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The Key Drivers of the Final Energy Consumption in the Italian and Swedish Residential Sector:

A Decoupling and Decomposition Analysis Between 1990 and 2018

by

Giovanni Poppi, poppi.giova@gmail.com

Abstract

This thesis analyses the energy consumption of the Italian and Swedish residential sector during the last two decades. It has two main purposes: (1) to test the Environmental Kuznets Curve (EKC) hypothesis that stipulate a decoupling relation between environmental harm and economic growth and (2) to investigate on four factors that could explain such decoupling relation. The key factors are the change in population, the residential energy intensity, the fuel-mix composition, and the floor area inhabited. The decoupling analysis is conducted thanks to the Tapio's decoupling method, while the decomposition thanks to the LMDI decomposition index analysis. The results show that both the Italian and Swedish residential sector confirms the EKC hypothesis, and they present a favourable decoupling; it has been registered a strong decoupling period between 1996-2007 for Sweden and 2010-2018 for Italy. The main causes are attributable to improvements in energy intensity and to a shift from oil to other fuels. Furthermore, the study reveals that in the Swedish case, after 2007, a growing population and an increase in the floor area inhabited have been the major causes to an incrementation in residential energy consumption.

Keywords: Residential, Tapio decoupling, LMDI decomposition.

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1 Introduction

1.1 Research problem

The residential sector is one of the major energy consumer and CO_2 producer. According to the International Energy Agency (IEA), the global energy consumption by end-uses, such as water and space heating, cooking, air conditioning and electrical appliances, account nowadays for 20% of the total energy consumption (IEA, 2018). What is more, the household's energy consumption is associated with the global production of CO_2 that in 2018 reached the value of 2033 Mt (IEA, 2018). The high consumption of final energy and the emission of greenhouse gas in the residential sector is an urgency that needs to be analysed in more detail.

Focusing on a European perspective, the consumption of energy and the environmental harm caused by the residential sector have changed over time. The most exciting fact is that in the last twenty years, the European consumption of energy and, in particular, the production of CO_2 has slightly but substantially decreased (ODYSSEE, 2021). In particular, the share of final energy consumption has decreased by 10% and the CO_2 production by 117 mt CO_2 from 1990 to 2018 (IEA, 2018). What is more, within the European union-28, the decreasing trend is not homogeneous. In other words, some countries have a more exponential trend and in different times in comparison to others (Pablo-Romero & Sánchez-Braza, 2016). Studying the causes of such trends in energy consumption and CO_2 production and the differences between diverse countries is paramount for societies today.

The growing interest in residential's energy savings and CO_2 reduction is due to two leading causes. The first one is the need to diversify the type of fuel. Indeed, the studies on residential environment savings have their roots in the first oil crisis in 1973-1974 (Ang, 2004). During this time, economic and political pressure forced researchers to quantify and find solutions about the switching from oil. The second motive that can explain the growing interest in residential energy savings is the global warming urgency. In particular, at the Paris climate conference in 2015, it set a target limit to global warming below 2° C (Burleson, 2016). In this way, 195 Governments must present their International Nationally Determined Contributions (INDCs) to communicate the targets they have reached and their future commitments. The EU's INDCs show the commitments to reduce 40% of the residential CO_2 emissions by 2030 compared to 1990 (Change, 2014).

However, the Environmental Kuznets Curve (EKC) hypothesis provide a positive aspect regarding the energy consumption problem. Indeed, according to this theory, industrialized societies face, at a certain point of their industrialization, a decoupling state between CO_2 production and environmental growth (Grossman & Krueger, 1995). In other words, the nation's GDPs growth is associated with a reduction of their CO_2 emissions. There are two main methods that researchers and policymakers have adopted to test the EKC hypothesis. The first one is called *decoupling analysis* and it permits to analyse the intensity of the decoupling. The second one is called the *decomposition analysis* and it permits to find the factors that *could explain the decoupling.* We introduce them in more detail as follow.

Decoupling studies measure the relation between greenhouse gas (GHG) emissions and economic growth. Nejat et al. (2015) gives a global overview of the residential sector and, thanks to a decoupling analysis, confirm such hypothesis for the developed world. It means that a decrease in CO_2 emission in the residential sector is associated with an increase in GDPs. What is more, a particular focus on Europe-28 confirms such hypothesis and the fact that in five Nordic countries, i.e., Sweden, Denmark, Luxemburg, Finland, and Holland, the decoupling between the two variables have been more intense.

On the other hand, the decomposition method analyses the impact of critical drivers explaining the change in an energy variable. In other words, the change in an aggregate variable, e.g., CO_2 emission or energy consumption, is divided into factors that explain such change. In the residential sector, Xu & Ang (2014) provides a literature review of the twenty major decomposition studies. The results show that for most research, an increase in the energy variable is due to population growth or an increase in the number of dwellings. On the contrary, a decrease in energy intensity due to energy efficiency explains the decrease in the energy aggregate variable.

However, these studies have not addressed the issue of (1) analyse a deep relation between decoupling and decomposition, (2) compare two countries representative of the south and north of Europe and (3) include the fuel-switching variable in a decomposition study. To clarify, as regards the first literature gap (1), it has previously researched the decomposition of an energy variable change into factors that can explain it. Also, it has been researched on the residential decoupling trend between CO_2 production and economic growth. What is more, these two methods have already been combined in a few studies to find a decoupling relation between environmental harm and economic growth and, secondly, a possible reason to explain such change thanks to the decomposition analysis. However, there is a research gap in the identification of meaningful periods through decoupling analysis and their analysis through a decomposition method. To clarify, a meaningful period is characterised by a similar decoupling within its years—for example, a favourable period characterised by an intense decoupling between GDPs growth and CO_2 production.

What is more, (2) there is a literature gap regarding the comparison between the residential sector of the South and North of Europe. Indeed, Unander et al., 2004 has focused on the decomposition of the Nordic residential energy and Greening Ting & Krackler, 2001 and Schipper et al., 1997 have researched the decomposition of energy in the OECD-10. However, there is a gap regarding the comparison between two countries of the north and south of Europe.

For this reason, Italy and Sweden are the representatives' countries of the south and north of Europe. It has been selected these two countries particularly because they have particular differences in residential fuel composition. The Italian residential sector is indeed characterised by natural gas consumption while the Swedish one by district heating and electricity.

(3) The residential fuel mix composition is an important key variable for our decomposition research. Switching from one fuel to another is an essential factor that could explain changes in energy consumption. However, residential fuel mix composition is a variable that has received minor attention in decomposition studies. For this reason, we want to fill this gap and include the role of fuel mix composition as a critical driver that could explain changes in residential energy consumption. What is more, this research includes a unique decomposition model that explains changes in residential energy consumption as the sum of four factors, i.e., changes in population, energy efficiency, fuel switching, and floor area inhabited.

1.2 Research purpose and questions

The following study about the Italian and Swedish residential sector has a dual objective. The first one is the fragmentation of the time 1990-2018 into sub-periods that present similar types of decoupling between environmental damage and economic growth. Once obtained such periods, we move towards the second aim, which is to investigate how the residential fuel mix consumption has changed during the periods obtained in the decoupling analysis. Moreover, we want to know how particular key drivers could explain such changes in final energy consumption. In this way, firstly we expect to confirm the EKC hypothesis between a decoupling in the Italian and Swedish residential sector; secondly, we expect to find reasons that could explain such decoupling.

So, this thesis aims to test the Environmental Kuznets Curve (EKC) theory on the Italian and Swedish residential sector between 1990 and 2018 thanks to a decoupling analysis. Later, a decomposition study provides a possible explanation of the decoupling results. To do this, the aggregate variable residential final energy consumption is decomposed as the sum of four variables. They are population growth, fuel mix composition, energy intensity and floor area inhabited.

At this point, the research project seeks to answer the following two research questions:

- What are the periods that present most of the decoupling type, between GDPs output and CO_2 production, in the Italian and Swedish residential from 1990 and 2018?

- To what extent do the four key factors – population growth, energy intensity, switching fuels, and floor area inhabited - contribute to changes in the Italian and Swedish residential energy consumption in the period 1990-2018 and in the sub-periods obtained in the decoupling analysis?

It is important to identify years with different decoupling intensities because it permits to isolate periods that have a prevalence of years with the same decoupling type. What is more, it is essential to know the if such periods have a stop or continue to growth and the reasons behind such trends.

We expect that both Italy and Sweden should confirm the Environmental Kuznets Curve hypothesis. What is more, we expect that Sweden reach the turning point earlier in comparison to Italy. The turning point is the moment characterized by strong decoupling, meaning that GDPs are growing, and CO_2 are decreasing. This is because of the research conducted by Pablo-Romero & Sánchez-Braza (2016). They have indeed already tested that Sweden have surpassed the EKC turning point. We expect that Italy also surpass have surpassed the turning point.

Regarding the four key factors, we expect that improvement in energy intensity should explain decreasing trends in energy consumption. While changes in population growth should explain increases in energy consumption. We consider switching fuels and floor area inhabited two unpredictable variables. It will be interesting to measure their role in the Italian and Swedish enery consumption.

A particular focus on the Italian and Swedish residential sectors is because both countries experience a favourable decoupling between economic growth and environmental harm. However, we expect the two countries different decoupling intensities and different periods. The main reason is that they have shared a different fuel mix composition between 1990 and 2018.

The main limitation of the research regards the residential fuel mix composition and, in particular, the renewables sources. Indeed, data on the final residential consumption consist of the sum of six fuels, i.e., *oil, coal, gas, heat, wood, and electricity*. Renewable sources are embedded into these six fuels and particularly *heat* and *electricity*. It is important to stress that all the six fuels are not double counted. For example, if the natural gas is used to generate electricity, in our study it will be counted in the *gas* fuel. For this reason, the fuels *electricity* and *heat* are composed by renewable sources, e.g., biomass, solar, hydropower and geothermal and nuclear power. However, due to lack of data in the residential sector, it is not possible to separate the aggregate variable *heat* and *electricity* into the renewable sources and nuclear power that compose them. A focus on such source as a decomposition variable in the residential sector could be interesting for future research.

The thesis is divided into six sections. Chapter 2 presents the EKC hypothesis and the theory behind the decoupling and decomposition methods. In addition, it reviews the existing literature in the field. After that, chapter 3 shows where the data for our quantitative study comes from. Subsequently, the decoupling and decomposition model is displayed in chapter 4. Chapter 5 analyses the data and describes the decoupling and decomposition results. Next, the results are discussed in chapter 6 and chapter 7 provides conclusions and a summary of the research.

2 Theoretical framework

The following study lays its foundations on the Environmental Kuznets Curve hypothesis, which assumes a decoupling trend between environmental harm and economic expansion. Tapio's elastic index method measures the residential decoupling, and it permits the identification of periods that are analysed in more detail. Indeed, the final energy consumption of the Italian and Swedish residential sector is divided, with an LMDI decomposition method, into four key drivers that can explain changes in such periods. The variables that compose the key drivers are the Italian and Swedish populations, the energy intensity, the residential fuel mix energy consumption and the total floor area inhabited.

2.1 Environmental Kuznets Curve hypothesis

The Environmental Kuznets Curve (EKC) hypothesis claims a divergent relation between economic growth and environmental degradation. To clarify, it enounces that societies' economic growth causes initially an increase in environmental harm. However, the relation between economy and environment reaches a turning point where environmental degradation decreases, although the economy continues to grow (Grossman & Krueger, 1995). Represented on a two-axis chart, the shape of this relation follows an inverted U-curve that has the economic output on the x-axis and the environmental damage on the y-ones. The EKC theory is a development and adaptation from economic studies by Simon Kuznets. The American economist developed the theory that economic levels affects the Gini coefficient, an index that measures the economic disparities within the population, with the same trend of the EKC, i.e., an initial increase followed by a decrease in economic disparities (Kuznet, 1955).

A way to test such hypothesis is through the decoupling analysis. The decoupling analysis is a tool to monitor the relationship between economic growth and environmental degradation. To clarify, in environmental terms, decoupling is a positive phenomenon that happens when there is a positive association between an increase in economic growth and a decrease in environmental harm. OECD describes decoupling as "breaking the link between "environmental bads" and "economic goods"" (OECD, 2002). In other words, the description underlines the urgency already promoted by the World Commission on Environment and Development to commit towards a sustainable development that can combine economic growth and environmental sustainability (WCED, 1987).

There are three main methods to measure environmental decoupling (Wu, Zhu & Zhu, 2018). The OECD is the first to develop a decoupling index method (OECD, 2002) easy to understand but cannot distinguish between different types and intensities of decoupling. One year later, Vehmas, Kaivo-oja & Luukkanen (2003) and Vehmas, Luukkanen & Kaivo-oja (2007) develop the *Variation Analysis method* (VA), and for the first time, it has been conducted a study on 15 industrialized countries using the concepts of weak and strong decoupling and re-linking. Weak decoupling occurs when the change in environmental harm in the period studied has a lower intensity than the increase in GDP. In other words, the environmental damage can increase but with a lower intensity than the economic growth. On the contrary, strong decoupling, which societies should aspire to reach, always implies a decrease in environmental harm. Lastly, the concept of re-linking derives from the assumption that the weak and strong decoupling conditions could not hold in the future. In this way, the relation between environmental damage and economic output could have a positive value. So, re-linking means that the environmental harm is greater than the economic growth. However, the *Variation Analysis* method cannot succeed in distingue between non-decoupling and re-decoupling (Wu, Zhu & Zhu, 2018)., a problem that has been overcome by Tapio (2005).

Tapio further develops the decoupling analysis index thanks to its Tapio Elastic Index Method (TEA). The model has been invented to describes the degrees of decoupling between energy consumption and CO_2 production in the EU transport sector between 1970 and 2001. It is a method that is widely adopted for studying many sectors that includes energy consumption and environmental pollution.

Tapio's decoupling index D_{t-1}^{t} measure the correlation between economic growth and CO_2 emissions. As shown in equation (1), the decoupling index is related to the change in CO_2 emissions and the change in economic output from year t to t-1. Tapio's model has the advantage that it can focus on individual years.

$$D_{t-1}^{t} = \frac{(CO2^{t} - CO2^{t-1})/_{CO2^{t-1}}}{(GDP^{t} - GDP^{t-1})/_{GDP^{t-1}}} \qquad (1)$$

The decoupling index is successively classified into decoupling, coupling and negative decoupling states, as Table 1 shows. Decoupling is divided into three sub-states: strong, weak, and recessive. Strong decoupling is the most desirable state. It occurs when the change in GDP during the period has a positive outcome, together with a negative value in CO_2 production. Weak decoupling implies that change in GDP is positive, but the change in CO_2 is growing too, to a decupling rate between 0 and 0.8. It means that there is economic growth and moderate environmental damage. Then, recessive decoupling happens when both changes in CO_2 production and GDP outcomes are decreasing under 0, and the decoupling index has a value of more than 1.2. It is a less desirable state because it implies that the environmental damage is greater than the weak decoupling state. Coupling states are subdivided into the expansive and recessive coupling. Both sub-states denote a decomposition index between 0.8 and 1.2. Values near 1 imply that the change in values between the two variables (CO_2 and GDP) are similar. Under these circumstances, the state of coupling occurs. Expansive coupling occurs when a change in GDP and CO_2 have values respectively more and less than 0.

On the contrary, recessive coupling happens if there is negative economic growth, and CO2 is decreasing. Finally, a state of negative decoupling is subdivided into expansive, strong, and weak negative decoupling. It is not a desirable state. There is environmental degradation and economic growth in expansive negative decoupling, but changes in CO_2 consumption are more meaningful than the changes in GDPs. Strong negative decoupling is the worst state that could happen, and it does when both GDPs and CO_2 are negative. Then, in weak negative decoupling, both variables have negative outputs, and the results in the index between 0 and 0.8 implies that the difference between the two changes is marginal.

Table 1: Tapio's decoupling, coupling and negative decoupling states (Tapio, 2005).

Decoupling type	**Decoupling sub-states**	**ΔGDP**	**ΔCO_2**	**D**
Decoupling	*Strong decoupling*	> 0	< 0	< 0
	Weak decoupling	> 0	> 0	0 – 0.8
	Recessive decoupling	< 0	< 0	> 1.2
Negative decoupling	*Strong negative decoupling*	< 0	> 0	< 0
	Weak negative decoupling	< 0	< 0	0 – 0.8
	Expansive negative decoupling	> 0	> 0	> 1.2
Coupling	*Expansive coupling*	> 0	> 0	0.8 – 1.2
	Recessive coupling	< 0	< 0	0.8 – 1.2

Previous research in the residential sector about the EKC hypothesis and the decoupling studies help us to know what has been discovered until now and what we would expect from our research. The study conducted by Nejat et al. (2015) gives us an overview of the global energy consumption and CO_2 production in the residential sector. Indeed, it has been estimated that the residential sector is responsible for the 27% of the global energy consumption and 17% of CO_2 emissions. The author also analyses a clear distinction between developed and developing countries. The former has reduced their CO_2 emissions from 2000 to 2011, while the latter has not. Urbanization, an increasing population, and economic growth are the main drivers to such an increase in developing countries. Focusing on a European perspective, the relationship between residential energy consumption and income from 1990 to 2013 confirms the EKC hypothesis for all the EU-28 countries (Pablo-Romero & Sánchez-Braza, 2016). The results reveal those five countries, i.e., Sweden, Denmark, Luxemburg, Finland, and Holland) have already surpassed the turning point of the EKC theory.

Tapio's decoupling studies in the residential sector focus particularly on the Chinese area. Zhao, Zhao & Yuan (2019) finds that the Chinese residential sector follows a decarbonization trend from 2005 to 2015. Urban areas are shifting from expansive negative decoupling to weak decoupling, even reaching strong decoupling in 2007-2008. Strong decoupling has been registered, especially in heavily industrialized provinces. However, such a decoupling trend has not occurred in rural areas. Ma et al. (2016) confirms the general state of weak decoupling of the Chinese residential sector. The author ulteriorly investigates the decoupling relation from 1994 to 2012 between CO_2 emissions and variables such as population (weak decoupling), economic growth (expansive decoupling), energy intensity (strong decoupling) and energy consumption (weak decoupling).

The first part of our research focuses on the decoupling relation between economic growth and environmental harm in the Italian and Swedish residential sector from 1990 to 2018. Tapio's decoupling method helps us investigate the type of decoupling in the two developed countries. We choose this method both for the possibility to analyse every single year and for the variety of decoupling types that it offers.

It is important to stress that we use Tapio's decoupling analysis as a tool to find periods between 1990 and 2018. We expect to find different time blocks characterized by a prevalence of decoupling type. For example, as Nejat et al. (2015) has mentioned previously, Sweden has, in general, already reached the turning point in the EKC hypothesis of decoupling between CO_2 production and GDPs growth. For this reason, we would expect for the Swedish residential sector a series of years characterized by a prevalence of strong decoupling types. The main aim of this first part of the study is to identify such periods and isolate them.

Once we obtained these time blocks, we move more profound, particularly from the residential CO_2 production to the residential final energy consumptions of the single fuels (oil, natural gas, electricity etc). In this way, the second part and the research of our study identify and analyse the leading causes of residential final energy consumption changes in the periods given by the decoupling analysis. The Logarithmic Mean Divisia Index (LMDI) Decomposition analysis enables all that.

After reviewing the previous literature about the EKC theory and decoupling studies, we expect to confirm the following hypothesis, as regards the decoupling analysis. We expect that both the Italian and the Swedish residential sector confirm the EKC theory in the period 1990-2018. In addition, we predict that the two nations reveal different types of decoupling, such as weak and strong decoupling. Moreover, we suppose that Sweden will experience a period of strong decoupling in an earlier period than Italy. This is because of the work already conducted by Pablo-Romero & Sánchez-Braza (2016) that confirms that Sweden had an earlier period of strong decoupling compared with Italy.

2.2 LMDI Decomposition

The Index Decomposition method is a powerful analytical tool to analyse the impact of key drivers on trends in energy use (Ang, 2004). It had its roots in the oil crisis of 1973, when energy researchers developed a method to quantify the impact of energy change in the industry. After that, policymakers and researchers have used the Index Decomposition analysis in many applications areas, especially regarding energy and the environment.

In a focused study, Ang (2004) identifies two types of decompositions index, i.e., Laspeyres and Divisia index. The main difference between the two is that the former is easier to understand, while the latter is more methematical. In detail, the Laspeyres index measures the percentage variations of the items that compose the aggregate variable. While the Divisia index measures the logarithmic change of those items. In the following study, we will use a type of Divisia index developed by Ang (2005), called Log Mean Divisia Index (LMDI). The reason is that we want to quantify the precise impact of the change in final energy consumption and not just the percentage variation between the years in examination.

The LMDI allocates the changes in a period of an energy-related aggregate (e.g., energy consumption or CO_2 production) as the sum of the changes in particular key drivers or effects. The general formula of the LMDI index is shown in equation (2), where V is the energy-related aggregate, ΔV is the change between time T and time 0 and Δ ΔV_{X_n} are the key drivers' changes. The variable X represents therefore the single key driver that compose the aggregate. The sum of Δ ΔV_{X_n} explain the change in V.

$$\Delta V_{tot} = V_T - V_0 = \Delta V_{X_1} + \Delta V_{X_2} + \ldots + \Delta V_{X_n}. \tag{2}$$

The additive LMDI provides a formula for obtaining ΔV_{X_n} that is given in equation (3).

$$\Delta V_{X_n} = \sum_i \frac{V_i^T - V_i^0}{\ln V_i^T - \ln V_i^0} \cdot \ln \frac{X_{n,i}^T}{X_{n,i}^0} \quad (3)$$

Where *i* is a sub-category of the aggregate, for example, if the aggregate would be final energy consumption in a particular sector, *i* could be the sum of the single fuels that compose the final energy consumption. The sum of Δ ΔV_{X_n}represent the key drivers' effects that can explain the change in the aggregate variable V from year T to year 0.

In decomposition analysis, Ang (2004) identifies three main effects or drivers that could explain effects in the aggregate variable. Such effects are:

- The activity effect. It represents the size of the sector studied. It means the "actors" involved in the research. For example, it could be the passengers in the transport sectors or the numbers of dwellings or inhabitants in the residential one.

- The intensity effect. It measures the efficiency within the sector. It is usually a relationship between the energy used per unit of activity. For example, it could be the relation between the final energy consumption and the floor area inhabited in the residential sector. A decrease in this variable could imply energy efficiency within the sector.

- The structural effect. It measures the different share of output related to the whole sum of the outputs. It is a percentage that analyses the shifts from one item to another.

At this point, the LMDI decomposition index could be simplified by the formula given by equation (4):

$$\begin{aligned} &\Delta\, Aggregate\ energy/environment\ indicator \\ &\quad = \Delta\, Activity\ +\ \Delta\, Intensity + \ \Delta\, Structural \end{aligned} \quad (4)$$

Previous studies about LMDI decomposition analysis in the residential sector choose different aggregate and effects variables. Most of the literature uses residential energy consumption (REC) as the aggregate variable to study and decompose (Zhang et al., 2015; Chong et al., 2017; Holzmann, 2013; Golove & Schipper, 1997; Shorrock, 2000; Unander et al., 2004; Park & Heo , 2007; Achão, C., & Schaeffer, 2009; Höjjati & Wade, 2012). On the other hand, LMDI studies decompose the CO_2 emissions produced by the residential sector (Greening Ting & Krackler, 200; Donglan, Dequn & Peng, 2010; Fan et al., 2013). In the following study, we choose final energy consumption as the aggregate variable. The main reason for this choice is that it enables to research particulars details, such as the energy consumed by every fuel. Switching fuel, e.g., from oil to gas or electricity, is one of the effects that our research analyze. It is time to present the main key drivers chosen and studied in previous research.

In terms of residential energy consumers, the population is the primary variable that represents the activity effect of previous research (Golove & Schipper, 1997; Schipper et al., 1997; Greening Ting & Krackler, 2001; Unander et al., 2004; Achão, C., & Schaeffer, 2009; Donglan, Dequn & Peng, 2010; Rogan, Cahill & Gallachóir, 2012; Fan et al., 2013, Zhang et al., 2015). The number of dwellings is the other choice for researchers to investigate the residential activity level (Shorrock, 2000; Höjjati & Wade, 2012; Chung, Kam & Ip, 2011). In almost all the studies, the activity effect positively affects changes in final consumptions. This means that, the increasing population and number of households have a rising effect in terms of energy consumption and CO_2 production. The only diversity has been registered in regional studies where the activity effect decreases the aggregate variable because of the deurbanization from rural to urban areas (Zhang et al., 2015; Donglan, Dequn & Peng, 2010).

Xu & Ang (2014) described the energy intensity effect as "the specific energy required to provide a unit of energy service". Regarding the specific energy requirements, the literature is divided between using the final energy consumption or subdividing it per end-use, e.g., space cooling, refrigerators, kitchen appliances etc.). On the other hand, the energy service is often used in the total floor area or the energy service associated with the end-use, e.g., floor area for space heating.

Previous studies demonstrate that the energy effect has been the primary driver to decrease the aggregate variable change. In particular, Schipper et al., (1997) finds that in the OECD-10 countries, declining changes in residential energy consumption from 1973 to 1991 must be attributable to improvement in energy intensity. The same results have been confirmed by Unander et al. (2004), with a particular focus on the Scandinavian countries. In addition, in the US, residential energy declines from 1990 to 2005 are attributable to energy efficiency given by energy initiatives such as the introduction of building codes (Höjjati & Wade, 2012).

The structural effect represents the share of the fuels or the end-use energy consumptions in relation to the whole energy consumption. Previous studies have registered the effect of switching from one fuel to another. Greening Ting & Krackler (2010) has conducted a decomposition analysis focusing on the OCDC-10 countries from 1970 to 1990, and he discovers that Sweden has the highest percentage value (77%) of decrease in residential carbon intensity. The structural effect is the primary driver (66%) of such decrease. The cause has to be found in the energy initiative to shift towards less carbon intensity mixes for generating electricity. On the contrary, the author argues that Italy has increased the percentage of carbon intensity (45%) and that the Italian fuel mix is the main responsible (53%). The results for Sweden have been confirmed by Schipper et al. (1997). The author claims that fuel mix, and in particular electric heating in new Swedish dwellings, has been the most effective response in CO_2 decline.

The following LMDI analysis aims to decompose the final energy consumption of the Italian and Swedish residential sector into four effects that contain variables already encountered in previous research. The activity effect is represented by the population, the structural effect by the share of different fuels and the intensity effect by consuming final energy per floor residential area. In addition, another effect that we call the lifestyle effect represents the relation of the dwellings floor area per inhabitants. At this point, what would we expect from the variables that compose the four effects? In other words, what is the theory and previous research that explain changes in population, energy intensity and fuel mix in the residential sector?

A decrease in population could be attributed to the low fertility rates in Europe (Human fertility database, 2020). Such values could be attributable to social and economic factors. Indeed, the postponement of childbearing towards older age could be the main reason to lower fertility rates (Yoo & Sobotka, 2019). Another reason that could explain such a decrease has been attributable to economic factors and the precarious employment that young people are facing. Such as the inactivity of the young population in Europe Eurostat (2019), and the difficulties combining a job and having a child (Oláh, 2003). In addition, it has been proved that a welfare state that promotes family policies thanks to generous parental leave and job rights have a positive effect on fertility rates.

On the contrary, immigration could cause an increase in population. The Push and Pull theory by Ravenstain (1889), revisited by Everett Lee (1966), tries to explain the factors behind the choice and the need to emigrate. "Push" factors that induce people to leave their own country are attributable to unfavourable conditions, i.e., unemployment, war, natural calamities etc. On the contrary, "pull" factors attract more favourable conditions, i.e., job opportunities, better education, or institutions. In the discussion part of our research, we investigate the push and pull causes that could explain changes in the Italian and Swedish immigration and population trends situation.

Nejat et al. (2015) identifies four factors and energy policies that could influence changes in energy intensity. The first one is the stipulation of the building's energy codes (BECs). They are a reglementary instrument emitted by policymakers to set energy performance rules at the dwelling's design stage (Aydin & Brounen, 2018). Secondly, electric appliances standards guarantee a threshold of energy efficiency that households need to respect. In addition, the author claims that labels and inhabitant environmental education could give information and raise population awareness. Last but not least, incentives, for example, taxes, are essential tools to discourage energy consumption and drives energy transitions (Borozan, 2018; Henryson, 2018; Martinsson, 2011).

Transitions towards different fuel shares can be explained by the Multi-Level Perspective theory (Geels, 2002). According to this theory, a substitution occurs when a landscape pressure allows niches to evolve and transform the current regime. The pressure can be economical (for example, a change in market competition), socio-political (e.g., policy changes) or environmental (for example, global warming). Di Lucia (2014) uses an MLP approach to show the Swedish transition towards low-carbon district heating, and she claims that environmental and socio-political pressures are the leading causes of the transition from oil to biomasses and renewables.

The environmental pressure as the main force to disrupt the regime could be more easily understood by the research of Nejat et al. (2015). As Table 2 shows, the author displays the CO_2 emissions from different energy sources. Electricity and natural gas are the less carbon-intense fuel, followed by liquid biomass fuel and oil products. On the contrary, coal, solid municipal waste, and solid biofuel and in particular agriculture bioproducts account for most CO_2 emissions.

Table 2. CO2 emissions from different fuels.

Energy source	**Kg CO_2 per mmBtu**
Coal coke	113.67
Municipal solid waste	90.70
Biomass fuels (solid)	
Agricultural byproducts	118.17
Peat	11.84
Solid byproducts	105.51
Wood	93.80
Natural gas	53.06
Oil products	
Kerosene	75.20
Liquefied petroleum gases	61.71
Crude oil	74.54
Biomass fuels (liquid)	
Vegetable oil	81.55
Ethanol	68.44
Biodisel	73.84
Electricity (kg CO_2 per kW h)	0.624

At this point, from the decomposition analysis we expect to confirm the following hypothesis. We expect that a decrease in final energy consumption could be attributable by a decrease in energy intensity and changes in the structure of the aggregate variable. On the contrary, we predict that an increase in final energy consumption could be explained by an increase of the activity factor.

3 Data

3.1 Decoupling data

GDPs per capita (measured in current US dollars) and the production of residential CO_2 (measured in $MtCO_2$) are the two variables that compose the decoupling analysis. $MtCO_2$ means metric tons of carbon dioxide equivalent and it measure the emission from different greenhouse gas emissions according to their global warming potential. Decoupling data comes from two different sources. GDPs per capita have been gathered from the International Monetary Fund (IMF, 2021). While the CO_2 emission comes from the ODYSSEE database (ODYSSEE, 2021). The ODYSSEE database is the main source that has been used in this study. The advantage of the this database is that present national data divided by sectors. In this way, the Italian and Swedish residential sector's data are displayed in an accurate and accessible way.

3.2 Decomposition data

Regarding the decomposition method, we gather data to collect a dataset with four variables. They are the residential final energy consumption (FC), the population trend (P), the total floor area inhabited (m^2), and the residential final energy consumption of the six fuels that compose the aggregate final consumption ($FC^{f\ (oil,\ gas,\ electricity,\ coal,\ and\ heat)}$). The energy consumption is measured in Mtoe, i.e., megatonne of oil equivalent. It is a unit of measure for energy that is equivalent to burning one tonne of crude oil and divide it to 10^6. The four variables have been gathered from the ODYSSEE database. However, the ODYSSEE database has in turn collected these data from others database. In particular, the decomposition data, gathered in the ODYSSEE database, come from national databases, such as ISTAT and MISE (Minister of the Economic Development) for the Italian case, and Swedish Energy Agency and Statistic Sweden for the Swedish one. Table 3 reassume where all the variable's sources.

Table 3: Variables names, descriptions, units and sources.

Name	**Description**	**Unit**	**Source**
GDPs	Gross domestic product per capita	US dollar	IMF
CO_2	CO_2 emissions by the residential sector	MtCO2 = Metric tons of carbon dioxide equivalent	ODYSSEE
FC	Final energy consumption in the residential sector	Mtoe = Megatonne of oil equivalent M	MISE, Swedish Energy Agency
P	Population	k	ISTAT, Statistic Sweden
m^2	The total floor area inhabited	m^2	ISTAT, Swedish Energy Agency
FC^f	The residential final energy consumption of six fuels *f*, i.e., oil, gas, electricity, heat, wood, and coal	Mtoe = Megatonne of oil equivalent M	MISE, Swedish Energy Agency

It is important to stress that there are two main limitations. The first one is that there is no data available regarding the production of CO_2 caused by the electricity fuel in the Italian residential sector before 2004. We have tried to overcome such limitation by dividing the decoupling analysis periods before and after 2004. For this reason, it is worthy to remember that the Italian production of residential CO_2 before 2004 do not count the production of electricity CO_2. The second limitation regards the variable fuel mix composition (FCf). In the following study, we could not fragment the electricity and heat power into the source that compose them. We consider it a limitation because it would have been more precise to distinguish and quantify the effects of renewable sources and nuclear power on residential final energy consumption. It is worthy to remind that the electricity and heat fuels are composed just by renewable and nuclear sources. If for example the fuel natural gas generates electricity, it will be counted in our study in the natural gas category.

4 Methods

4.1 Decoupling Model

The decoupling model formula is the same of used by Tapio for his study in the transport sector. The main difference between Tapio's and our research is that the CO_2 presented in equation (5) are not caused by the transport sector but by the residential one.

$$D_{t-1}^{t} = \frac{(CO2^{t} - CO2^{t-1})/_{CO2^{t-1}}}{(GDP^{t} - GDP^{t-1})/_{GDP^{t-1}}} \tag{5}$$

To measure the decoupling relation between economic growth and environmental damage, we calculate the decoupling index D_{t-1}^{t} for every year between 1990 and 2018. In this way, the starting point is the difference between the year *t-1=1990* and *t=1991* and it continues until the year 2018. Once obtained all the twenty-eight decoupling index, we select blocks of time characterized by a prevalence of decoupling type, e.g., weak or strong decoupling. We would like to stress that this method for obtaining sub-periods, by gathering similar decoupling index, is our own method. Later, the decomposition analysis permits to study such sub-periods in more detail.

4.2 Decomposition Model

The LMDI decomposition analysis permits to quantify the causes or possible explanations to an aggregate variable change. There are two kinds of LMDI decomposition methods, i.e., multiplicative and additive. In the former method, the change in the aggregate is explained by the multiplication of the key drivers changes; while in the additive one, such change is the sum of the factors changes. What is more, in the multiplicative decomposition, the aggregate variable is given by the relation between the variable in the two different years. While, in the additive decomposition, the aggregate variable is given by the difference between the variable in the two different years. Our model follows the additive decomposition method. We choose the additive one because we consider that an aggregate variable explained as the sum of key factors it easier to understand than the multiplication of such factors. In addition, the same reason regards the aggregate variable. We consider that the difference of the aggregate variable between two years is easier to understand than the relation one.

In detail, the aggregate variable is the residential final energy consumption (FC). The changes in aggregate variable from a year $t-1$ to a year *t*, using the years obtained thanks to the decoupling analysis, is the sum of the following key drivers change:

- The activity effect ($\triangle ACT$): it represents changes in population.

- The intensity effect ($\triangle INT$): it represents the change of how much energy is used in the floor area inhabited.

- The structural effect ($\triangle STR$): it represents the change in the use of the six fuels that compose the aggregate final energy variable FC.

- The lifestyle effect ($\triangle LIFST$): it is the relation between the floor area inhabited and the population.

According to equation (6), final energy consumption is intended as the sum of the six fuels (f). This means that the aggregate variable is the sum of the residential consumption of oil, gas, heat, electricity, coal, and wood. Such summation is ulteriorly developed into a summatory of the multiplication of four variables (P, $m^2/_P, FC/_{m^2}, FC^f/_{FC}$). Each variable represents the key driver effects ($ACT,\ INT\ STR\ and\ LIFST$) of our analysis. The equation (6) is a unique model, and the main novelty is given by using the single fuels to study the aggregate variable.

$$FC = \sum_f FC^f = \sum_f P \cdot \frac{m^2}{P} \cdot \frac{FC}{m^2} \cdot \frac{FC^f}{FC} = \sum_f ACT \cdot LIFST \cdot INT \cdot STR \qquad (6)$$

At this point, to quantify the four effects, we apply the equation (3) presented in the theoretical chapter 2. The results of the equations (7-10) quantify and explain the changes in the four key variables from the year *t* to *t-1*. Such years correspond to the decoupling periods previously obtained.

$$\Delta ACT = \sum_f \left[\frac{\left(FC_f^t - FC_f^{t-1}\right)}{\left(\ln FC_f^t - \ln FC_f^{t-1}\right)} \right] \cdot \ln\left(\frac{P^t}{P^{t-1}}\right) \tag{7}$$

$$\Delta INT = \sum_f \left[\frac{\left(FC_f^t - FC_f^{t-1}\right)}{\left(\ln FC_f^t - \ln FC_f^{t-1}\right)} \right] \cdot \ln\left(\frac{\frac{FC^t}{m^{2^t}}}{\frac{FC^{t-1}}{m^{2^{t-1}}}}\right) \tag{8}$$

$$\Delta STR = \sum_f \left[\frac{\left(FC_f^t - FC_f^{t-1}\right)}{\left(\ln FC_f^t - \ln FC_f^{t-1}\right)} \right] \cdot \ln\left(\frac{\frac{FC_f^t}{FC^t}}{\frac{FC_f^{t-1}}{FC^{t-1}}}\right) \tag{9}$$

$$\Delta LIFST = \sum_f \left[\frac{\left(FC_f^t - FC_f^{t-1}\right)}{\left(\ln FC_f^t - \ln FC_f^{t-1}\right)} \right] \cdot \ln\left(\frac{\frac{m^{2^t}}{P^t}}{\frac{m^{2^{t-1}}}{P^{t-1}}}\right) \tag{10}$$

The change in final energy consumption FC from year *t* to *t-1* is the sum of the key drivers change as equation (11) shows. Table 4 is a recapitulatory schema with all the variables name and measure encountered until now.

$$\triangle FC = FC_t - FC_{t-1} = \triangle ACT + \triangle INT + \triangle STR + \triangle LIFST \tag{11}$$

Table 4: Variables names, descriptions, and units.

Name	**Description**	**Unit**
FC	Residential final energy consumption	Mtoe
P	Population	k
m2	Floor area inhabited	m^2
FC^f	Fuel final consumption	Mtoe
ACT	Population (activity effect)	k
INT	Energy intensity effect	Mtoe/m^2
STR	Fuel switch (structural effect)	Mtoe
LIFST	Lifestyle effect	m^2/k

5 Empirical Analysis

Data from the residential sector of Italy and Sweden are analysed. Sweden presents a meaningful decrease in CO_2 production although keeping its final energy consumption constant. Regarding Italy, both final energy consumption and floor area inhabited have a regular increasing trend, while CO_2 production is slightly decreasing.

5.1 Data analysis

In this first part of the empirical analysis, we analyse the data that compose the decomposition and decoupling's formula. These are data from the Italian and Swedish residential sectors. They are the amount of CO_2 produced, the GDP per capita, the final energy consumption, the total floor area inhabited, and the share of different fuels consumed. The two countries' data are shown in different graphs because Italy and Sweden present differences in term of population. Such variable indeed affects all the variables in our research.

Figure 1 shows the relation between the GDPs per capita and the CO_2 produced by the Italian residential sector. By the beginning of the century, an increase in GDPs per capita, associated with a decrease in CO_2 production, seems to confirm the EKC hypothesis of the decoupling between economic growth and environmental damage. It is essential to mention that figure 1 represent the production of CO2 excluded electricity, due to lack of data from the period 1990-2004. However, as it is possible to notice in Figure 2, the production of CO_2 included electricity reflects the decreasing trend of the previous graph for 2004-2018 but it has a higher value. This means, that the decoupling between GDPs and CO_2 happens both when electricity consumption is included, i.e., after 2004, and when it is not.

Figure 1: Italian decoupling between GDPs per capita and residential CO_2 production (Source: Odyssee, IMF).

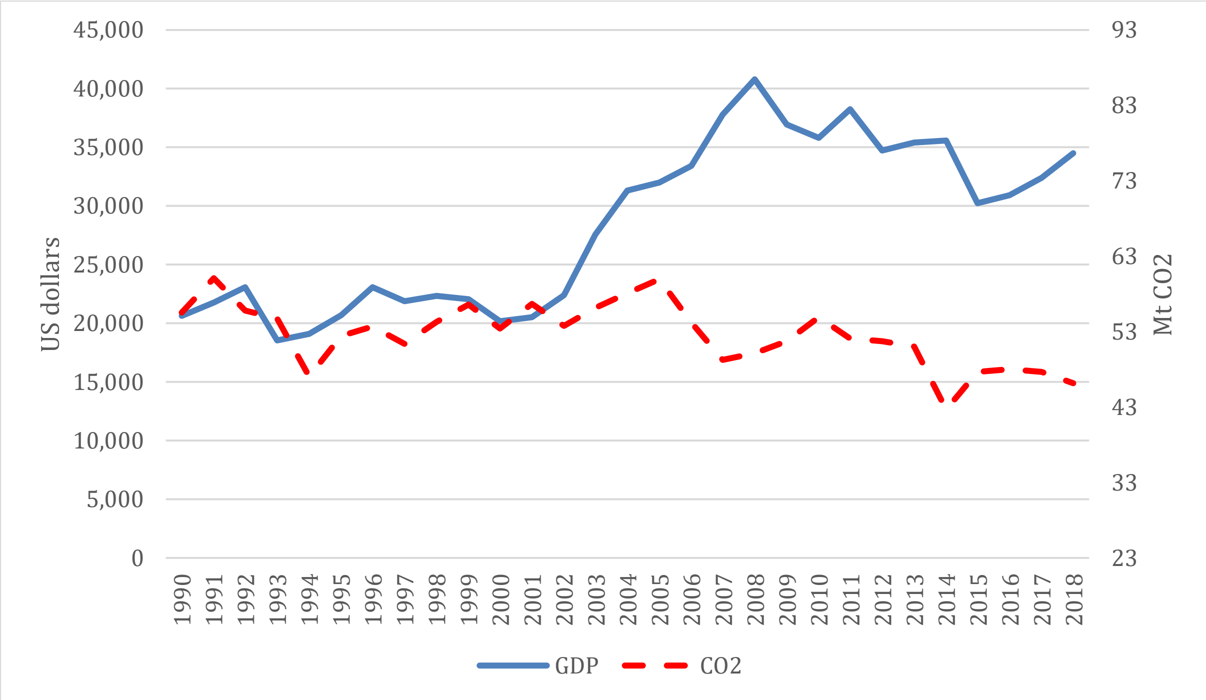
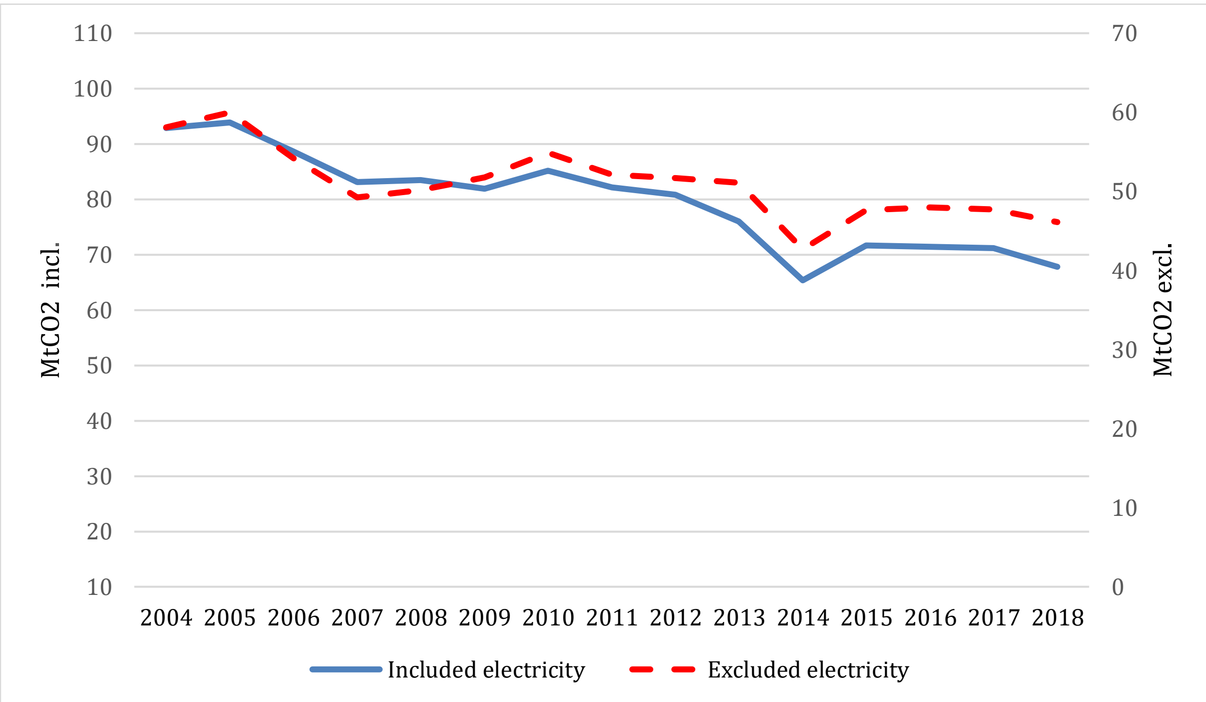
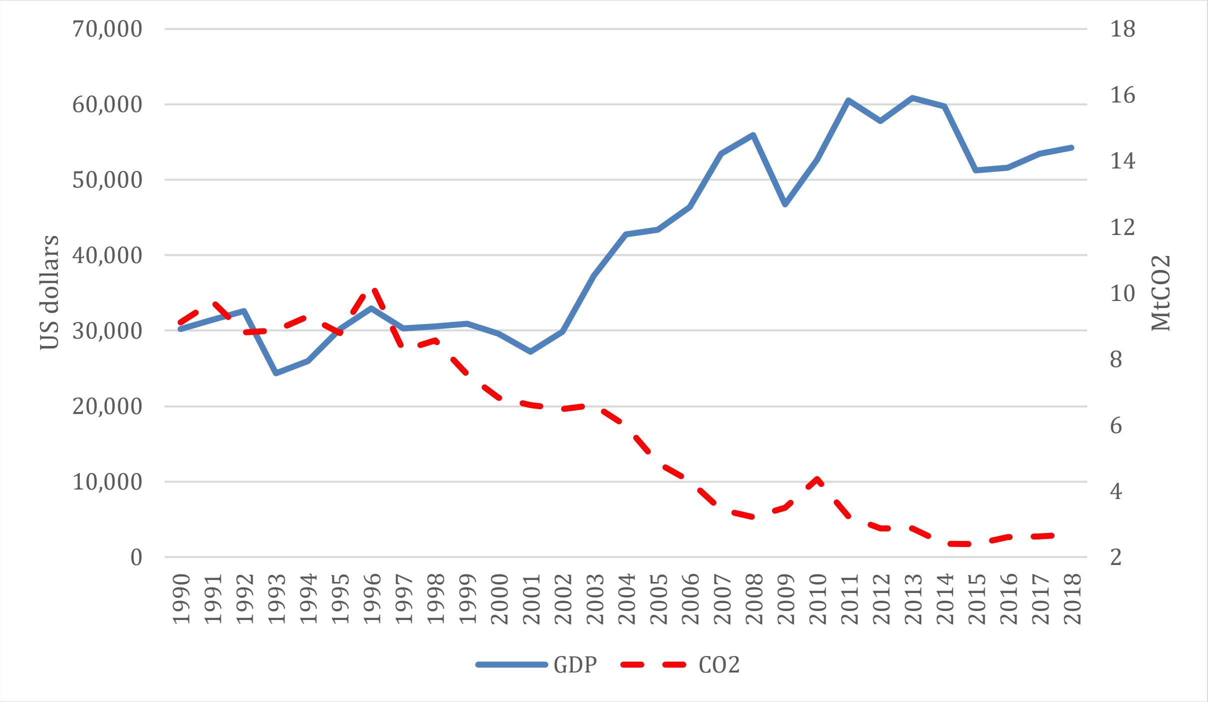


Figure 2: Italian residential CO_2 emissions included and excluded electricity (Source: Odyssee).



In Sweden, the decoupling between GDPs per capita and residential CO_2, as Figure 3 displays, is prominent. In particular, from 1996 to 2008, Sweden has decreased its production of CO_2 by around 66%, and a considerable economic growth has accompanied such increase.

Figure 3: Swedish decoupling between GDPs per capita and residential CO_2 production (Source: Odyssee, IMF).



The relation between the residential CO_2 production and the final energy consumption in the Italian and Swedish dwellings are shown in Figure 4 and 5. Regarding Italy, a slight decoupling between such variables reveals that the decrease in environmental harm is associated with an increase in final energy consumption, but both trends are marginal. On the other hand, in Sweden, the decrease in CO_2 production is associated with a slight but meaningful decrease in final consumption. For this reason, it will be exciting to know the key factors that have enabled both Italy, which has decreased its emission increasing the final consumption, and Sweden, which has decreased the environmental harm keeping its final consumption almost constant, changes in final energy consumption. Trends in floor area's dwellings size could be an essential factor affecting final energy consumption.

Figure 4: Italian relation between residential final energy consumption and CO_2 produced (Source: Odyssee).

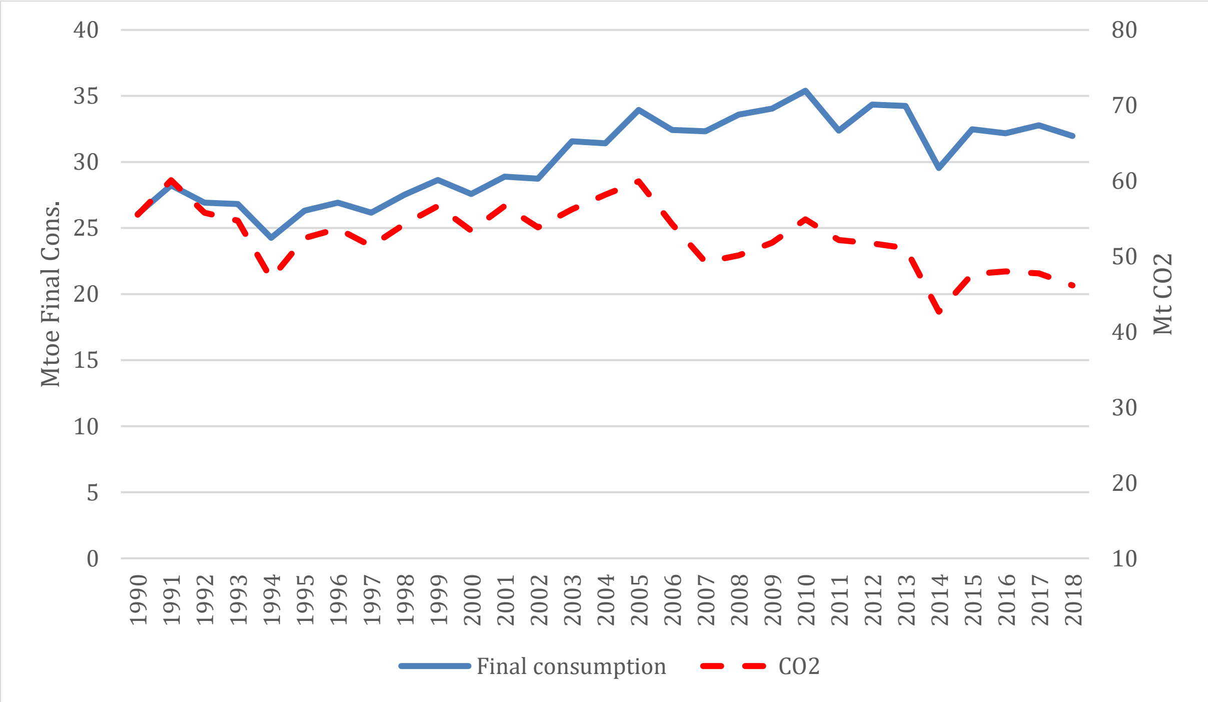
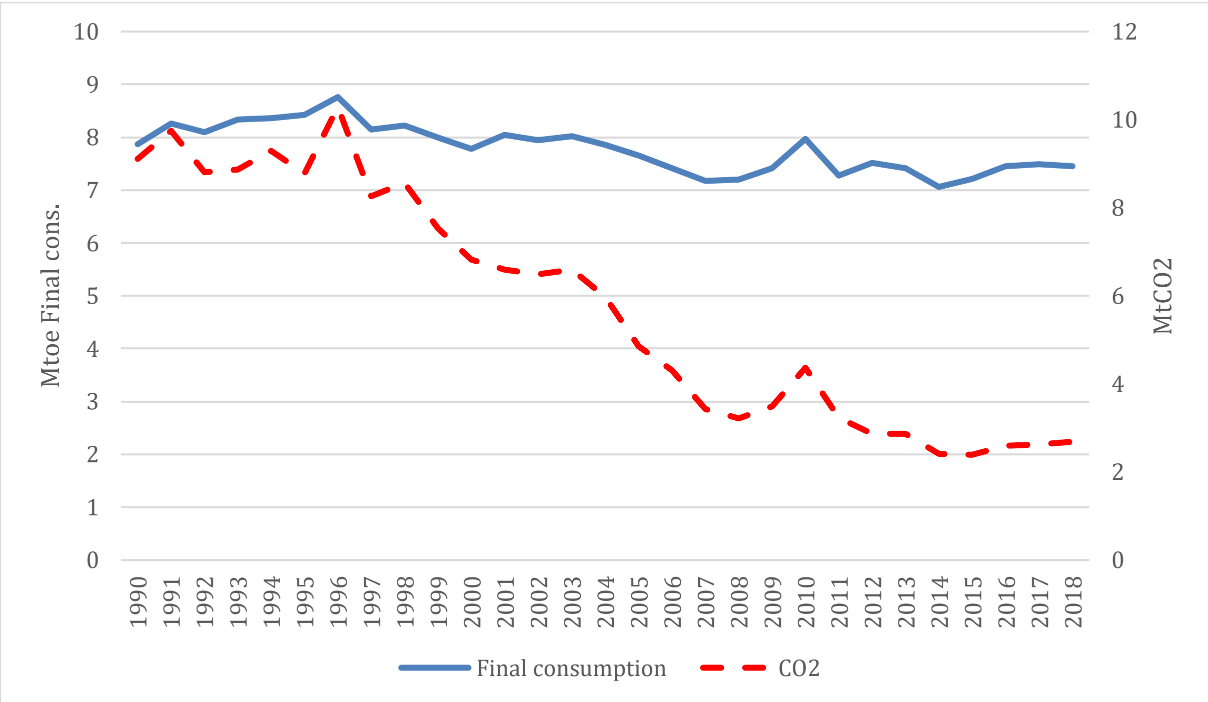
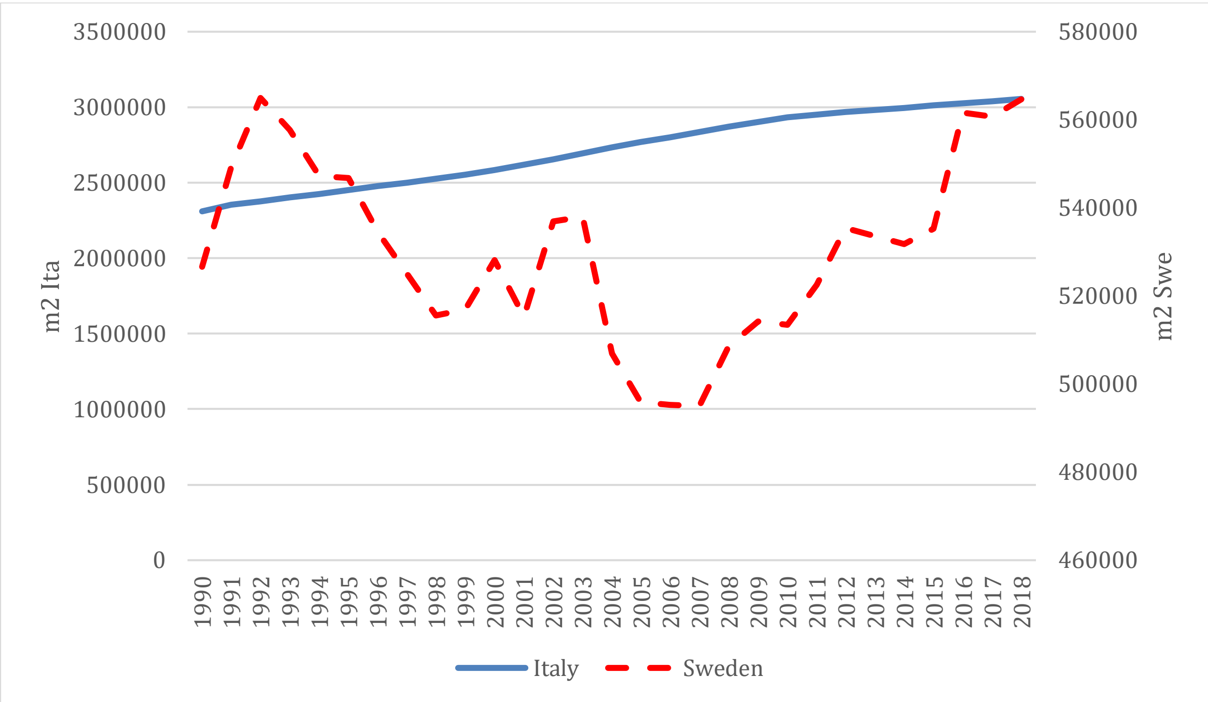


Figure 5: Swedish relation between residential final energy consumption and CO_2 production (Unit: Mtoe, Mt CO_2; Source: Odyssee).



Italy and Sweden have different trends regarding the m^2 of floor area inhabited. As Figure 6 shows, Italy displays a constant increase in our research period while Sweden has a more complex trend. It has an initial increase, but a decrease follows it until 2007. After that, it constantly grows until 2018. However, it is essential to mention that the Swedish jumping trend is due to the fact that in Figure 6 there are different scales for Italy and Sweden. Indeed, the Swedish scale is much more restricted. For this reason, variations in the values appear more prominent.

Figure 6: Italian and Swedish residential floor area inhabited (Source: Odyssee).



Final energy consumption is the sum of the consumption of the single fuels, and the two countries have changed their different fuel's share during the research period. The main difference in fuel share between Italy and Sweden, as it is possible to notice in Figure 7 and Figure 8, is that the Italian residential sector has a predominant abundance of natural gases compared to Sweden. On the contrary, the Nordic country has an outstanding share of electricity and heat consumption compared to Italy. In either case, both nations have changed their fuel share, and the effect of such alteration on final consumption is measured in the decomposition analysis.

Figure 7: Share of fuels of Italy's residential sector final consumption (Source: Odyssee).

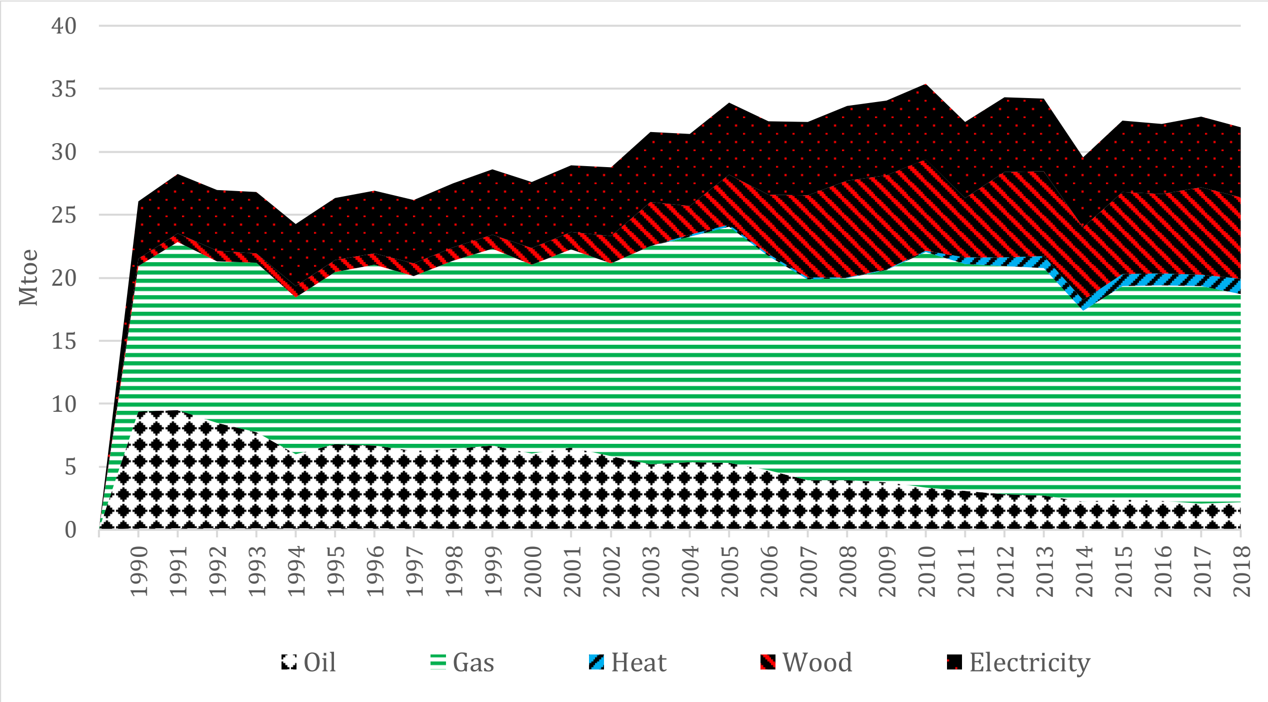
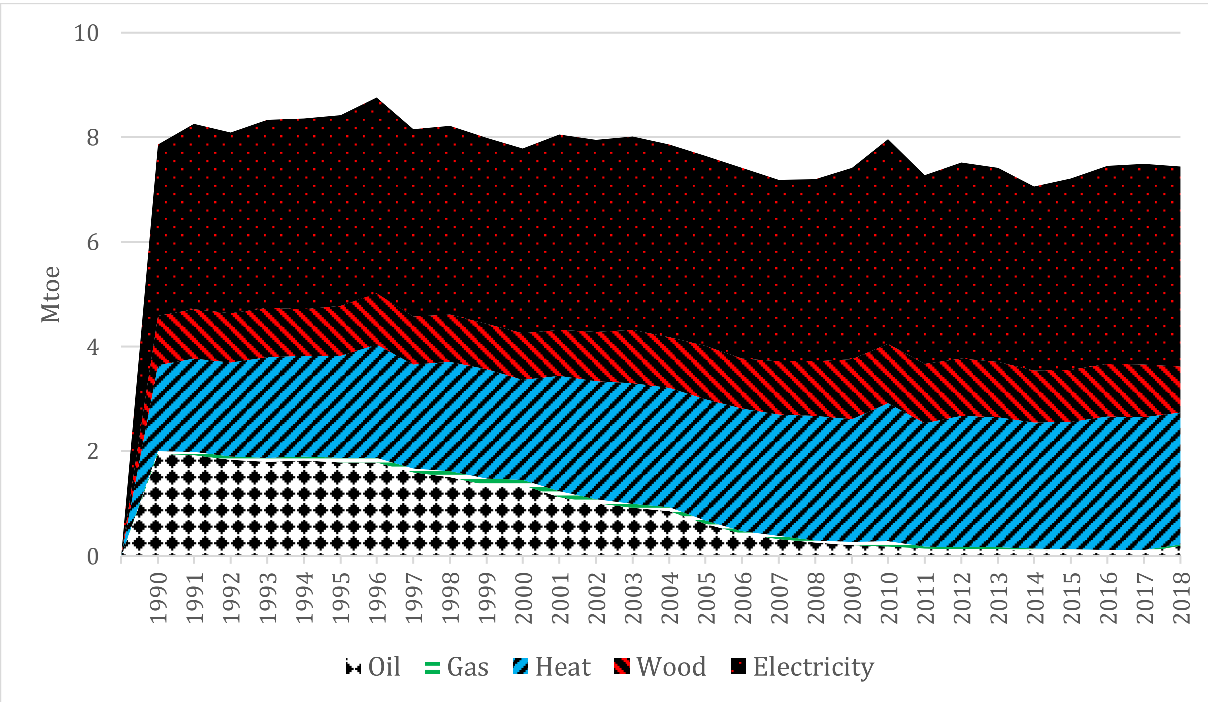


Figure 8: Share of fuels of Sweden's residential sector final consumption (Source: Odyssee).



5.2 Results analysis

The second part of the empirical analysis reveals both the decoupling and the decomposition results. It is important to stress that there is a connection between such results. Indeed, the decoupling results serve as a tool to find sub-periods for the decomposition analysis. In other words, the decoupling results reveal to us which kind of decoupling, between CO_2 and GDP, has occurred in every single year in examination. Once we obtained the decoupling results for every year, we divide the whole period, i.e., 1990-2018, into different ones. Such periods have the characteristic to contain most of the decoupling type, for example, a majority of strong or weak decoupling type. In this way, it will be interesting to study the key drivers of household's final energy consumption in different periods that present meaningful relations between CO_2 emission and GDP per capita.

Figure 9 shows the results of the decoupling analysis of Italy. Italy experienced a strong decoupling from 2010 to 2018. Indeed, apart from a year of strong negative decoupling in 2015 and a weak negative decoupling in 2012, Italy's strong decoupling was experienced from 2010 to 2018. On the contrary, from 1994 to 2010, there is a prevalence of weak decoupling and strong negative decoupling. To sum, the periods in which there is more prevalence in terms of decoupling are 1994 - 2010 and 2010 - 2018. The former characterized by a prevalence of weak decoupling and the latter by a prevalence of strong one. However, it is essential to keep in mind that there is a lack of data on CO_2 production, including electricity, until 2004. For this reason, we divide further the period 1994 – 2010 into two different ones such as 1994 - 2004 and 2004 - 2010. To sum, the decoupling analysis of Italy in the period 1990 - 2018 has enabled us to find three periods that we use for our decomposition. Such periods are:

- The first period: 1994 – 2004.
- The second period: 2004 – 2010.
- The third period: 2010 – 2018.
- The whole period: 1994 – 2018.

Figure 10 reveals the results of the decoupling analysis for Sweden. The Scandinavian country has faced a long period of strong decoupling from 1995 to 2007. Before and after that Sweden has a period characterized mainly by weak decoupling. For this reason, the periods from this analysis for the decomposition are the following: 1990-1996, 1996-2007 and 2007-2018.

- The first period: 1990 – 1996.
- The second period: 1996 – 2007.
- The third period: 2007 – 2018.
- The whole period: 1990 – 2018.

Figure 9: Decoupling results of Italy.

1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Weak	Strong	Weak negative	Strong	Weak	Weak	Weak negative	Weak	Strong negative	Weak negative	Weak	Strong	Weak	Weak

First period (1994-2004). Weak decoupling prevalence (excluded electricity)

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Weak	Strong negative	Strong negative	Weak	Weak negative	Strong negative	Strong	Weak negative	Strong	Strong	Strong negative	Strong	Strong	Strong

Second period (2004-2010). Weak decoupling prevalence (included electricity)

Third period (2010-2018). Strong decoupling prevalence

Figure 10: Decoupling results of Sweden.

1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Weak	Strong	Strong negative	Weak	Strong	Weak	Weak negative	Weak	Strong	Weak negative	Weak negative	Strong	Weak	Strong

First period (1990-1996). Weak decoupling prevalence

Second period (1996-2007). Strong decoupling prevalence

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Strong	Strong	Strong	Weak	Strong negative	Weak	Strong	Weak negative	Strong	Weak negative	Recessive decoupling	Weak	Weak	Weak

Third period (2007-2018). Weak decoupling prevalence

Figure 11 and Figure 12 reveal the results of the Italian and Swedish decomposition analysis. The total change in final energy consumption is decomposed as a sum of key factors changes. Such changes are the population (activity effect), the energy intensity (intensity effect), fuel's switching (structural effect) and the relation between the floor area inhabited and the population (lifestyle effect). What is more, our results are structured following the four periods obtained by the decoupling analysis. The results of both countries are shown in Appendix A.

Figure 11: LMDI decomposition results of Italy (Unit: Mtoe).

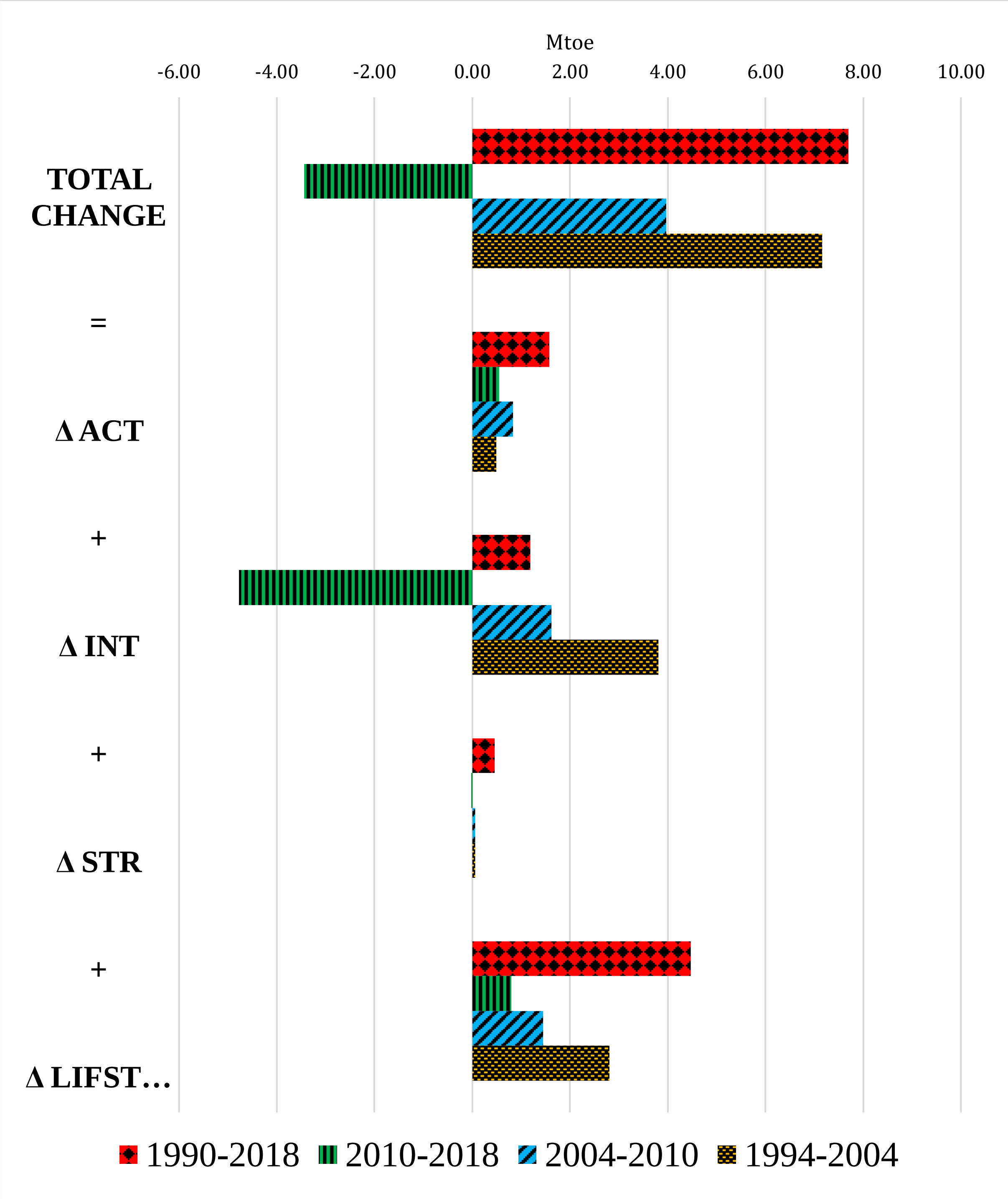
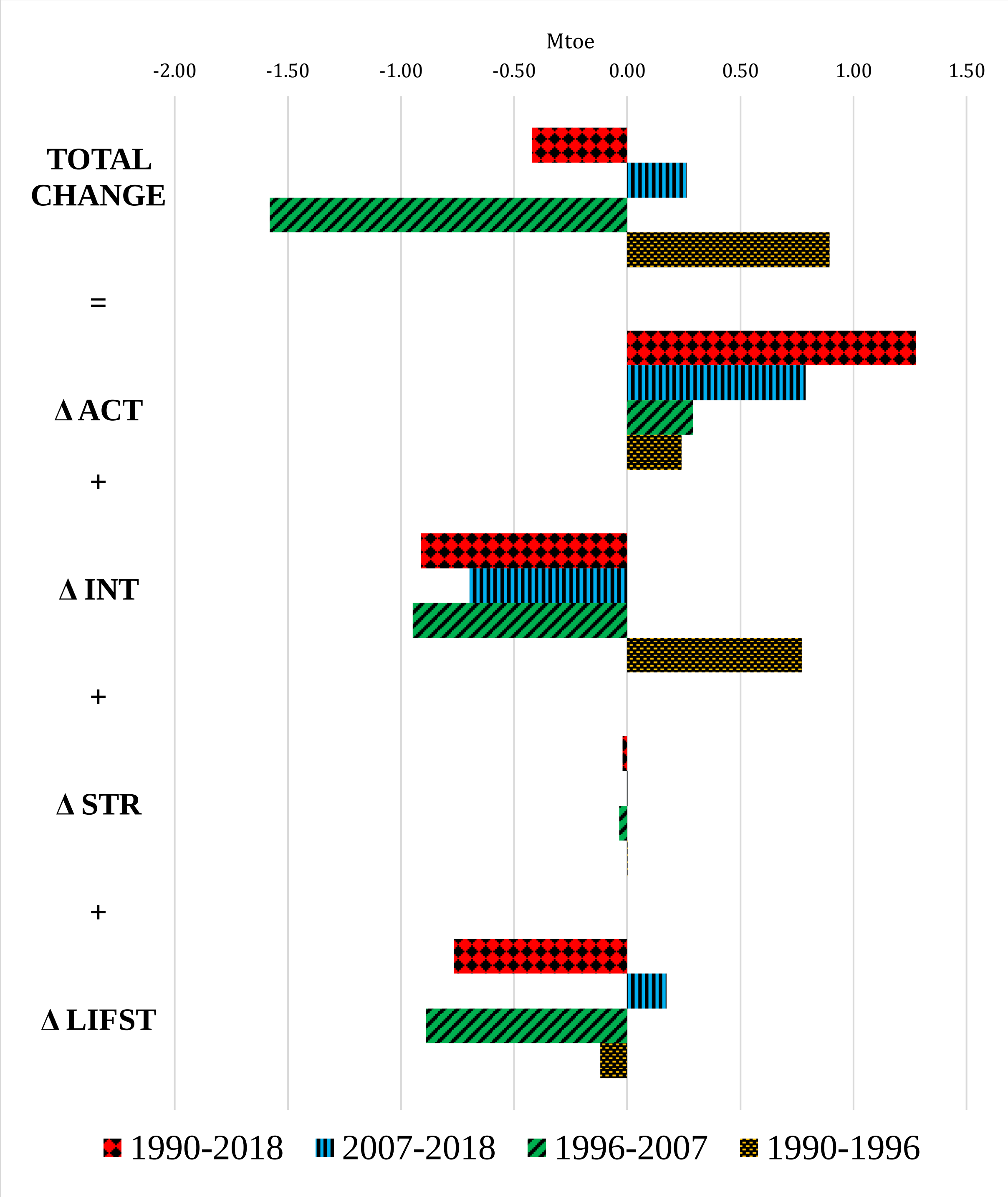


Figure 12: LMDI decomposition results of Sweden (Unit: Mtoe).



The total change effect

Regarding Italy, the total change in final consumption in the whole period 1994-2018 has an increase of 7.69 Mtoe. However, values in final energy consumption are constantly decreasing through the three periods. There has been a trend change between the second and the third period, i.e., between 2004-2010 and 2010-2018. In the latter period, the consumption sees a decrease of -3.44 Mtoe.

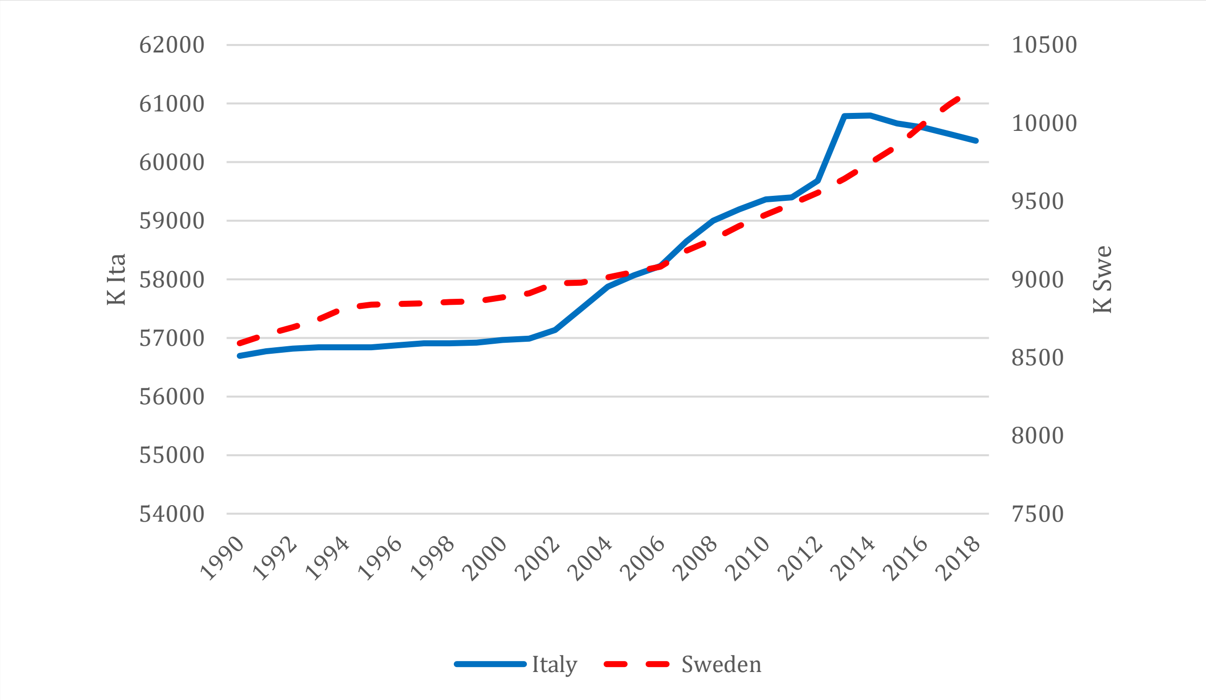
On the contrary, in Sweden, the final consumption has a reduction of 0.42 Mtoe in the whole period 1990-2018. Such decrease has been driven by the results obtained in the second period (1996-2007), which has contributed to reducing 1.58 Mtoe residential consumption. On the contrary, the previous and following periods, i.e., 1990-1996 and 2007-2018, have contributed to an increase in final energy consumption, respectively of 0.89 and 0.26 Mtoe.

Italy has so registered an increase in final consumption in the whole period. However, it is constantly reducing its energy consumption. On the contrary, Sweden has registered a decrease in total energy consumption, and it could be attributable to a golden period between 1996 and 2007. However, during the last period, the decreasing trend in final consumption has stopped and increased. What have been the main factors influencing such changes, and in particular the decrease in final consumptions of the Italian period 2010-2018 and the Swedish one 1997-2004? The decomposition of the total change into four different key drivers will help us find an answer.

The activity effect

In general, changes in population in Italy have a marginal increase in final consumption. Indeed, it has an increase of 1.58 Mtoe in the whole period. The positive value is due to minimal positive increases during the three subperiods. As Figure 13 shows, it is essential to note that the Italian population after 2013 decreases. This fact has an important role in the final consumption results. On the other hand, in Sweden the population is constantly growing. As a result, the activity effect has been the main driver of an increase in final consumption. An increase in 1.28 Mtoe is attributable to changes in population from 1990-2018, and the third period has been the most important. It is the main difference with the Italian's activity effect that in its third period saw a decrease if we compare with the previous one. The discussion part gives possible reasons for our results.

Figure 13: Italian and Swedish population (Source: Odyssee).



The intensity effect

The Italian energy intensity's effect has been the main driver affecting a decrease in final consumption in the whole period. In other words, it is the factor that is most negative in final consumption between 1994 and 2018. The structural effect seems to be the most negative in Figure 11, but we must remind that such variable is a percentage that will be analysed separately. The intensity effect was responsible for increasing just 1.91 Mtoe. Such results are attributable to an improvement in the energy intensity of the Italian residential sector in the third period, which saw a decrease of 4.77 Mtoe.

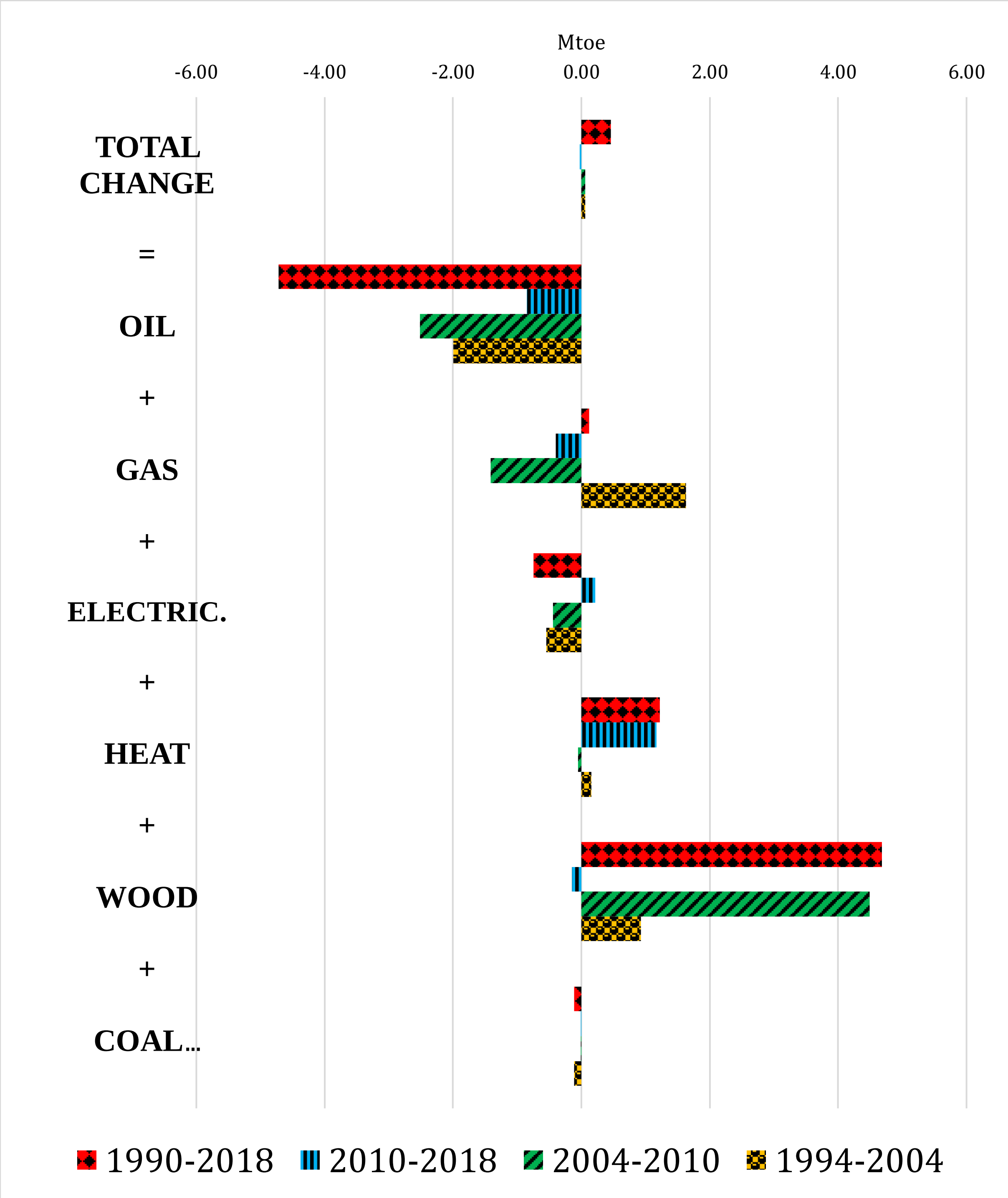
Similarly, in Sweden, the energy intensity effect is the main factor affecting the decrease in the final consumption in the period 1990-2018. It is interesting to notice that the intensity factor enabled the decrease in consumption both in the second, where the effect is greater, and in the third period. On the contrary, energy intensity is still a substantial driver of the increase in energy consumption in the first period.

The structural effect

The structural effect measures the impact of the change of fuels' switch in the given period. It means the increase or decrease of final consumption produced by switching fuel consumption for another fuel. It is important to analyse every single fuel because, as we have seen in Table 11 and 12, the sum of the single fuel's change tend to be 0. This is because the change within a fuel tends to be compensated by the consumption of other fuels. For this reason, this variable's analysis aims to investigate which specific fuel's change contributes to increase or decrease the final consumption of energy.

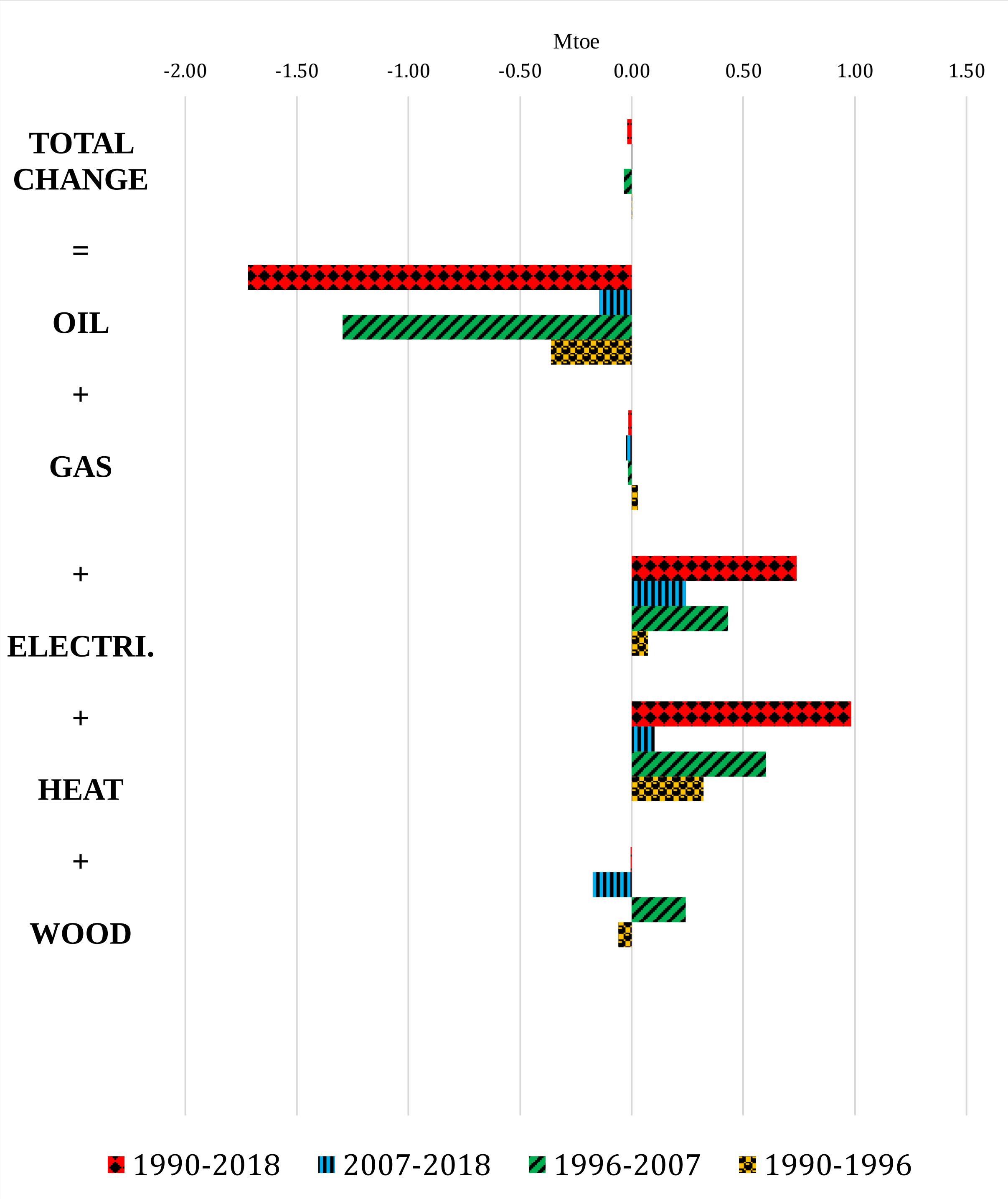
Figure 14 shows the changes in fuel switching in Italy in the four periods. It is important to stress that this effect does not measure the difference in fuel consumption but their relationship with the final consumption, i.e., the sum of all the fuel's consumption. The results indicate the changes in the percentage of fuel composition in the given period. For example, the value -4.72 regarding oil consumption in the period 1994-2018 reveals that the relation between oil consumption and the sum of all the fuel's consumption, i.e., the final consumption, have a decrease of 4.72 Mtoe. The change in oil consumption is the main factor contributing to a decrease in final consumption. In the whole period switching oil for other fuels contributes to 4.72 Mtoe. Such change in oil consumption mainly happened in the second and first period of our study. It is interesting to notice that the consumption of wood is the main factor that contributes to an increase in final consumption, in particular during the second period. This could signify that an increase in wood consumption could have compensated for decreasing oil consumption in the second period. The percentage of gas consumption has decreased in the second and third period and could be compensated by an increase in the percentage of heat consumption.

Figure 14: LMDI decomposition results of Italy's Δ Structure.



Also, for Sweden, as Figure 15 indicate, the percentage of oil switching for other fuels is the primary driver in final consumption in the whole period. In particular, a decrease of 1.72 Mtoe is attributable to this phenomenon. The more remarkable changes in switching oil happened in the second period. During this period, oil consumption was replaced by greener type of energy such as heat and electricity. The detail results are shown in Appendix A

Figure 15: LMDI decomposition results of Sweden's Δ Structure (Unit: Mtoe).



The Lifestyle effect

The relation m^2/population in Italy has been the factor that has contributed the most to an increase in final consumption. However, looking at the three sub-periods, the lifestyle effect is constantly decreasing. Figure 6 and Figure 13, i.e., trends in floor area inhabited and population, help us to understand such phenomenon. The trend in the Italian population reveals to us that the demographic increase between 2000 and 2013 has been the main driver of the decreasing value in the lifestyle effect. The floor area inhabited has seen a rise during these years but not as much. So, the Italian lifestyle effect has a positive result in the whole period but is constantly decreasing.

On the contrary, Sweden has different values and trends in the effect of the relation m^2/population on final consumption. Such a factor has contributed to a decrease in the final consumption in the whole period. The second period (1996-2007) has contributed to the negative effect in final consumption. Also, in this case, it is worthy of looking at Figure 6 and Figure 13 to understand such relation. The main driver of the decreasing values given by the lifestyle effect has been reducing the m^2 inhabited in Sweden until 2007. After this date, Sweden residential sector has a rise both in inhabitants and floor area. As a result, Sweden lifestyle effect has contributed to a negative value in final consumption in the whole period, but such value is currently increasing.

6 Discussion

In the following chapter, we discuss the results obtained in the decomposition analysis. We discuss the possible reasons that can explain changes in the activity, structural, intensity and lifestyle effects. In other words, we consider the facts that regard the trends about change in populations, fuel switching, energy intensity and floor area inhabited.

The activity effect

How can we explain the major key driver in the Swedish residential consumption increase, and in particular in the 2007-2018 period? What is more, how can we explain the little effect that population have in the Italian case? As stated in chapter 2, fertility and migration trends can explain such demographic changes.

One of the reasons behind the differences in activity effect in the two countries could be attributable to their differences in fertility ratios. In the period 1990-2018, Sweden registered a higher fertility ratio than Italy, reaching in 2018 the value of 1.91 versus the Italian 1.5 value. It is interesting to notice that after 2000 the Swedish fertility rates increase and after 2007, they stabilize (Gapmider, 2021). Such increase happens also in Italy but with a lower intensity. An economic cause that could clarify such differences between Italy and Sweden is their youth employment situation. Indeed, Sweden has one of the lowest shares of young people between 20 and 34 years old unemployed, i.e., the 9% and 8% of young women and men, while Italy has one of the highest shares in Europe, i.e., 32% and 22% of young women and men (Eurostat, 2019). What is more, the average age at which young people leave the parental home follows the same trend. The lowest European value is represented by Sweden (21 years), while one of the highest by Italy (30) (Eurostat, 2017). Such economic factors could deeply influence the autonomy to take important decision such as the choice of having a child.

Immigration flows could be another reason for changes in the activity effect. The migration net ratio, i.e., the difference between immigrants and migrants, of the two counties could explain the differences in the population trends. The main fact to discuss is that in Italy after 2012 the migration net has a tremendous decrease, meaning that the people leaving the country are much higher than the ones coming. It seems that Italy is not more an attractive country for immigrants (Camilli, 2018). The main reason is attributable to the Bossi-Fini law of 2002, a law that does not permit a practical legal way for immigrants to work in Italy. Indeed, immigrants who come from outside of the EU are enabled to work only if they already have a job contract. What is more, immigrants need to renew their residency permit every two years; however, if they are without a job contract at that moment, the Bossi-Fini law forbid the permit's renovation. The only practical way is to have a relative and to ask for a family reunification permit. (Camilli, 2018). The working difficulties to have residence permits are attributable to the decrease in the migration ratio and population growth.

On the contrary, in Sweden after 1996 the immigration trends had seen an important increase. The "pull factors" that lead refugees immigration to escape firstly from the Yugoslavian civil war in the 90s and secondly from Iraq, Afghanistan, Somalia, Palestine, and Syria in the 2000s are attributable to be the main reason for an increase in population growth (Tegunimataka, 2021)

The intensity effect

The Italian energy intensity results in our decomposition analysis can be attributable to an efficient energy policy. As Figure 14 displays, the most meaningful decrease in final energy consumption happens in the period from 2010 and 2018. Such a result is explained by the implementation of material guidelines and building codes by the Italian Government. The Energy Performance in Building Directive (EPBD), constantly implemented by 2005, has the aim to set minimum energy performance requirements, to include mandatory integration of renewable sources, and to introduce energy efficiency checks. Moreover, tax incentives have also played an important role in residential energy efficiency. For example, the "55% tax credit", introduced in 2014, allows building owners to renovate and recover 55% of their investment (IPEEC, 2015).

The Swedish decomposition results show that the energy intensity effect is the major contribution to a decrease in final energy intensity; such a decrease happens earlier if we compare it with the Italian case. The main reason for that is that Sweden has started its climate strategy in the late 80s. Indeed, in 1988 the first climate target established a carbon-emission limit. Moreover, the setting of ambitious short- and long-term targets together with an increasing funding on energy research and development (R&D) enabled Sweden to reach important and early results in dwellings energy efficiency (Di Lucia, 2014).

The structural effect

There is a common trait in the Italian and Swedish structural effects results, such as the shift from oil, as the major indicator of reduction in energy consumption, to other fuels. In the Italian case, wood consumption has been the major contributor to increases in final energy use. According to a study conducted by Istat (2013), Italy is the first global importers of residential burning wood. What is more, the results obtained in our results, such as an important structural change regarding wood in the period 2004-2010, could be explained by changes in the Italian fuel prices in that period. Indeed, in 2005, the price of gasoline, one of the main sources in the residential sector, increased by 45%; and wood could have been a possible substitution for many Italian households. It is a possible solution because it has been estimated that the 21,4% of

Italian families are currently heating their houses with burning wood (Pettenella & Andrighetto, 2011).

Regarding Sweden, structural change of oil consumption has been compensated by cleaner type of energy consumption such as district heating and electricity. Such a favourable transition has been the results of substantial milestones. The most important is the introduction of two carbon taxes in 1991 and 2004, the reform in the electricity market in 1996 and the presentation of the Tradable Renewables Electricity Certificate in 2003 (Di Lucia, 2014).

The lifestyle effect

The most interesting factor regarding the lifestyle effect is the Swedish change in the relation between floor area and population from being a source of decreasing energy consumption in the period 1996 – 2007, to a cause of increases in energy consumption. This fact seems to reflect the results of a study conducted by Statistic Sweden (Statistic Sweden, 2019). According to it, after 2010 Sweden residential sector faced an exponential increase in the construction of new multi-dwelling building, i.e., dwelling with three or more apartment. The floor area of such apartments has an average of 59 square meters and tend to vary between regions. For example, it has been registered that the Stockholm region has the smallest living space per person, i.e., 33 square meters (Statistic Sweden, 2020). The exponential construction of new multi-dwelling building could reflect our Swedish decomposition results and could be a solution to the small living spaces in particular Swedish areas.

7 Conclusion

This research analyses and investigate the energy consumption of the Italian and Swedish residential sector from 1990 to 2018. The Environmental Kuznets Curve hypothesis have been tested thanks to the Tapio's decoupling method. It reveals that the economic growth and environmental damage in the Italian and Swedish residential sector have decoupled from in the whole period in examination. In particular, a prevalence of strong decoupling years occurred in Italy in the period from 2010 to 2018 and in Sweden from 1996 to 2007. The LMDI decomposition analysis have permitted us to investigate further and to analyse the possible causes of such decoupling.

The overall picture of our decomposition analysis shows that the Italian residential sector has increased its final energy consumption from 1990 to 2018, while the Swedish one has decrease it. In Italy, the main causes to such results are attributable to a high energy intensity in the period from 1994 to 2010. While in Sweden, the decrease is attributable to an efficient energy intensity and a reduction in the floor area inhabited per person in the period from 1996 to 2007. Swedish positive results are attributable to well-timed energy politics that drove energy efficiency to regulate residential energy consumption.

However, the main finding of our research is that the situation for both countries changes in recent times. Indeed, Italy has seen a great decrease in final energy consumption after 2010 and energy intensity has been the driver to such change. The major explanations to this result are attributable to the efficient energy politics in the residential sector after 2005. Building codes and tax incentives had driven the Italian residential sector to such changes in energy intensity. Regarding Sweden, the golden period of reduction in residential consumption has stopped after 2007 and it has started to slightly increase. The main drivers to such an increase are a growing population and the floor area inhabited per person. Indeed, demographic factors such as high fertility trends and a high migration ratio, together with many multi-dwellings built, permitted the final consumption to invert its trend after 2007.

What is more, both Italy and Sweden presented a change in energy consumption due to switching from oil to other fuel. The Italian decrease in oil consumption has been compensated by an increase in wood consumption, while in Sweden it has compensated by a consumption in district heating and electricity. Future research should focus on the decomposition of a particular fuel consumed in the residential energy. For example, what are the drivers of the consumption of electricity, and in particular the renewable sources that generate it, in the European residential sector?

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Appendix A

Table 5: Italian decomposition results (Unit: Mtoe).

	1994-2004	2004-2010	2010-2018	1990-2018
Δ Population	0.49	0.84	0.55	1.58
Δ Lifestyle	2.80	1.46	0.80	4.48
Δ Intensity	3.81	1.62	-4.77	1.19
Δ Fuel switch	0.06	0.06	-0.02	0.46
Total change	7.16	3.97	-3.44	7.69

Table 6: Swedish decomposition results (Unit: Mtoe).

	1990-1996	1996-2007	2007-2018	1990-2018
Δ Population	0.24	0.29	0.79	1.28
Δ Lifestyle	-0.12	-0.89	0.17	-0.77
Δ Intensity	0.77	-0.95	-0.70	-0.91
Δ Fuel switch	0.00	-0.04	0.00	-0.02
Total change	0.89	-1.58	0.26	-0.42

Table 7: Decomposition results of every singular fuel switch, Italy (Unit: Mtoe).

	1994-2004	2004-2010	2010-2018	1990-2018
Δ Coal	-0.11	0.00	0.00	-0.11
Δ Oil	-2.00	-2.52	-0.85	-4.72
Δ Gas	1.63	-1.42	-0.40	0.12
Δ Heat	0.15	-0.05	1.17	1.23
Δ Wood	0.93	4.49	-0.15	4.68
Δ Electricity	-0.55	-0.44	0.21	-0.75

Table 8: Decomposition results of every single fuel switch, Sweden (Unit: Mtoe).

	1994-2004	2004-2010	2010-2018	1990-2018
Δ Coal	0.00	0.00	0.00	0.00
Δ Oil	-0.36	-1.29	-0.15	-1.72
Δ Gas	0.03	-0.02	-0.02	-0.02
Δ Heat	0.32	0.60	0.10	0.98
Δ Wood	-0.06	0.24	-0.17	0.00
Δ Electricity	0.07	0.43	0.24	0.74