TÉCNICO LISBOA

The Rebound Effect of Household Energy Use in Portugal

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ABSTRACT

The main objective of this thesis is to examine possible scenario of the technological progress in term of an increase in energy efficiency taking a place in Portuguese private households. This work analyses what changes appear after implementation of the specific energy efficiency policies supporting the reduction of energy consumption (CO_2 emission, contributing to climate change) in particular sections in households. This paper provides problem analysis of an increase of energy consumption after efficiency improvements caused by consumers' behavioural response to changes in an increase of energy efficiency and decrease of the energy service price. That problem according to energy economics definition is called rebound effect.

This work delivers the measurements of the rebound effects appearing in private transport and consumption of electricity in Portuguese households. Based on Portuguese official statistics I calculated three types of rebound effects: direct, indirect and economy-wide. The direct rebound effect is described as an additional energy consumption of the same carrier due to additional income. The indirect rebound effect also constitutes an increase in energy consumption but for other energy carriers. The economy-wide rebound effect is the additional energy consumption required for the production of the additional consumption of non-energy products. In particular, I analysed how potential energy savings of a 10% increase in the energy efficiency use of different energy carriers are reduced by the rebound effect. The largest size of the rebound effect (direct + indirect) is observed for electricity as the most convenient and useful energy carrier in Portuguese households, having the greatest share in annual household expenditures regarding only expenses on energy carriers. In addition, there is significant size of economy-wide effects, having the largest rebound in sector of electricity, gas and then following: sector of food products, paper products and then coke and refined petroleum products. The results showed that the direct and indirect rebound effect for gasoline amounts to 0.83% and 2.2% respectively. It means that 0.83% of potential energy savings constitutes an increase in consumption of gasoline. The value of 2.2% corresponds to an increase in consumption of other energy carriers then gasoline. The situation of diesel oil is similar to gasoline. The direct and indirect rebound effect for that fuel is assigned to value of 0.87% and 1.2%. Confronting that value of the indirect rebound to gasoline it is smaller by 1%. The reduction of the price of the electric energy service entails an increase in the consumption of electricity amounting 2.61% of potential energy savings. The indirect rebound effect for electricity represents 10.9%.

Improved technologies in households may contribute to economy-wide rebound effects through entailing a new production in sectors and increasing the economic growth of country. The total economy-wide rebound effect for gasoline, diesel oil and electricity is equal to 5.9%, 3.0%, 15.7% respectively. The largest share of that rebound effect belongs to sector of electricity, gas, steam and air conditioning supply and amounts to 41.5% of the total economy-wide rebound effect.

Key words: rebound effect; energy efficiency; direct, indirect, economy-wide rebound effect

RESUMO

O objectivo principal desta tese é examinar possíveis cenários de avanço tecnológico a partir de um aumento na eficiência energética nas residências privadas Portuguesas. Este trabalho analisa as mudanças que se sucedem depois da implementação de específicas políticas de eficiência energética visando a redução no consumo de energia (emissões CO_2, que contribui para mudanças climatéricas) em específicas secções das residências. Este documento fornece uma análise do problema do aumento de consumo de energia após melhoramentos de eficiência provocados pelo comportamento dos consumidores em resposta ao aumento de eficiência energética e pela diminuição no custo do serviço. Este problema, de acordo com a terminologia da economia energética, designa-se por efeito de ressalto.

No presente trabalho a quantificação do efeito de ressalto relativos aos transporte privado e consumos de energia elétrica em habitações familiares Portuguesas é modulada. Baseado nas estatísticas oficiais Portuguesas, calculei três tipos de efeito de ressalto: directo, indireto e ressalto na economia. O efeito de ressalto directo é descrito como consumo adicional de energia devido principalmente a um aumento de receitas. O efeito de ressalto indirecto também contribui para um aumento do consumo de energia, porém devido a outras fontes energéticas. O efeito de ressalto na economia é a energia adicional consumida requerida para a produção de adicional consumo de produtos não-energéticos. Em particular, analisei o potencial de poupança energética com um aumento de 10% da eficiência energética pelo uso de diferentes vectores energéticos que são reduzidos pelo efeito de ressalto. A maior quantidade de efeito de ressalto (directo + indirecto) é observado na eletricidade como o mais conveniente e útil distribuidor de energia nas residências Portuguesas, tendo a maior parcela dos gastos domiciliares anuais referentes apenas despesas com vectores de energia. Adicionalmente, há um valor significativo dos efeitos de ressalto na economia, tendo os maiores ressaltos sido no sector da electricidade, gás e por conseguinte: sector de produtos alimentares, produção de pape e produtos petrolíferos refinados. Os resultados mostram o efeito directo e indirecto do efeito de ressalto na gasolina tem valores de 0,83% e 2,2%, respectivamente. A situação para gasóleo é simular à da gasolina. O efeito directo e indirecto para o combustível atribuído é de 0,87% e 1,2%. Confrontando os valores do ressalto indirecto para a gasolina, o valor é inferior a 1%. A redução do preço do serviço de energia eléctrica implica um aumento do consumo de electricidade num montante de 2,61% de poupança de potencial energético. O indirecto efeito de ressalto para a electricidade representa 10,9%.

Um melhoramento das tecnologias nas residências podem contribuir para um efeito de ressalto na economia, provocando assim um aumento no crescimento económico do país. O efeito total de ressalto na economia para gasolina, diesel e electricidade é igual a 5,9%, 3,0%, 15,7% respectivamente. A maior aplicação do efeito de ressalto pertence ao sector da electricidade, gás e equivale a 41.5% do efeito total provocado pelo efeito de ressalto na economia.

Palavras Chave: efeito de ressalto; eficiência energética; efeito de ressalto directo, indirecto e na economia

1. INTRODUCTION

1.1. Context and motivation

Technological progress and environmental policies leading to improvements in energy efficiency are essential to reduce the usage of energy consumption and mitigation of carbon emissions simultaneously, and thus promote sustainability (Binswanger, 2001). The household sector is a significant contributor to overall energy consumption (INE, 2013), and offers a large scope for improvements in energy efficiency through the replacement of non-efficient appliances by more efficient and innovative appliances providing the same amount of energy service while consuming less. However, it is difficult to make consumers aware of these potential gains and to energize them to support government targets (Thomas & Azevedo, 2013).

An energy efficiency gain leads to the reduction of energy service price and entails an increase of demand for energy services (more electrical appliances, more kilometres driven by automobiles, higher room temperatures etc.) (Sorrell, 2007). Therefore, in that situation the possible diminution of energy consumption and GHG emissions, which are caused by technological upgrade of household appliances is partially offset by the price reduction of energy service. This effect is known in the fields as a rebound effect and is treated as gap disregarded by many policymakers supporting energy efficiency policies. The simplest definition says that rebound effect is equal to the difference between potential energy savings, which are determined from engineering estimation, and actual energy savings, after taking into consideration changes in consumer caused by the decrease in the price of energy services or operating cost with an efficiency (Thomas & Azevedo, 2013).

In this work I estimate the rebound effects in private transport and consumption of electricity in Portuguese households based on data coming from the national statistics of the Portuguese economy. After obtaining the empirical results, I am able to find the size of the three types of rebound effects: direct, indirect and economy-wide. The direct rebound effect is described as additional energy consumption of the same carrier due to additional income. The indirect rebound effect also constitutes an increase in energy consumption but for other energy carriers. The economy-wide rebound effect is additional energy consumption due to additional consumption of non-energy products. More detailed explanation pertaining that problem in energy efficiency is delivered in Chapter 2 – The rebound effect.

Analysing various reports and articles dedicated to estimation of rebound effects, I can conclude that their size depends on many factors such as the estimation method used, the data availability or the level of economic development of the country under study. Brannlund et al. (2007) found that the rebound effect for Sweden after an increase in efficiency in both heating and transport is equal to 15% and 106% for direct and indirect respectively. Another example for this same actions provides Mizobuchi (2008) presenting the numbers for Japanese households: 5% for direct and 22% for indirect rebound effect in transport and 111% and 84% respectively for electricity in heating. The evidence of economy-wide rebound effects is not as available as for direct and indirect rebound effects. The various values have been obtained in that estimations analysing economy-wide efficiency investments and they vary by country. Following paper of Guerra and Sancho (2011) the economy-wide rebound effect appeared due to efficiency improvements taking a place in industrial sector and is equal to 91%.

Sorrell (2007) in his papers analysed various studies and he found the economy-wide rebound effect in Norway for electricity and oil amount more than 100% and 10% respectively. According to Vikstrom (2004), in Sweden 15% of increase in energy efficiency in non-energy sectors and 12% of increase in energy sectors leads to the economy-wide rebound effect amounting to 50-60%.

1.2. Portuguese Energy System and energy efficiency

Portugal is a country, which does not possess any fossil fuel reserves. Hence, all conventional energy sources, such as coal, peat, crude oil and their products and natural gas are imported from other countries (IEA - statistics, 2013). It means that Portugal is totally dependent on supply of those fuels. To reduce this dependency, the government decided to start developing and implementing renewable energy-based technologies and increasing energy efficiency.

Portuguese domestic primary energy consumption dropped from 25,000 to 21,500 ktoe between 2000 and 2011. According to the figure below (Figure 1-1), the import of crude oil decreased over the last 10 years. The likely explanation is the significant rise in the oil price occurring during this period, which contributed to a reduction in the use of fuel for private transportation. In 2000 oil was the most important energy source in Portugal, whose share in total primary energy supply was equal to 61%. The other shares were 8% for natural gas, 16% for coal and 15% for renewables. In contrast, year 2012 exhibits a different energy mix. The amount of oil used at that time was equal to 9,292 ktoe, representing 43% of total primary energy supply. The natural gas gained importance in Portuguese economy, whose consumption almost doubled in 12 years from 2,064 in 2000 to 3,950 ktoe in 2012. Here it should be mentioned that before 1996 Portugal did not use natural gas at all, so the present trend shows the desire to increase the share of this fuel in energy sector (IEA - statistics, 2013).

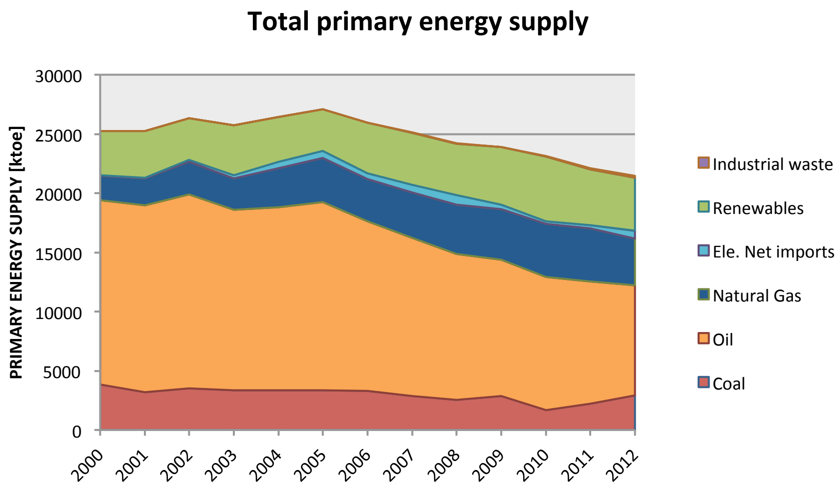

Figure 1-1 Total primary energy consumption in Portugal (DGEG, 2013)

Over the last decade, the shares of different sectors in the total energetic consumption in Portugal do not vary substantially. The sector with the highest share of energy consumption is industry, energy, water supply and sewerage with the percentage equal to 40.7% basing on year 2011. Over the years 2000-2011 the energy consumption in this branch varied considerably. The next largest consumer is household sector with private transportation, which uses 31.8% of total final energy. The private transportation constitutes 17.1% of total consumed energy in Portugal. It means that more than half of the energy used in households is consumed by vehicles.

The next significant consumer of energy is industry of wholesale and retail trade, repair of motor vehicles and motorcycles, transportation and storage, accommodation and food service activities with a share of 14.6%. The energy use by sectors of construction (3.1%), public administration and defence, compulsory social security, education, human health and social work activities (4.2%), agriculture, forestry and fishing (2.4%) are not significant and over last decade the energy consumption in that sectors is on this same, relatively low level in comparison to other sectors (Figure 1-2).

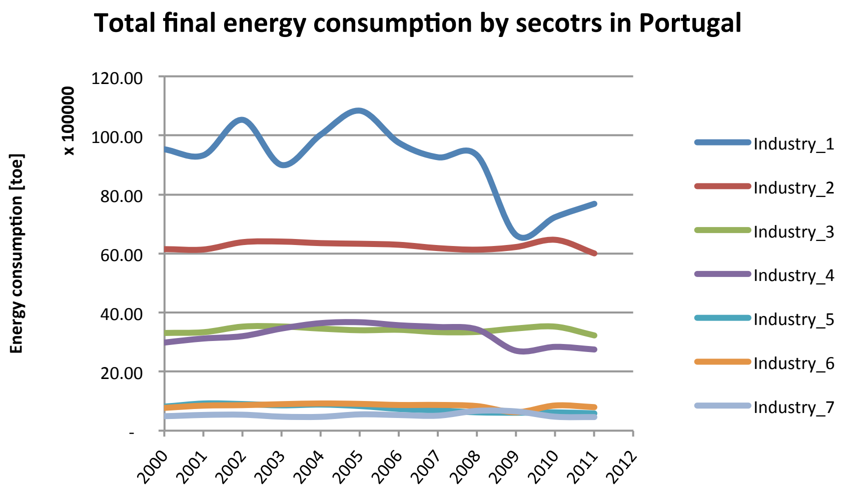

Figure 1-2 Total final energy consumption by sectors in Portugal (INE, 2013)

Below is presented the list of industries with the largest energy consumption in Portugal. That list relates to Figure 1-2.

Table 1-1 The list of industries with the largest energy consumption in Portugal (INE, 2013)

Industry_1	Industry, energy, water supply and sewerage
Industry_2	Households (total)
Industry_3	Households (only transport)
Industry_4	Wholesale and retail trade, repair of motor vehicles and motorcycles; transportation and storage;
Industry_5	Construction
Industry_6	Public administration and defence; education; human health and social work activities
Industry_7	Agriculture, forestry and fishing

Focusing on household sector I can distinguish different sections, where the type and amount of particular energy carrier is consumed. Figure 1-3 presents an impression of different energy uses in Portuguese households. The largest consumer is transport, which accounts for 54.6% of total final energy consumption. The second place belongs to cooking which represents 17.8% and corresponds to the consumption of electricity and natural gas. Water and space heating have a share of 10.7% and 9.8%, respectively. Space cooling possesses the smallest share in total final energy consumption (INE – Statistics Portugal, 2013).

The total energy demand for transport in private households increased mainly due to change of some individual aspects in life such as desire independence on public transportation and increase own comfort (Weber & Perrels, 2000). Being independent on public transport is one of the factors contributing to larger oil consumption, what reflects in driven cars by single person, for instance many people go to workplace separately even if they live close to each other (Steg & Gifford, 2005). According to the figure below, vehicle fuels constitute a crucial part in total energy consumption in households and also in total energy consumption in all country. Therefore in domestic section there is a need to increase the energy efficiency and make population to be more aware about eco-driving and possible profits obtained due to change in that behaviour.

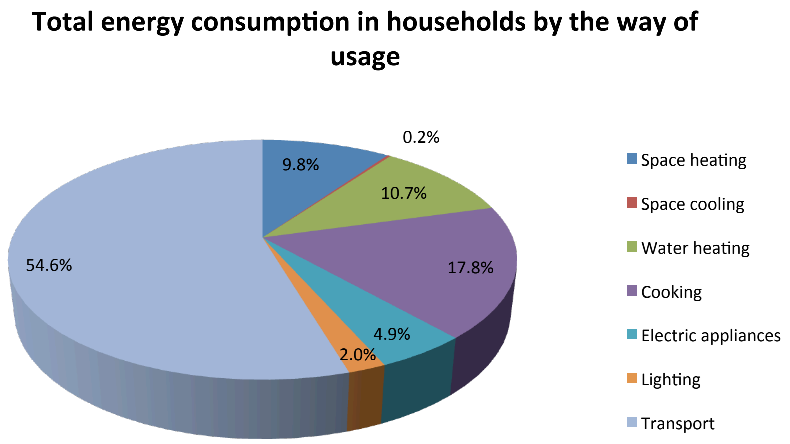

Figure 1-3 Total energy consumption in households by the way of usage 2010 (INE, 2013)

Although the technical efficiency of automobiles grew significantly in last decades, many households still use cars coming from nineties. Those cars are dramatically different considering consumption of fuel in comparison to more efficient and innovative automobiles produced in recent years. Many people are not aware of consumption of their non-efficient cars. And here appears question asked by households: Is an efficiency investment in new car is profitable taking into consideration kilometres driven per year, maintenance and life cycle assessment? (de Haan, Mueller, & Scholz, 2009)

If I analyse electric appliances, which are much less costly than vehicles but all together contribute to significant consumption of the energy I can observe large progress in energy efficiency in private households. In previous years, many households decided to change their old and non-efficient electric appliances on more efficient ones including mainly refrigerators and freezers, space and water heaters. In addition many old buildings have been renovated in order to gain energy efficiency (IEA, 2008).

1.3. Contributions of the thesis

Consideration the energy efficiency is a crucial topic in all European countries having ambitious plans to reduce the energy consumption. The European Union countries implement many environmental policies supporting an increase of energy efficiency in different sectors such as buildings or transportation in order to achieve more valuable status of sustainability through the climate change mitigation, environmental protection or reduction of dependence on import of fossil fuels. There is an important problem in all these policies concerning the rebound effects, which is not taken into account by many policymakers. Rebound effects are often ignored in that type of policies.

In my work I would like to prove how crucial is careful analysis of energy efficiency policies and aware about possible effects that might arise. Importance of the rebound effects is aspect which should have included in any efficiency improvements in order to obtain the actual picture of future energy consumption statistics.

Thanks to my work I am able to observe how hypothetical efficiency improvements in Portuguese families may lead to decrease in energy consumption in their own households and in whole Portuguese economy as well. After delivering the relevant calculation and analysis I can conclude if implementation of energy efficiency policies into life has large advantages - significant decrease in the usage of energy - and also whether magnitude of appeared rebound effects is as great as to make that policy having no sense.

Moreover my work contributes to enhance knowledge pertaining the energy efficiency and stimulated effects in Portugal. There is really small amount of papers dedicated to rebound effects problem in Portuguese households. In the future that work can be developed using various estimation methods in order to perform different, possible scenarios using other assumptions than those used in this work. Additionally, many countries do not consider that problem at all. Therefore this work can also help to understand much deeper the specificity of the rebound effect in south European country and make other scientists to follow the essence of this thesis to provide a picture of rebound effects in other countries.

1.4. Structure of the thesis

Following the structure of this thesis, CHAPTER 1 contains information pertaining energy efficiency aspects and gives the introduction to problem about rebound effects. In addition, this part includes also information about situation of energy system and energy usage in Portugal in different sectors and different sections in private households. Based on many statistics I included figures and graphs presenting the consumption of various fuels in last years and future trends. The chapter gives also information about the issue of energy efficiency in technical and political context.

CHAPTER 2 delivers the definitions related to the energy efficiency policies and effects stimulated by them. The definitions show different types of rebound effects and literature review proves that is common phenomena in many developed and developing countries. In addition, there are also illustrated differences between various estimation methods of rebound effect, when capital costs of new appliances are taken into consideration.

CHAPTER 3 contains basics of input-output analysis, including Leontief's model, which is used in the calculation of coefficient matrix, needed further in computation of economy wide rebound effect. There are included all equations used in work to estimate direct, indirect and economy-wide rebound effects obtained in private transport and electricity, which help to understand built model. Moreover, part of this chapter describes all data collected and used during the work such as household budget survey and energy consumption in households and industries.

CHAPTER 4, as the last part of thesis, is dedicated to discussion of estimated rebound effects in Portuguese households. In addition this chapter analyse drivers of consumer response to changes in energy efficiency and energy prices. This chapter provides also information about the evolution of potential savings and solutions helping to deal with rebound effects.

2. THE REBOUND EFFECT

Many countries in the world are dealing with achieving the significant reduction of energy consumption coming from fossil fuels. These fuels highly contribute to global warming through emission of greenhouse gases, especially CO_2. The best way to achieve the objective is implementation of energy efficiency policies throughout the economy (Sorrell, 2007). Considering energy efficiency policies, being responsible for sustainable development, it is important to account for effects stimulated by this activity, often ignored by many policymakers. These undesirable effects are rebound effects, which according to paper of Thomas & Azevedo (2013) are defined as changes in energy demand following an efficiency investment (decrease energy consumption) due to changes in consumers' behaviour.

In other words the rebound effect is equal to the difference between potential energy savings, PES, which are determined from engineering estimation, and actual energy savings, AES, after taking into consideration changes in consumer caused by the decrease in the price of energy services or operating cost with an efficiency. Rebound effects are usually given in percentage using equation below (1). For example, if rebound effect is equal to 10% means that 90% of the potential energy savings are achieved.

$$\mathrm{R} = \frac{\mathrm{PES} - \mathrm{AES}}{\mathrm{PES}} \cdot 100\% \qquad (1)$$

To better illustrate the concept of rebound effect, consider the following example: a person makes a decision to purchase a more efficient new automobile. I assume the number of kilometres driven per month or year are as the same as for older car. Then the amount of gasoline consumed decreases in the newer automobile, which is caused by higher efficiency. This contributes to reduction of the energy service price, resulting in an increase in demand for kilometres driven or an increase in speed of the car while driving. Finally it contributes to increase in use of the energy services called rebound effects (Mizobuchi, 2008).

2.1. Types of rebound effect

Three types of rebound effects are usually considered:

- **Direct rebound effect**: Efficiency improvements lead to lower price of the energy services, which leads to an increase in energy consumption. For instance, when consumers switch from non-efficient electric heater to more efficient one, they may heat their rooms up for longer time or may increase temperature to provide greater comfort in contrast how they did previously because of lower heating service costs (Thomas & Azevedo, 2013) (IRGC, 2013). Another example says that a factory invests in more effective machinery lowering the cost of unit production entailing an increase in total output (Sorrell, 2007).

- **Indirect rebound effect**: Energy cost savings as an additional income might be re-spent on other goods and services linked also with energy/carbon intensive consumption. For example, the savings obtained through purchasing an efficient car or replacing the most consuming household electric appliances could be spent on additional air travel or purchasing another innovative appliance to household to raise the standard of living. Both spending leads to an overall increase in energy consumption, what contradicts the assumptions contained in energy efficiency policies (Freire-Gonzalez, 2011).

- **Economy-wide rebound effect**: The economy-wide rebound effect is the additional energy consumption due to additional consumption of non-energy products. After carrying out energy efficiency investments, additional income is spent on non-energy products and services, which are provided by sectors, which require to consume more energy to satisfy demand for exact product (IRGC, 2013).

Contemporary analysis of the rebound effect focuses on correlation between energy savings and energy efficiency. This correlation is not complete, because the two phenomena counteract, studied by economists for years (Chitnis & Sorrell, 2012):

- **The substitution effect** – it lies on the fact that the factor which becomes cheaper is used by the users to replace the factor, which simultaneously becomes relatively more expensive. This way for instance, if energy becomes cheaper, people have less incentive to ensure the insulation of the wall.

- **The income effect** – it appears when making energy services cheaper, it leads to relative enrichment of buyers. Feeling wealthier, they can afford to buy more of something they already bought less. On this principle, the cheapening of 1 km driven by automobiles meant that people drive more than before. Our prosperity is evaluated on higher level when there is opportunity to provide private transport more often.

Those effects described above can contribute to changes in spending/consumption patterns due to changes in consumers' behaviour. For instance, through achieved energy efficiency consumers buy more frozen food, do laundry more often, switch lights on for longer time because of having energy efficient appliances. But changes in consumers' behaviour vary in each households and depend on many factors such as the standard of living, prestige, lack of knowledge in the application of the energy efficient equipment, lifestyle, habit, time, needs, wants and so on. Estimation of direct, indirect and economy-wide rebound effects are also associated with changes in spending patterns (IRGC, 2013).

2.2. Evidence of rebound effect

The primary source of the rebound effect concept is British economist William Stanley Jevons. In the mid-nineteenth century it was believed that the improvement of the steam engine so as to use less coal will lead to a decline in demand for this raw material and, consequently, to mines closure. Meanwhile Jevons correctly foresaw that the improvement of the steam engine will contribute to the emergence of new applications and that demand for coal - on the contrary - will increase. He was right and the economy of the second half of the nineteenth century was characterized by an unprecedented increase in demand for coal (Alcott, 2005).

Repeatedly environmental policy ignored the rebound effect. The textbook example of a wrong solution is the American program of federal support for solar collectors in the 1970s (Platzer, 2012). The U.S. government has allocated significant resources to subsidize solar installation mounted on the roofs of private houses. The intention was to reduce oil imports from politically unstable regions. Meanwhile, the installation of solar panels caused the cheapening of heating homes and caused a fashion for replacing the windows which were used previously for much larger ones, leading to increase in demand for energy. As a result, the dependence on crude oil supply expanded.

Next example relates to the Toyota Prius. It is a hybrid car, which - using advanced technology (a combustion engine and electric one, and some of the energy from the fuel is consumed to charge a powerful battery) – helps to reduce consumption by about 20%. To some it seemed that this new technology will reduce the demand for fossil fuels. It turned out not to be. American research laid bare a few embarrassing details. First of all, the Toyota Prius is often purchased by wealthy families for which it is usually the second or third automobile. It does not replace old vehicles, but complements them. As a result, the number of kilometres travelled increased so much that the fuel consumption increases, despite the fact that additional, hybrid vehicle is more economical than the old ones (de Haan et al., 2006).

In transport sector, the rebound effect appears in the search for more comfortable cars, or investments in road infrastructure. Without that people restrict their travelling, appreciating their time and convenience. However using the improvement, they decided to get to work from further distances. On this principle in many wealthy countries realized that the rebound effect worsens situation contributing to improvement of energy efficiency in the use of certain resources (Mizobuchi, 2008).

Therefore rebound effects may reduce the size of the energy savings, which were achieved. There are also many other papers, analysing the magnitudes of rebound effects which vary in different countries meaningfully. Researchers proved that rebound effects are higher in developing countries. Following the report of Wang et al. (2012) direct rebound effect for private passenger transport in Hong Kong has been estimated and amounts to 35% - 45%. For instance, in Mexico was the plan to replace cooling appliances such as refrigerators and air-conditioners (Davis et al., 2012). Results showed that energy consumption decreased in case of replacement of refrigerators but highly slightly and for air-conditioners even went up. It turned out that program is an expensive way in reduction of electricity consumption.

Additional evidence of the rebound effects is presented in Table 2-1, where are included estimations of increase in energy consumption (or GHG emission) due to efficiency improvements in private households in different areas. The values vary significantly. They are dependent on collected data, method used, country economy, analysed energy carriers and many other assumption such as considering capital costs of new efficient appliances or predictions of consumers' behaviours (spending patterns).

Table 2-1 Literature review of rebound effects in different countries incurred due to efficiency improvements in private households

Authors	**Country**	**Action/ Area**	**Direct rebound effect**	**Indirect rebound effect**
Chitnis et al. (2012)	United Kingdom	Efficiency/ Heating, Lighting	2%	3–11% with capital costs, 15–20% without capital costs
Freire-Gonzalez (2011)	Catalonia (Spain)	Efficiency	36-49 %	16-20%
Frondel et.al (2007)	Germany	Efficiency/ Private Transport	N/A	57-67%
Mizobuchi (2008)	Japan	Efficiency/ Heating, Transport	111% (heat.); 5% (transport)	84% (heat.); 22% (transport)
Nassen et al. (2009)	Sweden	Efficiency/ Heating, Transport	N/A	10-20%
Thomas et al. (2013)	USA	Efficiency/Electricity, Natural Gas, Gasoline	10% (assumed)	5-15%
Wang et al. (2012)	Hong Kong	Efficiency/ Private transport	35-45%	N/A

Rebound effects are also noticeable in developed countries, but mostly in a group of household with low incomes, which are not fully satisfied by demand for energy and other goods and services. Gillingham (2011) analysed the incentives for consumers to purchase cars consuming less fuel than non-efficient cars. The increase in fuel efficiency leads to driving more by consumers. Frondel et al. (2010) also estimated the rebound effects appearing in travels for German households. He obtained results, being in the range of 57% to 62%, which indicates a significant increase of fuel consumption after implementation of efficient automobiles. He observed the fuel price elasticity is different for households varying vehicle mileage, which results in higher rebound effect in households with low driving intensity.

Looking at the effects of some actions of energy efficiency policies classified as "pro-environmentally friendly" it does not necessarily discredit such activities. Improving the efficiency of cars and household electric appliances or installing solar panels of course makes sense. However, the rebound effect requires to analyse whether the individual reduction of energy consumption by some actions actually leads to the decrease in pressure on the environment and dependence on fuels.

Looking at the evidence of economy-wide rebound effect there are not many papers dedicated to that problem, but in order to understand it more clearly few estimations has been provided in various countries. These estimations correspond to efficiency improvements in other sectors than private households such as industry.

For the record the economy-wide rebound effect entails larger production of outputs due to efficiency improvements, what further contributes to economic growth. This effect is analysed at the macroeconomic level, because it has rebound in entire economy. Sometimes the economy-wide rebound effect is also defined as a secondary effect. According to the paper of Greening et al. (2000) that definition says in the economy are significant correlations between prices, outputs of goods and resources in various sectors and any changes related with an increase in energy efficiency taking a place in any sector can influence on prices and magnitudes of outputs in other sectors.

The economy-wide rebound effects are often estimated using input-output analysis. The one of examples showing this type of rebound effect pertains efficiency improvements in South Korean nuclear power plant. There were analysed CO_2 emissions coming from that investments using data of future emissions intensity for the potential energy savings baseline and emissions data gained from the input-output multipliers. The result was equal to 12% of rebound effect (Howells et al.,2007). The next example is delivered by Guerra and Sancho (2010), in which they provided measures of the Spanish economy. They obtained results showing underestimations for the rebound effect being lower than 100% and underestimations for the rebound effect greater than 100%.

Additionally, below is Figure 2-1 presenting different sizes of the economy-wide rebound effect in various countries. I can see that these values vary significantly and have numbers from 10% to even over 100%. Rebound effect larger than 100% is called backfire and means that the energy consumption after the efficiency improvement is higher than before.

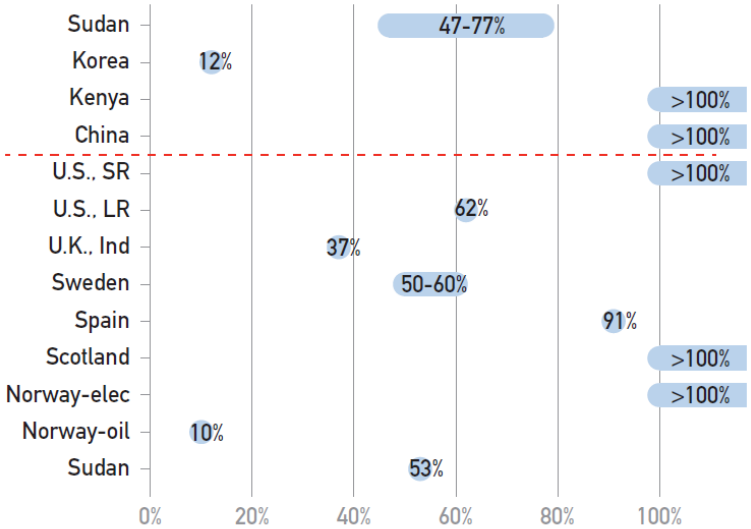

Figure 2-1 The evidence of economy-wide rebound effects in various countries (IRGC, 2013)

2.3. Capital costs and rebound effect

There is large number of papers dedicated to estimation of rebound effects. The majority of these articles do not consider the significant aspect of capital costs of purchased, new more efficient appliances. Accounting for capital costs may lower the size of the rebound effect, because in the reality energy efficient appliances are usually more expensive than replaced inefficient models what may entail a drop in demand for energy services. That evidence for Japanese households provides Mizobuchi (2008) in his paper. He extended the scope of the research of the rebound effect for Sweden carried out by Brannlund (2007) and took into account capital costs. Mizobuchi performed estimation of the rebound effect for 2 scenarios: with capital costs and without them and obtained respective results of 27% and 115%, what proved that the magnitude of rebound effect is frequently overestimated.

In order to better illustrate difference in calculation of rebound effect with and without capital costs, figure below is attached (Figure 2-2) presenting 2 separate graphs. The vertical axis is assigned to energy consumption, and the horizontal axis to energy service demand. The level of efficiency of the energy service is representing by μ-lines, where index 0 corresponds to initial situation when energy efficiency does not take a place yet, index 1 – potential energy savings and indexes 2 and 3 corresponds to actual energy savings.

Following graph a) in Figure 2-2 where capital costs are not considered, there is decrease in the energy consumption from E_0 to E_1 caused by the efficiency improvements (from μ_0 to μ_1). Initially demand for energy service is constant, but due to lower operation cost of the energy service, that demand starts increasing and obviously energy consumption as well. This growth after improvement is rebound effect. Manipulating variables from graph I can express it by following equation:

$$R(no\ capital\ costs) = \left|\frac{E_2 - E_1}{E_0 - E_1}\right|\ x\ 100\% \qquad (2)$$

Graph b) in Figure 2-2 accounts for capital costs of improvements. An increase in the energy efficiency contributes to decrease of the energy consumption and then to lower price of the energy service. However, capital costs cause an increase in the price of energy service what results in a drop of demand for that service. Finally, the size of rebound effect is lower than in previous case. Equation according to the graph can be assigned as follows:

$$R(capital\ costs) = \left|\frac{E_2 - E_3}{E_0 - E_1}\right|\ x\ 100\% \qquad (3)$$

To explain why so important is consideration of capital costs I provide here for clarity, simple example of 2 scenarios. Let us assume that some household makes improvement buying new efficient car. It has to decide to purchase a car consuming 5dm^3 or 7dm^3 per 100km. Kilometres driven per month are constant and equal to 1000km, so monthly consumptions for these cars are 50dm^3 and 70dm^3. The price of diesel oil is 1.3€. Going further monthly expenditure on the fuel is 65€ and 91€ respectively. The results shows that there is 26€ of savings in month. This amount of money can be spend on more fuel to provide bigger number of kilometres driven per month or on other goods and services which also require energy consumption to satisfy consumers.

Now let us take into account capital costs of each car. Less consuming car costs 15,000€ and more consuming car costs 11,000€. Life cycle of each of them is 15 years. Dividing difference between prices of these cars by total number of month in period of 15 years, I obtain an increase in monthly expenditure for less consuming car. After calculations this value is 22€, what finally gives only 4€ of total savings. In this case, household achieves less savings so spends less money on other goods and services what results in smaller increase in the energy consumption after the efficiency improvement in contrast to the case without consideration of capital costs.

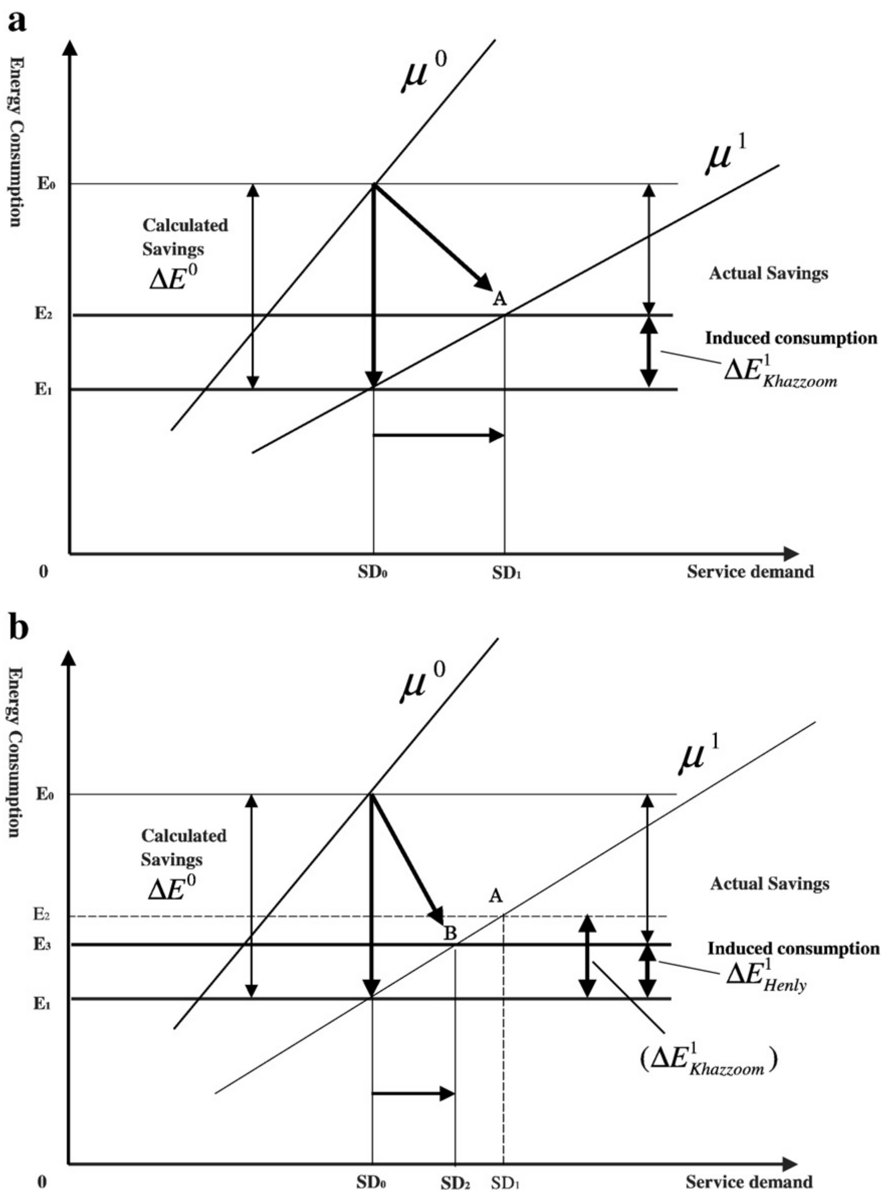

Figure 2-2 a: Rebound effect without capital costs. b: Rebound with capital costs (Mizobuchi, 2008)

3. METHODOLOGY

3.1. Approach and method

In this subchapter the model of the direct, indirect and economy-wide rebound effect is derived. This model does not take into consideration the efficiency investments – the capital costs of new, purchased appliances. In this work it is assumed there is no essential difference in costs between conventional, less-efficient appliances and more efficient devices. So according to the paper of Mizobuchi (2008) our results would be smaller if I account for efficiency investments made in Portuguese private households.

The estimation of the rebound effect was performed assuming a proportional spending pattern. In addition I assume that there is no substiution effect of other goods, when the price of energy services decrease due to the efficiency improvements. The estimations for the direct, indirect and economy-wide rebound effect are expressed in percentage terms for the case of electricity, gasoline and diesel oil consumed in Portuguese private households. For all energy carriers is assumed the efficiency improvement equal to 10%. This assumptions are according to improvements taking a place in last years (IEA, 2013).

The results part provides the sizes of rebound effects expressed in percentage and in final energy through following the general Eq.1 saying in the simplest words that rebound effect is difference between potential energy savings and actual energy savings.

Summary of key symbols

Symbol	Description
ε	Fraction of savings in %
$\mathbf{e}$	Energy coefficients of sectors in toe/€ [vector] [82x1]
E_i	Consumption of i – energy carrier in household
$\mathbf{L}$	Leontief matrix [82x431]
$\mathbf{x}$	Total output of Portuguese sectors [vector] [82x1]
$\mathbf{y}$	Domestic final demand in households in € [vector] [431x1]
E_{DR}	Energy consumption in households from direct rebound effect in toe [scalar]
E_{IR}	Energy consumption in households from indirect rebound effect in toe [scalar]
E_{ER}	Energy consumption in households from economy-wide rebound effect in toe [scalar]
E_B	Total final energy consumption in households in base case in toe [scalar]
E_E	Total final energy consumption in households in efficient case in toe [scalar]
E_R	Total final energy consumption in households in rebound effect case in toe [scalar]
	$E_R = E_E + E_{DR} + E_{IR} + E_{ER}$
y_i	Final demand for i – energy carrier in € [scalar]
y_j	Final demand for j – goods and services in € [scalar]
y_T	Total final demand in the base case in € [scalar]

Analysing total energy consumption in Portuguese households, I can distinguish three cases of that consumption, which appear in:

- the base case, where is no efficiency improvements, E_B
- the efficient case, where efficiency improvements is considered, but there is no evidence of rebound effect. This consumption presents potential energy savings possible to gain in households if demand for energy and other goods and services does not increase, E_E
- the rebound effect case, where is the evidence of an increase in the demand for energy service and other goods caused by lowering the price of energy services and income effect, E_R.

Below are presented different three cases of the energy consumption in Portuguese households. Also three cases of expenditures in private households can be estimated in this same way, because is assumed that the percentage increase in the efficiency improvement is equal the percentage decrease in the price of energy service.

Firstly, the base case of Portuguese household energy consumption is divided into consumption of considered energy carrier, providing single energy service (i.e. transport), E_i and consumption of other energy carriers E_j. The total energy consumption in private household is derived from the national statistics, which include the consumption of particular energy carrier in household sector and industry sector.

$$E_B = E_i + \sum_{j=1;\neq i}^{n} E_j \qquad (4)$$

Assuming that household decided to carry out an efficiency improvement, which contributes to an increase of the efficiency and provides the reduction in the price of energy service. Then, temporal energy consumption in household is going to decrease. It is assumed that the energy consumption falls down by the value of an increase in efficiency. Unfortunately, in the reality that situation does not look so perfectly and happens rarely. Usually, the size of an increase in fuel efficiency is larger than a decrease in fuel consumption. It depends on the way of how vehicle is driven and other aspects of consumers' behaviour entailing greater fuel consumption after the efficiency investment. In the efficient case I assume that the consumer's behaviour turns into more environmental-friendly and sustainable and the percentage increase in the efficiency of automobile is equal to the percentage decrease in the price of energy services:

$$E_E = E_B - \varepsilon \cdot E_i \qquad (5)$$

The third case is called the rebound effect case and presents the energy consumption of Portuguese households, where the demand for energy and other goods and services increases after making the efficiency improvements inducing a decrease in the price of energy and other goods. The energy consumption in the rebound case is simply computed through accounting for the energy consumption in the efficient case and all, the direct, indirect and economy-wide rebound effects occurring in Portuguese private households:

$$E_R = E_E + \underbrace{E_{DR} + E_{IR} + E_{ER}}_{\text{Direct + indirect + economy-wide rebound effect}} \qquad (6)$$

Using all these data – the three expenditure and energy consumption cases – I am able to develop and simulate model of direct and indirect rebound effect following the basic definition of that phenomena, which can be expressed by a simple formulation, saying that the rebound effect is percentage difference between the potential energy savings, which assume there is no rebound effect after an increase of efficiency and the actual energy savings obtained through engineering estimation. Following this definition, the Eq.7 can be written in the following way, where the potential energy savings is difference between the energy consumption in the base case and the efficient case and the actual energy savings are expressed as a difference in energy consumption between the base case and the rebound effect case:

$$R[\%] = \frac{E_R - E_E}{E_B - E_E} \qquad (7)$$

According with my assumptions, I have 10% of energy savings in each particular energy carrier – diesel oil, gasoline and electricity. To calculate the money savings for each energy source I multiplied the final demand for energy carrier and percentage amount of energy savings.

In order to compute the direct rebound effect for each specified energy carrier, I use data of the final demand for each particular energy source and the total expenditure of household in the base case. The direct rebound effect is expressed in the monetary value and according to Portuguese currency in €:

$$y_i^{DR} = \varepsilon \cdot y_i \cdot \frac{y_i}{y_T} \qquad (8)$$

The rebound effects in scientific papers are always expressed in the units of energy, here in tonne of oil equivalent, describing an increase in the energy consumption after the efficiency improvement. This unit is more reliable than the monetary units, because the main target of energy efficiency policies is the reduction of the energy consumption, not reduction of household expenditures. The Eq.9 follows the amount of energy which household consumes due to an increase in demand for the energy service caused by lower price of it:

$$\mathrm{E_i^{DR}} = \varepsilon \cdot y_i \cdot \frac{y_i}{y_T} \cdot \frac{E_i}{y_i} = \varepsilon \cdot y_i \cdot \frac{1}{y_T} \cdot \mathrm{E_i} \qquad (9)$$

In order to compute the indirect rebound effect, Eq.10 below is given for that rebound effect appearing in the Portuguese private households. It is also expressed in the units of energy and presents changes in demand for energy when income effect occurs and the saved money is re-spent on other goods and services linked also with energy/carbon intensive consumption:

$$\mathrm{E_{ij}^{IR}} = \varepsilon \cdot y_i \cdot \frac{y_j}{y_T} \cdot \frac{E_j}{y_j} \qquad (10)$$

In this work I assumed that all saved money is re-spent on energy carriers and other goods and services. Further in my calculations I use the vector of household expenditures of all 431 products and the values of computed money saved coming from each defined energy source and obtained from the efficiency improvements. Then it is likely to receive the vector of values with money, which are re-spent on all goods and services according with the proportional spending pattern:

$$\mathbf{y_i^{ER}} = \mathbf{y} \cdot \frac{\varepsilon \cdot y_i}{y_T} \qquad (11)$$

For instance, in 2008 year Portuguese private households spent on gasoline 727.5mln € overall. By making 10% increase in energy efficiency households would be able to save amount of money equal to 72.75mln €. As I mentioned before, this whole money is re-spent on goods and services according with the proportional spending scenario. Generated vector is used in computation of economy-wide rebound effect.

Manipulating by Leontief's matrix, which expresses the amount of € of output in all 82 sectors generated by 1€ of final demand of each particular domestic product, I may compute an increment in total output in all industries induced by an increase in demand for all goods and services caused by savings money in Portuguese families. In order to obtain that vector I multiply the Leontief's matrix and vector coming from the Eq.11. Then the formulation is as follows:

$$\mathbf{x_i^{ER}} = \mathbf{L} \cdot \mathbf{y_i^{ER}} \qquad (12)$$

Finally, to calculate the economy-wide rebound effect in each particular sector and for each improvement, I sum the energy consumptions of all energy carriers, including natural gas, biofuel, fuel oil, LPG and etc. All sizes of energy must be expressed in this same units, here is in tonne of oil equivalent (toe). Then I create the diagonal matrix with that total energy consumptions, getting a square matrix. Then I multiply it by vector derived in the Eq.12 and the last equation is as follows:

$$\mathbf{E_i^{ER}} = \mathbf{diag(e)} \cdot \mathbf{x_i^{ER}} \qquad (13)$$

3.2. Economy-wide rebound effects

3.2.1. The Leontief's model

In this work, in order to compute the rebound effect, the input-output analysis is used as a tool. This type of account is used to study the economic condition and structure of complex economic systems. The complexity of the system means that can be distinguished in it a number of sectors, each of which produces a specific product, other than the other sectors. The size of the system is analysed as the entire national economy, distinguishing such branches as industry and trade, agriculture and forestry, construction, transport and communications, trade and services etc. (Peterson, 1991).

My work is based on a more complex structure of the input-output analysis. The Leontief's model is used in my estimation. That model has been developed by Wasilly Leontief, who examined how changes in one economic sector may influence the other sectors. This is a further extension and deepening of the methodology for designing input-output balances. In addition, it is assumed stability of the relationship between inputs and outputs. On the basis of the structure of the Leontief model there is the assumption on the stability of the relationship between some elements of the array – intermediate consumption (United Nations, Department for Economic and Social Affairs, Statistics Division, 1999).

The final equation for Leontief's model is:

$$\mathbf{x} = \mathbf{L} \cdot \mathbf{y} \qquad (14)$$

where x-total output, y-final demand, L-Leontief's matrix.

L matrix is called as a Leontief's matrix of economic system. Elements standing in the k-th column in the Leontief matrix inform how much the final demand in other sectors change, if output of k-th sector will increase by unit with a constant output in the other sectors. The sum of the k-th column elements of in Leontief's matrix is equal to the increase in the value of final demand of the entire economic system as a result of the increase in value of output of k-th sector of unit with a constant output in other sectors. The sum of m-th row elements in the matrix L is equal to the increment of final demand in m-th sector as a result of simultaneous increase in the value of output in each branch by the unit. In order to obtain the Leontief's matrix I use the identity matrix and the input-output coefficients matrix:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}} \qquad (15)$$

where the matrix of technical coefficients is defined as:

$$\mathbf{A} = \mathbf{Z} \cdot \mathbf{diag}(\mathbf{x})^{-\mathbf{1}} \qquad (16)$$

where x-total output, Z-matrix of intermediate consumption. Each technical coefficient expresses the amount of intermediate input of type i which is required to generate an additional unit of output of type j.

The final balance for all sectors in the input-output table may be expressed by 2 equations below. The Eq.17 says that the total output of one particular sector is equal to the sum of consumptions of product coming from that sector in all sectors plus the final demand of that sector.

$$\mathbf{Z} \cdot \mathbf{i} + \mathbf{y} = \mathbf{x} \qquad (17)$$

The Eq.18 says that the total input of one particular sector is equal to the sum of supplies of product coming from that sector to all sectors plus the value added of that sector.

$$\mathbf{i}' \cdot \mathbf{Z} + \mathbf{v}' = \mathbf{x}' \qquad (18)$$

3.2.2. The Systems of National Accounts

The input-output model, which is based on a symmetric input-output coefficients comes from the framework of supply and use tables supplying by the System of National Accounts. In this chapter is provided description of the System of National Accounts and the concept of products, activities, supply and use. The System of National Accounts delivers a set of internally consistent, logical and integrated macroeconomic accounts, balance sheets and tables compiled according to the applicable standards and rules of statistics to measure the effects of economic activity in a market economy. That statistics are carried out in the form of supply and use tables ensuring total integrity between data (United Nations, 2014).

In this section I explain few basic input-output formulation describing relations between commodities and industries in an economy. The activity of a specific industry is the usage of commodities to produce its own commodities. Commodities are the inputs, which are used in the production process and in order to complete the final demands. If every industry in an economy receives a primary commodity produced in some industry in that economy, then the amount of commodities and the amount of industries will be equal. Below it is presented the designation of symbols used in the formulation describing the Systems of National Accounts in the commodity-industry framework (Santos, 2011).

Summary of key symbols

Symbol	Description
U	input matrix where each element u_{ij} is the value of purchases of commodity i by industry j (dimensions are commodities by industries)
V	output matrix where each element v_{ij} is the value of the output of commodity j that is produced by industry i (dimensions are industries by commodities)
y	final demand
x/x'	industry output/input
q/q'	commodity output/input
v'	value added

Eq.19 corresponds to balance of the commodity output. To obtain that data I must multiply the input matrix U, where each element u_{ij} is the value of purchases of commodity i by industry j. At the end the final demand must be added.

$$\mathbf{U} \cdot \mathbf{i} + \mathbf{y} = \mathbf{q} \qquad (19)$$

Eq.20 presents formulation how to compute the industry input. The input matrix and vector of value added are needed.

$$\mathbf{i}' \cdot \mathbf{U} + \mathbf{v}' = \mathbf{x}' \qquad (20)$$

To provide calculation of industry output I use simple formulation, where the output matrix is used in multiplication. The Eq.21 follows that:

$$\mathbf{V} \cdot \mathbf{i} = \mathbf{x} \qquad (21)$$

The commodity input is derived from the following equation:

$$\mathbf{i}' \cdot \mathbf{V} = \mathbf{q}' \qquad (22)$$

The industry technology model has been used in this work. I assumed a rectangular activity by commodity system (industry-commodity framework). Below are presented the formulas connecting Leontief's matrix to the source data. In the industry technology model, A, the matrix of input-output coefficients possesses elements describing the value of commodity inputs to each dollar's worth of commodity output. That matrix can be estimated using Eq.23:

$$\mathbf{A} = \mathbf{U} \cdot \mathbf{diag}(\mathbf{x})^{-1} \cdot \mathbf{V} \cdot \mathbf{diag}(\mathbf{q})^{-1} \qquad (23)$$

Then, Leontief's matrix for the economic system can be derived according to Eq.24:

$$\mathbf{L} = \mathbf{V} \cdot \mathbf{diag}(\mathbf{q})^{-1} \cdot (\mathbf{I} - \mathbf{A})^{-1} \qquad (24)$$

The previous expressions were taken from Miller and Blair (2009, p. 197).

3.3. Data collection - Portuguese National Accounts

3.3.1. Energy consumption in Portuguese households

For this thesis the information about energy consumption in Portuguese households and all industries has been collected from the Institute of National Statistics of Portugal, providing Energy National Accounts (INE, 2013), which include dataset pertaining consumptions of different energy carriers for 2011 year in all economic sectors divided according to classification of CAE Rev2 on 82 sectors.

Analysing this data I can see that the total energy consumption in private households has been estimated at 6,003,471 toe for 2011. I can also distinguish shares of each energy source in the total energy use. In accordance with Figure 3-1 the biggest share in households belongs to diesel oil amounting 34.9%, consumption of electricity is equal to 19.7% and gasoline contribute to a share of 17.7% in total energy consumed. It is significant to notice that consumption of fuels in automobiles used in private transport by Portuguese families amounts to 3,225,161 toe, which gives over 50% of total energy consumed in households. Having regard to this, I can say that private transport is the most energy and carbon intensive activity in the household sector.

Natural gas with a share of 4.3% provides energy for cooking and water heating. LPG is an important supplier of space and water heating as well as cooking. Firewood is still the second main source of energy consumed domestically (if I exclude transport fuels), but its importance decreased in the last decade. Electricity having a share of 19.7% in total energy consumption plays a major role in the domestic sector, since most of appliances use this type of energy source. The increase of electricity consumption in recent years is mainly related with an increase in thermal comfort and larger number of electrical appliances in households.

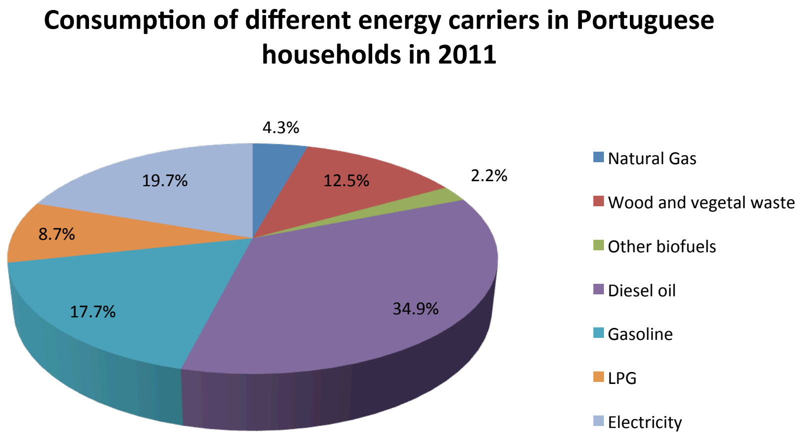

Figure 3-1 Consumption of different energy carriers in Portuguese households - 2011

3.3.2. Household budget survey

Data pertaining domestically produced final demand in basic prices has been derived from Institute of National Statistics of Portugal. It refers to the detailed information about expenses of Portuguese families in year 2008. The provided information is about average household demand for goods and services, including expenditures on energy carriers (INE, 2013).

The total average expenditure by private household in 2008 amounts to 22,231€. The number of registered household was over 3.9mln. The sector where Portuguese families spent the largest part of their incomes was trade and services with a share of 39.3%. That sector includes wholesale and retail trade, repair of motor vehicles and motorcycles (23.2% of total expenditure), transport and storage (2.9%) and accommodation and food service activities (13.1%). The second largest consumer of household incomes is industry. In that sector most of the money is spent on food, beverages and tobacco (7.6%), oil refining products such as gasoline and diesel oil (1.9%) and electricity, gas, water (3.1%) (Figure 3-2). Taking into consideration different numbers of households consuming vehicle fuels, it was possible to compute annual the average amounts of money spent on gasoline or diesel oil per household, which are equal to 462€ and 387€, respectively. For electricity that value is 579€.

Looking at the detailed table of final demand, providing information about 431 products consumed by households, expenses on energy carriers and electricity have large shares in total annual expenditures.

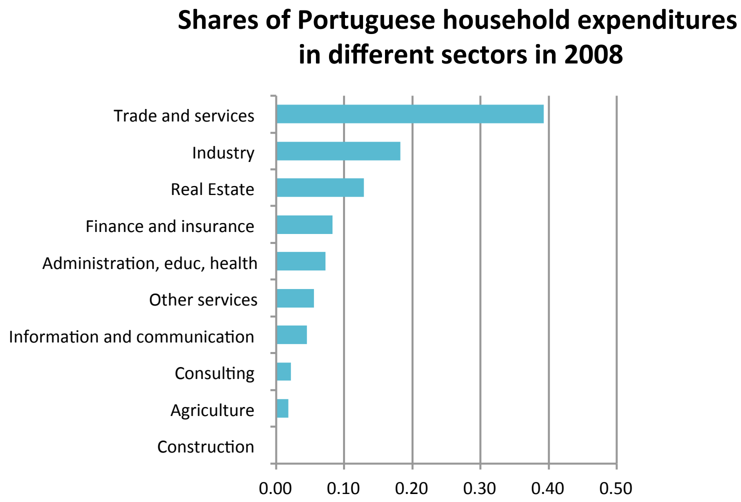

Figure 3-2 Portuguese households expenditures in different sectors in 2008

3.3.3. Total outputs and energy consumption in Portuguese sectors

In this work the total outputs in all 82 sectors in the Portuguese economy have been derived in order to get the matrix of input-output multipliers used in calculation of the economy-wide rebound effect. The largest amount of the output is in the following sectors: manufacture of food products (11,959mln €); electricity, gas, steam and air conditioning supply (15,498mln €); real estate activities (16,080mln €); public administration and defence; compulsory social security (17,647mln €); construction of buildings (17,787mln €); wholesale trade, except of motor vehicles and motorcycles (17,816mln €). These values expressed in percentage share of output of the single sector in the total output of all sectors presents as follows: 3.6%, 4,7%, 4.9%, 5.3%, 5.4% and 5.4% respectively for each sector listed before.

The consumption of different energy carriers is really diversified in Portugal. The most important fuels in those 82 sectors are coal and lignite, diesel oil, electricity (as source of energy) and natural gas. The largest shares belong to that energy carriers and are equal to 13%, 16%, 19%, 23% respectively analysing the energy consumption of all energy carriers. Taking into consideration each particular sector, the most energy intensive are following sectors: manufacture of coke and refined petroleum products (808,045 toe); land transport and transport via pipelines (827,693 toe); manufacture of other non-metallic mineral products (1,357,480 toe); manufacture of paper and paper products (1,717,114 toe); electricity, gas, steam and air conditioning supply (4,728,130 toe).

The most reliable is presentation this data of Portuguese sectors in the form of magnitude of consumed energy expressed in tonne of oil equivalent per million € of sector output. Computing that values I can obtain the numbers for each sector showing the total energy consumption in that sector over one million € of generated output in that sector as well. The most energy intensive sector in the Portuguese economy is manufacturing of paper and paper products. In this sector in order to produce one million € of output, 631.6 toe has to be consumed. The second sector in that classification is water transport with the value amounting 361 toe/mln €. The sector of electricity, gas, steam and air conditioning supply has the third place on this list with 305.1 toe/mln €. The lowest numbers belongs to non-manufacturing sectors, exactly to sectors providing services, where the energy consumption is not important factor in the generation of output.

4. RESULTS and DISCUSSION

In this chapter is investigated the magnitude of the direct, indirect and economy-wide rebound effects from the energy savings gained from the efficiency improvements in consumption of gasoline, diesel oil in private transport and electricity in Portuguese households. The target of these energy efficiency policies is the achievement of many goals in economy such as the reduction of primary energy consumption and the emission of greenhouse gases, mainly CO_2, or lowering the dependence on supply of fossil fuels coming from countries, where political and economic situation is not always stable like from North Africa. The results of rebound effects are expressed in physical units – tonne of oil equivalent – as well as percentages and are significantly different for each particular and analysed energy carrier. It highly depends on the size of expenditure on each energy carrier and way how savings are re-spent on other goods and services also linked with energy consumption requirements. As a reminder in this work I assumed that energy savings obtained in each energy carrier are equal to 10%. In addition this work provides the evidence of the economy-wide rebound effect appearing in different 82 sectors in Portuguese economy. It shows an increase in consumption of energy carriers due to an increase in demand for goods and services caused by money savings obtained in private households. So households are able to increase their income making the efficiency improvements, but assuming if the energy service is on this same level like before improvements and new investments are not significant in single household. That situation results in an increase in total output in sectors, because of the growth of final demand for produced units.

As I mentioned in chapter 2, the possibility of appearance the backfire effect, developed by Jevons – meaning that efficiency investment contribute to higher energy consumption of fuel than before improvements – is not common. In that case the rebound effect would be larger than 100%. After our estimation for Portugal, I can say it is impossible to obtain that effect, which is usually inherent for developing countries (IRGC, 2013).

At the beginning of this work I delivered the evidence of the rebound effect measures in different countries. In those papers, providing that measures are used different methods for estimation of rebound effect. In addition scientists may do various assumptions such as consideration of capital costs or spending patterns, which ricochet on the final value of the rebound effect. That results in a big difference of the sizes of rebound effect in all countries. Moreover, each country is meaningfully different if I account for economic situation. Comparing our results to other studies, direct and indirect rebound effects in private Portuguese households are much lower than in other regions. It is caused by different method and assumption used in this work. More detailed analyse of our results is delivered further in this work with comparisons to other reports.

4.1. Direct and indirect rebound effect

This part of thesis are presents the final results of direct and indirect rebound effects appearing in private Portuguese households for 2 domestic sections: transport and electricity consumption. The energy savings for each particular energy carrier are equal to 10%. I adopted this number following the decision made by the Council of Ministers Resolution, which enacted a National Action Plan for Energy Efficiency setting a goal to increase energy efficiency, corresponding to 9.8% of total final energy consumption. That plan consists of many programmes and measures being important for Portugal to achieve at least the minimum of 10% increase in energy efficiency. The National Action Plan for Energy Efficiency contributes to the larger meaning of implemented energy efficiency policies and assumes the presence of efficiency investments in all sectors, where are the greatest potential energy savings. Implementation of that plan can help to save significant amounts of energy carriers, especially natural gas and crude oil. The increment in energy efficiency takes a place in the following sectors: transport, residential and services, industry and public sector. In all those sector are realized projects such as efficiency improvements in urban mobility, transport efficiency system or vehicle and home renewal (EEA, 2011). For the record this work focuses on improvements and stimulated effects in Portuguese households accounting for consumption of gasoline and diesel oil in private transport and electricity consumption.

First of all, in order to illustrate more visually differences between the three energy consumption cases, Figure 4-1 is enclosed below. The numbers of energy consumption are expressed in physical units – tonne of oil equivalent. The base case, efficient case and rebound effect case is presented for each particular energy carrier in the form of 3 columns groups. The rebound effect case accounts for all rebound effects: direct, indirect and economy-wide. After analysis of that figure, I can conclude that there are small deviations between the efficient case and rebound effect case in consumption of

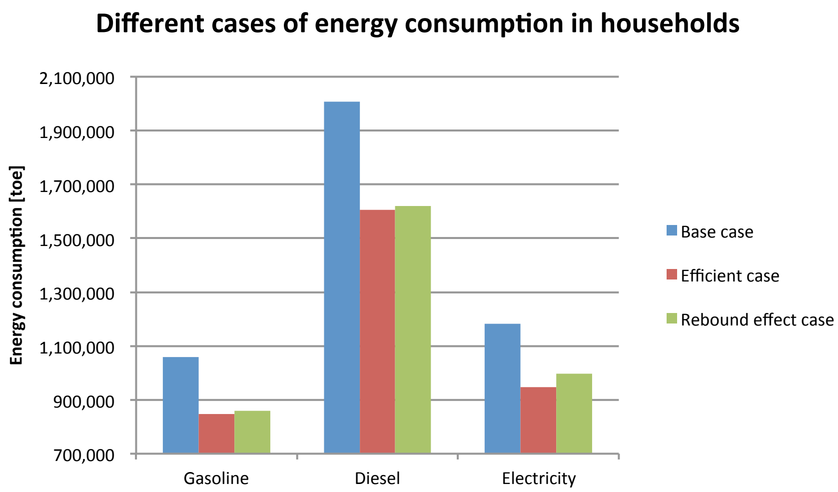

Figure 4-1 Different cases of energy consumption in households in respective to energy carrier

gasoline and diesel. The consumption in the rebound effect case is greater but not meaningfully. Looking at the group of columns corresponding to electricity, the situation presents itself slightly differently. I can observe larger deviation than in vehicle fuels. It may mean that electricity constitutes more important energy carrier in households and the fraction of it in total annual expenditures is larger in comparison to gasoline and diesel oil.

The next illustration Figure 4-2 shows the results of computed direct, indirect and economy-wide rebound effects for Portuguese private households in more detailed version and present them in the units of percentages. After accounting for the energy efficiency savings in the private transport, I obtain the values of the actual energy savings, when the price of energy service decreases and consumer does not change its behaviour on more sustainable but starts consuming more energy, what contributes to the reduction of potential energy savings assumed by energy efficiency policy.

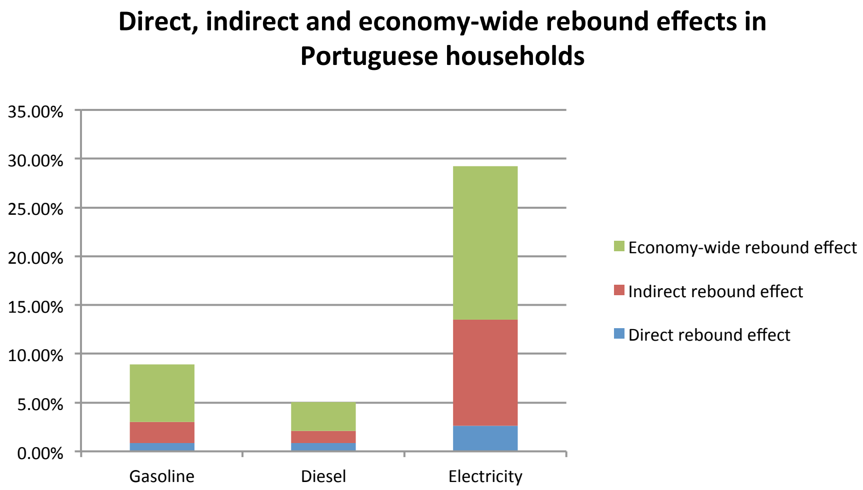

Figure 4-2 Direct, indirect and economy-wide rebound effects in Portuguese households

The first column corresponds to the percentage change in consumption of gasoline. I see that the direct rebound effect amounts to 0.83%. It means that value is a fraction of potential energy savings, assigning to an increase in consumption of gasoline, due to reduction of the price of that energy service. The rest are actual energy savings. There is also evidence of indirect rebound effect, having larger magnitude. The size of it is 2.2%. This amount of potential energy savings is re-spent on other goods and services linked directly with consumption of other fuels in household. The direct rebound effect is almost 3 times smaller than the indirect rebound effect for gasoline. It shows that the indirect rebound effect has more significant meaning in analysis of potential efficiency improvements in households. The largest share in total magnitude of rebound effect for gasoline belongs to economy-wide rebound effect and is equal to 5.7%.

The situation of diesel oil is similar to gasoline. The direct rebound effect for that fuel is assigned to value of 0.87%. It is slightly greater value in comparison to gasoline. The position for indirect rebound effect represents 1.2% of potential energy savings. Confronting that to gasoline it is smaller value by 1%. It is related to the price of fuel. Although the annual expenditures in households on both fuels are similar – over than 720mln € each, consumption of gasoline and diesel oil varies considerably. The economy-wide rebound effect for diesel oil is much smaller in comparison to gasoline and amounts to 3.0%.

During analysis of private transport section is worth to mention about one significant solution, which actually may lead to decrease consumption of gasoline and diesel oil successfully. The good option to reduce fuel consumption is replacement non-efficient car on more-efficient one. But it has to be taken into account that each particular household is not able to replace current vehicle on less fuel consuming because of the budget constraints. For this group of households is good to implement the awareness of eco-driving. That solution has application for households with new-purchased efficient automobiles as well.

Eco-driving is a way of driving, which is both environmentally-friendly and economical. Eco-friendly because it reduces the negative impact of the car on the environment emitting less greenhouse gases, and economical because it leads to the real fuel savings. The savings resulting from eco-driving indicate the reduction of fuel consumption from less than 5% to as high as 20% (Stillwater & Kurani, 2013). The eco-driving does not mean slow driving style, not burden engine too much and allows to drive smoothly and dynamically. Motorists who drive under the rules eco-driving, over a distance of 350km can save about 3-3.5 litres of fuel (assuming 10-15% savings resulting from the application of the eco-driving principles in based on car with a petrol engine, consuming average of 6.7 l/100 km). Assuming 15,000km as annual number of kilometres driven by household and moving in accordance with the principles of eco-driving it gives around 150 litres of fuel saved. The eco-driving is not straining the engine and other drive components. Changing gears at low revs relieves the clutch, and the systematic control of the vehicle allows the removal of any faults before any more serious failure appears (Barkenbus, 2010; Kircher et al., 2014).

The way of eco-driving is not the only factor affecting the level of fuel consumption. It is also a good technical preparation of the car. The engine must be efficient and well-adjusted, car suspension and brakes cannot generate additional rolling resistance. An important element of eco-driving is the ability to predict the situation on the road. Each stop and acceleration means greater fuel consumption. Therefore drivers should regulate their speed in order to hit the green light as often as possible. Summarizing the eco-driving requires significant changes in consumers' behaviour, but if only consumers knew how much money can save then would be able to handle with those changes (JRC-IET, 2013).

In addition, Portugal as a country with the great opportunities with production of electricity from renewable energy sources should start promoting electric vehicles. Having large installed capacity of wind- and hydropower it seems to be one of best solutions to increase the energy efficiency and decrease dependency on import of fossil fuels. Portugal already produces more than 40% of total generated electricity from renewable energy sources.

The last energy carrier analysed in this work is electricity, which has the largest share in expenditures on all energy sources used by households. For instance, annual expenses on gasoline and diesel oil in 2008 in Portugal were 727.48 and 762.26mln € respectively while on electricity was 2278.57mln €. Figure 4-2 above in the third column shows the results of changes in consumption of electricity, being strongly different in comparison to efficiency improvements in Portuguese private transport. The reduction of price of that energy service entails an increase in consumption of electricity amounting 2.61% of potential energy savings.

The indirect rebound effect for electricity represents 10.9%. That is really large value, if you look at energy carriers analysed before. So obtaining an additional income thorough energy cost savings, household re-spends that money on other goods and services linked also with energy/carbon intensive consumption. The economy-wide rebound effect for electricity has the largest size accounting for all rebound effects. It represents value equal to 15.7%. Total rebound effect for electricity gained the highest percentage value which is 29.2%. It means that the potential energy savings obtained by engineering estimation will be reduced by that value and the actual energy savings will become 70.8%. Here I can observed that household making efficiency improvements in electricity section spends large fraction of saved money on vehicle fuel, what means that in term of consumers' wants and needs, households desire to drive more. In terms of the electricity consumption, it is more treated as a need, because following analysis of the indirect rebound effect in vehicle fuels, there is no significant growth in consumption of goods and services linked directly with the electricity consumption.

Table 4-1 presents values of all rebound effects appeared due to efficiency improvements expressed in percentage as well as in physical units – tonne of oil equivalent – and potential energy savings possibly achieved through 10% efficiency improvements in each energy carrier. As I did not consider capital costs, our results can be partially overestimated. Accounting for capital costs of efficiency investments may lower the size of the rebound effect, because in the reality the energy efficient appliances are usually more expensive than replaced inefficient models what may entail decrease in demand for energy. That evidence for Japanese families provides Mizobuchi (2008). He carries out estimation of the rebound effect for 2 cases, in which one he considers capital costs and in another one does not. He obtains respective results of 27% and 115%.

Additionally, I decided to observe any possible changes arising from efficiency improvements and changes in consumers' behaviour when an increase in energy efficiency is larger and equal to 20%. Analysis showed that there are no any changes in the sizes of direct or indirect rebound effects for each particular energy carrier. It is caused by our assumption saying the percentage increase in energy efficiency is equal to the percentage decrease in the price of energy services for all analysed fuels. So potential energy savings are larger if I assume 20% of gains in energy efficiency, but due to obtaining larger additional income in households more money is re-spent on energy and other goods and services in comparison to 10% improvement. Finally all rebound effects are equal whether we consider 10% or 20% of efficiency improvements.

Table 4-1 Direct, indirect and economy-wide rebound effects stimulated by efficiency improvements

Fuel	POTENTIAL ENERGY SAVINGS [toe]	REBOUND EFFECT					
		Direct rebound effect [toe]	Direct rebound effect [%]	Indirect rebound effect [toe]	Indirect rebound effect [%]	Economy-wide rebound effect [%]	Economy-wide rebound effect [toe]
Gasoline	105,955	882	0.8%	2,332	2.2%	6,213	5.9%
Diesel	200,806	1,751	0.9%	2,444	1.2%	5,929	3.0%
Electricity	118,295	3,084	2.6%	12,902	10.9%	18,571	15.7%

4.2. The economy – wide rebound effect

This subchapter is dedicated to analysis of the economy-wide rebound effect induced by efficiency investments in Portuguese private households. That rebound effect contains macroeconomic effects such as the energy consumption induced by a lower market price for energy, changes in economic structure, economic-competiveness investment and disinvestment, and labour market changes resulting from energy efficiency investments.

Improved technologies in households may contribute to economy-wide rebound effects through entailing a new production in sectors and increasing the economic growth of country. The total economy-wide rebound effect expressed in physical units for gasoline, diesel oil and electricity is 6,212 toe, 5,929 toe, 18,571 toe, where potential energy savings follow 105,955 toe, 200,806 toe, 118,295 toe, respectively. That gives expressed in percentage rebound effects amounting accordingly 5.9%, 3.0%, 15.7% for each energy carrier. These values are calculated in the base of numbers expressed in tonne of oil equivalent. The rebound effect is this same if we use magnitudes of rebound effect and potential savings given in monetary units. Knowing how much money Portuguese households may save from efficiency investments and knowing the way how that money are re-spent, the economy-wide rebound effects for each particular energy carrier can be obtained. All savings are re-spent according to proportional spending patterns and capital costs of new appliances are not accounted for, so final results are equal, irrespectively if physical or monetary units are used.

For gasoline, the economy-wide rebound effect amounts to 5.9%. It says that percentage of potential energy savings is an increase of energy consumption after efficiency investment. Real energy savings have value of 94.1% of potential energy savings and are equal to 99,742.49 toe. The actual energy savings for gasoline, but given in monetary units are 68.48mln €. The potential monetary savings for gasoline, diesel oil and electricity give numbers 72.75, 76.23, 227.86mln €. Analysing diesel oil, that savings represent 194,877.26 toe and 73.98mln €. Savings from electricity corresponds to numbers equal 99,723.94 toe and 192.09mln €.

Table 4-2 The evidence of actual energy savings coming from the economy-wide rebound effect

	Gasoline	Diesel	Electricity
Expenditure on energy carrier [mln €]	727.48	762.26	2,278.58
Consumption of energy carrier [toe]	1,059,551.03	2,008,064.27	1,182,950.13
Potential monetary savings [mln €]	72.75	76.23	227.86
Potential energy savings [toe]	105,955.10	200,806.43	118,295.01
Actual monetary savings [mln €]	68.48	73.98	192.09
Actual energy savings [toe]	99,742.49	194,877.26	99,723.94
Economy-wide rebound effect [%]	5.9	3.0	15.7

Below is Table 4-3 representing sectors with the largest economy-wide rebound effects. Unsurprisingly, the greatest share belongs to electricity, gas, steam and air conditioning supply and amounts to 41.5% of total economy-wide rebound effect appearing in Portuguese private households.

Table 4-3 The economy-wide rebound effect in particular sectors

SECTOR	Economy-wide rebound effect [toe]	Economy-wide rebound effect [%]	Share in economy-wide rebound effect [%]
Electricity, gas, steam and air conditioning supply	12,753	3.00%	41.52%
Manufacture of food products	1,748	0.41%	5.69%
Manufacture of paper and paper products	1,574	0.37%	5.13%
Manufacture of coke and refined petroleum products	1,378	0.32%	4.49%
Land transport and transport via pipelines	1,377	0.32%	4.48%
Retail trade, except of motor vehicles and motorcycles	1,146	0.27%	3.73%
Crop and animal production, hunting	1,075	0.25%	3.50%
Accommodation	942	0.22%	3.07%
Wholesale trade, except of motor vehicles and motorcycles	913	0.21%	2.97%
Food and beverage service activities	907	0.21%	2.95%
Manufacture of other non-metallic mineral products	870	0.20%	2.83%

Due to our assumption, saying that an increase in efficiency improvements reduces the price of particular energy service by this same value, this type of rebound effect is equal to all considered energy carriers. Also shares in each sector are this same. The other sectors where appears significant an increase in energy consumption due to an increase of efficiency in private households are manufacture of food products, paper and paper products, coke and refined petroleum products with share of 5.7%, 5.1%, 4.5% of total economy – wide rebound effect. The table also includes values of the economy-wide rebound effects representing of total energy savings of all energy carriers and the absolute value of the economy-wide rebound effect in the most energy-intensive sectors.

4.3. Discussion

In this chapter, a discussion of computed rebound effects in Portuguese private households is included and also description of drivers of consumers' response to changes in energy consumption after energy savings obtained by the efficiency improvements. Analysed results and other evidence of the rebound effect in different countries showed that after efficiency improvements actual energy savings were not gained as policymakers assumed. It is caused by not accounting for predictions of consumers' behaviours. The main reason is difficulty to change lifestyles of households, being not desire to change their habits. That is really meaningful to understand by policymakers, what possible changes in consumers' behaviour can appear after efficiency investments and what responses can be expected after that.

For households regarding their behaviour, the most important aspect is the reduction of their expenditures. Daily activities may affect the operating costs of the house and private transport. Through judicious use of household appliances consumers can lower the amount of their energy bills. The financial benefits of energy efficient way of life are not reserved only for the residents of houses with a high standard of energy. Each building can reduce the amount of energy consumed. The easiest way, which requires no cash outlay is to follow the rules, such as using public transportation, switching the light off, turning off unused electronic devices, running washing machines and dishwashers only when full load or off the heating during the airing of rooms. But more noticeable savings can be achieved by investing in additional warming house and the exchange of traditional windows, lighting and appliances/electronics with energy-efficient models. Really often after purchase of more efficient appliances, consumers are not fully aware of usage of that device as efficiently and correctly as should be. They are not focus on technical issues and familiarization with efficient use of it, but only on awareness of purchasing these appliances, what they think, it automatically contributes to more sustainable lifestyle. So here are needed sociotechnical methods allowing to integrate and to implement new thinking of consumers about more efficient usage of energy contributing appropriately to reduction of energy consumption. Unfortunately, there are also some other social and behavioural aspects, which cause appearance of rebound effect in private households after efficiency improvements and which are not easy to control them.

Here are listed 3 points pertaining approaches to changes in energy consumption of consumers' behaviours in private households. The first point concerns the improvement of efficiency in energy – consuming products. The next one is influencing on households to decide to purchase that appliances. The third point is about changes in consumers' behaviours and familiarization with correct way of usage of acquired new efficient products. To make efficient investments meaningful all those points must be carried out to avoid problem of the rebound effect.

The one of the most important drivers of consumer responses to changes in energy efficiency is perception of prices (Kahneman & Tversky, 1979). Usually households are not fully aware of magnitude of electricity bills or monthly/annual spending on vehicle fuels. Often that expenditures constitute not significant fraction in total expenditures. In Portuguese household average expenses on electricity and vehicle fuels do not exceed 3% and 2% respectively. It means that Portuguese families spend more money on other goods and services which are not directly related to consumption of energy carriers by them. Here appears problem to deal with the second point discussed above, saying about to encourage the purchase of efficient devices. There may be some questions such as what significant benefits can be obtained in households due to efficiency investments and how quickly expense on investment returns (Simon, 1959).

The prestige and status effects are also considered as one of drivers of consumers responses to changes in energy efficiency (de Haan et al., 2006). Conspicuous and visible consumption drives to full satisfaction of biological and physical needs. For instance, when one household purchase sport car, consuming more fuel than traditional automobile and providing higher status of living, then the other household can follow it to provide more luxurious lifestyle as well. However, that status effect can also be considered in positive aspect such as support for environmentally friendly technologies like photovoltaic panels installed on households' rooftops or non-emitted electric cars. In that case when consumer is willing to increase his status, he chooses green products instead of non-sustainable products even if green products would be more expensive. However, that eco-activities in households might be not sufficient to influence on demand for energy. Additional income is gained and status effect is raised, what results in rebound effects (Griskevicius et al., 2010).

Consumers often do not possess sufficient knowledge about efficient usage of acquired appliances. Lack of that information leads to the reduction of potential energy savings. It pertains many devices used in private households. For instance, most of the electricity in household is consumed by refrigerator. So it is important to familiarise with correct use of it. The irrational use of the refrigerator may cause an increase in the annual cost of electricity. It can be solved by setting the optimum temperature - in the refrigerator at a level no lower than 7 degrees C, and the freezer is not less than -18 degrees C. Any additional reduction in temperature will result in higher energy consumption. Also important is the correct exploitation such as regular defrosting refrigerator, dusting with an external heat exchanger. In case of car driving, there is the speed limit below which the consumption of fuel is economic and above which that consumption increases significantly. The owner of car usually treats time as more important factor than consumption of fuel, what results in saved time and larger demand for fuel.

Different lifestyles driving by Portuguese households can highly influence on possible emerging of rebound effect (Druckman et al., 2010). In households are large social and behavioural differences, which contribute to inequalities in access to all goods and services related with energy consumption. Many of these differences are dependent on individual values, attitudes and preferences, what results in unequal amounts of energy consumed in households. So spending patterns and their changes are significant factor in analysis of potential appearance of rebound effects. Many studies showed that lifestyle patterns usually favour the use of electricity over the other forms of energy. For instance, now there is common that Portuguese households decide to replace their gas ovens and stoves on electric ones. The motivation is electric appliances are able to provide better control of temperature and more functions such as different programmes of cooking. In addition that replaced non-efficient appliances usually are used as a backup or as additional service. Moreover, in recent years due to continuous change of people lifestyle, where are time constraints and dual career strategies, position of frozen food has been strengthened, which leads to increase of energy consumption (Hand & Shove, 2007). In case of private transport, households deciding to change non-efficient automobile, do not often sell the old automobile because of small profitability and awareness of having an extra car, ensure the independence for other member of family.

Energy consumers are used to certain habits and routines that is not easy to influence on. That behaviours are often more constant and resistant to changes and they describe the drivers of consumer response to changes in increase of energy efficiency (Hobson, 2003). These habits entail a reduction of potential energy savings induced by efficiency improvements and potential money savings in Portuguese households (Marechal, 2009). From the other point of view, investments in new green products may cause abandonment of old habits by motivating people to save more energy and then save more money, what gives to consumers the greatest satisfaction (Thøgersen & Ölander, 2003). For instance, a household decides to make improvement in lighting, buying new more efficient bulbs. To become more sustainable consumer of energy, behavioural changes should take a place. Here I think about paying attention on switching lights off in unused rooms in that moments.

Nowadays convenience and saving time are factors having really great importance for people in their standard of life (Jalas, 2002). Technological progress made a huge step in recent years, providing much larger efficiency of appliances and allowing to save more time during some activities. The best example comes from private transport. To save time during long-distance travel, driver increases his speed, consuming more fuel. That response to increase of energy efficiency in automobile is not economic and environmentally friendly. Another example describes consumption of electricity: Lately people are more inclined to buy frozen food, which is usually defrosting just before meal using microwaves. This activity could be reduced by defrosting food in the surrounding temperature, but it involves more time and is less convenient, what not gratifies consumers (Hand & Shove, 2007).

The next driver of consumer response to changes in energy efficiency and energy prices corresponds to the insatiability of wants and needs. Households are not usually able to fully satisfy their needs and wants. Depending on time, when some of them are fulfilled, others can be created. In case of incomplete satisfaction of wants and needs, there is large possibility of occurrence of rebound effect. According to study of Sorrell (2007), the greatest probability of appearance of rebound effect is in low-income groups and developing countries. Those groups usually spent all saved money from efficiency improvements, because of the greater needs. Rebound effects in high-income groups are not strongly evident, because demand for needs is lower in comparison to low-income groups (van den Bergh, 2011). For instance, low-income group making efficiency investment in transport is able to save some money. That money is spending on food, clothes or in other sector to complete their needs. In high-income group that situation should not have happened. Insignificant rebound effect may occur, but only related with larger wants of that group.

4.4. Potential solutions for dealing with rebound effects

Many papers providing estimations of rebound effects in different economies presents results where expected energy savings are reduced by an increase in energy consumption due to decrease of price of energy service. That results vary meaningfully and are between few per cent to even over 100%. In Portuguese household I observed the largest rebound effect when analysing electricity. It means that implemented all energy efficiency policies, promoting the reduction of energy consumption by replacement of non-efficient appliances on more "green" appliances and trying to influence a change in consumers' behaviours, which help to avoid typical non-environmental-friendly habits and routines in households have invisible gaps for policymakers. Many scientists analysing induced effects arising from efficiency investments think that policymakers in implemented energy-efficiency policies should include different scenarios, which contains effects that may result. Carrying it out, the plan of reduction in consumption of energy looks more realistic and there are no surprises after efficiency improvements pertaining unexpected growth of demand for the energy or goods and services requiring energy consumption as well.

Energy efficiency policy may result in unexpected implications. The engineering computations are only estimation to forecast possible effects. That is not simple to exactly predict behaviour of consumer after efficiency investments made in households. Many households are able to change their routines in order to obtain some outcome. That outcome is called "saving money". In other households, that elimination of non-environmentally-friendly habits is impossible or constrained. Some household do not care about the size of bills coming from consumption of the electricity and vehicle fuels, because that bills do not constitute important fraction of total expenditures. Other households through saving money are able to satisfy their needs and wants on the higher level, so they spend all increase in income on different goods and services, directly and indirectly related with energy consumption.

In that situation, policymakers were forced to solve that problem and find answer on question how to reduce the magnitude of rebound effects in private households. In recent years were studied energy efficiency policy implications taking in consideration economic and other social sciences approaches. There are few reasonable solutions worth to mention, which presents the best ways to dealing with rebound effects.

The first solution often carried out by policymakers and supported by economists is imposition of higher energy prices (Guerra & Sancho, 2010)(Sorrell, 2007). That strategy causes that households are more interested in their energy consumption. The consumers more carefully pay attention to their non-sustainable habits. For instance, if cost of electricity goes up, families try to switch light off in unused rooms or to make washing during the hours with lower tariff. When price of gasoline or diesel increases, consumers travel less and use more often public transportation, what results in other positive effects such as smaller traffic jams or decrease in the level of noise.

Rebound effects often are not taken into consideration when policies are implemented. It contributes to incorrect estimating of demand for energy after efficiency investments. Although that estimations sometimes consider rebound effects, but only through mentioning small part of this problem using not professional expressions. Then suitable definition system of rebound effects needs to be provided and included in scenarios and models of the efficiency investments (IRGC, 2013).

From the other point of view policymakers should really carefully analyse possible effects, which can appear after increase of energy efficiency. Implementation of new energy efficiency policies, decreasing the energy consumption and reduction of CO_2 emission may turn out as a not-effective ways to gain more sustainable economy. Usually if calculation says that rebound effect gets size of few percentage, then that energy efficiency programme should be considered as a not fully worth to implement.

It was mentioned before, rebound effects totally vary in different income groups. High-income groups present much lower changes in demand for energy and other goods and services due to changes in the price of them. Their needs and wants are more fulfilled than in low-income groups. Similar statistics are showed if I consider developed and developing countries. In that second group, needs and wants increase proportionally with the rate of development of that country. To deal with occurrence of rebound effect in that places, it is really important to provide for society a better understanding of that problem in order to avoid it or at least to reduce the magnitude of rebound effect, but still keeping right social and economic development of country (Polimeni, 2008).

Another important aspect helping to cope with the reduction of rebound effects is systematic delivery of rebound effect estimation statistics. Many scientific reports and articles dedicated to rebound effects are only analysed in certain amount of countries, the most pertains the United States and developed countries in Europe and Asia. Many countries do not provide that statistics at all, but supplying that data publicly we could notice the size of rebound effects in different years and changes due to taken steps constraining occurrence of them. In addition the estimations of rebound effects may contribute to that other countries follow them what can result an increase in meaning and importance of rebound effects.

The other important aspect is to provide more estimations concerning indirect and economy-wide rebound effects. Potential energy savings obtained from engineering estimates in regional energy efficiency policies should be reduced by the size of the direct rebound effect, because changes in demand for energy from indirect and economy-wide rebound effects are only available in national scales. In addition estimated rebound effects for national energy efficiency policies should be reduced by both direct and indirect rebound effects.

Good solution for dealing with rebound effects induced by efficiency improvements in households is implementation special mechanism helping to control the value of energy consumed, for instance in energy service such as heating (Ehrhardt-Martinez et al., 2010). These appliances and controlling systems may influence on consumers' behaviour to be more sustainable and reduce energy consumption in households. In addition, provided better explanations and meanings of rebound effect has to be deliver to consumers in order to gain significant changes in households habits and routines.

5. CONCLUSIONS

The main target of this thesis was numerical estimation of the rebound effects: direct, indirect and economy-wide coming from energy efficiency improvements in average Portuguese household. I analysed efficiency improvements in private transport and in electricity consumption. As recently was mentioned, the rebound effect contributes to the reduction of potential energy savings, what further usually turns out that the implemented energy efficiency policies were not as efficient as expecting. Initially, the implementation of energy efficiency policies leads to decrease of energy consumption and GHG emission. However, this also further leads to the price reduction of energy services and goods and then to an increase in real income, assuming this same consumption of energy service, goods and services after efficiency improvements. After that according to the additional wants and needs appeared in private households, a part of actual money savings is spent, which entails additional consumption of energy.

This work provided the explanation and computation of the rebound effect using the input-output analysis in order to show how that gap, being often ignored by policymakers, constitutes the significant problem in Portuguese energy system dealing with reduction of energy consumption and having the target to gain more sustainable status and be less dependent on supply of fossil fuels such as natural gas.

Various analysed scientific papers prove that quantified actual and potential energy savings are different in comparison to the results obtained for Portugal. It depends on the used methods, the economic situations in countries, the energy efficiency policies and many other aspects and assumptions. It is also a little difficult to compare various estimations of the rebound effect, because each estimator has individual approach to that topic and has many ways to manipulate data used in computation.

In this work I proposed the model supplying by the input-output framework. That method allows us to calculate rebound effect being induced by energy efficiency improvements in Portuguese households. The model assumed the proportional spending pattern of saved money, but in the reality is difficult to predict consumers' behavioural responses to changes in an increase in energy efficiency.

The main conclusion in this work is that an constant increase in energy efficiency does not have to lead to a drop in energy consumption. In Portuguese households, making efficiency investments in private transport and in domestic electric appliances, the magnitudes of all types of rebound effect vary meaningfully regarding particular energy carriers: gasoline, diesel and electricity. The changes in consumption of electricity shows this energy carrier is the most convenient in usage for consumers, because there is observed the largest rebound effect, including both direct and indirect rebound effect. Moreover the indirect rebound effect has greater importance, what means that Portuguese households re-spend more saved money on other goods and services than on consumption of the particular energy carrier, where the efficiency has been gained.

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