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Measurement of the direct rebound effect on residential electricity consumption in the European Union Countries

VERSÃO DEFINITIVA APÓS DEFESA PÚBLICA

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Resumo

Devido ao efeito *rebound* causado pela melhoria na eficiência energética, a diminuição no consumo de energia pode não ser traduzida como o esperado. Este estudo é o primeiro a estimar a magnitude do efeito *rebound* direto para o longo e curto prazo bem como o impacto que as mudanças climáticas têm no consumo residencial de eletricidade para os países da União Europeia. Para analisar o efeito *rebound* direto, foram utilizados dados em painel de 1996 a 2017 tendo sido aplicado o modelo ARDL em painel. Os resultados mostram que o efeito *rebound* direto no longo prazo é de 35%. As mudanças climáticas têm um efeito positivo no consumo de eletricidade tanto no curto como no longo prazo. Este estudo sugere que os formuladores de políticas, ao formular as políticas energéticas, devem ter tanto o efeito *rebound* quanto as mudanças climáticas em conta.

Palavras-chave

Efeito *rebound*; Consumo residencial de eletricidade; Eficiência energética

Resumo Alargado

Atualmente existe uma maior preocupação dos países com o elevado consumo de eletricidade, devido à necessidade de satisfazer a procura sem interrupções. Sendo que o setor doméstico é um dos setores que mais energia consome, os países estão a tentar contrariar essa realidade. Uma das formas para conseguirem diminuir o consumo de energia é o uso de medidas de eficiência energética. O uso dessas medidas levou à necessidade de desenvolver umas tecnologias mais eficientes, esperando que esse progresso tecnológico melhore a eficiência energética. Melhorias na eficiência energética levam a uma redução no custo efetivo de energia o que, por consequência, provoca um aumento na procura dos serviços energéticos. Este fenómeno é chamado de efeito *rebound*. Este efeito deve ser considerado para a formulação de políticas, pois é importante perceber se as medidas que estão a ser adotadas são eficazes na diminuição do consumo de eletricidade ou se estas medidas produzem o efeito contrário.

Este efeito pode ser classificado em três diferentes efeitos, o efeito *rebound* direto, o efeito *rebound* indireto e o efeito *rebound* em toda a economia. A literatura existente resume três métodos para estudar a magnitude do efeito *rebound,* o primeiro método é o modelo de equilíbrio geral e suas expansões, o segundo é a abordagem quase experimental e o último é uma variedade de métodos econométricos. Essa literatura foca-se mais na estimação do efeito *rebound* direto, apontando para uma melhor facilidade na obtenção dos dados como justificação, pois a grande parte usa métodos econométricos para estimar a magnitude do efeito *rebound* direto.

Este trabalho tem como objetivo contribuir para a literatura atual, medindo o efeito *rebound* direto no consumo residencial de eletricidade nos países da união europeia e também descobrir qual é o impacto das alterações climáticas no consumo de energia, ajudando a perceber se as medidas adotadas neste conjunto de países estão ou não a ajudar a reduzir o consumo de energia.

Para a elaboração do estudo foram utilizados alguns dos países pertencentes à União Europeia e com dados anuais de 1996 até 2017. As variáveis utilizadas foram o consumo de energia elétrica como variável independente, e como variáveis dependentes foram utilizadas, o preço de energia que foi decomposto em três preços, o preço de queda, recuperação do preço e o preço máximo histórico, sendo o valor do coeficiente do preço de queda a magnitude do efeito *rebound* direto; o produto interno bruto em per capita como proxy do rendimento das famílias; a precipitação e os *degree days* que são a soma dos *cooling and heating degree days*, esta ultima variável também é utilizada para estudar o impacto das alterações climáticas no consumo de energia. Foi utilizada a metodologia painel ARDL, este modelo pode ser aplicado com variáveis estacionarias em nível e também nas primeiras diferenças e tem a capacidade de capturar efeitos de curto e longo prazo. Foram realizados testes de *cross-section* e posteriormente testes de 2ª geração de raízes unitárias devido a presença de *cross-section dependence* e também o teste de cointegração para avaliar as possíveis relações de longo prazo.

Os resultados finais mostraram que o efeito *rebound* direto era de 35% no longo prazo, sendo um valor em conformidade com a literatura já existente. Também o impacto das alterações climáticas no consumo de eletricidade é examinado, concluindo que o consumo de energia aumenta tanto no curto como no longo prazo sob as mudanças climáticas. Reformas regulatórias para atrair investimentos em fontes de energia renováveis e alertar as pessoas com campanhas educacionais para estas saberem a importância de medidas de economia de energia são algumas políticas que se podem adotar para ajudar a reduzir a magnitude do efeito *rebound* e as alterações climáticas.

Abstract

Due to the rebound effect caused by the improvement in energy efficiency, the decrease in energy consumption may not be translated as expected. This study is the first to estimate the magnitude of direct rebound effect for the long and short run and the impact of climate change on residential electricity consumption for the European Union countries. In order analyse the direct rebound effect a panel data from 1996 to 2017 was used, and a panel ARDL model was applied. The results show that the magnitude of the direct rebound effect in the long run is 35%. The climate changes have a positive effect on the electricity consumption both in the long and short run. This study suggests that policy makers should have both the rebound effect and the climate changes in mind when formulating their energy policies

Keywords

Rebound Effect, Residential electricity consumption, Energy efficiency

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Acronyms list

ARDL	Autoregressive Distributed Lag
CGE	Computable General Equilibrium
CSD	Cross Section Dependence
DD	Degree Days
DFE	Dynamic Fixed Effects
EE	Energy Efficiency
GWH	Gigawatt Hour
HICP	Harmonised Indices of Consumer Prices
KWH	Kilowatt Hour
MG	Mean Group
OLS	Ordinary Least Squares
PMG	Pooled Mean Group
RE	Rebound Effect
R&D	Research and Development
VIF	Variance Inflation Factor

1. Introduction

Nowadays, countries are becoming more concerned in improving energy efficiency, in order to reduce the electricity consumption and to reduce carbon dioxide emissions. Thus, it also becomes more important for countries to have the rebound effect into account, since this pursue of higher levels of energy efficiency may not lead to a decrease in the electricity consumption.

In 2007, European Union leaders adopted an objective for 2020 which committed them to reduce average annual energy consumption by 20%. Therefore, energy efficiency measures are increasingly recognized driver to achieve this end. Energy certification of buildings, regular inspections of heating and air-conditioning systems of buildings, support for education programs aimed at helping European citizens to understand how they can increase their energy savings or, also, various initiatives as a way to stimulate public and private investment in the field of energy efficiency of buildings in order to send a signal of confidence to the markets and thus encourage investors to move towards energy efficiency are some measures taken to improve energy efficiency (Gouardères, 2018).

One of the ways to reduce electricity consumption is to use energy efficiency measures, and with the great expansion of the adoption of these measures it has been necessary to develop an increasingly efficient technology. Most of the current literature states that technological progress can improve energy efficiency, but improvements in energy efficiency can lead to a reduction in the effective cost of energy. This reduction means that the demand for energy services and goods increases and, consequently, it leads to increased energy consumption. This phenomenon is called rebound effect (Wang, Lu, & Wang, 2014).

A rebound effect of 10% means that 10% of expected savings are offset by increased consumption. This effect can result from both efficiency improvements that make a good or service cheaper and by changing the consumption pattern due to changes in the behaviour of the consumer. For example, consumers can choose to enjoy more of their household appliances because the cost of using them is lower and this will end up not decreasing the consumption of electricity. Also, consumers may choose to drive further and/or more often following the purchase of a fuel-efficient car because the operating cost per kilometre has fallen. Similarly, consumers may choose to heat their homes for longer periods and/or to a higher temperature following the installation of loft insulation, because the operating cost per square metre has decrease. Or also, for example, renewable energies have been growing rapidly both in terms of demand and efficiency and it can turn out to be a serious problem about the energy rebound effect since, as the energy efficiency of renewable energies increases, renewable energy becomes increasingly accessible and the demand for it increases. As a result, there may be an increase in waste of energy (Jin & Kim, 2019).

Wang, Lu, & Wang, (2014) indicate that the rebound effect may have arisen due to the lack of knowledge on the market reaction to the energy efficiency measures. In fact, it was thought that an improvement in energy efficiency would reduce energy consumption and, contrariwise, that did not happen. Because of this, the rebound effect must be considered for effective policy formulation.

Energy efficiency is a growing discussed theme in the world, mainly in the European Union countries. Still having stages to accomplish, many strategies are being implemented to achieve those steps. However, are we going in the right path? Does these strategies are attaining the intended goals, as the reduction of the energy consumption? This paper aims to answer those questions, to check whether the implemented strategies are having a positive result. As we have seen before, the rebound effect has been widely studied and the findings have shown that the energy efficiency measures may lead to its opposite result, which is an increase in the energy consumption. This paper aims to measure the direct rebound effect of the residential electricity consumption, for the European Union countries. The relevance of this study is high, since these countries have been putting their efforts into obtaining good results of energy efficiency in order to reduce the electricity consumption. Thus, this paper is important to see if the implemented strategies are leading us to the desired electricity consumption reduction. Also, this essay also pretends to check the impact of the climate changes on the electricity consumption. For that, a panel ARDL model will be applied, an innovation for the rebound effect literature. This method is able to provide estimations of the magnitude of the rebound effect for the short and long run, simultaneous. An advantage from this model to others is its capacity of estimate relations between the variables, regardless if they are I (0) or I (1).

This study is divided as follows: Literature review, which will contain the description of the main articles on the subject under study and the main differences and similarities between the articles; Data and Methodology, where the data, description of the variables and the model to be estimated are presented; Presentation and discussion of data where it is presented how the results answer the question of departure and, finally, the conclusion, where the main contributions of the essay will be presented.

2. Literature Review

In this chapter will be presented the literature review on the rebound effect, which can be divided in three main aspects: the theoretical explanation, the empirical evidence and the definition of the direct rebound effect.

2.1 Theoretical explanation on the rebound effect

The concept of energy rebound effect begins and ends with the idea that energy consumption decreases with higher levels of energy efficiency. Sometimes the opposite may happen and growth in efficiency can backfire (Jin & Kim, 2019).

The rebound effect originates from the "Jevons Paradox", described by the English economist William Stanley Jevons in his book "*The Coal Question" in 1865*. He has argued that technological progress improved the efficiency of energy use, but energy consumption has also increased (Zhang & Peng, 2017). Such fact can be explained because these advances generate rapid economic growth leading to an increase in energy demand. Also, increasing energy efficiency leads to a decline in the actual cost of useful energy which can cause an increase in energy consumption due to the behavioural change of consumers.

The ideas of Jevons were later adopted by some economists, such as Khazzom (1980) and Brookes (1990), during the decades of 1980 and 1990 in the context of an impending energy crisis (oil crisis in 1973 and the 1979 energy crisis) and later due to concerns about climate changes (Font, Mcdowall, Freire-gonzález, Kemp, & Voet, 2016). Khazzoom (1980) highlighted that improvements in energy efficiency could lead to increased demand for energy services and Brookes (1990) argued that energy efficiency would lead to economic growth that would sequentially increase energy consumption. Both have independently proved that increasing energy efficiency, paradoxically, tends to lead to increased energy consumption. Subsequently, Saunders (1992) describes the work of Khazzoom and Brookes as the postulate[1] of Khazzoom-Brookes (KB). In its original formulation, the K-B postulate states that: "with fixed real energy prices, energy efficiency gains will increase energy consumption above what it would be without these gains"(Saunders, 1992). This postulate stimulated a panoply of theoretical and empirical contributions within the energy economics, which resulted in a debate on the theoretical foundations and the importance of the rebound effect that continues to the present day (Steve Sorrell, 2007).

Most studies explain the rebound effect based on neoclassical economic theory, as is the example of Saunders (1992), who argued that improvements in energy efficiency would

[1] The term postulate indicates a starting assumption from which other statements are logically derived. It does not have to be self-evident or supported by empirical evidence.

increase total energy consumption and also that improvements in capital and labour productivity would have a similar effect (Wang, Han, & Lu, 2016).

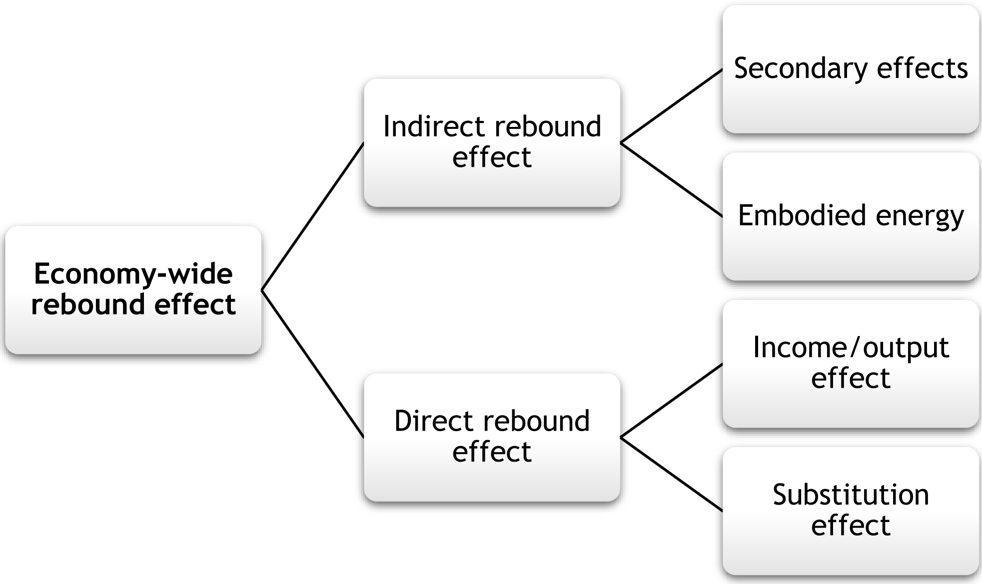

Figure 1-"Engineering" estimate of energy savings. Source:(Balint, 2013)

According to Sorrell and Dimitropoulos (2008) the energy rebound effect can be classified into three types: direct rebound effect, indirect rebound effect, and economic-wide effect. The direct rebound effect occurs when there is a reduction in energy service costs due to improvements in energy efficiency in these services, thus implying that the consumer has more money to spend on energy goods and services, which subsequently leads to an increase in energy consumption. The reduction of energy consumption that should have resulted from improved efficiency does not really happen or falls short of expectations. The indirect rebound effect occurs when reducing the effective cost of energy services leads the consumer to spend the money saved in other goods and services of which consume a lot of energy. This way, the energy consumption will increase in areas that are not directly affected by the improvements on the energy efficiency. The economy-wide rebound effect refers to an overall increase in energy consumption in the whole economic system due to improved energy efficiency and productivity. Some authors defined the economy-wide rebound effect as the sum of the direct and indirect rebound effects (Jin & Kim, 2019; Shao, Guo, Yu, Yang, & Guan, 2019). The direct rebound only exists at the micro-economic level, while the indirect rebound and economy-wide rebound occur at the medium and macroeconomic levels, respectively (Shao et al., 2019).

The direct rebound effect, relative to the energy efficiency improvements by consumers, it is decomposed into two effects: a substitution effect, where the consumption of energy services is cheaper than the consumption of other goods and services thus existing a substitution from the consumption of other goods and services to a consumption of energy services, maintaining a constant level of utility or consumer satisfaction; and an income effect, where, due to improvements on the energy efficiency, the real income will be higher thus allowing to achieve a higher level of utility, increasing the consumption of goods and services, including the energy services As for the direct rebound effect for producers, it is decomposed into: a substitution effect, whereby the cheaper energy service substitutes for the use of capital, labour and materials in producing a constant level of output; and an output effect, whereby the cost savings from the energy efficiency improvement allows a higher level of output to be produced thereby increasing consumption of all inputs, including the energy service. The indirect rebound effect it is decomposed into: the embodied energy, which is the energy used to produce and\or install more efficient energetic goods or services, such as the installation of thermal insulation; and the secondary effects, which occur when consumers use the energy savings to buy other goods and services which themselves need energy to provide (Balint, 2013). The figure 1 shows the scheme of this classification.

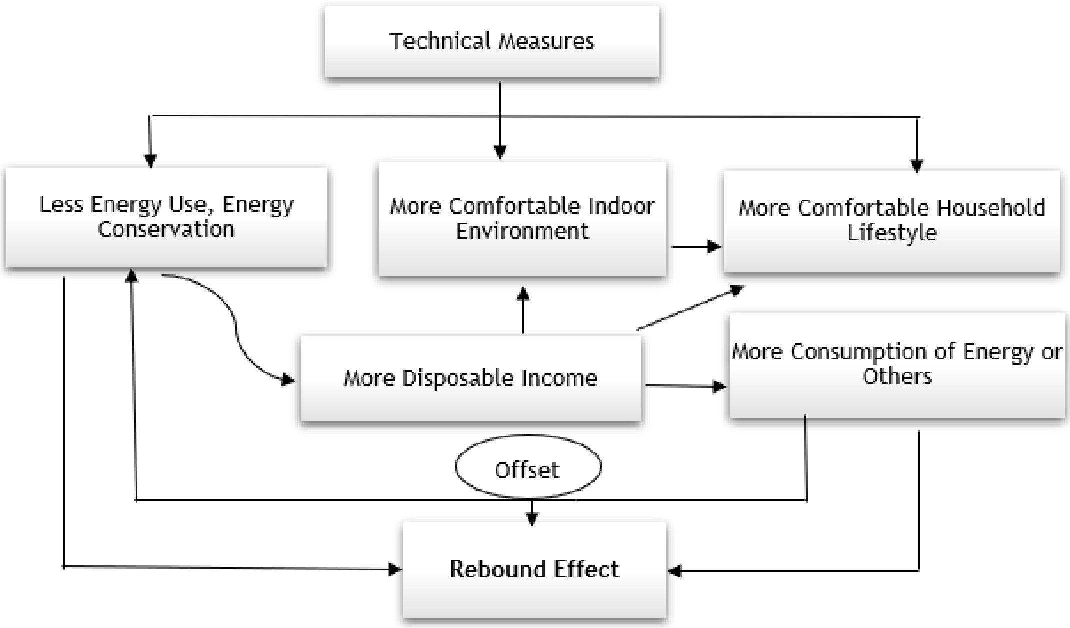

Figure 2-Formation process of rebound effect in household sector. Source:(Ouyang et al., 2010)

The direct rebound effect in household energy efficiency have been commented widely in the literature (Alvi, Mahmood, & Naeem, 2018; Labidi & Abdessalem, 2018). Figure 2 depicts the formation process of energy rebound effect in the household sector. The possibility for modern living brought by technical innovation and the disposable income increase brought by energy efficiency improvements are the sources of the energy rebound. The rebound effect depends on the energy consumers income. The magnitude of the rebound effect tends to be higher in the lower income countries or amongst lower income consumers in wealthier countries (Ouyang, Long, & Hokao, 2010).

2.2 Empirical evidence on the rebound effect

There are many methods to estimate the magnitude of the rebound effect. From the existent literature it is possible to resume three of the main methods (Wen, Ye, Yang, & Li, 2018). The first method is the general equilibrium model and its expansions. The literature relating this model mostly estimate the economic-wide rebound effect. For example, Wei and Liu (2017), use a global computable general equilibrium (CGE) model to study the global rebound effects on energy use and related emissions caused by an energy efficiency improvement. The results show very large rebound effect on energy use (70%) and related emissions (90%) in 2040 at the global level with regional and sectoral differences. The second method is the quasi-experimental approach. This method relies upon measuring the demand for the energy service before and after an energy efficiency improvement, in order to estimate the energy rebound effect (Sorrell & Dimitropoulos, 2008). The last method is a variety of econometric methods, which includes a cross-sectional analysis, time series and panel data.

Some literature focus in the last method to calculate the direct rebound effect, mainly on two factors that influence the residential consumption of electricity, namely economic and climatic factors (Wangpattarapong & Maneewan, 2008). Zhang and Peng (2017), Wang, Han, and Lu (2016) and Wang, Lu, and Wang (2014) are examples of those works, who studied the rebound effect for China using both economic and climatic variables. These authors use variables such as the residential electricity price and consumption, the population, the available income of households, cooling and heating degree days and rainfall, to estimate the rebound effect of the residential energy consumption and, also, to check whether the improvements on the energy efficiency lead to a decrease on the residential energy consumption.

Alvi et al. (2018) and Labidi and Abdessalem (2018), more recently, in addition to study the rebound effects on the residential electricity consumption, also investigated the impact of climate change on electricity consumption and whether energy subsidies had an impact on the rebound effect. Alvi et al. (2018) used the cooling and heating days to study their impact on electricity consumption and concluded that, under the climate change, the electricity consumption increases both in the long and short run. Labidi and Abdessalem (2018) used the price of electricity with and without electricity subsidies for domestic use and concluded that the removal of subsidies, in addition to raising the price of electricity, moderated the residential rebound effects. In general, they concluded that the rebound effect is higher in families and this factor should be considered in the formalization of energy policies.

Su et al. (2019) studied the rebound effect in Tawain's residences, performing a survey in many households. The appliance-specific rebound effects were also studied. A number of appliances with and without EE label were employed to analyse the rebound effect of energy efficient appliances. The difference of electricity consumption between appliances with and without EE label was the actual saving due to efficiency improvement. Comparing this actual savings to the expected saving based on the BOE, the appliance-specific rebound effects can be obtained. The rebound effect in Taiwan was 72% for AC, 11% for lighting, 3% for TV, and 70%

for refrigerator. The rebound effect was very large for AC and refrigerator. The overall rebound effect, weighted on electricity consumption, was at least 33% in Taiwan's residential sector. Note that the rebound effect estimated in this paper was limited to the difference of electricity consumption between households with old appliances and those with EE-labelled appliances.

Other authors as, Roubaud et al. (2018), rather than studying the rebound effect on residential electricity, have opted to study the direct rebound effect of the residential gas demand for the French households. They have used an OLS regression and the ARDL model to estimate the magnitude of the direct rebound effect for the residential gas consumption in France. They use as variables the residential consumption of gas, the income, the price of gas, the population growth and the heating degree days. They have concluded that the direct rebound effect is, approximately, 53% in the short run and 60% in the long run.

All these authors who studied the rebound effect have shown that it can be calculated from several ways and, also, that it can be not only calculated from electricity consumption but also from other sources of energy, like the natural gas.

2.3 Definition of direct rebound effect

Several articles have the direct rebound effect as central question. This essay will also focus on the direct rebound effect resulting from efficiency improvements in the residential energy consumption. Previous studies have shown that the direct rebound effect can be estimated from one of two energy-effiency elasticities, the elasticity of energy demand $\eta_\varepsilon(E)$ and the elasticity of energy service $\eta_\varepsilon(S)$ (Sorrell, Dimitropoulos, & Sommerville, 2009; Zhang & Peng, 2017). From the relationship $S=\varepsilon E$, the link between these two elasticities can be easily obtained as follows:

$$\eta_\varepsilon(E)=\eta_\varepsilon(S) - 1 \qquad (1)$$

On what ε is defined as the ratio of useful energy output to energy input and $\varepsilon=S/E$ is the economical definition of energy efficiency. If the energy efficiency increases, the energy consumption will decrease. So, it is obtained the price of energy service (cost) $P_S = P_E/\varepsilon$. Obtaining $\eta_\varepsilon(S) > 0$ or $\eta_\varepsilon(E) < 1$, is the only way for the energy savings, originated by improvements on the energy efficiency, to be effective.

Many scholars Berkhout, Muskens, and Velthuijsen (2000) and Khazzoom (1980) have commonly presented a definition of direct rebound effect (RE) as being:

$$\text{RE}=\frac{\text{Expected savings}-\text{Actual savings}}{\text{Expected savings}}=\eta_\varepsilon(S)=1+\eta_\varepsilon(E) \qquad (2)$$

- If RE > 1, the rebound effect is named backfire effect;
- If RE = 1, the rebound effect is named total rebound effect;
- If 0 < RE < 1, the rebound effect is named partial rebound effect;

- If RE = 0, (no rebound), the rebound effect is named zero rebound effect;
- If RE < 0, the rebound effect is named super conservation effects.

Rebound effect of 0% means full achievement of energy reduction, while 100% means complete failure. Also, if rebound effect is greater than 100%, efficiency improvement measures can even increase energy use, which is called as “backfire effect”. When a backfire effect is noted, energy efficiency improvement measures are not very useful as energy reduction policies (Sang-hyeon Jin, 2007).

Notwithstanding, since it is difficult to calculate the energy efficiency (ε), the energy rebound effect is often estimated from one of three price elasticities: η_{Ps} (S) is the elasticity of demand for energy services with respect to the energy cost of energy services (Ps); η_{P_E}(S) is the elasticity of demand for energy services with respect to the price of energy(P_E); η_{P_E}(E) is the elasticity of demand for energy with respect to the price of energy (Labidi & Abdessalem, 2018; Zhang & Peng, 2017). In this study the η_{P_E}(E) elasticity will be used to measure the direct rebound effect.

However, authors like Khazzoom (1980) argue that the measure of the rebound effect can be simplified, unlike equation (2), relying on two hypothesis: exogeneity, since energy efficiency is not affected by changes in energy prices (i,e. P_E does not depend on e, and any changes in energy effiency derive from outside the model) and symmetry, since consumers respond the same way to a decrease in energy prices as to improvements in energy efficiency. The negative of either η_{Ps}(S), η_{P_E}(S) or η_{P_E}(E) can be taken as an approximation η_ε(S) and, hence, they can be used to measure the direct rebound effect (Labidi & Abdessalem, 2018; Zhang & Peng, 2017).

In this essay, to estimate the direct rebound effect, it was chosen the negative elasticity of energy demand with respect to energy price, based on the data availability. Thus equation (3) is used to estimate the size of direct rebound effect of residential electricity consumption for European Union Countries:

$$RE = -\eta_{P_E}(E) = -\frac{\partial \ln(E)}{\partial \ln(P_E)} \quad (3)$$

The effect of perceived lower costs on energy use is called “price elasticity” is the ratio between the percentage changed in energy use and the percentage changed in energy price. These percentages vary by commodity and over time and depend on the ability of consumers to respond to price changes. The higher the observed price elasticity of energy services is, the greater the rebound effect is (Sang-hyeon Jin, 2007).

3. Data and Methodology

The following topic will be an identification and a description of the variables used, a description of the methodology and a presentation of the model used. At the end of the chapter, specification tests will be performed.

3.1 Description of the data

For this essay it was used a panel dataset with annual frequency and the time horizon of 1996 until 2017 for the countries belonging to the European Union. The adopted countries were Austria, Belgium, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Slovenia, Spain, Sweden and United Kingdom. The remaining European Union countries were excluded due to lack of data. The countries under review share the objective to ensure that they achieve the common goal of reducing energy consumption. The model of the demand for residential electricity consumption in countries European Union can be written as follows:

$$ln\, E_{it} = \alpha_0 + \beta_1 lnP_{Eit} + \beta_2 lnPIBpc_{it} + \beta_3 lnDD_{it} + \beta_4 lnPR_{it} + \mu_{it} \qquad (4)$$

In which,

- E_{it}: electricity consumption in households in state i, in period t. This variable was obtained on the Eurostat database in GWh. It was converted later into KWh.

- PE_{it}: Real domestic electricity price (base 2010, unity euro) per KWh in state i, in period t. The discharge price is calculated in two different ways. The values for the electricity price variable are half-yearly and relate only to the DC consumption band, which, according to Eurostat, is the average consumption and reference band for comparative purposes between the European Union. Although the values are semi-annual, only the values of each first semester will be used, assuming this price as the average annual price. We calculate the actual euro price through HPIC. This variable was obtained on the Eurostat database.

- $GDPpc_{it}$: Gross Domestic Product per capita (base 2010, unity euro) in state i, in period t. This variable is a proxy of disposable income of households, the growth of this variable is one of the reasons for the increase in energy consumption. The higher the income of families, the greater the ability to pay for them and this will lead to an increase in the demand for goods. There is a positive relationship between income and energy consumption, since, as the disposable income increases, the frequency of use of household appliances also increases, as well as their electricity consumption. This variable was obtained in the World Bank database.

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- PR_{it}: Precipitation in state i, in period t. Being a climatic variable it can have influence in the electricity consumption. This variable was obtained from the Climate Change Knowledge Portal, World Bank.

- DD_{it}: Degree days in state i, in period t. This variable is calculated by adding heating degree days (HDD) and cooling degree days (CDD). This variable shows the need of energy for the heating and cooling of buildings. It will be highly correlated with the electricity consumption, since both with heat and cold weather we resort to equipment's to mild the temperature on the houses. In addition to being used to study the rebound effect, it will also be a variable used to study the impact of climate change on electricity consumption. These variables were obtained on the Eurostat database.

3.2 Methodology

The rebound effect can be estimated using more than one methodology. Examples of those different methodologies are the Panel Threshold Model (e.g. Zhang & Peng, 2017), the Error Correlation Model (e.g. Alvi et al., 2018), and the One-way Model (e.g. Labidi & Abdessalem, 2018).

The econometric software used for data analysis is Stata15. The panel autoregressive distributed lag (ARDL) model is performed. This methodology is also used by Roubaud et al. (2018) to examine the long and short run marginal impact of independent variables on the dependent variable. This estimator is known for its efficiency in the estimation of variables as I(0) and I(1) and has as advantage to support the inference of parameters based on standard tests.

When energy prices increase, consumers will try to improve their energy efficiency to save money. However, if energy prices fall, consumers cannot remove the cost savings derived from energy efficiency improvements. Therefore, it is more accurate to estimate the rebound effect with the price elasticity of energy demand in periods of falling price. But the price of energy is fluctuating, because it can either increase or decrease. We include this non-symmetry of energy price effect in our method by using a price decomposition method developed by Dargay (1992) and Gately (1993) a method which decomposed the price into three parts:

$$P_{E_{it}} = P_{E_{it}}^{max} P_{E_{it}}^{cut} P_{E_{it}}^{rec} \quad (5)$$

Where, $P_{E_{it}}$ is the price of energy in the history , $P_{E_{it}}^{max}$ is the highest price in history, $P_{E_{it}}^{cut}$ is price fall, and $P_{E_{it}}^{rec}$ is price recovery in the history. In which:

$$P_{E_{it}}^{max} = max \{P_{E_{i1}}, P_{E_{i2}}, \ldots, P_{E_{it}}\}$$

$$P_{E_{it}}^{cut} = \Pi_{m=0}^{t} min\{1, ((P_{E_{im-1}}^{max} / P_{E_{im-1}})/(P_{E_{im}}^{max} / P_{E_{im}}))\} \quad (6)$$

$$P_{E_{it}}^{rec} = \Pi_{m=0}^{t} max\{1, ((P_{E_{im-1}}^{max} / P_{E_{im-1}})/(P_{E_{im}}^{max} / P_{E_{im}}))\}$$

To use this method in the logarithmic function, Haas and Biermayr (2000) made some changes from the original method. For example, figure 3 shows the natural log and the decomposition of natural log of the average residential electricity price for the European Union countries from 1996 to 2017. By applying the logarithmic in equation (5) we have:

$$ln\, P_{E_{it}} = ln\, P_{E_{it}}^{max} + ln\, P_{E_{it}}^{cut} + ln\, P_{E_{it}}^{rec} \quad (7)$$

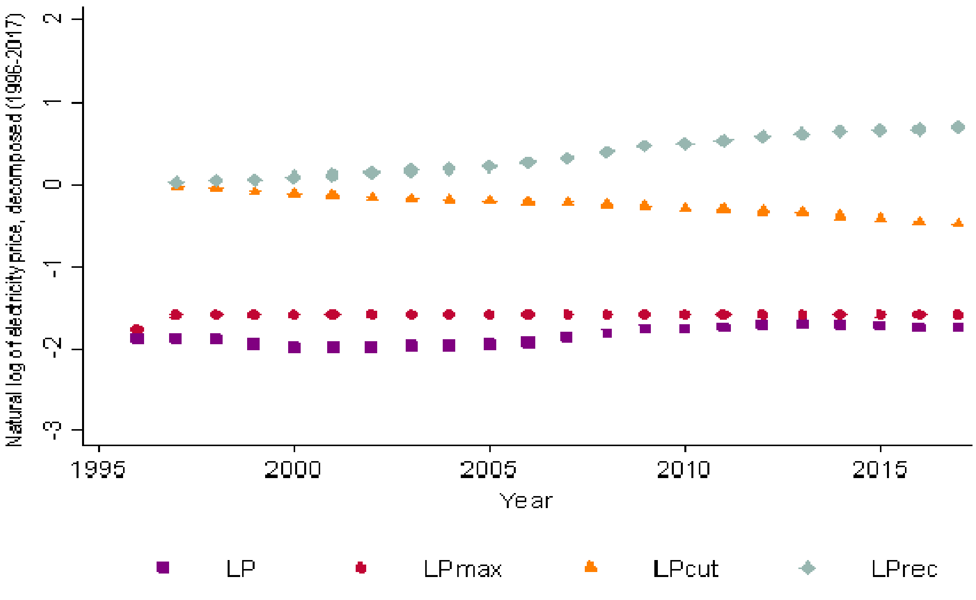

Figure 3-Decomposition of log residential electricity prices

Since the maximum historical values of the natural logarithm, according to the asymmetric price decomposition method, the equation of the ARDL model, including the long and short run relationship between the variables is:

$$\Delta ln\, E_{it} = \alpha_i + \sum_{j=1}^{k} \beta_{1ij}\, \Delta ln\, E_{i,t-j} + \sum_{j=0}^{k} \beta_{2ij}\, \Delta ln\, P_{E_{i,t-j}}^{cut} + \sum_{j=0}^{k} \beta_{3ij}\, \Delta ln\, P_{E_{i,t-j}}^{rec}$$
$$+ \sum_{j=0}^{k} \beta_{4ij}\, \Delta ln\, DD_{i,t-j} + \sum_{j=0}^{k} \beta_{5ij}\, \Delta ln\, GDPpc_{i,t-j} + \sum_{j=0}^{k} \beta_{6ij}\, \Delta ln\, PR\lambda_{1i} \quad (8)$$
$$+ \lambda_{1i} ln\, E_{i,t-j} + \lambda_{2i} ln\, P_{E_{i,t-j}}^{cut} + \lambda_{3i}\, ln\, P_{E_{i,t-j}}^{rec} + \lambda_{4i} ln\, DD_{i,t-j}$$
$$+ \lambda_{5i} ln\, GDPpc_{i,t-j} + \lambda_{6i} ln\, PR_{i,t-j} \varepsilon_{it}$$

Where E_{it}, $P_{E_{it}}^{cut}$, $P_{E_{it}}^{rec}$, DD_{it}, $GDPpc_{it}$,PR_{it} are, respectively, in natural logarithms, residential electricity consumption, price cuts, price recoveries, degree days, per capita GDP and precipitation. The coefficients $\beta_1 - \beta_6$ are the elasticities to be estimated and Δ denotes the first difference operator of the respective variable. The white noise term, ε_{it} is the residual term and it is assumed to be normally distributed. β represent the short-run coefficients both of dependent and independent variables and λ is the long-run coefficients. λ_{2i} ($ln\, P_{E_{i,t-j}}^{cut}$ coefficient) represent the short-run direct rebound effect and β_{2ij} ($\Delta ln\, P_{E_{i,t-j}}^{cut}$ coefficient) represent the long-run direct rebound effect.

3.3 Analysis and preliminary tests

This section shows the preliminary test on data to check the proprieties of the variables. The present study is carried out with a macro panel, so it is important to analyse the characteristics of the series and the *Cross Section*. Since it is a study with a set of countries with similarities, *Cross Section Dependence* (CSD) is expected. Also, it is important to analyse the descriptive statistics of the variables and the order of their integration. To check for the eventual presence of *Cross-Sectional Dependence*, the Pesaran CD test was performed (Pesaran, 2004). In Table 1 it can be seen the descriptive statistics of the variables and the results the CD-test.

Table 1-Descriptive statistics and cross-sectional dependence

Variables	Descriptive statistics					Cross section dependence (CDS)		
	Obs.	Mean	Std. dev.	Min.	Max.	CD-test	corr	abs(corr)
LEC	440	30.3231	1.5509	26.794	32.7438	29.41***	0.486	0.582
LPEC	440	-0.2449	0.1839	-0.9887	0	50.56***	0.836	0.836
LPER	440	0.3585	0.3386	0	1.7976	55.00***	0.911	0.911
LDD	440	7.8696	0.4019	6.7951	8.7334	28.99***	0.48	0.505
LGDPpc	440	10.2485	0.4971	8.8627	11.5695	51.05***	0.844	0.844
LPR	440	6.6505	0.3448	5.5611	7.4489	9.65***	0.159	0.346
DLEC	420	0.0108	0.0418	-0.1521	0.1842	15.71***	0.269	0.317
DLPC	420	-0.0234	0.0401	-0.2358	0	4.11***	0.069	0.239
DLPR	420	0.0328	0.0572	0	0.5242	4.67***	0.079	0.214
DLDD	420	-0.0055	0.1064	-0.3004	0.3197	32.3***	0.547	0.583
DLGDPpc	420	0.019	0.0902	-0.1948	0.3973	56.7***	0.964	0.964
DLR	420	0.0014	0.2082	-0.0846	0.8729	10.93***	0.185	0.384

Notes: The prefix 'L' stands for natural logarithmic and 'D' stands for first difference. The CD-test has N (0,1) distribution, under H_0: *croos-section independence*. ***, **, * significance at 1%, 5% and 10%, respectively.

By analysing the results, cross sectional dependence was detected. This means that any shock that affects a country in this study, will also affect the rest of the countries, either negatively or positively. Because of the existence of cross-sectional dependence, second generation unit root tests need to be performed in order to check the integration orders of the variables. For that matter, CIPS test (Pesaran, 2007) was performed. The results can be seen in Table 2.

Table 2-Second generation unit root tests.

Variables	Without trend	With trend
LEC	0.325	2.524
LPEC	-0.787	0.887
LPER	-2.428***	-1.722**
LDD	-9.436***	-7.798***
LGDPpc	3.084	3.384
LPR	-10.123***	-8.484***
DLEC	-10.242 ***	-8.650***
DLPEC	-7.031***	-6.452***
DLPER	-10.363***	-8.729***
DLDD	-13.909***	-10.883***
DLGDPpc	-3.094***	-1.477*
DLPR	-16.006***	-13.404***

Note: ***, **, * significance at 1%, 5% and 10%, respectively. H_0: series is I (1).

By observing the results from Table 2, we can conclude that all variables are either I (1) or I (0). The null hypothesis for CIPS test is, series is I (1). Hence, no variable is I (2), making the ARDL model appropriate.

To test for the existence of multicollinearity, which means, the correlation between different variables, a variance inflation factor (VIF) was computed, where values over 10 suggest the existence of multicollinearity. Even though the variables are from different natures, they can explain in the same way the dependent variable, presenting variables characteristics that are substitutes of one and other (Dormann et al., 2013). In Table 3 we can see the VIF and the correlation matrix, where que correlation coefficients cannot be higher than 0.8.

Table 3-Correlation matrix and VIF

	LEC	LPEC	LPER	LDD	LGDPpc	LPR
LEC	1.0000					
LPEC	-0.0538	1.0000				
LPER	-0.2467	-0.5016	1.0000			
LDD	0.3655	0.1998	-0.1623	1.0000		
LGDPpc	0.1349	0.1635	-0.1872	0.4160	1.0000	
LPR	0.2264	-0.0019	-0.2382	0.2872	0.3334	1.0000
Mean VIF	1.33					
	DLEC	DLPEC	DLPER	DLDD	DLGDPpc	DLPR
DLEC	1.0000					
DLPEC	-0.0823	1.0000				
DLPER	-0.1552	0.3347	1.0000			
DLDD	0.3361	-0.0146	0.0391	1.0000		
DLGDPpc	0.0753	-0.1261	-0.1044	0.0431	1.0000	
DLPR	0.0004	0.0069	0.0480	0.0358	0.0585	1.0000
Mean VIF	1.07					

The results show that the problem of multicollinearity is not present. As this analyse has a long period of 21 years, the existence of cointegration between values is expected. This test can only be performed with variables in the same order of cointegration – I (1). Due to the existence of Cross-Sectional Dependence in the variables, the Westerlund (2007) test of co-integration was performed. This test has as null hypothesis the non-existence of co-integration. In Table 4, we can see the test results.

Table 4-Co-integration test

	Statistics	Wiht trend	Without trend
Westerlund test	Variance ratio	1.422*	-1.9178**

Notes: ***, **, * significance at 1%, 5% and 10%, respectively.

By analysing the results we can conclude that the null hypothesis was rejected, thus proving the existence of co-integration between variables. Once the co-integration presence is detected, the next step is to estimate the short and long run relationships between the variables.

4. Results

Using an ARDL as the regression for our analysis, it is important to mention that there are three different estimators we can use, namely: Mean Group Estimator (MG), Pooled Mean Group Estimator (PMG), and Dynamic Fixed Effects (DFE) Estimator, developed by Pesaran et al. (1999).

In this study, we propose to use the Pooled Mean Group (PMG), as this estimator belongs to the class of dynamic panel models in which it is assumed that the number of observations T is as large as the number of individuals N. The PMG method assumes the presence of co-integration. Because of this, Westerlund cointegration test was performed. This approach not only makes the estimation of the long and short relations possible, but also provides the error correction coefficient which confirms the existence of the long run relationship. This coefficient measures the rate in which the dependent variable adapts itself to changes in the independent variable, before converging into its equilibrium level. Thus, the error correction coefficient must be negatively significant (Apostolidou et al., 2015). Since the null hypothesis was rejected, the presence of co-integration was denoted. Since the PMG estimator assumes the presence of co-integration, this was the selected estimator (Bergheim, 2008). In Table 5, the estimation results of the PMG can be seen.

Table 5- Estimation results

	Dependent variable LEC			
	Coefficients	Standard Error	t-Statistics	Probability
Long Run Coefficients				
LPEC	-0.3507***	0.1182	-2.97	0.003
LPER	-0.6205***	0.0997	-6.23	0.000
LDD	0.4424**	0.2103	2.10	0.035
LGDPpc	0.3287***	0.0909	3.62	0.000
LPR	0.1365	0.01266	1.08	0.281
Short Run Coefficients				
DLPEC	0.0995	0.0910	1.09	0.274
DLPER	-0.023	0.0603	-0.38	0.703
DLDD	0.1327***	0.0364	3.65	0.000
DLGDPpc	-0.0156	0.0236	-0.66	0.510
DLPR	-0.0088	0.0086	-1.02	0.306
ECM	-0.0985***	0.0249	-3.96	0.000
constant	2.2618***	0.5714	3.96	0.000

By analysing the results shown in Table 5, it can be seen that all variables are statistically significant when in long run unless the PR variable, that was shown to be not significant. The negative value of the estimated parameter coefficient for price-cut is indicating the magnitude of direct rebound effect in the long run, which is 35 percent. By analysing the coefficient of the Degree Days can also be concluded that an increase of 1% in the LDD causes an increase of almost 0,44% in the electricity consumption, in the long run. The positive coefficient of LPIBpc tells us that higher levels of PIBpc means higher levels of electricity consumption. In fact, an increase of 1% in the LPIBpc causes an increase of almost 0,33% in the electricity consumption.

The existence of the rebound effect it is not verified in the short run. A possible reason for that is the type of countries used in this study, which are developed. Since these countries tend to present smaller levels of rebound effect, the short run cannot capture this effect. The other reason can be the increasing wealth of households, which leads to greater demand of electricity due to the increasing use of electric appliances in the long run. In fact, only the DLDD variable is shown to be statistically significant in the short run, where an increase of 1% in the DLDD causes an increase of almost 0,13% in the electricity consumption. The coefficient of ECM is -0,1 and it's highly significant, which allows us to conclude that the model adjusts itself into equilibrium and confirms the existence of a long run relation statistically significant between the variables.

5. Discussion

The electricity price coefficient is negative and the coefficient on income is positive, as households consume a greater amount of electricity at higher income levels. These results are consistently with the literature on household energy consumption. As for the climatic variables, we observe positive and highly statistically significant coefficients of the DD showing a positive correlation between DD and electricity consumption.

The obtained results are in line with the existent literature which show a direct rebound effect for the residential electricity consumption of 35% in the long run, for the observed countries. This means that improvements in energy efficiency achieve 65% of the expected reduction in energy consumption for services. Although it is a low estimation of the rebound effect, these should be followed by additional measures to avoid a raise in the consumption of goods and services with high energy content. If the rebound effect it is not considered when projecting energy efficiency policies, those policies will not be as effective as expected (Freire-González, 2017; Hediger, Farsi, & Weber, 2018; Lekve Bjelle, Steen-Olsen, & Wood, 2018).

Since the respective coefficient is below zero, we can conclude the existence of a partial rebound effect, which is normal since the target countries of analysis are the developed ones. The existent literature points that the energy consumers wealth has a very high impact on the rebound effect, since it is more noticeable in countries with lower income or in consumers in richer countries with lower wealth.

The obtained results show the non-existence backfire effect, which means that, although the energy savings do not yet follow the energy efficiency, the policies implemented by the policy makers are, apparently, the right ones. Thus, improvements in energy efficiency can still be considered an effective approach to reduce residential electricity consumption. We have also found that the rebound effect can serve as an indicator for policy makers pursuing targets on both energy savings and economic growth. The ideal outcome for such policy makers is partial rebound effect with reduction in energy intensity, i.e. the values of rebound effects in the range from 0 to 100%. Also, even though every country used in this study belongs to the same group and are considered developed countries, there are still different economies between them. Thus, the energy efficiency policies may not be uniform amongst all European countries meaning that, although the objectives are the same, the path to achieve them will probably be a different one.

Regarding the impact of the climate change on the electricity consumption it is important to analyse the impact of the heating and cooling degree days, wherein both degree days increase the use of electricity. Thus, having in mind that an increase of 1% in the degree days results in a 0,44% increase in the electricity consumption in the long run and 0,13% in the short run, it can be concluded that the climate changes have a high and positive effect on the electricity consumption.

The results suggest that, in order to achieve energy and environmental sustainability, policy makers should place their concerns both in the rebound effect, that occurs from higher levels of energy efficiency, and in the climate changes when formulating their energetic policies. Hence, as a matter of long run policy, decision makers should put their efforts in regulatory reforms than can attract investments in the environmentally friendly sources of energy, namely, the renewable energy sources (Alvi et al., 2018).Also, educational campaigns to alert people of the importance of energy saving measures can help to reduce the magnitude of the rebound effect.

Research into energy rebound effects offers a new perspective on the efficacy of energy policy implementation. Policymakers need to guide consumer behaviour, refine, adapt and extend the predominant energy efficiency to reduce these effects and achieve more effective energy savings. Labidi and Abdessalem (2018) defend that energy policy makers should support energy efficiency incentives with politics that reduce the subsides and raise the electricity prices for the households. They also state that those subsides should be differentiated so that it does not harm the smaller income families.

Wang et al. (2016) indicate some political measures and practises in order to restrict the rebound effect: The Government could introduce a carbon tax, an energy tax, and/or an environmental tax to raise the price of energy services (the cost of energy consumption), which reflects the benefits of efficient energy. At the same time, the Government should use the new increased tax in energy savings for air pollutant emission reduction and not as a subsidy to cover policy risk. Only then can we radically restrain the rebound effect; Revealing consumers final energy consumption habits through a follow-up survey provides an understanding of the details of costs and usages across the entire panoply of household appliances. Related laws must be formulated to steer consumer behaviour to sustainability; The other key point would be to accelerate the restructuring of the energy industry, increase expenditure on clean energy R&D to raise the proportion of clean energy in terminal energy consumption. The goal of the energy industry and the posited structural reform would be to introduce renewable energy sources such as: wind turbines, hydro-electric power, nuclear energy, and solar power as strategic energy sources to reduce dependence on fossil fuel. This should realise an optimal allocation of energy resources and produce maximal societal and environmental benefits.

We can also state that certain behaviours, habits and life styles are drivers for the reduction of the residential energy demand an its negative environmental effects. However, let the families know the importance of improve energy efficiency in their homes and to promote energy saving behaviours it is vital to achieve the best results in terms of energy economics and reduction of the related carbon dioxide emissions (Roubaud, 2018).

6. Conclusions

The objective of this investigation consists in the estimation of the direct rebound effect and, also, to see the impact of the climate change on the electricity consumption for some countries of the European Union over the 21-year time horizon (1996-2017) introducing degree days and asymmetric price decomposition. The ARDL approach was used to examine the long and short run marginal impact of the independent variables on the dependent variable. This study contributes to the existent literature not only by analysing the magnitude of the direct rebound effect on the residential electricity consumption for the European Union countries, but it also measures the impact of the climatic changes on the electricity consumption, since it is important to evaluate the energy efficiency improvements politics throw the rebound effect estimation. Some strategies to reduce the rebound effect are also listed. An example of those strategies is that the energy policy makers should support energy efficiency incentives with policies that reduce the subsidies and increase the electricity prices to families. Notwithstanding, those subsidies should be differentiated so they do not harm the lower income families.

In future investigations, besides the rebound effect on a domestic level for energy, it can be also performed essays for transports or on an industrial level, using natural gas or even coal.

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