of households haven't obtained a university diploma and around 10% haven't studied higher than middle school. As seen in Chapter 2, low education is one of the (sub-)causes of energy poverty.

Figure 4.5 – Highest level of education per income decile in 2016



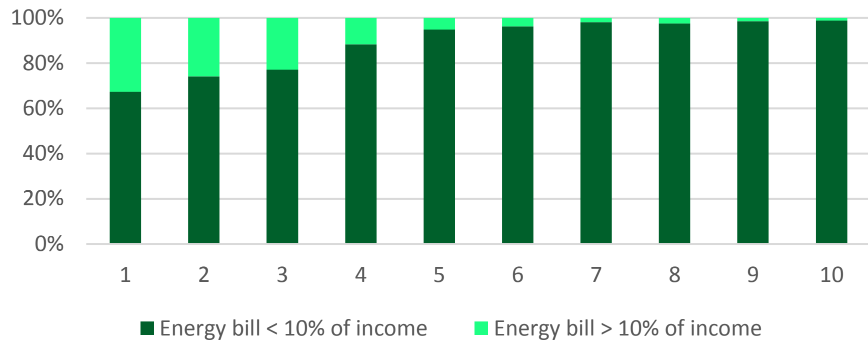
Source: HBS 2016

Energy bills

Total annual energy bills also increase with the level of income (Figure 3.2). This means that richer households consume more energy than poorer households. This isn't surprising as higher income classes are characterized by bigger families living in greater dwellings. However, energy bills represent a higher proportion of income for poor households. This was represented in Figure 3.3. While the first income class dedicated around 8.5% of its income to energy in 2016, the last income class only spent 2.7% of its income.

In most definitions of energy poverty seen earlier in Chapter 2, the threshold is set at 10% of income which is devoted to energy. Although in practice energy poverty is broader than such a threshold (i.e. inefficient dwellings, high energy bills, low income, difficulties to understand and poor awareness about energy consumption), it is still interesting to know the share of people who do actually spend more than 10% of their income on energy and whether this proportion decreases with income. Indeed, Figure 4.6 shows that more than 30% of the first income decile spend at least 10% of their income on energy. This proportion is decreasing with the level of income.

Figure 4.6 – Energy poverty threshold (10%) per income decile in 2016



Source: HBS 2016

In conclusion, lower income classes live in older (and potentially) less renovated housing, spend a higher share of their income on energy bills, most earn only one income and they are less educated. All these factors highly augment their chance of facing energy poverty. Housing renovation offers a solution to this issue, but it must be financed. If low-carbon investments are profitable, financing should not be an issue for Belgian owners. Indeed, in each region households can borrow at very low rates to finance energy efficiency investments[30]. Nevertheless, if low-carbon investments are not profitable, regional governments could for instance encourage low-income owners to invest by subsidizing the share of costs that could not be recovered by energy efficiency savings.

4.3. CONCLUDING REMARKS ON LOW CARBON LEVERS AND ENERGY POVERTY

This chapter's analysis makes three principal contributions to the literature. Firstly, it shows that 20% of tenants live in social housing. All of which find themselves in the first four income deciles. The owner of social housing, namely the State, is responsible for making a budget available to renovate this buildings stock. A total approximate budget of 115 million € should be made available for the next 30 years by Belgian governments in order to renovate the whole social housing buildings stock.

Secondly, the important number of tenants demonstrates that the split incentives issue is very likely to arise in Belgium. In the context of decarbonization, there are two paths that can be followed to prevent energy poverty of tenants who do not live in social housing. On the one side, providing

[30] See section 2.4.

incentives for owners to invest in their rented buildings. On the other side, increasing financial support for tenants.

Finally, around half of the first three income decile remain owners. Since they are relatively poor, a lack of financial resources could potentially prevent them from investing in low-carbon alternatives. There are two concluding implications for low-income owners. On the one hand, if low-carbon investments are profitable, current regional measures allow them to borrow at rate of 0% to 2% so poor owners should not encounter too many barriers to invest in energy efficiency. On the other hand, if low-carbon investments are not profitable, regional governments could provide a form compensation for unrecovered costs, in addition to current green loans and subsidies.

Chapter 5: Carbon tax and energy poverty

Carbon taxes can also have a distributive impact on households. Hence, a carbon tax implementation in the Belgian residential sector could potentially increase energy poverty in the short and medium term. Chapter 1 has provided some insight on carbon taxes around the world and the different mechanisms behind them. Carbon tax revenues can be used for different purposes. The current “trend” in countries taxing carbon is to use revenues to compensate households from increases in energy prices through lump-sum transfers (e.g. like in France, Switzerland, British Columbia…). A well-designed compensation scheme could possibly prevent an increase in energy poverty. This chapter investigates the impacts of a carbon tax implementation on Belgian households. To do so, it is important to first analyze energy consumption of households. Afterwards, this chapter analyzes the ways in which different compensation schemes can mitigate the impacts of a carbon tax on poor households.

5.1. DETERMINANTS OF HOUSEHOLDS’ ENERGY CONSUMPTION

For the analysis, the carbon price was set at 10 €/tCO_2 which is the 2020 carbon price for trajectory options A, B and C (Table 1.2 in Chapter 1). The distributive impact of a 10 €/tCO_2 on households is quite small[31]. However, each trajectory option intends to highly increase carbon prices by 2030 and 2050 which means that the distributive impact will also increase. A carbon price of 10 €/tCO_2 was chosen because it is likely to be the first carbon price if a carbon tax is implemented in Belgium.

5.1.1. Changes in HBS 2016 database

For this part of the analysis, the database was slightly modified. In order to compute households’ carbon emissions, only those having positive gas and oil bills were kept. In the sample, 1 204 households consume oil and 2 516 consume gas[32]. This leaves us with a database of 2 286 households (i.e. 1204 using oil and 1082 using gas) whose combined weights account for 2 252 187 households. To keep a substantial amount of observations in each income class, income quartiles will be used in the rest of this analysis.

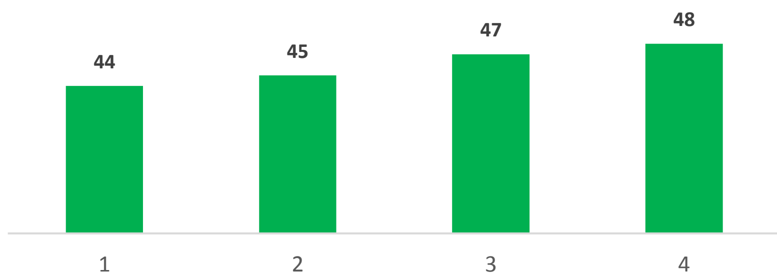
[31] In other words, the analysis shows that there are small differences in carbon tax impacts between income quartiles.
[32] It wasn’t possible to estimate exact gas expenditures for 1 434 households since they reported the amount they spend annually for gas and electricity combined. They were excluded from the sample. This could potentially weaken the accuracy of the results.

5.1.2. Households' carbon contributions

Following the implementation of a 10 €/tCO_2 carbon price, each household will pay a different amount based on its level of CO_2 emissions. These amounts are the households' "carbon contributions". The point of departure to compute households' carbon contributions is their annual energy expenses for gas and oil. Each household's annual energy expenses were divided by the average energy prices to get their annual consumption. In 2016, average prices of natural gas and oil were equal to 0.053 €/kWh and 0.488 €/l, respectively (FPS Economy, 2019b).

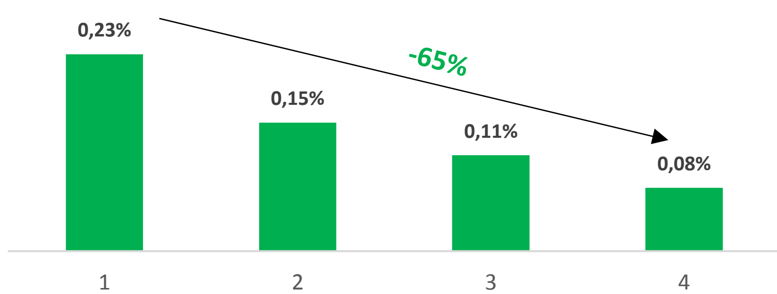
Then, households' annual consumption was multiplied by CO_2 emission factors for natural gas and oil which equal to 0.202 kg/kWh and 2.63 kg/l respectively. Finally, households' CO_2 emissions were multiplied by the carbon tax in order to obtain each household's carbon contribution. Households' average carbon contributions per income quartile are shown on Figures 5.1 and 5.2. On the one hand, average contribution rises with the level of income. On the other hand, contributions represent a higher share of income for the lowest income quartile. The last income quartile spends around 65% less than the first quartile (Figure 5.2).

Figure 5.1 – Average annual carbon contribution (in €/household) per income quartile



Source: HBS 2016, own calculations

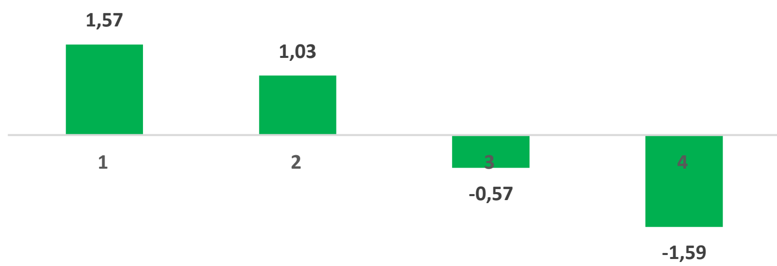
Figure 5.2 – Average annual carbon contribution (in % of income/household) per income quartile



Source: HBS 2016, own calculations

These figures allow to conclude that poorer households will be more impacted by the implementation of a carbon price on energy. Since they consume less, a complete uniform redistribution of the tax revenue would lead the poorest households to be better off with respect to a situation in which the carbon tax would not have been implemented. For instance, total carbon contributions of a 10 €/tCO_2 carbon price would have been equal to 105 million €[33] in 2016. This means that each household would have received a lump-sum 46€ as a compensation for the carbon price. Figure 5.3 shows the average gains and losses from this uniform compensation scheme. Whereas the two lowest income quartiles would benefit from a net gain of 1.57€ and 1.03€, the two highest income quartiles would lose on average 0.57€ and 1.59€.

Figure 5.3 – Average gains and losses (in €/household) from uniform compensation (46€/household)

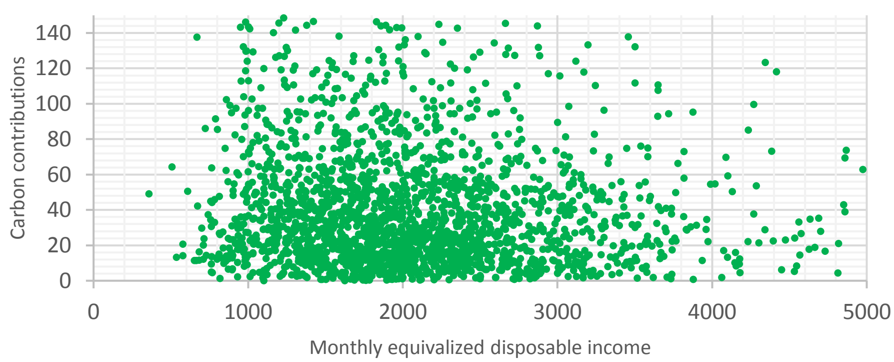


Source: HBS 2016, own calculations

5.1.3. Heterogeneity of energy consumption within income classes

A study of Christian Valenduc (2017), shows that a uniform lump-sum compensation might not be the optimal form of redistribution. He argues that energy consumption is "heterogeneous". This means that within income classes, households consume energy very differently. Figure 5.4 plots individual carbon contributions against households' monthly equivalized disposable income.

Figure 5.4 – Annual carbon contributions per household with a 10€/tCO_2 carbon price



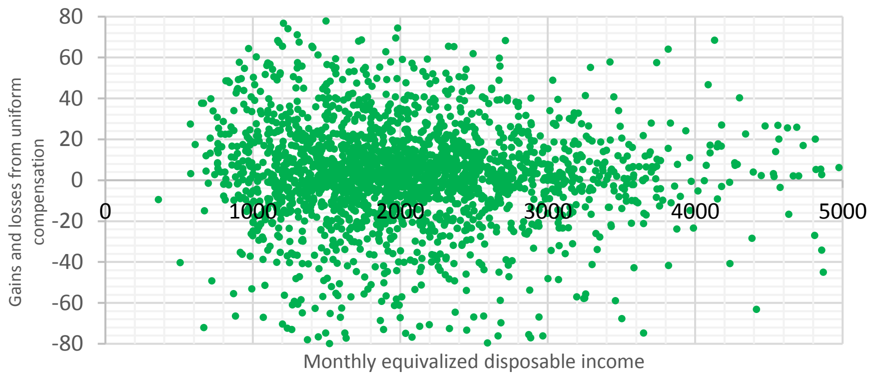
Source: HBS 2016, own calculations

Clearly, households contribute varied amounts among the same levels of income. As a result, a uniform compensation does not really prevent energy poverty for a substantial proportion of the

[33] This amount is likely to almost double if we add the carbon contributions of the 1 434 households for which gas expenses couldn't be estimated.

population. Households' gains and losses from uniform compensation are shown in Figure 5.5. The spread between the highest gains and the lowest losses is quite big. For this reason, many households won't be spared from suffering energy bills increases even if they have been compensated.

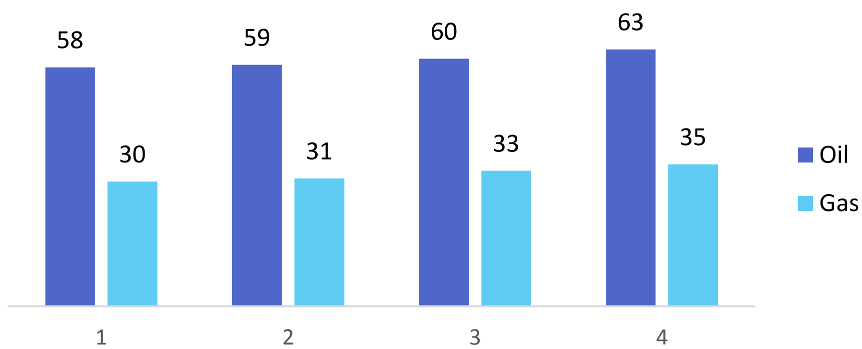
Figure 5.5 – Gains and losses from uniform compensation (46€/household)



Source: HBS 2016, own calculations

Valenduc (2017) says that several factors (other than income) seem to play a role in the way households consume energy. For instance, the type of fuel used by households. Whether a household uses oil or gas will have an impact on its carbon contribution. Figure 5.6 shows that using oil leads to carbon contributions that are almost twice as high as using gas. A uniform compensation set at the average contribution (46€) would be detrimental for household using oil.

Figure 5.6 – Average annual carbon contribution in €/household per income quartile (per fuel)



Source: HBS 2016, own calculations

This is a source of concern for the acceptability of such a reform (Valenduc, 2017). Although lower income classes will be strictly better off on average with a carbon tax and a uniform compensation, there remain many households within the same income class who will be under-compensated. To address this issue, a targeted compensation would be required. In order to design compensation in the best possible way, it is important to identify what determines households' energy consumption.

The rest of this chapter will be aimed at identifying the explanatory variables of carbon contribution and designing a targeted compensation scheme that will reduce the spread of contributions among income classes, especially for the first income quartile.

5.1.4. What determines carbon contributions of households?

Several factors influence energy consumption of households. In turn, carbon contributions are very different among households within the same income classes. This section is aims at identifying the determinants of households' carbon contributions using econometrics. The analysis uses data from HBS 2016.

Linear regression and variables

The following linear regression was tested using an Ordinary Least Squares (OLS) method:

$$\begin{aligned} \log(carboncontri) &= \beta_0 + \beta_1\, gas + \beta_2\, house + \beta_3\, bfr1980 + \beta_4\, owner \\ &+ \beta_5\, yngcouple + \beta_6\, oldcouple + \beta_7\, monoparent \\ &+ \beta_8\, couplekids + \beta_9\, otherfam + \beta_{10} \log(income) + \beta_{11}\, vl \\ &+ \beta_{12}\, wal + \beta_{13}\, educlevel + \beta_{14}\, hhsize + \beta_{15}\, rooms + u \end{aligned} \tag{5.1}$$

where the dependent variable, *carboncontri*[34], is the contribution in €/per household with a carbon tax of 10€/tCO_2.

The different explanatory variables[35] are listed below:

- *gas*: binary variable (=1 if the household uses gas, =0 if it uses oil);
- *house*: binary variable (=1 if the household lives in a house, =0 if it lives in an apartment);
- *bfr1980*: binary variable (=1 if the household lives in a housing built before 1980, =0 if it lives in a housing built after 1980);
- *owner*: binary variable (=1 if owner, =0 if tenant or free housing occupation);
- *isoprsn* (base), *yngcouple*, *oldcouple*, *monoparent*, *couplekids*, *otherfam* (=1 if the household is an isolated person, a couple in which both are younger than 65, a couple in

[34] The logarithm of *carboncontri* was used because all contributions are higher than zero which tends to lead to asymmetrical distributions. Moreover, logarithms permit to obtain smaller parameters (Dejemeppe M., personal communication, 2017).

[35] *Note*: A descriptive table of the dependent variable, the explanatory variables and the control variables is shown in Table 5.2 in Appendix A. It shows the mean, the standard deviation, the minimum and maximum values and the 50%, 95% and 99% percentiles for each variable.

which at least one is older than 65, a single-parent family, a couple with 1 or more kids, another family type, respectively, =0 otherwise);

- *income*: household total monthly disposable income (in €).

Table 5.1 in Appendix A shows the intuition that lies behind each variable. The first column expresses the expected direction. The variable *gas* is expected to be negative. Indeed, households using gas are expected to contribute less because oil boilers emit more carbon than gas boilers (FPS Health, 2016). All other variables are likely to be positive. Firstly, households living in houses are expected to consume more than those living in apartments. Secondly, dwellings built before 1980 are expected to consume more because the first thermal regulations on energy performance of buildings were implemented in 1985 (Nolay, 2007; Uilhein & Eder, 2009; Allouhi et al., 2015). Thirdly, the analysis in Chapter 4 has shown that tenants consume less energy because they are smaller households, living in apartments. Fourthly, all family compositions are expected to consume more than isolated people which is the baseline variable. Finally, energy consumption increases with income. Consequently, the variable *income* is expected to be positive. Relevant alternative hypotheses are listed in the third column.

The different control variables are listed below:

- *bxl* (base), *vl*, *wal*: binary variables (=1 if the household lives in Brussels-Capital/Flanders/Wallonia, =0 otherwise);
- *educlevel*: high education (1), medium education (2), low education (3), no diploma (4);
- *hhsize*: number of people in the household (ranges from 1 to 10 people);
- *rooms*: number of rooms in the housing (ranges from 1 to 22 rooms).

These variables are used as control variables because redistributing the carbon tax revenue based on these criteria would be too complicated or for some, impossible. Controlling for these variables is necessary in order to avoid potential bias in the estimation of the explanatory variables' coefficients. For example, the education level is likely to have an influence on income. If *educlevel* is left out of the regression, the coefficient of *income* will be biased.

Results

The results of the estimated regression can be found on Table 5.3. The number of observations equals to 2 222 946 households which is lower than the modified sample's 2 252 187 households. This is due 32 non-responses[36] to the question about the age of the housing. Based on the R-

[36] The sample weights of these 32 households sum up to 29 241.

squared, it can be concluded that the model allows to explain 26.51% of the carbon contributions' variations. The resulting equation is the following:

$$\begin{aligned}\log(carboncontri) &= 2.4652 - 0.5958\, gas + \ 0.2437\, house + \ 0.1024\, bfr1980 \\ &+ \ 0.0074\, owner + \ 0.0692\, yngcouple + \ 0.1457\, oldcouple \\ &+ \ 0.1332\, monoparent + \ 0.1298\, couplekids + \ 0.0841\, otherfam \\ &+ 0.0868 \log(income) - 0.0251\, vl + 0.0155\, wal \\ &+ 0.0078\, educlevel - 0.0114\, hhsize + \ 0.0485\, rooms \end{aligned} \tag{5.2}$$

Conferring to the p-values, all coefficients are statistically significant. The null hypotheses can be rejected (Table 5.1, last column for the explanatory variables). A more surprising result is that the coefficient of the variable *owner* is very small which means there is almost no difference in contribution between owners and tenants. Following the introduction of a carbon tax, owners are expected to contribute 1% more than tenants, *ceteris paribus.* This could potentially reflect split incentives issues. If owners are less likely to invest in energy efficiency of rented buildings, tenants are expected to consume more than they should.

The magnitude of other coefficients is higher. The most important difference is between households using gas and households using oil. A household using gas has a carbon contribution that is 60% higher than a household using oil *ceteris paribus*.

Fisher test for family compositions

The coefficients of the different family compositions are very close, especially for the variables *oldcouple, monoparent* and *couplekids.* The estimated coefficients of *monoparent* and *couplekids* are even included in each other's' confidence intervals.

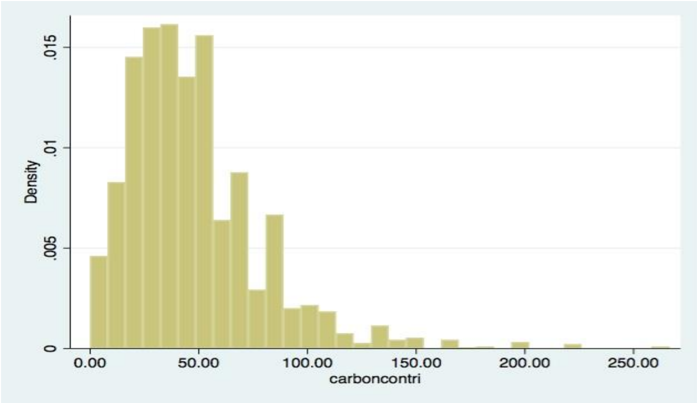
In order to make sure the coefficients aren't equal; a Fisher test was used. The p-value of the Fisher test that assesses whether the coefficients of *monoparent* and *couplekids* are equal revealed to be equal to 0.0964. This means that the null hypothesis that $\beta_7 = \beta_8$ can be rejected at a significance level of 5% but not at a significance level of 10%. The p-values for the other equalities of coefficients among family compositions were equal to zero.

Controls and checks

The presence of heteroscedasticity could invalidate the standard errors as well as the statistical significance tests of the model. Therefore, the null hypothesis that *errors are homoscedastic* was tested using two tests: Breusch-Pagan test and White test (see Appendix B). In both tests, the null hypothesis was rejected. It means that there is heteroscedasticity in the model. This can be solved by using "White/Eicker" standard errors which are consistent to an arbitrary form of heteroscedasticity. Estimated coefficients should remain unchanged even with new standard errors. Table 5.4 reveals the results with White/Eicker standard errors and correct significance tests. Fortunately, all estimated coefficients remain statistically significant.

Another control that was made relates to the influence of potential outliers on the estimated coefficients. Although quite normally distributed, carbon contributions are atypically high for certain households (Figure 5.7). Table 5.2 shows that the carbon contribution of the 95th percentile is more than twice as high as the median. Moreover, the carbon contribution of the 99th percentile is 50% higher than the 95th percentile which is a very high increase. The results of the regressions without the 99th and the 95th percentiles can be found in Appendix C. Since no significant change was observed in the coefficients, results with the complete sample were kept.

Figure 5.7 – Distribution of the variable *carboncontri*



Source: HBS 2016, own calculations

5.2. TARGETED COMPENSATION

The results of the regression imply that a series of factors influence households' carbon contributions across all income quartiles. The type of fuel used, the type of housing, the construction age of the housing, the tenure status[37], the family composition and the level of income[38], all proved to have an impact on households' carbon contribution. A targeted compensation based on these different criteria would therefore be most likely to reduce the spread of gains and losses from compensation observed in Figure 5.5.

[37] Although the regression model showed that there is a very small difference in carbon contributions between tenants and owners, using it as a criterion in combination with other criteria might still help to reduce the spread.
[38] The level of income won't be used as a criterion in this analysis because it would mean compensating less lower income households as they consume less. However, the aim here is to make lower income classes better off under a situation in which a carbon tax is implemented. It will be discussed in the last part of this chapter (section 5.3).

Before deciding on which criteria to condition targeted compensation, it should be clear to whom the compensation should be given. In the uniform compensation presented in section 5.1.2, recipients were households. However, in many countries which have implemented a carbon price, compensations are directly given to individuals. For instance, in Switzerland, each individual receives a certain amount of compensation through the health insurance system (Worldbank Group, 2017). Changing the compensation recipient could potentially also influence the distribution of gains and losses. For this reason, it will be the starting point of this analysis.

This section compares different levels of targeted compensation[39]. First, a uniform redistribution with a variation in the recipient of the compensation (household, consumption unit or individual). Then, six redistribution schemes based on each criterion individually. Thereafter, ten redistributions based on different combinations of criteria. Finally, three redistributions that include all criteria. A summary of the different redistribution schemes together with their compensations per unit is shown in Appendix D.

5.2.1. Indicators comparing different schemes

Three indicators will be used to compare the different compensation schemes. Firstly, the *average gains and losses from compensation per income quartile*. A compensation scheme that prevents energy poverty to increase should allow a transfer from the highest income quartiles to the lowest income quartiles. This means that the first two income quartiles should gain, and the last two income quartiles should lose from compensation (cfr. uniform compensation). Secondly, *the standard deviation of gains and losses from compensation*. It measures the spread of the distribution. The lower the spread, the less heterogeneous are carbon contributions and the more acceptable the reform. Lastly, *the percentage of households from the first income quartile that is still contributing more than 50% of the amount it was compensated with*. This allows to measure the remaining impact of the tax on poor households. The lower the percentage, the less households are impacted. Table 5.5 below shows the three indicators for each compensation scheme.

[39] For more convenience, the assumption of a full redistribution of the tax revenue is made.

Table 5.5 – Comparing indicators for all compensation schemes

		Type of redistribution	Income quartile 1			Income quartile 2		Income quartile 3		Income quartile 4	
			Average	Standard deviation	Remaining carbon tax impact	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Uniform		Per household	1,57	29,79	7,92%	1,03	30,73	-0,57	29,69	-1,59	30,04
		Per consumption unit	-1,23	31,38	13,25%	0,34	30,72	1,44	31,62	-0,77	31,31
		Per person	-2,21	36,73	19,45%	0,08	34,91	2,77	36,58	-1,09	35,67
Individual criteria		Fuel	1,95	26,35	3,76%	1,28	27,41	-0,39	26,36	-2,31	26,59
		Housing type	-1,18	28,29	7,23%	1,35	30,04	0,39	28,99	-0,65	28,71
		Housing age	1,24	29,68	6,99%	1,08	30,53	-0,70	29,68	-1,25	30,01
		Family composition	-0,17	29,19	7,91%	1,14	29,95	-0,07	29,64	-0,79	29,54
		Isolated person	-0,21	29,23	7,13%	0,72	29,99	-0,01	29,59	-0,46	29,81
		Tenure status	-1,49	28,81	6,78%	0,81	29,97	0,43	29,52	0,06	30,09
Combinations	1	Fuel - housing type	0,57	25,93	3,60%	1,46	27,17	0,21	25,99	-1,96	26,07
	2	Fuel - family composition	1,10	25,91	3,88%	1,16	26,92	0,09	26,29	-1,99	26,14
	3	Fuel - isolated person	1,01	25,93	3,98%	0,93	27,02	0,06	26,21	-1,69	26,35
	4	Fuel - housing age	2,17	26,27	3,67%	1,28	27,35	-0,46	26,35	-2,40	26,56
	5	Fuel - tenure status	0,44	26,45	4,13%	1,16	27,20	0,12	26,31	-1,52	26,61
	6	Fuel - housing type - housing age	0,88	25,86	3,23%	1,50	27,13	0,07	25,98	-2,10	26,04
	7	Fuel - housing type - isolated person	0,11	25,65	3,76%	1,20	26,85	0,41	26,01	-1,57	25,98
	8	Fuel - housing type - family composition	0,17	25,61	3,35%	1,43	26,77	0,46	26,06	-1,86	25,77
	9	Fuel - housing type - tenure status	0,20	26,16	3,85%	1,51	27,09	0,25	26,09	-1,74	26,16
	10	Housing type - isolated person	-1,66	28,04	7,62%	1,15	29,05	0,60	29,56	-0,30	28,67
All criteria		Fuel - housing type - housing age - isolated person	0,48	25,51	2,81%	1,40	26,71	0,41	26,03	-2,01	25,70
		Fuel - housing type - housing age - family composition	0,53	25,56	2,81%	1,22	26,81	0,26	25,99	-1,77	25,90
		Fuel - housing type - tenure status - isolated person	-0,19	25,53	3,24%	1,23	26,73	0,35	26,16	-1,30	26,07

Source: HBS 2016 data, own calculations

5.2.2. Units of redistribution

Whether the tax revenue is redistributed to households, consumption units or individuals also potentially influences the distribution. In this first part of the compensation analysis, compensation on two other recipients were tested: per consumption units and per person. The amounts of the three uniform compensation are as follows: 46 € per household, 29 € per consumption unit and 20 € per person. Compensations per consumption unit and per person are then multiplied with the number of consumption units/people in each household to get the exact compensation.

Surprisingly, redistributing the tax revenue per consumption unit or per person makes the lowest income quartile worse off than in a situation without carbon tax. Its average loss would be 1.23€ and 2.21€ depending if the redistribution is made per consumption unit or per person, respectively. When individuals are the recipients, the third income quartile seems to be overcompensated. On average, they gain 2.77 € from compensation. The standard deviations of the former two compensation schemes are higher for all income quartiles than under a redistribution per household, especially those of a compensation per person. Moreover, around 13% and 19% of households still spend more than 50% of the compensation they received under compensations per person and per consumption unit, respectively. This is much higher than under a compensation per households (i.e. 7.92%).

Between these three compensation schemes, a compensation per household has the smallest spread of gains and losses. Moreover, it fits best to prevent energy poverty. Lower income quartiles are better off than without tax and less households are highly impacted by the tax. Consequently, in the next compensation schemes, the tax revenue will always be redistributed per household.

These results represent important contributions to the discussion. They show that simply following a model in place in another country (i.e. compensation to individuals in Switzerland) would not fit to the Belgian situation.

5.2.3. Individual criterion

Conceptually, there are five different criteria on which targeted compensation could be based: the fuel used (gas or oil), the type of housing (house or apartment), the housing's construction age (before or after 1980), the tenure status (owner or tenant) and the family composition[40]. Since the results of the regression in section 5.1.4 revealed that isolated people contribute less on average than all other households, there will also be a sixth compensation scheme in which isolated people will be compensated differently than others.

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[40] Family categories were slightly adapted for the analysis to reflect the results of the Fisher test in section 5.1.4. Four categories were kept: isolated people; families with kids (couples or single parents); couples with at least one above 65 years old (without kids) and other families.

Compensating households based on their fuel allows to keep almost the same average gains and losses for each income quartile as under a uniform compensation by highly reducing the standard deviation and the impact on poor households (from 7.92% to 3.76%). The other compensation schemes seem to be less appropriate. Even though the impact on poor households and all standard deviations have decreased compared to uniform compensation, they did less than under a compensation based on the fuel used. Additionally, all average gains and losses from these compensations (except based on the age of housing) are negative for the first income quartile. Again, this is an issue for the acceptability of the reform. If the first quartile is worse off with a carbon tax, then it is very likely that the poorest households will fall into energy poverty.

5.2.4. Combination of criteria

Several combinations of criteria were tested. Since differentiating compensation based on the fuel used had a significant influence on the reduction of standard deviations and the impact on poor households, this criterion was used in nine of the ten tested combinations. The compensation in which it wasn't used (combination n°10 in Table 5.5) does have higher standard deviations in all income quartiles and impact on poor households (7.62%). It is a substantial proof that compensating based on households' heating fuel is imperative if we expect to decrease the spread of gains and losses and prevent energy poverty. Furthermore, the lowest income quartile is worse off than without carbon tax. This compensation scheme is expected to worsen the difficulty of household to pay for energy.

The first five compensation schemes (combinations n°1-5), combine the fuel used with each of the five other criteria: type of housing (combination 1), family composition (combination 2), isolated people (combination 3), construction age of housing (combination 4) and tenure status (combination 5). The final four compensation schemes (combinations n°6-9) combine the fuel used, the type of housing and each of the four other criteria. The combination "fuel - housing type" was used as a default combination because it had the lowest impact on poor households (3.6%) and standard deviations of the first five compensation schemes.

All combinations allow a transfer (at least) from the last to the first two income quartiles. Both the impact on poor households and standard deviations have decreased compared to a uniform compensation scheme per household. However, combining more criteria did not allow to decrease these two indicators much further than under a compensation simply based on the fuel used.

5.2.5. All criteria

Since the sample is not big enough, combining more than four criteria would question the validity of the different compensation amounts. Therefore, three different combinations that include four criteria were tested. The first one combines the fuel used, the type of housing, the construction age of housing and whether the household is an isolated person or not. The second one combines the three first criteria and the different categories of family composition. The last one combines the fuel used, the housing type, the tenure status and isolated people.

Again, all three final combinations do not allow to reduce the two last indicators much more than under a compensation based on the fuel used. Still, the two first combinations with four criteria provide the lowest remaining impact of carbon tax (both 2.81%) and standard deviations so far including a transfer from the last income quartile to the two poorest income quartiles.

5.3. POLICY IMPLICATIONS OF A TARGETED COMPENSATION

The previous section has shown that some compensation schemes are better at preventing an increase in energy poverty following the introduction of a carbon tax than others. A compensation scheme based on *the type of fuel used, the type of housing, the construction age of housing and whether the household is an isolated person or not* and a compensation scheme based on *the type of fuel used, the type of housing, the construction age of housing and the different categories of family composition* provide the best indicators.

Until now, only numbers provided by the analysis were considered. However, in practice, a targeted compensation has different policy implications: it is complex to implement, and compensating households differently could potentially provide wrong incentives. These two issues will be discussed into further detail in this section. Finally, this section will also mention the issue of the carbon tax revenue use. In the analysis, it was assumed that the tax revenue was only used to compensate all households. However, this could differ in practice.

5.3.1. Complexity of implementation

A targeted compensation combining several criteria could be difficult to implement in practice. The more criteria used, the higher the administration costs of compensation. Administration costs could include collecting data about households, determining the appropriate level of compensation for each combination of criteria, monitoring compliance of households to the different criteria, etc…. In practice, it would be much easier to implement a targeted compensation which has the least number of criteria.

The previous analysis has shown that two combinations (of four criteria) permit the lowest decrease in the spread of gains and losses and in the remaining impact of the tax on poor households. However, the decrease in those two indicators is not very important compared to a compensation based on one criterion: the type of fuel used. Therefore, in practice a tradeoff arises between the cost of implementing a complex compensation scheme and the benefits this compensation scheme could provide.

A compensation based on the fuel used allows for a great improvement in the indicators and would be much easier to implement. Moreover, it could be complemented with a certain income requirement, such as in France for example. French households who have an equivalized disposable income that is below 10 700 €/year are eligible to compensation (Arrêté du 26 décembre 2018 modifiant le plafond et la valeur faciale du chèque énergie, 2018). Data on households' incomes could possibly be obtained through annual tax declarations in Belgium which would decrease the cost of monitoring compliance of households with the compensation schemes. However, the monitoring cost of households' compliance with the type of fuel used would still remain which is potentially complex as well.

5.3.2. Providing wrong incentives

Targeting compensation means providing different amounts to households with different characteristics to compensate from the differences in energy consumption resulting from different characteristics. In a way, this means that households consuming more energy will receive a higher compensation. Therefore, policy makers should make sure that the targeted compensation does not provide the wrong incentives.

For instance, a compensation based on the fuel used could eventually persuade households having a gas boiler to replace it by an oil boiler in order to receive a greater compensation. This would make it worse as oil emits around 25% more carbon than gas (FPS Health, 2016). Therefore, the difference between the amount received by households using gas and households using oil should be just low enough to prevent from the change in fuel to be profitable.

Fortunately, in practice, different arguments can encourage the use of fuel types as a compensation criterion. Firstly, the amount received by households is not very high compared to the price of boilers. The average price of an oil boiler is around 6000 €. Therefore, it is quite unlikely that households will be able to finance a new boiler with the compensation they earn. Secondly, there are some practical implications to consider when changing boiler. For instance, oil boilers take more place than gas boilers. This will discourage households living in smaller houses or apartments to make the transition from gas to oil. Finally, it would be possible to complement the compensation with a legislation that aims to prohibit the transition from gas to oil.

5.3.3. Other carbon tax revenue uses

In the analysis, there were two assumptions which could differ in practice. The first assumption was that all households were compensated. A system could be imagined were only poorest households would be compensated. This would allow to transfer even more revenue from the highest income quartiles to the lowest income quartiles. It is the case in France, for example, where only households below a certain level of income are compensated. The French system has a positive impact on households, especially since only poor households are compensated (Chiroleu-Assouline, 2015).

The second assumption was that the tax revenue was completely used to compensate households. We have seen in section 1.2.2 that carbon tax revenues are used to finance different things. If only poor households are compensated, there would potentially remain an important share of the revenue which could be used to finance low-carbon investments of the residential sector. For instance, financing social housing renovation or providing renovation subsidies to poor owners when low-carbon investments are not profitable (cfr. results of Chapter 4).

5.4. CONCLUDING REMARKS ON CARBON TAX AND ENERGY POVERTY

This chapter has provided important results on the impacts of the implementation of a carbon tax in Belgium and on the ways in which a compensation scheme can help mitigating these impacts. Firstly, energy consumption is heterogeneous. Households in the same income classes consume very differently resulting in very different carbon contributions. This implies that a uniform compensation would not be appropriate in targeting energy poverty.

Secondly, there are different determinants of energy consumption and carbon contribution. These could be used as criteria in a targeted compensation. The determinants are: the type of fuel used; the type of housing; the construction age of the housing; the tenure status; the family composition and the level of income.

Thirdly, compensation should be done to households and not individuals or consumption units. This differs from the Swiss carbon tax compensation system.

Fourthly, different compensation schemes combining these different determinants were analyzed. The compensation scheme which is the most useful to prevent energy poverty and which is the least complex to implement would be one in which households are compensated differently whether they use oil or gas.

Finally, only a share of the revenue could be used to compensate only poor households (e.g. under a certain income threshold) and the rest could be used to finance low-carbon investments such as those presented in Chapter 4.

Conclusion

The research question, this paper has been trying to answer was: *from a policy point of view, how to deal with energy poverty in the context of the decarbonization of the Belgian residential buildings sector?*

The decarbonization of the Belgian residential buildings sector requires a profound transformation. This transformation is based on two levers. First, mass renovation of residential buildings which can mainly be achieved through insulation. Second, a transition towards carbon-free heating systems such as heating pumps and solar thermal technologies. In order to stimulate the achievement of these two levers, Belgium can also implement a carbon tax.

The main challenge associated with the decarbonization of the residential sector is that it potentially has distributive impacts on households. Indeed, poor households are likely to suffer more from the implementation of decarbonization policies than others. On the one hand, they will be affected by any measure requiring them to invest in low-carbon alternatives such as, housing renovation and carbon-free heating systems. Different barriers prevent them from doing so: the important split incentives issue, as many poor households are leaseholders their lack of resources and possibly, their lack of knowledge about energy efficiency. On the other hand, if decarbonization is associated with the introduction of a carbon tax, poor households will be those suffering most from the increases of energy prices. Hence, decarbonization will potentially increase energy poverty.

In Belgium, energy poverty is quite present. Around 15% of the population is reported as being at risk of "measured energy poverty" (mEP) which is one of the three main indicators used in Belgium (Delbeke and Meyer, 2018). Federal and regional governments have already implemented measures to address this issue. Nevertheless, energy poverty has remained stable since 2009. These policies will not suffice to contain energy poverty in the context of decarbonization.

This thesis has tried to identify which policies would be necessary to implement, in order to mitigate the impacts of decarbonization on energy poor households. For this purpose, an analysis of the individual data retrieved from the Belgian Households Budget Survey 2016 database was conducted. Based on the results of this analysis, a series of policy recommendations are proposed. Firstly, there is a serious need for social housing renovation. Around 20% of tenants live in social housing. It is the State's responsibility to renovate the whole social housing buildings stock. An approximate budget of 115 million € per year would be needed in order to renovate all social housing by 2050.

Secondly, the issue of split incentives needs to be resolved. This issue is likely to prevent poor tenants from living in energy performant housing because owners do not have any incentives to renovate it. Several measures allow to address split incentives in Belgium starting with providing owners with enough incentives to renovate their rented buildings. This can take the form of a strengthening of energy performance requirements associated with compliance controls; an increase in green loans and subsidies directly targeting rented buildings or a mechanism in which owners receive part of the energy savings from renovation (e.g. such as in Italy). Other measures that could be implemented in Belgium concern the increase in financial incentives for tenants. For instance, through on-bill financing.

Thirdly, when low-carbon investments are not profitable, poor Belgian owners also need to be supported. Belgian federal and regional governments could potentially compensate these owners from the unrecovered costs. This form of compensation could, for instance, be financed by carbon tax revenues.

Fourthly, in the case of a carbon tax implementation in the Belgian residential buildings sector, energy poverty could be addressed by a well-designed compensation scheme targeting poor households. Indeed, the impact analysis of a carbon tax provided in Chapter 5 has shown that energy consumption is heterogeneous. Households within the same income classes consume very differently. In this way, a differentiated compensation scheme could potentially decrease heterogeneity among households' carbon contributions. An econometric analysis permitted to find five determinants of households' carbon contributions: the type of fuel used, the type of housing, the housing's construction age, the tenure status and the family composition. According to analysis results and policy implications associated with the implementation of targeted compensation schemes, a compensation based on the fuel used by households (i.e. gas or oil) would be most appropriate to prevent an increase in energy poverty. Also, the easiest to implement. However, this compensation should be complemented with measures that prevent people to opportunistically shift from gas to oil boilers.

Finally, not all Belgian households subject to a carbon tax could be compensated. For instance, only households below a certain level of income could receive compensation. This allows to address energy poverty directly and to make a share of carbon tax revenues available to finance other measures. Carbon tax revenues could be used to finance low-carbon investments of poor households, which would also allow to prevent an increase in energy poverty. For example, the renovation of social housing or the provision of subsidies for poor owners.

These different policy recommendations complement the literature by linking decarbonization and energy poverty. Moreover, they have allowed to answer the research question that was inquired by this thesis.

Nonetheless, some issues have not been addressed in this thesis and would need more research in the future. First, it would be interesting to investigate the third barrier that prevent households from investing in low-carbon alternatives: their lack of knowledge about energy efficiency. Are poor households less informed on energy efficiency? How to educate everybody about this matter? Through the availability of free energy audits/energy counselors for households below a certain income level? Another path for future study is to improve the quality of the results obtained in the carbon tax analysis. This can be done by dissociating the expenses on gas and electricity of the 1 434 households in the HBS 2016 which would allow to obtain more accurate results.

In conclusion, the topic discussed by this thesis is at a crossroad between this Millennium's social, economic and environmental issues. A zero-carbon residential buildings sector can have great potential in terms of individuals' well-being. However, when designing decarbonization policies, all aspects must be considered. Otherwise, it can have serious impacts on households.

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