# The Rebound Effect of Household Energy Use in Portugal

## Extended abstract of Master Thesis

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## INTRODUCTION

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, which provide 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 (Sorrell, 2007). Therefore, in that situation the possible diminution of the energy consumption and GHG emissions, which are caused by technological upgrade of the 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 (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 empirical results I am able to find the size of the three types of rebound effects: direct, indirect and economy-wide.

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 the paper of Guerra and Sancho (2011) the economy-wide rebound effect appears 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 to 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%.

This work is focused on Portugal, which is a country not having 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. The import of crude oil decreased over the last 10 years. The likely explanation is the significant rise in the oil price, which occurred during this time 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 (IEA - statistics, 2013).

Focusing on household sector I can distinguish different sections, where the type and amount of particular energy carrier is consumed. Figure 1 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 consumption of electricity and natural gas. Water and space heating have a share of 10.7% and 9.8%, respectively (INE – Statistics Portugal, 2013).

The technical efficiency of automobiles raised 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)

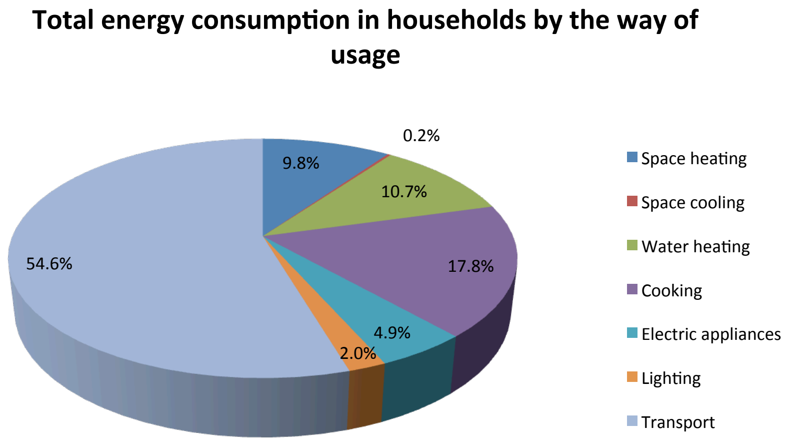


Figure 1. Total energy consumption in Portuguese households by the way of usage 2010 (INE, 2013)

# THE REBOUND EFFECT

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 are defined as changes in energy demand following an efficiency investment due to changes in consumers' behaviour.

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 units. For example, if rebound effect is equal to 10% means that 90% of the potential energy savings are achieved.

$$R = \frac{\mathrm{PES} - \mathrm{AES}}{\mathrm{PES}} \cdot 100\%$$

## 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, which entails 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).

# METHODOLOGY

This thesis derives the model of the direct, indirect and economy-wide rebound effect. This model does not take into consideration the efficiency investments – the capital costs of new, purchased appliances. In this work is assumed there is no essential difference in costs between conventional, less-efficient appliances and more efficient devices. 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. For all energy carriers is assumed the efficiency improvement equal to 10%.

## The Leontief's model and System of National Accounts

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 our estimation. This model has been developed by Wasilly Leontief, who examined how changes in one economic sector may influence the other sectors. It 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´s 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 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. 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).

## Data collection - Portuguese National Accounts

### a. Energy consumption in Portuguese households

For this thesis I collected the information about the energy consumption in Portuguese households and all industries 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.

Analysing this data I can see that the total energy consumption in private households is equal to 6,003,471 toe for 2011. The biggest share in households belongs to diesel oil amounting to 34.9%, consumption of electricity is equal to 19.7% and gasoline contributes to a share of 17.7% in total energy consumed. Total consumption of the vehicle fuels in private transport by Portuguese families amounts to 3,225,161 toe, what gives over 50% of total energy consumed in households.

### b. Household budget survey

Data pertaining domestically produced final demand in basic prices also comes 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 sector where Portuguese families spent the largest part of their incomes was trade and services with a share of 39.3%. That sector includes the 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%).

## c. Total outputs and energy consumption in Portuguese sectors

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 (3.6%); electricity, gas, steam and air conditioning supply (4.7%); real estate activities (4.9%); public administration and defence; compulsory social security (5.3%). construction of buildings (5.4%).

# RESULTS and DISCUSSION

## a. Direct and indirect rebound effect

This part of thesis 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%.

In order to illustrate more visually differences between the three energy consumption cases, Figure 2 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

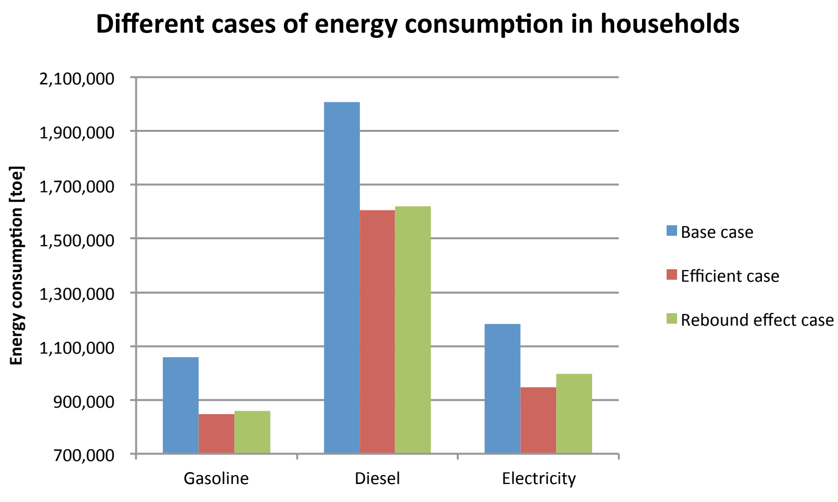


Figure 2 Different cases of energy consumption in households in respective to energy carrier

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 3) 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.

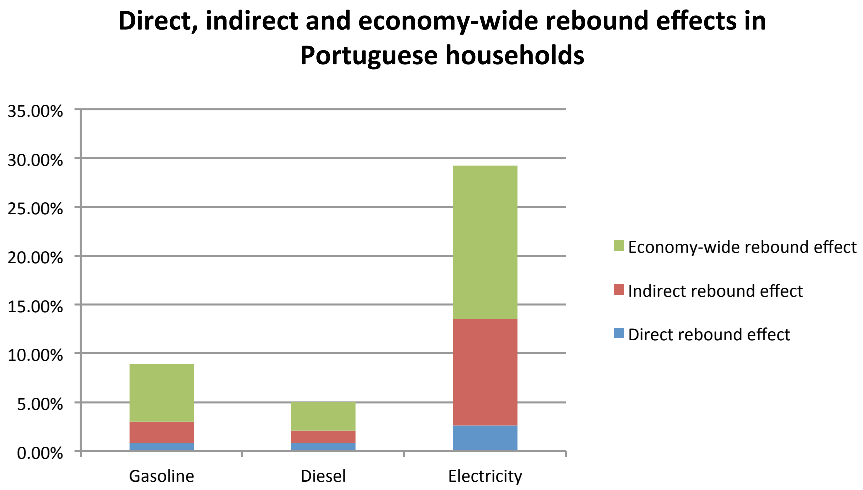


Figure 3 Direct, indirect and economy-wide rebound effects in Portuguese households

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 720 mln € each, the 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%.

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 762.26 mln € respectively while on electricity was 2278.57 mln €. Figure 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 to 2.61% of potential energy savings.

The indirect rebound effect for electricity represents 10.9%. That is really large value, comparing it to energy carriers analysed before. So obtaining the additional income thorough energy cost savings, a 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 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.

Table 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 [toe] | Economy-wide rebound effect [%] |
| 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% |

## b. The economy-wide rebound effect

The economy-wide 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 the 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.

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 68.48 mln €. The potential monetary savings for gasoline, diesel oil and electricity give numbers 72.75, 76.23, 227.86 mln €. Analysing diesel oil, that savings represent 194,877.26 toe and 73.98 mln €. Savings from electricity corresponds to numbers equal 99,723.94 toe and 192.09 mln €.

### c. Discussion

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 lack of 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.

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.

# 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.

The main conclusion in this work is that the 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 particular energy carrier, where the efficiency is gained.

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