ENERGY EFFICIENCY AND REBOUND EFFECT FOR HOUSEHOLD GAS CONSUMPTION: EVIDENCE FROM ANKARA

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ZEHRA İLKNUR YILMAZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
EARTH SYSTEM SCIENCE

JULY 2019

Approval of the thesis:

ENERGY EFFICIENCY AND REBOUND EFFECT FOR HOUSEHOLD GAS CONSUMPTION: EVIDENCE FROM ANKARA

submitted by **ZEHRA İLKNUR YILMAZ** in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY in Earth System Science Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Cemal Can Bilgin
Head of Department, **Business Administration** ________________

Prof. Dr. Ramazan Sarı
Supervisor, **Business Administration, METU** ________________

Prof. Dr. İsmail Yücel
Co-Supervisor, **Civil Engineering** ________________

Examining Committee Members:

Prof. Dr. Bülent Gültekin Akınoğlu
Department of Physics, Middle East Technical University ________________

Prof. Dr. Ramazan Sarı
Business Administration, Middle East Technical University ________________

Prof. Dr. Hasan Şahin
Department of Economics, Ankara University ________________

Prof. Dr. Uğur Soytaş
Department of Business Administration, METU ________________

Assoc. Prof. Dr. Ayşen Sivrikaya
Department of Economics, Hacettepe University ________________

Date: 19.07.2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: Zehra İlknur Yılmaz

Signature:

ABSTRACT

ENERGY EFFICIENCY AND REBOUND EFFECT FOR HOUSEHOLD GAS CONSUMPTION: EVIDENCE FROM ANKARA

Yılmaz, Zehra İlknur
DOCTOR OF PHILOSOPHY, Earth System Science
Supervisor: Prof. Dr. Ramazan Sarı
Co-Supervisor: Prof. Dr. İsmail Yücel

July 2019, 173 pages

Increasing energy demand and concerns about energy security and climate change have led to energy efficiency to become one of the important energy policy objectives in many countries. It is conceived that energy efficiency improvements will decrease energy consumption and CO_2 emissions. However, actual efficiency savings are often less than projected savings because of consumer behavior. This concept is known as the rebound effect which is an important factor to be considered while estimating results of energy policy measures related to energy efficiency. While the rebound effect has been studied for developed countries, studies in developing countries are limited. Moreover, most studies have been focused only on economic analysis by neglecting social factors.

In this study, direct rebound effect for space heating targeting households in Ankara is studied by using primary and secondary data related to economic and social indicators for energy efficiency applications in buildings. Moreover, the demographic, dwelling characteristics and behavior factors that have an effect on gas consumption are explored and concomitantly inferences and recommendations are made to policymakers in Turkey.

Keywords: Rebound Effect, Space heating, Consumer Behaviour, Demographic Factors, Behavioural Factors, Household Characteristics, Policy Recommendations

ÖZ

HANELERDE ENERJİ TÜKETİMİ İÇİN ENERJİ VERİMLİLİĞİ VE GERİ TEPME ETKİSİ: ANKARA ÖRNEĞİ

Yılmaz, Zehra İlknur
Doktora, Yer Sistem Bilimleri
Tez Danışmanı: Prof. Dr. Ramazan Sarı
Ortak Tez Danışmanı: Prof. Dr. İsmail Yücel

Temmuz 2019, 173 sayfa

Artan enerji talebi ve enerji güvenliği ile iklim değişikliği konusundaki kaygılar birçok ülkede enerji verimliliğinin önemli enerji politika hedeflerinde biri olmasına yol açmıştır. Enerji verimliliği iyileştirmelerinin enerji tüketimini ve CO_2 salımlarını azaltacağı düşünülmektedir. Fakat tüketici davranışları sebebiyle gerçekleşen enerji tasarrufları genellikle öngörülen tasarruflardan daha az olmaktadır. Enerji verimliliği ile ilintili enerji politika önlemi sonuçlarının ölçülmesinde önemli bir faktör olan bu kavram geri tepme etkisi olarak bilinmektedir. Geri tepme etkisi gelişmiş ülkelerde çalışılmış olmasına rağmen gelişmekte olan ülkelerde yapılan çalışmalar sınırlıdır. Ayrıca, çalışmaların çoğunluğu sosyal faktörleri göz ardı ederek ekonomik analizlere odaklanmıştır.

Bu çalışmada, mesken ısıtma için doğrudan geri tepme etkisi Ankara'daki haneler için enerji verimliliği uygulamalarına yönelik ekonomik ve sosyal göstergelere dayalı birincil ve ikincil verileri kullanarak çalışılmıştır. Ayrıca, gaz tüketimi ile ilintili demografik, bina özellikleri ve davranışsal faktörler araştırılmış ve beraberinde Türkiye'deki politika yapıcılara çıkarımlarda bulunulmuş ve öneriler verilmiştir.

Anahtar Kelimeler: Geri Tepme Etkisi, Mesken Isıtma, Tüketici Davranışı, Demografik Faktörler, Davranışsal Faktörler, Hane Özellikleri, Politika Önerileri

To My Grandfather

ACKNOWLEDGEMENTS

There is a long list of people I would like to thank during this wonderful journey.

First I sincerely thank to my parents and my brother for their encouragement and moral support.

I want to express my gratitude to my supervisor Prof. Dr. Ramazan Sarı for his guidance, support, and encouragement during the process.

I would like to express my sincere thanks to Prof. Dr. Bülent G. Akınoğlu, Prof. Dr. Hasan Şahin and Dr. Bora KAT for their positive encouragement during my Thesis Committee meetings. Moreover, I want to express my special thanks to Prof. Dr. Akınoğlu for his follow-ups and reminders. I want to extend my special thanks to Prof. Dr. Ayşen Yılmaz for her sincere support and guidance.

Ph.D. has been a very enjoyable journey for me. ESS has attached many friends to my life. Canet, Semiha, Özge, Fahman, Selin, Melike, Uğur, Sıfat I want to thank you all for making this process fun and joyful. It wouldn't be that much enjoyable without you. Moreover, I want to thank Çağrı for his backup support at TÜBİTAK while I'm away for classes and studying. Last but not least, I want to thank EL15 for being there for me all the time when I need their support and help.

Thanks to my friends Gamze, Betül, Elif their love and continuous support during all the time I'm talking about my thesis and work. Hale and Sonnur Hanım, you were always there for me and helped me a lot.

Last but not least I'm grateful to Fahman and Volkan for their support.

I want to thank Başkent Doğalgaz Dağıtım A.Ş. for supporting me with the natural gas data.

This work was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) Grant Number: 117K942.

TABLE OF CONTENTS

ABSTRACT v

ÖZ vi

ACKNOWLEDGEMENTS viii

TABLE OF CONTENTS ix

LIST OF TABLES xi

LIST OF FIGURES xii

LIST OF ABBREVIATIONS xiii

CHAPTERS

1. INTRODUCTION 15

1.1. Background 15

1.2. The Objective and Scope of the Thesis 18

1.3. The Motivation of the Study 19

2. LITERATURE REVIEW AND THE MAIN PILLARS OF THE THESIS 21

2.1. Direct Rebound Effect 21

2.1.1. Direct Rebound Effect for Space Heating 22

2.1.2. Direct Rebound Effect in the Transport Sector 31

2.1.3. Direct Rebound Effect for Other Sectors 44

2.2. Direct and Indirect Rebound Effect 57

2.3. Economy-wide Rebound Effect 67

2.4. Macroeconomic Rebound Effect 77

2.5. Social Determinants on Rebound Effect 81

2.6. Policies Developed for the Rebound Effect 87
2.7. Main Results of Literature Review 90
3. DATA AND METHODOLOGY 93
3.1. Data Collection and Preparation 94
3.1.1. Questionnaire 95
3.1.2. Energy Certificate and Gas Consumption 96
3.2. Model Building: Rebound Effect Estimation Method 99
3.2.1. Model Generations Based on Various Factors 103
3.2.2. Variable Selections 103
3.2.3. Estimation Technique 104
3.2.4. Model Pool and Analysis 105
4. RESULTS 107
4.1. Interpretation of Descriptive Statistics 107
4.2. Identification of the Variables 112
4.3. Empirical Results 114
4.4. Rebound Effect Calculation According to Different Income Groups 117
4.5. Diagnostics Tests 119
4.6. Results on Consumer Behaviour 127
5. POLICY IMPLICATIONS 131
6. CONCLUSION AND DISCUSSION 135
REFERENCES 139
APPENDICES 165
A. Questionnaire 165
CURRICULUM VITAE 173

LIST OF TABLES

Table 3.1. Distribution of the Sample according to Districts....................................99
Table 4.1. Summary statistics for gas heating consumption and heating intensity..108
Table 4.2. Summary statistics of the variables..110
Table 4.3. Regression results for demography, dwelling and behavior parameter groups...113
Table 4.4. Pooled OLS Estimations and Instrumental Variable Estimations 116
Table 4.5. Income Segregated Models...118
Table 4.6. Levene's Test of Equality of Error Variances for OLS Backward..........122
Table 4.7. Levene's Test of Equality of Error Variances for OLS Stepwise 122
Table 4.8. Levene's Test of Equality of Error Variances for 2SLS Backward 122
Table 4.9. Levene's Test of Equality of Error Variances for 2SLS Stepwise 122
Table 4.10. Pearson's Correlation Matrix for Gas Consumption and Independent Variables 123
Table 4.11. Durbin Watson Test Results for OLS (Backward) 123
Table 4.12. Durbin Watson Test Results for 2SLS (Backward).............................123
Table 4.13. Durbin Watson Test Results for OLS (Stepwise)................................124
Table 4.14. Durbin Watson Test Results for 2SLS (Stepwise)...............................124
Table 4.15. Multicollinearity statistics..126

LIST OF FIGURES

Figure 3.1. Estimation Methodology Flow Diagram 94

Figure 3.2. Data screening and cleaning 98

Figure 4.1. Normal P-P Plot of Regression Standardized Residual Dependent Variable: logarithm of gas consumption: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise 120

Figure 4.2. Histogram of residual: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise 121

Figure 4.3. Plot of the residual and predicted value for model: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise 125

Figure 4.4. Insulation results in a decrease in heating expenditure 128

Figure 4.5. Savings from heating expenditure after the insulation 129

Figure 4.6. Insulation protects the environment 130

LIST OF ABBREVIATIONS

AIDS	Almost Ideal Demand System
ARDL	Auto-Regressive Distributed Lag Cointegration
CFL	Compact Fluorescent Lamp
CGE	Computable General Equilibrium
CHAID	Chi-Square Automatic Interaction Detection
CO_2	Carbon dioxide
E-I-O	Energy-Input–Output
E3MG	Energy-Environment-Economy Model at the Global
ESCO	Energy Service Company
EU	European Union
GDP	Gross Domestic Product
GLS	Generalized Least Squares
ICT	Information and Communication Technologies
IEA	International Energy Agency
IPAT	Impact Population Affluence Technology
I-O	Input-Output
kWh	kilowatt-hour
LA	Linear Approximation
LCA	Life Cycle Assessment
LED	Light Emitting Diode
MLI	Modified Laspeyres Index

MSC	Master of Science
NASA	National Aeronautics and Space Administration
No	Number
QAIDS	Quadratic Almost Ideal Demand System
OLS	Ordinary Least Square
ORANI-G	A general equilibrium model of the Australian economy
PV	Photovoltaic
R&D	Research and Development
2SLS	Two-Stage Least Squares
3SLS	Three-Stage Least Squares
SUR	Seemingly Unrelated Regression
STIRPAT	Stochastic Impacts by Regression on Population, Affluence, and Technology
UK	United Kingdom
USA	United States of America
USDA	United States Department of Agriculture
VIF	Variance Inflation Factor
ENNDF	Energy-Environmental Non-Radial Directional Distance Function

CHAPTER 1

INTRODUCTION

1.1. Background

Energy efficiency and technological improvements have been very important in global energy policy discourses mainly due to the need for energy conservation and greenhouse gas (GHG) emissions reduction. Technological improvements lead to more efficient energy services (such as fuel, heating, cooling, etc.), which decreases the cost of the services. However, lowering the price of this service increases demand. In other words, energy service improvements lower service costs, which results in a rise in consumption of the energy service or other goods. This situation is called the rebound effect. For instance, the driver of a more fuel-efficient car would make extra miles or would spend the gain on other goods (Sorrell, Dimitropoulos, and Sommerville, 2009).

The rebound effect stems from the "Jevon's Paradox", which stated that improved efficiency of coal engines increased coal consumption. Brookes (1979) and Khazzoom (1980) argued that after energy efficiency implications, energy use may increase compared to the level without the improvement. Khazzoom and Brookes started the debate on the rebound effect which was founded by Jevons in 1865. Brookes (1979) focused on macro effects, whereas Khazzoom (1980) worked on direct and micro rebound impacts (Azevedo, 2014). However, the studies on this topic have exploded in recent years and the exact definition, size, relevance and explanations on the rebound effect are controversial (Turner, 2012; Peters et al., 2012). It is argued by Sorrell (2007) that the effect of the rebound effect would decline in time as the demand saturates.

The value of the rebound effect could be more than one, i.e. it could exceed the potential savings. This means that after energy efficiency implementation, the consumption of energy does not decrease, but rather it increases. This situation is described as the backfire effect in the literature. As a result, backfire effect is the offset of the savings aimed to be obtained via energy efficiency activities (Lin and Liu, 2015; Sorrell, Dimitropoulos, and Sommerville, 2009; Greening, Greene, and Difiglio, 2000). Super conservation is the opposite of the backfire effect. It can be defined as the actual savings being more than the expected savings.

There is also a prebound effect defined in the rebound effect literature. It is the gap between actual consumption and theoretical or calculated consumption (Galvin and Sunikka-Blank, 2016). It could be the consumption of less energy than calculated (Sunikka-blank et al., 2012). Prebound effect with low-income households addresses fuel poverty (Galvin and Sunikka-Blank, 2016).

The rebound effect can be divided into four types; direct rebound effect, indirect rebound effect, economy-wide rebound effect, and macroeconomic rebound effect (Greening, Greene, and Difiglio, 2000).

The direct rebound effect is the increased consumption of energy services whose price decreased with improvement in energy efficiency (Chitnis et al., 2013). Studies on the direct rebound effect show very different values. Different samples and research methods could be the reasons for different results (Ghosh and Blackhurst, 2014). Moreover, despite the fact that the number of studies on the direct rebound effect is high, the results of these studies are not consistent. The reason behind inconsistency could be the difference between the definitions, methodological approaches and data sources used. Direct rebound effect literature is mainly focusing on space heating and transport. There are also studies focusing on other areas e.g. agriculture, Information and Communication Technologies (ICT), industry.

The indirect rebound effect (so-called secondary rebound effect or income effect) can be explained as spending the money obtained from energy efficiency measures on other services and goods. Consumers' purchasing power is increasing with energy efficiency measures generally due to the income effect (Ghosh and Blackhurst, 2014). The empirical studies on indirect rebound effect had different difficulties like the definition of system boundaries and separation from other effects like introduction of new technologies or a general increase of standard of living, which would trigger new habits and needs (Peters et al., 2012).

Changes in consumer preferences, technological innovation and/or social institutions are referred to as the economy-wide rebound effect (Herring and Roy, 2012). It may be related to the substitution of energy for other production factors. It is also defined as macro-scale rebound effects. Most of the economy-wide rebound effect studies are focusing on a single country while some others have a broader focus.

The macroeconomic rebound effect is defined as the combination of economy-wide and indirect effects (Barker, Dagoumas, and Rubin, 2009). Energy efficiency improvements can have macroeconomic growth and price effects that are related in ways that lead to an increase in energy consumption (Zhang and Lin Lawell, 2017). Therefore, it can be stated that the macroeconomic rebound effect is composed of two different effects.

Rebound effect studies have been mainly focused on the fields of energy efficiency in buildings, industry, and transportation. The personal automotive transport is acknowledged as the most widely studied direct rebound effect area while the second most studied field is household heating (Sorrell, Dimitropoulos, and Sommerville, 2009).

It was stated by many authors that the rebound effect would be higher for developing countries (Freire-González, 2011). The reason behind the likelihood of higher rebound effects in lower-income groups and developing countries was reflected as the satiation of needs in previous findings (Bergh, 2011; Peters, Sonnberger, Dütschke, and Deuschle, 2012; Small and Dender, 2007; Sorrell, 2007).

1.2. The Objective and Scope of the Thesis

There are very few studies conducted in developing countries on the direct rebound effect (Azevedo, 2014). In order to achieve global climate change goals which are highly dependent on the success of decreasing energy consumption, better and greater focus on the rebound effect in developing countries is a necessity.

The focus of this dissertation is on the direct rebound effect for residential space heating and the relationship between the direct rebound effect and demographic, dwelling and household characteristics. Moreover, policy recommendations will be elaborated according to the results obtained. The primary and secondary data related to economic and social indicators for energy efficiency applications in buildings and natural gas consumption is collected from residential flats located in Ankara. The data on demographic, dwelling characteristics and behavior is collected via face-to-face survey, while natural gas data is obtained from Başkent Doğalgaz Dağıtım A.Ş., a gas distribution company operating in Ankara.

The aim of the dissertation is to calculate the direct rebound effect empirically and to identify the factors that are related to gas consumption. Regression models will be built to serve these purposes.

Contributions to the rebound effect literature are targeted in many ways. First, the direct rebound effect for residential households in a developing country would be calculated for the first time as a result of an on-site survey. Second demographic factors, dwelling and behavioral characteristics that have a relationship with gas consumption will be identified based on primary data directly collected from consumers. Third, according to the model results and interpretations from the model, policy recommendations will be made specifically for a developing country.

The dissertation is organized in five chapters. Chapter 2 provides comprehensive information about the literature on the rebound effect according to different types of the rebound effect as explained before. Chapter 3 reports on data and methodology. Chapter 4 is focused on the results. Chapter 5 is on policy implications literature and recommendation for Turkey based on the results obtained from literature, data analysis and modelling. Chapter 6 is focusing on the discussion of results and policies and gives the conclusion.

1.3. The Motivation of the Study

The Republic of Turkey Ministry of Energy and Natural Resources published the Energy Efficiency Strategy Paper for 2012-2023 in 2012. One of the main pillars of the Turkish 2023 national strategy objectives and energy policies is energy-saving and efficiency. Energy security, energy safety, decreasing external energy dependence, and climate change are the crucial components of the strategy. One of the targets of the strategy is to decrease building's energy demand and CO_2 emissions and mainstream environmentally friendly buildings integrated with renewable energy technologies.

"5627 Energy Efficiency Law" and "Buildings Energy Performance Regulation" put in practice obligation for existing buildings to have an Energy Identity Certification by May 2, 2017 in Turkey. The aim of the Certificate is to decrease the energy consumption of new and existing buildings, to maintain energy efficiency and finally, to cope with climate change and to protect the environment.

Achievement of these targets depends on decreasing energy consumption of buildings. The Turkish government is aiming to achieve these targets through regulations for new and existing buildings. However, the rebound effect is not taken into consideration during this process. On the other hand, the rebound effect could be defined as one of the very key elements of energy efficiency. Decreasing consumption does not depend only on technological achievements; it is quite related to consumer behavior. For this reason, additional measures and policies should be considered by the Turkish government to reach the targets. This dissertation would draw recommendations that would be useful for energy efficiency policies and energy efficiency targets for existing buildings in Turkey.

CHAPTER 2

LITERATURE REVIEW AND THE MAIN PILLARS OF THE THESIS

The section is dedicated to a comprehensive review of the literature on the rebound effect. It is divided mainly according to the types of the rebound effect. Moreover, a sub-section is dedicated to the studies focusing on factors affecting the rebound effect. Lastly, the main results of the literature review related to the main pillars of this dissertation are provided.

2.1. Direct Rebound Effect

Considerable empirical literature to estimate the direct rebound effect is typically based on the measurements in terms of energy service price elasticities, efficiency elasticities, and energy price elasticities (Sorrell and Dimitropoulos, 2008). The decision on which parameters to estimate direct rebound effects are generally determined based on the theoretical frameworks used in the study (Sorrell, 2007). Energy service price elasticity can be the most appropriate measure for the direct rebound effect, however, most of the time, it is very difficult to get the appropriate measure for the energy service price. Thus, as Sorrell and Dimitropoulos (2008) pointed out, the efficiency elasticity can be taken as a measure of the rebound effect since it is equivalent to an energy service price elasticity. In addition, elasticities of energy price would also act as a proxy to the direct rebound effect in econometric models that control for changes in efficiency (Henly, Ruderman, and Levine, 1988).

As any other rebound effect studies, the sectoral focus is very diverse for the direct rebound effect. The focus of most direct rebound effect studies is on transportation followed by household heating. This is due to the fact that many energy efficiency measures are targeted at this sector. For example, building retrofitting is typically aimed to improve the insulation of the building with the intention to decrease the consumption of energy. For transportation, improved vehicle efficiency would mean less energy needed to reach the same distance as before. However, both efficiency improvement measures are challenged by the occurrence of rebound effects. Thus, in this section, the sectoral focus of the studies to household heating, transportation, and other sectors are differentiated.

2.1.1. Direct Rebound Effect for Space Heating

Dubin, Miedema, and Chandran (1986) estimated the rebound effect for energy-efficient appliances in the USA by means of the elasticities. Results revealed that the rebound effect is 19% and 48%. Nesbakken (1998) estimated the rebound effect by means of energy price elasticity for different heating options (electricity, electricity and wood, electricity and oil, and electricity, oil and wood). In this study, the link between heating equipment and energy use was considered. Selection of heating technology is estimated by a discrete model while utilization of the heating technology is estimated by means of a continuous model. The data was obtained from the Norwegian Energy Survey conducted in 1990. It is found that the average rebound effect is 21% while it is 55% for electricity, 21% for electricity and oil, 18% for electricity and wood and 15% for electricity, oil and wood. Nesbakken (2001) estimated the short-term direct rebound effect to be between 15% and 55% for Norwegian households by means of Norway's microdata and econometric methods.

Guertin, Kumbhakar, and Duraiappah (2003) estimated the direct rebound effect for different income groups and for different energy services. The data was obtained from The Canadian Residential Energy End-use Data and Analysis Centre. The model was obtained in the two-step estimation procedure. First, the furnace and water heater efficiencies were calculated. Second, efficiencies for the water heater and furnace were used for the determination of the demand for energy services. The rebound effect was computed as the price elasticities of energy services. The rebound effect results were as follows: 47% for low-income group, 37% for the medium-income group and 29% for the high-income group. Hens, Parijs, and Deurinck (2010) used the measured data to show the importance of direct rebound. The data on measured temperature and consumption was collected in Belgium. Direct rebound is calculated by dividing the difference between calculated reference consumption and the normalized measured consumption to calculated reference consumption. The direct rebound effect for the first estate dwellings that were built in the fifties as one story dwellings, terraced in rows of two or four, ranged between 14 to 56% and on average 44%. In the second estate's two-story terraced houses, the rebound effect ranged between 54 to 69% with an average of 51%. Freire-González (2010) used econometric techniques for the estimation of the direct rebound effect for Catalonian (Spain) households for all energy services using electricity. It is concluded that the rebound effect is positive but less than one.

Madlener and Hauertmann (2011) estimated German residential households' direct rebound effect related to space heating by using panel data and a fixed-effects model. The data was collected by means of a repeated survey among 11,000 German households provided by the German Institute of Economic Research. The rebound effect is calculated according to the income and ownership matters as follows: 12.2% for owners of all income classes, 13.4% for owners of the low-income class and 40% for tenants of the all income classes households while it is 49.3% for the low-income tenant households. Sunikka-blank et al. (2012) focused on 3,400 German dwellings and found a prebound effect of 30%. Actual and expected energy consumption were compared to calculate the prebound effect. Rosenow and Galvin (2013) investigated and compared energy efficiency programs in the Germany and UK, namely the CO_2-Building Rehabilitation Programme and the Supplier Obligation. Galvez, Mariel, and Hoyos (2014) estimated the direct rebound effect in residential heating and domestic hot water services in Spain in 2012. While electricity and natural gas were evaluated in the study, data on residential CO_2 emissions, the amount of energy consumed per annum and unit variable cost of energy were used to calculate the direct rebound effect. The paper used gas consumption payment in each bill, the rated electrical power and variable cost per kWh of electricity and natural gas for 2012. The data is collected by means of a survey dedicated to this study. The demand for electricity and natural gas are analysed by a regression model. The rebound effect is calculated by means of price elasticities. The direct rebound effect is calculated as follows: electricity demand for homes that use more than one fuel is 71%, electricity demand for homes that use only electricity is 87% and natural gas demand is 109.4%. Since the direct rebound effect is greater than 100%, it can be concluded that there is a backfire effect for natural gas demand. Galvin (2014) estimated the direct rebound effect for energy consumption in the 28 countries of the European Union (EU) and Norwegian households by means of econometric methods and data from the years 2000-2011. The results were ranging from -100% to 552%. Galvin (2015) calculated the rebound effect for different post-upgrade heating energy demand and the results revealed that the rebound effect ranges between 28% and 39%. Galvin used elasticity for estimation and the data is obtained from a national survey for 1700 households German Energy Agency. Dineen, Rogan, and Gallachóir (2015) studied direct rebound effect based on Irish survey data on EU energy performance certificates. They used a quasi-experimental methodology. The percentage of rebound post-retrofit of roof and solid wall insulation in Partially Insulated Solid Wall dwellings for a different internal temperature assumptions were calculated separately from the percentage of rebound post-retrofit of roof and solid wall insulation, boiler and heating controls upgrade, solar hot water and high efficiency windows in Partially Insulated Solid Wall dwellings for different internal temperature assumptions. The rebound effect for roof and solid wall insulation plus boiler and heating controls upgrade, solar hot water and high efficiency windows in Partially Insulated Solid Wall dwellings under different temperature assumptions were found to be between

21% and 200% for different type of buildings namely, apartments, detached, semidetached, terraced. Lin et al. (2016) concluded that the rebound effect exists for the retrofitted buildings at the China's Hot Summer – Cold Winter region. Teli et al. (2016) made a study on 107 blocks of social housing owned by the UK government. According to the results, the prebound effect is found to be 40% while the rebound effect is 6%. Galvin and Sunikka-Blank (2016) concentrated on the conceptual links and behavioural impact of prebound and rebound effect and concluded that high prebound effect is related to low income and thereby fuel poverty. Moreover, it is also pointed out that the low rebound effect shows that heating of the buildings before the renovation was sufficient.

Grossmann et al. (2016) used elasticity to calculate the rebound effect for public buildings. The results indicated that one of the buildings used for the study had -113% of rebound effect while the others revealed results between −5.5% and 4.9%. Winther and Wilhite (2014) calculated the direct rebound effect for 28 Norwegian heat pump installed households with in-depth interviews conducted in 2012 and 2013 and concluded that the rebound effect exists for most of the households. Volland (2016) calculated the direct rebound effect for 11,000 US households as 30% by means of OLS and 2SLS procedures. Copiello and Gabrielli (2017) studied energy efficiency in buildings by means of a double-logarithmic model from natural gas and electricity consumption data for Italy during the period from 2004 to 2013 and estimated the rebound effect by elasticities as 47.44%. Li and Liu (2017) focused on urban houses in China and used the Linear Approximation Almost Ideal Demand System (LA/AIDS) model for the estimation of the direct rebound effect that was found to be 66%.

Holck et al. (2017) conducted scenario analysis for the Norwegian dwelling stock for 2016 – 2050 and concluded that there would be an increasing aggregated rebound effect which should be considered in policy implications. Hache, Leboullenger, and Mignon (2017) focused on 42 French houses and flats. It was concluded that more than half of those groups would have a positive rebound effect on energy efficiency measures at 58% on average while 11 would exhibit more than a 50% rebound effect and 19 of the groups would show no rebound effect even they would windfall behavior. Chi Square Automatic Interaction Detection (CHAID) model was used in this study. Galassi and Madlener (2017) made a study with 3,161 owner-occupiers and tenants in Germany by means of a Discrete Choice Experiment and argued that comfort is the reason behind the rebound effect while it is also the reason for the retrofitting decision. Aydin, Kok, and Brounen (2017) focused on residential heating for 563,000 Dutch households by using fixed-effects and instrumental variable approaches. The calculations for household owners and tenants revealed that the rebound effect is 26.7% for owners and 41.3% for tenants. Holzmann and Schmid (2018) studied the residential heating sector in Austria. Three different scenarios were formed for the estimations. The baseline scenario defined as BASE constituted a scenario representing a credible future direction for the Austrian residential heating demand and the scenario REB represented the baseline scenario that ignored consumer behaviour for 2008–2030 but accommodated energy demand data of 2007. In this context, patterns of consumer behaviour is used for BASE in 2007. Another scenario TEC totally ignored consumer behaviour and constituted on theoretical heating. The rebound effect is defined as the difference between scenarios BASE and REB. According to the results, the reboud effect would increase gradually and reach to 16% in 2030.

Lu, Zhang, and Chen (2017) studied the rebound effect for Energy Saving Performance Contracts on a real retrofitting project in Maryland, United States. The results showed that the rebound effect is 15% for the 17-year contract while it is ranging from 0.12% to 5.5% for the 14-year contract. Behaviour-based model was used in this study. Figus et al. (2017) studied the rebound effect for UK households for two different scenarios. The first scenario is an improvement of all household groups' energy efficiency by 10% while the second scenario is the improvement of the lowest income quintile household groups' energy efficiency by 10%. Household rebound in residential energy in the short-run is 76.53% and 73.82% in the long-run for the first scenario. Household rebound in residential energy in the short-run is 79.03% and 76.71% in the long-run for the second scenario. Household rebound in total energy in the short-run is 78.89% and 76.33% in the long-run for the first scenario. Household rebound in total energy in the short-run is 80.65% and 78.5% in the long-run for the second scenario. The economy-wide rebound in the short-run is 69.86% and 59.68% in the long-run for the first scenario. Finally, the economy-wide rebound in the short-run is 71.94% and 63.91% in the long-run for the second scenario. Computable General Equilibrium (CGE) model was used for this study.

Belaïd, Bakaloglou, and Roubaud (2018) calculated the direct rebound effect for residential gas demand as almost 53% in the short-run and around 60% in the long-run in France by means of the standard OLS regression and Auto Regressive Distributed Lag Cointegration (ARDL) approach using 1983–2015 annual time-series data. Sun (2018) made a theoretical model indicating that the direct rebound effect may be varied between different types of energy services. Empirical evidence from the 2009 Residential Energy Consumption Survey stated that Energy Star dishwashers reflects a negative direct rebound effect, which means that the rebound effect offset the energy efficiency savings. OLS and 2SLS methods were used to make estimations. Peters and McWhinnie (2017) predicted direct rebound effect for energy use in Australia based on household energy expenditure data and on both aggregate residential energy use data. They found that low-income households have the highest proportion of the rebound effect. The data was gathered from 1989 to 2015 in six states of Australia. The data on energy source-oriented residential energy consumption of energy in petajoules for annual aggregate state was obtained from the Australian Energy Statistics. The analysis concluded that the rebound effect of electricity calculated between 70% and 80%, gas and other fuels calculated between 0.44 and 0.63 according to Hunt and Ryan (2014, 2015)'s new method. Hediger, Farsi, and Weber (2018) studied the direct and indirect rebound effect in residential heating by taking preferences of the households into consideration by using a choice experiment. The double hurdle model was used to calculate the rebound effect and the data was gathered by online survey in 2015 with 3,555 respondents from Switzerland. The paper found out that the direct rebound was 12% on average, while the average indirect rebound effect was 24%. These effects have an overall rebound effect of around 33% on average.

Arrobbio and Padovan (2018) used the combination of analyses of cost, (market) value and eco-burden to evaluate and compare strategies defined as a ‘passive’ end-user investing in the insulation of the building and continue preferred behavior with an ‘active’ end-user who goes to behavioral change to save energy. It was concluded that these combined analyses are helpful in justifying the potential magnitude of the rebound effect. Niemierko, Töppel, and Tränkler (2019) argued that copula-based quantile regression has promising advantages over ordinary point-estimate methods. The regression technique can be helpful for the optimization of the thermal retrofit projects due to its robustness for the rebound effect and performance gap. Based on 25,000 data from German households, it was found that the rebound effect has significant variation among different kinds of retrofits being done and whether the household is energy-conscious or energy-wasting type. van den Brom, Meijer, and Visscher (2019) aimed to provide insight into the energy savings after thermal retrofitting and why it is often lower than expected. Almost 90,000 renovated buildings in Netherland were included in the sample space. It is found that prebound and rebound effects only partly explain the loss of the energy saving gains from the improved energy efficiency of the buildings. The other reasons are state of the building prior to the retrofit and socio-economic conditions of the occupants. In addition, deep renovation gave the highest average savings compared to other thermal retrofitting applications.

Coyne, Lyons, and McCoy (2018) used a quasi-experimental approach to find out the existence of the rebound effect following a thermal upgrade of the building in Ireland on social housing tenants. The survey of before and after the upgrade was conducted involving 260 households. Econometric panel data analysis was used to estimate the relationship between the gas usage and the energy efficiency improvement. It was found that the rebound effect from thermal upgrade is ranging from 33% to 43%. Fowlie, Greenstone, and Wolfram (2018) tried to find evidence whether the investments provide the aimed efficiency. The degree-day model was used to calculate the energy performance of the buildings. Monthly natural gas and electricity consumption was gathered through June 2008 to May 2014 and two types of data was gathered as an experimental sample and quasi-experimental sample, which consisted of 30,000 respondents in Michigan in order to participate in the weatherization assistance program. However, the estimated direct rebound effect was very small and it was not significant in their model. Also, it was concluded that the participants who joined the Weatherization Assistance Program lowered their energy consumption by 10-20%. Chen et al. (2018) investigated the rebound effect at smart homes and the magnitude of the rebound effect in China. Two experiments were conducted in order to observe the pattern of participants as a data source. A paired t-test was used to analyse the dataset. The rebound effect was estimated as 13.5% and varied among the participants. It was concluded that providing electricity usage recommendations and feedbacks may lower the rebound effect in smart homes. Moreover, it was stated that the magnitude of the rebound effect was 6.42% on appliance setting, 12.91% on environment setting and 20.24% on illuminating settings**.**

Garcia et al. (2017) studied the residential rebound effect through conducting serious games. NRG game was being implemented through two modelled houses. One of the houses had a low efficiency level and the other house had a high efficiency level. The responses of the participants who joined this experimental game were used as a data source. The rebound effect was calculated and it was between 0% and 120%. Safarzadeh and Rasti-Barzoki (2019) estimated the rebound effect under the Bertrand game model in a monopoly and it was concluded that 25-43% of the rebound effect would offset energy savings. Brøgger et al. (2018) studied heat consumption of 134,000 residential buildings in the building stock of Denmark and investigated pseudo-rebound effects by means of a hybrid bottom-up model and the relationship between the registered heat consumption and the calculated heat demand. It was concluded that pseudo-rebound effects exist for all building types. However, it was slightly smaller for the buildings with district heating and multi-family houses. Yang et al. (2019) calculated the direct rebound effect for urban households located in China by means of the error correction model employing panel data of 29 provinces in China for the period 1996-2014. The results showed that the direct rebound effect for Western, Eastern and Central regions was 89%, 46% and 26% in the long-run while it was 78%, 35% and 17% in the short-run. Scheepens and Vogtländer (2018) concluded that despite the efforts of most European countries for energy efficiency by better insulation, there was a rebound effect after the pay-back period. However, the rebound effect was lower for longer pay-back periods.

There are 27 articles where the direct rebound effect is empirically calculated. Country-wise analysis shows that four of the articles, namely, Grossmann et al. (2016), Galvin (2015), Madlener and Hauertmann (2011) and Sunikka-blank et al. (2012) conducted their studies in Germany while there are also three studies for the USA (Volland, 2016; Lu, Zhang, and Chen, 2017; Alfred et al., 2015). The direct rebound effect for space heating was calculated twice for China (Li and Liu, 2017; Cheng, Li, and Liu, 2018); Ireland (Dineen, Rogan, and Gallachóir, 2015; Coyne, Lyons, and McCoy, 2018); Norway (Nesbakken, 2001; Nesbakken, 1998), France (Belaïd, Bakaloglou, and Roubaud, 2018; Hache, Leboullenger, and Mignon, 2017), Spain (Galvez, Mariel, and Hoyos, 2014; Freire-González, 2010) and UK (Figus et al., 2017; Teli et al., 2016). Australia, Austria, Belgium, Canada, Denmark, Holland, Italy, EU-28 countries+Norway and Switzerland was focused once.

According to the analysis, 25 of the articles out of 27 conducted studies targeting residential houses. Lu, Zhang, and Chen (2017) focused on both residential and commercial buildings. Grossmann et al. (2016) was the only article targeting public buildings. Therefore, it is concluded that most of the studies in the literature that are calculating the rebound effect were focused on residential houses. Calculation of the rebound effect for public or commercial buildings is one of the gaps of the literature.

The occupancy and duration of usage is different for these buildings. Therefore, there is a need to focus on these buildings.

The magnitude of the rebound effect is mostly ranging between 0 and 100%. However, there are three studies (Grossmann et al., 2016; Teli et al., 2016; Sunikka-blank et al., 2012) where the super conservation effect, i.e., a rebound effect below 0, was observed. Backfire effect was encountered in three of the articles which are Dineen, Rogan, and Gallachóir (2015), Galvez, Mariel, and Hoyos (2014) and Garcia et al. (2017) while both super conservation and backfire is observed in one article (Galvin, 2014).

Hens, Parijs, and Deurinck (2010), Sunikka-blank et al. (2012), Coyne, Lyons, and McCoy (2018) and Dineen, Rogan, and Gallachóir (2015) used quasi-experiment methodology, while econometric modeling and elasticities is employed by the others. Other than these methodologies, scenario analysis (Holzmann and Schmid, 2018), the degree-day model (Alfred et al., 2015), consumer utility model (Peters and McWhinnie, 2017), CHAID model (Hache, Leboullenger, and Mignon, 2017), and TRNSYS simulations (Teli et al., 2016) are used for the calculations. In addition to these methodologies, game models are used by Garcia et al. (2017) and Safarzadeh and Rasti-Barzoki (2019).

2.1.2. Direct Rebound Effect in the Transport Sector

There is a wide-range of rebound effect studies on the transport sector. Wheaton (1982) made a study targeting 25 OECD countries. Cross-section data of 1972 was applied to econometric methods and the direct rebound effect was calculated as 6%. Blair, Kaserman, and Tepel (1984) estimated the short-term rebound effect for motor transport based on monthly data between 1967 and 1976 in Florida by means of OLS and GLS methods. The results were ranging between 25 and 40%. Mayo and Mathis

(1988) calculated the rebound effect for motor transport by means of yearly data for 1958 to 1984 with a two-equation demand model. It was estimated that the rebound effect was 22% in the short-term and 26% in the long-term. Gately (1992) calculated the direct rebound effect for the USA by means of time series data of 1966-1988 from a national survey and econometric methods as 9% for the short-term and long-term. Greene (1992) studied national personal transport in the USA via a time-series data of 1957-1989. The short-term and long-term rebound effect was ranging from 5 to 19% according to this study. Jones (1993) estimated the short-term and long-term direct rebound effects as 13% and 30%, respectively based on a yearly data of 1966-1990 by applying time series regression. Mayo and Mathis (1988) estimated a rebound effect of 20.3% by means of time series data from US national survey and econometric methods based on the elasticity of driving with respect to fuel efficiency.

Goldberg (1996), Puller and Greening (1999) and West (2004) estimated the direct rebound effect related to personal automotive transport by means of the US household survey data. Goldberg (1996) estimated a short-term rebound effect of 0% (data of 1984-1990), Puller and Greening (1999) made an estimation of 49% (data of 1980-1990) and West (2004) estimated 87% (data of 1997). Sorrell, Dimitropoulos, and Sommerville (2009), Walker and Wirl (1993), Johansson and Schipper (1997) and Haughton and Sarkar (1996) used econometric methods with aggregate panel data for personal automotive transport and estimated the direct rebound effect. The short-term and long-term estimation of Walker and Wirl (1993) was 10-20% and 27-30%, respectively, for the UK, France, and Italy. Haughton and Sarkar (1996) estimated 9-16% for short-term and 22% for long-term rebound effect in the USA. Johansson and Schipper (1997) calculated the long-term rebound effect 5 to 55% for 12 OECD countries.

Greene, Kahn, and Gibson (1999) calculated long-run rebound effect 20% by means of the household survey data obtained from the Residential Transportation Energy Consumption Surveys of US households, Energy Information Administration over a

15-year period. Matos and Silva (2011) focused on the rebound effect in Portugal for road freight transportation. The data was gathered from the road freight transportation sector between 1987 and 2006. The rebound effect was calculated through OLS and 2SLS methods and it was estimated as 24.1%. The functional form was decided as log-log model, in order to interpret elasticities. It was also concluded that fleet operators were more in favor of operational efficiencies rather than technological fuel efficiencies. De Borger and Mulalic (2012) investigated the components of fuel consumption in the Danish trucking industry. Aggregate time series data of years 1980-2007 was used for the calculations. Some relevant elasticities, and a formula were used to calculate the rebound effect and it was found as 9.81% in the short-run and 16.83% in the long run. The study concluded that an increase in fuel prices lead firms to buy more efficient trucks, thus it was stated that increases in fuel prices decrease the consumption but in a small amount.

Wang et al. (2012) focused on private passenger transport in Hong Kong by means of the data for the periods 1993–2009 and 2003–2009. The magnitude of the direct rebound effect for these two periods were 45% and 35%, respectively. Following this study, Wang, Zhou, and Zhou (2012) estimated the direct rebound effect for China's national passenger transport for the years 1994–2009 as 96% by using AIDS model. Small and van Dender (2004) worked on panel data of all USA states during 1961–2001 for USA’s personal transport and estimated the short-term and long-term direct rebound effects as 4.5% and 22% respectively**.** Frondel, Peters, and Vance (2007) made a similar study with panel data (1997-2005) for Germany's household personal transport and concluded that the direct rebound effect was between 56% and 66%. Frondel, Ritter, and Vance (2012) investigated heterogeneity of the rebound effect in the private transport sector. The data was obtained from household travel diary and panel estimation data based on the German Mobility Panel in Germany for the years between 1997 and 2009. Panel data estimation and the quantile regression approach was used to calculate the rebound effect and it was found that the average rebound effect was between 57% and 62%. It was also concluded that fuel taxes would have to keep its influence to reduce the rebound effect provided that it is coupled with other measures. For example, lowering payroll taxes would be beneficial to reduce the burden on poor citizens in order to keep the balance. Moreover, the results obtained from quantile regression suggests that households with high vehicle mileage has a smaller rebound effect when compared to households with low vehicle mileage according to fuel price elasticities.

Wang and Lu (2014) focused on freight transport in whole, eastern, central, and western China. The direct rebound effect was estimated by using panel data of 1999 to 2011, concluding that the long-term corresponding magnitude of the direct rebound effect for whole, central, eastern and western China was 51%, 84%, 80% and 78% respectively. Zhang et al. (2015) studied road passenger transport in China and estimated the direct rebound effect by means of a dynamic panel quantile regression approach. The data from 30 provinces from 2003 to 2012 was used in the study. It was found that short-term and long-term direct rebound effects were 25.53% and 26.56% on average. Gillingham, Jenn, and Azevedo (2015) concluded that fuel economy standards and other policies are causing a short-term medium size rebound effect. Odeck and Johansen (2016) compared the error correction model and the dynamic model for the Norwegian cities of Oslo, Bergen, and Trondheim. According to their results, it was concluded that the data used in the study was more appropriate for a dynamic model and the rebound effect was 26% in the short-run while it was 36% in the long run.

Galvin (2016) studied the rebound effect in the transport sector by means of a speed factor for an internal combustion engine pick-up van with automatic transmission and a plug-in electric car. According to the results, internal combustion engine cars had rebound effect stemming from the automatic transmission and electric cars had a 20.5% rebound effect. Steren, Rubin, and Rosenzweig (2016) calculated the rebound effect for more efficient cars as 40% after relevant policies were implemented. Vivanco, Kemp, and Voet (2015) made a study on the environmental rebound effect of seven different transport eco-innovations in Europe by means of the environmental rebound effect via Dynamic IPAT-Life cycle assessment and also on environmental superiority claims of these eco-innovations by the comparison of the macro-level scenarios (with and without innovation). The study indicated that catalytic converters, direct fuel injection systems, and park-and-ride facilities were environmentally superior compared to other innovations that focused on diesel engines in passenger cars, high-speed rail, a car-sharing schemes, and bicycle-sharing systems. Moreover, an environmental rebound effect was found to be high.

De Borger, Mulalic, and Rouwendal (2016) studied the rebound effect for Danish car transport. They used data collected from individual households on fuel efficiency, car use and a car in demand model and estimated the rebound effect to be between 7.5 and 10%. Zolnik (2016) made a study on the rebound effect in the transport sector with respect to increasing road capacity and fuel efficiency by means of the National Household Travel Surveys data of 2001 and 2009. It was concluded that there was a rebound effect in fuel economy. West et al. (2017) showed that consumers tend to buy fuel efficient, small, and less-performing cars as a result of fuel economy restrictions. Fukui and Miyoshi (2017) made a study on an increase in fuel tax for US air transportation and concluded that a positive rebound effect could prevent a decrease in jet fuel consumption and the rebound effect could be higher for larger carriers in the long run. Mishina and Muromachi (2017) focused on a study for hybrid electric vehicles by means of the data for 2010 – 2013 and Modified Laspeyres Index (MLI) decomposition method in four different regions of Japan, namely Kanto, Kinki, Chugoku, and Tohoku. The rebound effect was 5-20%, 12-18%, 13-22% and 12-20%, respectively for those regions.

Moshiri and Aliyev (2017) conducted a study on personal transport in Canada. The rebound effect calculated by AIDS, QAIDS models and SUR method from gasoline, other energy products and energy product data for the years 1997 – 2009 were found to be between 63% to 96%. Chai et al. (2016) studied the rebound effect in China according to exogenous efficiency policies and technological progress based on 1985-2013 data and concluded that China’s rebound effect was much more than those in the USA. Ajanovic, Haas, and Wirl (2016) concluded that CO_2 standards has not revealed the expected theoretical impact on the reduction of CO_2 emissions stemming from passenger transport in the EU because of the rebound effect. Moreover, they also concluded that the rebound effect is a consequence of service price elasticity.

Vivanco and Voet (2014) focused on the microeconomic environmental rebound effect for plug-in hybrid electric, hydrogen fuel cell cars and full-battery electric in Europe. The plug-in hybrid electric environmental rebound effect was between 82% and 138%. However, the results of the environmental rebound effect of hydrogen fuel cell and full-battery electric cars were highly negative. The reason for these highly negative results was the capital costs of hydrogen fuel cell and full-battery electric cars. Stapleton, Sorrell, and Schwanen (2017) investigated factors that have an effect on car travel in the UK since 1970 and showed that the rebound effect had increased since then and was 26% on average. Galvin (2017) studied the rebound effect stemming from an increase in average speed in 2014 and 2015 by trial sessions on 10 different 30 Formula 1 Grand Prix vehicles (each 3 times).

Llorca and Jamasb (2017) calculated the rebound effect as 4% for road freight transport in EU-15 countries for the years 1992 to 2012 by employing an energy demand function by means of a stochastic frontier analysis approach. Zhang and Lin (2018) calculated the rebound effect for China's road transport system over the sample period 2003–2013 between 7.2% and 82.2% by using a city-level dataset and a stochastic frontier rebound effect model. Adom, Barnor, and Agradi (2017) focused on road transport energy demand using the Pooled Mean Group Estimate and the panel fully modified ordinary least squares (OLS) in West Africa. The results showed that the long-run rebound effect for price elasticity was 28.6% while the short-run price elasticity in Ghana and Cameroon, respectively, had a direct upper bound rebound effect of 8.6% and 6.1% for aggregate road energy and 4.9% and 8.3% for gasoline demand. Ghoddusi and Roy (2017) developed a rebound effect model explaining both the demand and supply sides of the energy sources and used this model for different policies for the transportation sector. It was concluded that the supply-side was an important element in estimating the rebound effect.

Aune et al. (2017) focused on the feedback mechanisms for fuel efficiency improvements in the transport sector, such as the rebound effect, carbon leakages, and the “green paradox”. The model developed in this study showed that the rebound effect has an important effect on the transport sector as well as on other sectors because of the lower oil prices. Frondel and Vance (2018) used an instrumental variable approach in order to calculate the price of the fuel and elasticity of efficiency by using data of households travel habits in Germany. It was found that the magnitude of the fuel price elasticity was lower than fuel efficiency elasticity, which showed that efficiency standards counterbalance the impacts of reduced vehicle use because of the fuel taxes. The magnitude of the rebound effect was 67-69% by fuel efficiency elasticity. Moreover, it was stated that due to the rebound effect, 69% of energy-saving would be lost because of increased driving.

Zhang and Lin (2018) analysed the direct rebound effect in China's road transportation system between the years of 2003 and 2013. According to stochastic frontier model by means of the nation-wide dataset on the city-level, the magnitude of the direct rebound effect ranged from 7.2% to 82.2%. It was concluded that the rebound effect can be lowered by imposing carbon taxes since the rebound effect was negatively associated with retail fuel prices. Moreover, it was concluded that there was a huge potential for a fuel efficiency increase in eight economic regions of China. Moreover, the results indicated that the average rebound effect increased from 15.4% to 48.2% and China's average fuel efficiency rose from 65.4% to 77.5% at the same time. The growth rate of the rebound effect was almost ten times quicker than efficiency improvement. Menon (2017) studied the direct rebound effect on the two-wheeler transport sector in India by using aggregate time series data. The direct rebound effect was calculated through the OLS method and found as a partial rebound of 25.5%. The data was obtained from the Centre for Monitoring Indian Economy, Ministry of Petroleum and Natural Gas and Open Government Data

Platform India. The article suggested implementation of policies like carbon tax, registration tax etc. to reduce the rebound effect in India in the long run. The study further claimed that just raising the fuel price may not be successful in order to reduce the rebound effect since disposable income, which increased purchasing power in India, increased compared to the past.

Zolnik (2018) studied additional freeway capacity versus additional arterial capacity and calculated the rebound effect. The travel and household data was gathered from the National Household Travel Survey between 2001 and 2008. Dynamic Panel Data method was used to calculate the rebound effect that was found as 3% for the short run and 11% for the long run. Weber and Farsi (2014) investigated the rebound effect for Swiss private transportation. Different from other studies, cross-section micro level data only for 2010 from Micro census on Mobility and Transport was used in this study. Moreover, for the first time, a Geographical Information System was used to record actual travelled routes that was stated as a very trustable source of information in this paper. Simultaneous equations model, which is seldom used for the estimation of the rebound effect, was applied in the study and three-stage least squares method was used to estimate the substantial direct rebound effect. The result was that there was a substantial direct rebound effect that varied between 75% and 81%. Also, OLS method was applied to the same data. As a comparison to 3SLS, OLS method provided lower direct rebound effect results and was evaluated with the possibility of underestimating the magnitude of the direct rebound effect. As a policy suggestion, this paper concluded that technological improvements may not be effective for reducing the rebound effect and there was a need to search for alternative policies. However, because of the universal direct democracy in Switzerland, it was very difficult to impose publicly accepted taxes for private transport.

Kim (2017) focused on telecommuting by means of the 2006 Household Travel Survey data. Results indicated that there was a double rebound effect stemming from the telecommuting of the household head. Dimitropoulos, Oueslati, and Sintek

(2018) studied the effect of direct rebound in road transport subject and used meta-analysis approach, which consisted of 74 primary studies that represents several countries (US, EU countries, Israel etc.). Meta-regression analysis gave hints to understand differences between countries according to variables like gasoline prices, income and population density. It was found that the rebound effect was roughly 10-12% in the short-run and 26-29% in the long-run. Also, it was stated that the variations of the estimations change with the elasticity used and the types of the data. Furthermore, some demographic attributes such as population density and GDP per capita correlate with the rebound effect results. Sorrell and Stapleton (2018) investigated the long-run direct rebound effect in the road freight in UK by using aggregate time-series data through the years from 1970-2014. In total, 25 different model specifications and three different elasticities were used to examine the rebound effect. The results of the most robust model estimations indicated that the direct rebound effect was 49% and the mean of the all model estimations was calculated as a 61% direct rebound effect. 61% of rebound effect was around two times as large as the consensus estimate of direct rebound effect in this area.

Liu, Liu, and Lin (2018) studied the rebound effect in the transport sector in China between the years 1981 and 2015. Trans-log model was used to measure the effect of the technological progress and for the calculation of the rebound effect while ridge regression method was used to find model parameters. The data was gathered from "quarterly and regional GDP accounting program" that was published by China National Bureau of Statistics. The rebound effect was found as 78.3% for the period 1981-1990, 53.6% for the period of 1991-2000 and during 2001-2015, it was estimated as 71.3%, which provided an average of 68.3%. Increase in R&D investment, adjustment of China’s transport structure and limitations on fuel consumption for passenger cars were policy recommendation drawn by the study. Ruzzenenti (2018) developed an alternative method to elasticity to calculate the rebound effect for freight transport by means of the complex network theory and statistical mechanics of networks. The rationale behind this study was that elasticity might be misconceived or it could be misleading. However, it was not easy to apply this method to private transport because there were other factors rather than distance for decision-making. Li, Li, and Xie (2018) used AIDS model and I-O link between sectors and the data for 31 Chinese provinces between 1994 and 2015. The rebound effect was estimated to be more than 100% for transportation in rural China. To eliminate substituting behaviours, like using more transport services after energy efficiency improvements, it was recommended to put in practice policies like eliminating fossil fuel subsidies and promoting energy-saving lifestyle.

Czepkiewicz, Heinonen, and Ottelin (2018) investigated the reasons behind the negative relationship between urbanity and GHG from daily travel. Results showed that the rebound effect was among the most frequent clarifications while others are the compensation hypothesis, urban lifestyles, access to transport infrastructure, socio-psychological characteristics and social networks. Coulombel et al. (2018) studied the results of ridesharing and calculated the rebound effect that occurred through ridesharing. Transport land-use model was used in order to calculate the rebound effect in Paris, France. The data was gathered from census and fiscal data of the year 2015, which included demographic input and the transportation data gathered from road network and public transportation system. When travel time and trip distance were computed, it was concluded that the rebound effect was lower than the default model. In addition, CO_2 emissions were lowered because of the modal shift.

Zhang et al. (2018) studied the impact of Chinese government's The Central Rise Policy for the road sector in 2006. The CO_2 rebound effect was measured by a combination of LA-AIDS model and simulation method for six central provinces of China. Data was obtained from Chinese Statistical Yearbooks for 2002-2015. The CO_2 rebound effect was 4.70% between 2002 and 2005 and it was observed to be 8.01% between 2006 and 2015. This was explained by an indirect CO_2 rebound effect. It was recommended that the Chinese government should take additional actions while putting in practice the new Central Rise Policy to avoid a CO_2 rebound effect. Bauer (2018) investigated the effect of battery electric vehicles on consumer choice of purchasing vehicles in Norway. Surveys were conducted on 4,405 new car owners through an online platform. Multivariate logistic regression, correlation analysis, and linear regression methods were used. The rebound effect was calculated as 17.7%, which means 17.7% of battery electric vehicles would not be bought in case there was no battery electric vehicle in the market. Wang, Quiggin, and Wittwer (2019) studied the rebound effect of regulations made in Australia about the light vehicles fuel standards. CGE was used as the method while the theoretical framework was provided by the ORANI-G model. I-O table of years 2012-2013 and behaviours of economic agents were used as data source. The calculations were done for the year 2025. The direct rebound effect was calculated as between 25% and 29% while the economy-wide rebound effect was calculated as 49.99%.

Taiebat, Stolper, and Xu (2019) investigated the rebound effect for connected and automated vehicles by employing a microeconomic model of vehicle miles travelled choice under time and income constraints to United States National Household Travel Survey's fuel cost data in 2017. It was revealed that high income households' elastic demand was higher and all the households were more responsive to time costs than to fuel costs. There were six different scenarios developed and according to these results, there was a backfire effect especially for the high income group. Behl et al. (2019) used the Focused Information Criterion and quantile regression methods for quantile regression analysis to show that the direct rebound effect was heterogeneous in mobility demand for different percentiles of the distribution of distance travelled in Germany. The rebound effect was between 18.87% and 61.23%. Hamamoto (2019) calculated the direct rebound effect for hybrid electric vehicle usage by means of a regression model for Japan. The direct rebound effect was calculated as 262% or 393%, which signifies a backfire effect. Langbroek, Franklin, and Susilo (2018) concluded that there is rebound effect for active drivers in the Greater Stockholm region according to an experiment conducted in one day.

Pakusch et al. (2018) pointed out that despite sustainability policies, unforeseen rebound effects may occur from shifts in travel patterns.

Miyoshi and Fukui (2018) studied the rebound effect of jet fuel prices for air transport in Europe by the data obtained from the Association of European Airlines between the years 1986 and 2013 and three different equations were modelled for traffic demand, aircraft and fuel efficiency. The short-run rebound effect was 2.9% for 1986–1999 and 2.1% for 2000–2013 while it was 49% for 1986–1999 and 19% for 2000–2013. Li, Li, and Xie (2018) estimated the rebound effect for transportation in China's rural areas to be over 100% by the AIDS model. Slutsky decomposition was employed for income and substitution, which showed that the rebound effect was higher for poor households via income channels while it was higher for richer households via substation channel.

Transportation is the most widely studied area of the rebound effect. These studies started mainly in the 1990s. The reason behind the number of studies in transportation could be the amount of energy consumed in this sector. As an example, 29% of the energy consumption of U.S belongs to transportation (U.S Energy Information Administration 2018) and 34% in the EU (European Commission, 2019). Although there are many regulations about the environment and energy efficiency, the aimed efficiency might not be delivered due to the rebound effect.

Examination of the literature in terms of countries shows that most of the literature consists of articles with studies for USA (Blair, Kaserman, and Tepel, 1984; Mayo and Mathis, 1988; Gately, 1992; Greene, 1992; Jones, 1993; Greene, Kahn, and Gibson, 1999; Small and van Dender, 2004; Haughton and Sarkar, 1996; West, 2004; Puller and Greening, 1999; Goldberg, 1996; Winebrake et al., 2015; Leard et al., 2015), European countries, namely Germany (Frondel, Ritter, and Vance, 2012; Frondel, Peters, and Vance, 2007; Frondel and Vance, 2018; Behl et al., 2019), UK (Walker and Wirl, 1993; Stapleton, Sorrell, and Schwanen, 2017), Sorrell and

Stapleton, 2018), Denmark (De Borger and Mulalic, 2012; De Borger, Mulalic, and Rouwendal, 2016) and Norway (Odeck and Johansen, 2016; Bauer, 2018) as well as China (Wang, Zhou, and Zhou, 2012; Wang and Lu, 2014; Zhang et al., 2015; Zhang and Lin, 2018; Liu, Liu, and Lin, 2018; Li, Li, and Xie, 2018; Wang et al., 2012). With the exception of China, there were very few studies that were conducted in developing and underdeveloped countries, but recently there were studies conducted in India (Menon, 2017) and in some Western African countries (Adom, Barnor, and Agradi, 2017). As it was previously mentioned by Milne and Boardman (2000) and Baker, Blundell, and Micklewright (1989), the rebound effect is needed to be closely focused in developing countries since they are more prone to offsetting the gains of energy efficiency. Energy efficiency activities are well regulated in for instance EU countries compared to developing countries since transportation is one of the main contributors to pollution. Thus, EU countries would put importance on the rebound effect because they would like to see the return on their budgets given to energy efficiency projects (Llorca and Jamasb, 2017). This phenomenon is supported by means of the rebound effect studies targeting EU countries.

Most of the articles were on road freight and passenger transport. However, most of the transportation mediums were not investigated, such as marine transport, rail transport, and aviation. Studies focusing on these areas are very few. Such an outcome might be explained through the share of the mediums in total energy consumption. Passenger vehicles have a great share in total energy consumption (Energy Information Administration (EIA), 2016) and it is more widely studied than others. Furthermore, it may also be incorporated with the different sectoral characteristics of the transportation mediums. For instance, any road vehicle is more likely to be owned by households in comparison to aviation or rail transport vehicles, which require a change in behavioural characteristics. Although energy consumption of aviation and marine transport are not as high as road freight or passenger transport, the GHG emissions of marine and aviation transport was 27% of GHG emissions in EU-28 countries (European Environment Agency, 2018). Because of relatively high GHG emission, these transportation mediums would be recommended to be studied in the future.

Econometric methods are dominant over any other methods in the transportation rebound effect literature. Methods of OLS, GLS, two-equation demand model, AIDS, FMOLS, 3SLS, quantile regression approach, error correction model, double logarithmic model, 2SLS, stochastic frontier analysis approach, SUR method, QUAIDS, simultaneous equations model, dynamic model, ridge regression method, instrumental variable approach, meta-regression analysis, multivariate logistic regression, which all carry the characteristic of econometric methods, were used to calculate the rebound effect in transportation. There is also the Modified Laspeyres Index (MLI) decomposition that is not econometrics but used by Mishina and Muromachi (2017).

The estimated rebound effect magnitudes are generally varying between 0% and 80% although there are some exceptions for China as mentioned by Wang, Zhou, and Zhou (2012) and Li, Li, and Xie (2018). Also, there are some studies which are partially more than 80% due to constraints or the provinces that are targeted in the studies (Wang and Lu, 2014; Zhang and Lin, 2018).

2.1.3. Direct Rebound Effect for Other Sectors

There are different areas where the direct rebound effect is studied. Werner (2015) studied the rebound effect in ICT sector by means of data collected from EU27 countries and statistical analysis. The magnitude of the rebound effect was varying for different countries. The rebound effect should be taken into account in the costs of advantages of ICT development, such as increase of quality of life, easier social communication, and better, new goods and services, which facilitate daily life and work. Havas et al. (2015) studied the rebound effect of solar hot water and photovoltaic systems installed in an Australian town of about 9,000 households. The rebound effect was calculated as 15% for electricity usage by adopters of photovoltaic systems in this study by logistic regression analysis. Lin and Xie (2015) focused on the rebound effect in the food industry. The direct rebound effect was found to be 34.39% by means of an econometric model based on the trans-log cost function. The data between 1980-2012 on the amount of input factors, the gross output value and their prices was obtained from China Statistical Yearbooks, China Industry Economy Statistical Yearbooks, China Energy Statistical Yearbooks, China Urban Life and Price Yearbooks, Almanacs of China's Finance and Banking, and the CEIC database. This was the only study of the rebound effect in the food industry. Buhl et al. (2017) focused on the rebound effect for living labs. The rebound effect was not calculated and four conclusions were drawn according to the obtained results. The first conclusion was that technological and behavioural triggers should be taken into account to monitor and mitigate the rebound effect. Second, the indirect effect is a crucial part of the product or service rebound effect estimation in living labs. Third, product and service interventions are applicable to living labs as a conclusion which was drawn from the second one. Lastly, time use, which is stemming from user behaviour, is an important aspect in monitoring and mitigating the rebound effect.

Saunders (2014) studied sustainable consumption and commented that efficiency gains related to the usage of resources would involve a rebound effect that could highly reduce, or even reverse, the consequent savings of natural resources. Takase, Kondo, and Washizu (2005) studied household consumption patterns and introduced a simple method to evaluate an income rebound effect (direct). It was concluded that for more sustainable consumption patterns, the income rebound effect should be taken into account. Yang and Jianglong (2017) estimated a rebound effect of China's electricity generation sector (from fossil fuel) by means of joint dynamic OLS and seemingly unrelated regressions were found as 11.6%. Galvin (2015) studied the rebound effect of ICT on social practices and social-technical structures. Al Irsyad and Nepal (2016) focused on street lighting in Jakarta/Indonesia and concluded that the rebound effect had a negative effect on the government's policies related to efficiency in street lighting. Energy tax, environment tax and energy subsidy reduction were the policies that were aiming at decreasing the rebound effect by increasing energy prices. However, Indonesia's focus was on decreasing energy prices and increasing public infrastructure. Therefore, it was more appropriate to use a new additional tax for the improvement of energy efficiency in Indonesia. Buhl and Acosta (2016) made a study on the impact of decreasing the working hours on ecological sustainability, enhanced life satisfaction and social equity. The results showed that decreasing working hours had a negative effect on ecological sustainability because of the rebound effect. Grant, Jorgenson, and Longhofer (2016) focused on the rebound effect stemming from energy efficiency activities for the power sector. They used data on CO_2 emissions from different countries and the results showed a positive rebound effect. Lin and Tian (2016) used the dynamic OLS and seemingly unrelated regression methods for the first time based on the trans-log cost function to estimate the rebound effect in China's light industry with a result that was found to be 37.7%.

Hill, Tajibaeva, and Polasky (2016) made a study on the fuel market rebound effect. Decrease in the price of low carbon fuel alternatives could increase the fuel consumption and this would have a negative effect on climate mitigation strategies. The study focused on United States Renewable Fuel Standard and concluded that if the rebound effect on the Renewable Fuel Standard would not be considered, the Renewable Fuel Standard could reduce GHG emissions. However, when the rebound effect would be considered for the results, it would be noticed that the Renewable Fuel Standard actually increases GHG emissions while all fuel GHG intensity targets are met. Schleich, Mills, and Dütschke (2014) estimated the direct rebound effects for moving to more energy-efficient compact fluorescent lamps or light-emitting diodes from incandescent lamps or halogen bulbs. Data from a large national survey of German households and econometric methods were used for estimation. The total rebound effect was ranging between −2 and 23%. Liu et al. (2016) calculated the rebound effect for the household air conditioner as 67% in China where "The Air Conditioner Energy Efficiency Standard" was implemented. The study introduced the life cycle based method for the first time.

Georges et al. (2017) made a study on residential heat pumps which provide a direct control flexibility service and concluded that power modulation service had a rebound effect. Nilsson, Bergquist, and Schultz (2016) identified the rebound effect as one of the types of the negative spill over. Baum and Gross (2016) pointed out that there is a relationship between sustainability and the rebound effect. Sarr and Swanson (2016) concluded that transfer of resource-conserving technologies to the developing countries would foster further use of the natural capital. Kemp, Worden, and Owen (2016) showed that social risk was related to rebound effect dynamics in the global mining industry. Galvin and Gubernat (2016) argued that Schatzki's practice theory approach could be beneficial for the wide scale measure of the rebound effect in the society and made a case study with the data collected from Germany. According to the results of the case study, it was concluded that Schatzki's method was 100% higher than the traditional methods. Wang and Lin (2016) indicated that electricity subsidy reform would decrease a 20% rebound effect in residential electricity consumption. The electricity subsidy reform was implemented to control increasing electricity demand stemming from rapid economic growth.

Deng and Dong (2016) made a study on the coal efficiency increase in China's Shandong Province by means of the impulse response function and concluded that there was a rebound effect in the short-run. Copiello (2016) investigated three paradoxes that was accounted for the CO_2 emission reduction resulting from energy efficiency applications and concluded that there was a relationship between the rebound effect and third paradox materials used for energy efficiency applications that were energy intensive. Shao and Rodriguez-Labajos (2016) made a study on reduction of working hours by applying a dynamic panel regression approach on the data collected from 55 countries between the years 1980-2010. They concluded that there is a relationship between environmental effects and working hours. These results were not applicable for developing countries since workers in developing countries tend to work over time or to find a part-time job. Lin and Zhao (2016) calculated the rebound effect for China's textile sector as 20.991% by using the Morishima elasticities of substitution combined with asymmetric energy prices, trans-log cost function, and other econometric methods. Poon (2015) made a study on existence of expected financial risk derived from the Green Deal programme that was launched by the UK Government by taking into account the rebound effect. According to the results, it was concluded that by not taking into account the rebound effect, 14% of the total 1787 sample measures would not be able to pay-back the investment. By taking into account the rebound effect, the repayment period for lighting, building fabric and heating and cooling would extend by 13%, 70% and 23.3%, respectively. Airehrour et al. (2016) indicated that the rebound effect would play a crucial role in the "Internet of Things" area and suggested to collect a wide range of data for the ICT sector and employ that data in IPAT analysis.

Liu and Lin (2016) implemented an energy-environmental non-radial directional distance function on China's building construction industry to measure the effect of technological advances on energy efficiency. Moreover, they concluded that 21.8% of the energy conversation was offset due to the direct rebound effect. Lin and Tan (2017) calculated the energy rebound effect for China's six most energy intensive sub-industries as 90.75% by means of the latent variable approach. Zhang and Peng (2017) calculated the average rebound effect for Chinese household's electricity consumption as 72%. Du, Li, and Bai (2017) studied China's construction industry between 1990 and 2014 and calculated the energy rebound effect as 59.5%. Lin, Chen, and Zhang (2017) used Logarithmic Mean Divisia Index method and the total factor productivity model to estimate energy rebound effect for China's nonferrous metals industry over the period 1985–2014 and the rebound effect was found to be approximately 83.02% with a downward trend. Qiu and He (2017) introduced a new rebound effect called “pollution rebound effect” and focused on air pollution in China derived from motor vehicles. They investigated the effectiveness of the Chinese green transport policies and calculated the pollution rebound effect as −41.05% for the short-term and −24.6% for the long-term by using time-series data from the period 1984-2014. The negativity of the rebound effect was an indication of the non-existence of the direct rebound effect, thereby proving the effectiveness of the Chinese green transport policies.

Deng and Newton (2017) made a study for photovoltaic (PV) installations in Sydney and concluded that the rebound effect was detreating 20% of the carbon emission reductions from solar PV. Portal and Laureano (2017) investigated whether the Brazilian Allowance for Corporate Equity (Allowance for Corporate Equity type - type system) reduced the debt tax bias. It was concluded that the interest on equity treatment increases the debt tax bias, leading to a rebound effect stemming from this policy on the risk-taking behaviour and corporate capital structure. Zink and Geyer (2017) argued that circular economy activities would lead to an increase in the overall production and as a result, the rebound effect would occur. In this study, a new rebound effect called circular economy rebound effect was defined.

Labidi and Abdessalem (2018) analysed the size of the direct rebound effect of electricity use in Tunisian households. The data was gathered through National Institute of Statistics and The National Environmental Satellite, Data, and Information Service of Tunisia. The direct rebound effect was calculated as 81.7%. The findings indicated that if subsidies of electricity was cancelled, effects of the direct rebound effect would be lightened. Double-log functional form was used to estimate price elasticicities. Ouyang et al. (2018) used the data gathered from 14 cities between 2003-2013 in Yangtze River Delta urban agglomeration from Chinese Statistical Yearbooks. The direct rebound effect was analysed through dynamic OLS and seemingly unrelated regression processes. The direct rebound effect was calculated as 40.04%. It was concluded that there was an obvious substitute relationship between energy and capital factors and energy and labour factors. Wang et al. (2018) used Cobb-Douglas production function and Logarithmic Mean Divisia Index decomposition model to calculate the rebound effect of energy consumption in sectors of agriculture, animal husbandry, forestry, fishery, industry, construction, transportation, warehousing and postal services, wholesale, retail and lodging, and catering in China from 1991 to 2014. The results showed that the direct energy rebound effect was increased from 64.05% in 1991 to 990.54% in 2001 and then decreased to 6.56% in 2014. Inglesi-lotz (2018) applied decomposition of CO_2 emission to BRICS countries (Brazil, Russia, India, China, and South Africa) from 1990 and 2014. The results of the decomposition showed that since energy intensity was revealed to be the negative contributor to CO_2 emissions (as energy intensity decreased emissions continue increasing), the rebound effect exists for South Africa from 2008 to 2014.

Amjadi, Lundgren, and Persson (2018) studied the direct rebound effect for the fuel and electricity demand in Swedish heavy industry. Stochastic input demand frontier was used for the calculation of the rebound effect and firm-level unbalanced panel data was applied from four different energy intensive sectors for the years between 2000-2008 (iron and steel, pulp and paper, chemical, and mining sectors) which was provided by Statistics Sweden. The results showed that there was a remarkable rebound effect in all sectors for both fuel and electricity. It was found that the average electricity rebound effect was around 76% in the chemical sector, 86% in the iron and steel sector, 84% in the pulp and paper sector and 82% in the mining sector. Furthermore, it was estimated that the average fuel rebound effect was around 65% in the iron and steel sector, 64% in the pulp and paper sector, 62% in the chemical sector and %58 in the mining sector. It could be drawn from these results that energy efficiency improvements require additional policy measures to eliminate the rebound effect. Pohl, Hilty, and Finkbeiner (2019) investigated whether life-cycle assessment (LCA) case studies on environmental effects was taken into account for ICT usage. By examining 25 case studies, it was concluded that user-related effects like rebound had not been taken into consideration in LCA analysis.

Mizobuchi and Takeuchi (2019) studied the rebound effect for change of air conditioners with more energy-efficient ones in households in Japan and made the calculation for summer and winter as 7.87% and almost 100%, respectively. The higher magnitude in winter was explained to be the result of a power-saving effect, which is switching air-conditioners.

Chen et al. (2018) calculated the direct rebound effect for China's manufacturing industry with trans-log cost function and expanded the energy-cost function with an asymmetric influence constraint of energy price by taking into account the asymmetric energy price. The direct rebound effect was calculated as 44.2% for the years 1991 and 2013 and data was obtained from the China Statistical Yearbook, CEIC database, China Energy Statistical Yearbook, and the BP Energy Statistical Yearbook. The policy recommendations were: (1) energy prices which were underestimated should be taken into account externally, (2) Chinese manufacturing industry should move to a new development model from a traditional one which was simple and sizeable and (3) the Chinese government should imply policies to provide assistance for the Chinese manufacturing industry to reduce energy consumption. Lütolf et al. (2018) pointed out that demand-response aggregators, which are the source of active power reserves and have a role in frequency control, would yield a rebound effect when an increase is observed after the power reserve is activated. Scenarios with forced outages, ramping behaviour, and historical reserve activations were investigated and it was concluded that the rebound effect had a very low effect in normal operations while it led to power oscillations, which caused instabilities in the entire power system meaning severe, non-decreasing power oscillations in the power system. Moreover, it was shown that the rebound effect has a positive effect on the Area Control Error and Automatic Generation Control (when ramping) and negative effect on Automatic Generation Control when there was a forced unit outage.

Makov and Font Vivanco (2018) studied the rebound effect for smartphone reuse for the first time and calculated the rebound effect to be 29% on average ranging from

27% to 46% by a household demand model and environmentally-extended input output analysis. The study extended to other regions under different consumer behaviour patterns and it was seen that there was backfire effect. The data for economic savings based on actual resale prices was obtained from 6,500 sales on eBay.com and the degree of imperfect substitution of new and used smartphones were determined by means of survey data. The results that were obtained were questioning circular economy activities. Berbel, Gutiérrez-Martín, and Expósito (2018) focused on increasing irrigation efficiency in water scarce areas and pointed out that a potential rebound effect may be due to irrigated area expansion, crop mix intensification, market forces and agricultural policy but not to irrigation efficiency. Aoyang and Hao (2018) investigated the impact of new irrigation technologies in USA by means of data obtained from various resources, including spatially-explicit soil characteristics from the SSURGO soil survey on the website of the USDA Natural Resources, wells and water rights from the Water Information Management and Analysis System maintained by the Kansas Water Office Conservation Service and Weather data from the North America Land Data Assimilation System maintained by NASA. Data was obtained from these sources for 1991 to 2010 and a Dynamic Joint Estimation Framework was used for modelling. The rebound effect was higher for the farmers with greater water rights. It was concluded that 10% decrease in water rights resulted in a 5% decrease in water use in the long-run. Moreover, when the majority of the water rights was reduced, Low Energy Precise Application's rebound effect diminished by 15.4%.

Su (2019) studied the key determinants affecting the household's appliance-specific electricity consumption by employing regression models. The results showed that the determinant factors affecting household electricity consumption are household indoor floor area, income and owning the house. In addition, the direct rebound effect of various electricity-based appliances was also obtained by means of the difference of electricity consumption between appliances with and without an energy efficient label. It was found that the rebound effect for air conditioners, refrigerators, lighting and TV were 72%, 70%, 11% and 3%, respectively. Wang, Wen, and Xie (2018) investigated the relationship between technical progress and the energy rebound effect in the industrial sector. The rebound effect was evaluated by using a trans-log cost function model employed to China's iron and steel industry over 1985-2015. It was found that the estimated average energy rebound effect was 73.88%. The high level of rebound effect was due to relatively cheap price of energy input in China's economy. Thus, energy conservation policies should not only focus on technical/efficiency progress but also to employing energy price reform.

Alvi, Mahmood, and Nawaz (2018) studied the direct rebound effect of household electricity consumption in Pakistan. Econometric co-integration and error correction model was applied to the time series data from 1973 to 2016 to estimate the rebound effect. It was found that the short run rebound effect was 42.9% and the long run rebound effect was 69.5%. Li, Sun, and Wang (2018) focused on the rebound effect in energy consumption, which was caused by technological progress in China in the regions of Beijing, Tianjin, Hebei. The Cobb-Douglas production function and neoclassical growth model were used as the model framework. I-O data of the three regions for the years between 1996-2015 was used as data source. There were many rebound effect estimations with relation to technology and energy savings for each region. It was found that especially for the Hebei region, there was a growth trend for the rebound effect for that period and the average rebound effect of Hebei was higher than other regions. In the long term, it was estimated that the rebound effect would significantly offset the energy savings in the Hebei region. Li et al. (2017) focused on the Chinese textile industry, which was distributed to three parts namely, the manufacture of textile wearing, the manufacture of textile and apparel, and the manufacture of chemical fibres. A decomposition model was used for this study and data was obtained from The National Bureau of Statistics of China and the Ministry of Environmental Protection of China for the period between 2001 and 2014. The rebound effect was calculated in terms of water environmental stress and it was shown that it rose from 2002 to 2011 and diminished between 2012 and 2014. The existence of a rebound effect could be interpreted taking into account that waste water treatment was not as effective as expected.

Wang, Zeng, and Liu (2019) studied the rebound effects from technological improvement in various economic sectors in China. A panel quantile regression approach was used with panel data covering the years 2001-2013. The rebound effects of CO_2 emissions were estimated through the relationship of various sectoral technological improvement and CO_2 emissions. It was found that heavy and light industry sectors contributed to CO_2 rebound effects, while service and construction sectors contributed to CO_2 prebound effects. Foell (2019) focused on residential energy systems of five generations of the Hari family, so the sample size was only five. Retrospective bottom-up simulation was used to estimate end-use energy for each consumption technology. The results revealed that energy rebound effect had become more obvious with the availability of land, resources and energy availability. Lin and Lin (2020) focused on heating industry for China's energy conservation strategy. A trans-log production function was established incorporating asymmetric energy price decomposition. A seemingly unrelated regression method was employed and the results showed a 60.04% direct energy rebound effect. Liu, Du, and Li (2019) calculated the direct rebound effect for China's industrial sectors by means of the demand elasticity of useful energy service with respect to energy service price. However, they improved this method and decomposed the direct rebound effect into substitution and output. The result was a 37% direct rebound effect and the substitution and output's contribution was 13.1%.

Muñoz et al. (2019) studied the rebound effect for a waste water treatment plant and the price rebound effect was calculated for the THERBIOR pilot plant as 86% which was due to low price of THERBIOR. Lunacek et al. (2018) focused on the effect of electric water heater control on the grid via two strategies for Immediate Load Control and Uninformed Delayed Control. The rebound effect for Immediate Load Control was higher and between 0 and around 170% and it was between 0 and around 40% for Uninformed Delayed Control by a co-simulation framework in

USA. In addition to the above, Lu et al. (2018) investigated the rebound effect for China's textile industry for manufacture of textile, manufacture of textile wearing and apparel and manufacture of chemical fibres. The overall rebound effect was the sign of an amplification of waste water discharge. While the rebound effect for manufacture of textile wearing and apparel was strong, manufacture of textile also had the same consequence of overall rebound and rebound for manufacture of chemical fibres was negative. Julien Walzberg, Merveille, and Cheriet (2018) calculated the rebound effect for human health, ecosystem quality and climate change endpoint categories as 6 %, 13 %, and 24 % by means of an Agent Based Model approach for 100 Canadian households. Bitaraf and Rahman (2018) studied the rebound effect ratio and duration for curtailed wind energy, Load Reduction Energy Ratio and demand response for utilities with high wind energy penetration. The results revealed that demand response causes about a 10% reduction in the curtailed wind energy. De Zotti et al. (2018) used a Monte Carlo simulation study for demand flexibility for transmission system operator balancing services and estimated daily and strict rebound whose difference was -35%. The results was pointing out that overall flexibility provision was restricted by 35% in Denmark.

Bedoya-Perales et al. (2018) investigated the rebound effect for quinoa expansion in Peru and it was concluded the extension of the market since 2008 caused changes in land-use in Peru and technological improvement increased the number of companies in the country. Li, Liu, and Du (2019) focused on an increase in the energy rebound effect oriented to the market for China. Based on a panel data model, which was partially linear functional-coefficient, the energy rebound effect was calculated as 20% for 2013. Figge and Thorpe (2019) defined a new rebound type which was symbiotic rebound stemming from opportunity cost related to the circular economy.

While most of the studies on the direct rebound effect was focused on household space heating and transportation, there are also other studies covering different areas. In terms of economic sector/actor being examined, some studies try to estimate the direct rebound effect not only for households but also for other economic sectors such as industry, agriculture, and service.

For households, studies on the direct rebound effect, apart from heating and transportation, include those that analyse a given technological improvement for the rebound effect. Such studies focus on electricity use (Labidi and Abdessalem, 2018; Zhang and Peng, 2017; Alvi, Mahmood, and Nawaz, 2018), air conditioners (Mizobuchi and Takeuchi, 2019; Liu et al., 2016), household appliances (Su, 2019), solar PV and solar hot water installation (Deng and Newton, 2017; Havas et al., 2015).

Other than household-level studies, the industrial sector is the area that represents the most widely studied sector. Most of the studies in this field are conducted for China. Industry oriented studies differ in terms of the specific focus of the industry being analysed. Most of the industries are energy-intensive sectors. For instance, six energy-intensive industries are the focus of Lin and Tan (2017) while whole industrial sectors are studied in Liu, Du, and Li (2019). Chen et al. (2018) focused on the direct rebound effect for efficiency improvement in the manufacturing industry. Light industry is assessed in Lin and Tian (2016). Amjadi, Lundgren, and Persson (2018) analysed the heavy industries. Some other more specific industrial sectors that were examined are the textile industry (Lin and Zhao, 2016), nonferrous metals industry (Lin, Chen, and Zhang, 2017), construction industry (Du, Li, and Bai, 2017; Liu and Lin, 2016), coal industry (Deng and Dong, 2016), power generation (from fossil fuels) industry (Yang and Jianglong, 2017), iron and steel (Wang, Wen, and Xie, 2018), and food industry (Lin and Xie, 2015).

The agriculture sector is another sector being analysed for the direct rebound effect. The studies in this area are typically focused on the rebound effect from efficiency improvement of the irrigation system. Berbel, Gutiérrez-Martín, and Expósito (2018) and Aoyang and Hao (2018) focused on irrigation efficiency.

Other various sectors that can be found in the literature are the service sector, energy system, and various economic sectors. Various economic sectors (Wang, Zeng, and Liu, 2019) and energy sectors (Wang et al., 2018) are studied in addition to demand response (Bitaraf and Rahman, 2018; De Zotti et al., 2018).

The magnitude of the rebound effect for these studies is mostly between 0 and 1 while there are very few cases that shows backfire or super conservation.

Except for China, this area is only studied for Pakistan by Alvi, Mahmood, and Nawaz (2018) as a developing country case.

2.2. Direct and Indirect Rebound Effect

The combination of both direct and indirect rebound effects is addressed as the total micro-level rebound effects or simply total rebound effects **(**Hediger, Farsi, and Weber, 2018**)**. This part provides a comprehensive view of the literature on these effects.

Lenzen and Dey (2002) calculated the rebound effect for different income groups and food and heating sectors. Econometric methods were used with 1993-1994 Australian Household Expenditure Survey data in this study. According to their estimation, combined direct and indirect effect was between 45-123%. Brännlund, Ghalwash, and Nordström (2007) calculated the direct and indirect rebound effect for transport and heating with econometric methods corresponding to Swedish consumer demand data between 12.9 and 16.1%. Mizobuchi (2008) estimated the rebound effect monthly time-series data (1990-1998) of Japanese households on durable (partially used) and nondurable commodities. The combined direct and indirect rebound effect was estimated by involving capital costs and not involving them as 27% and 115%, respectively for food, heating and transport sectors. Nässén and Holmberg (2009) calculated the rebound effect between 5-15% with an equation called “price effect” using data from the Swedish Household Budget Survey, which was conducted for different goods and services split into income classes. Kratena and Wüger (2010) used national survey data and econometric methods for combined direct and indirect rebound effect for gasoline (86%), heating fuel (37%) and electricity (-38.5% - super conservation). Druckman et al. (2011) estimated combined direct and indirect for food, household thermostat and transport actions as 7%, 51%, and 25%. UK quarterly time series data from 1964 to 2009 were employed with econometric methods. Thomas (2012) calculated the combined direct and indirect rebound effect for electricity, natural gas, and gasoline in terms of primary energy rebound (21%, 27%, and 18%, respectively) and CO_2 rebound (19%, 29% and 19%, respectively) by means of I-O analysis. Murray (2011) estimated the combined direct and indirect rebound effect for household electricity conservation as 10% and reduced vehicle fuel consumption as 20% by means of econometric methods employed to Australian Household Expenditure Survey data.

Freire-González (2011) estimated the direct plus indirect rebound effect in the use of energy in households for Catalonia. Income elasticity was used to calculate the rebound effect and the results showed that it was 56.47% for the short-term and 65.31% for the long-term. Santos, Matias, and Abreu (2018) studied the energy efficiency and the rebound effect through the method of evolutionary algorithms. Through the algorithm, some possible future scenarios for the rebound effect and energy efficiency were created and the rebound effect was calculated via life cycle cost analysis method for the air conditioner and lightning. Chitnis et al. (2012) focused on direct and indirect rebound effect for UK households by means of the income elasticity and GHG intensity of 16 categories of household goods and services. The results showed that the rebound effect was between 5% and 15% for these measures like cavity wall insulation, loft insulation, condensing boiler, light-emitting diodes etc. Thomas and Azevedo (2013) estimated the indirect rebound effect for electricity, natural gas and gasoline by taking the direct rebound effect as 10% in terms of primary energy, nitrogen oxides, sulphur dioxide and CO_2.

Econometric methods were used for this estimation and the indirect rebound effect had a range between 4% and 43%.

Yu, Zhang, and Fujiwara (2013) conducted a survey for household energy consumption survey in 2010 in Beijing. Direct plus indirect rebound effects for air conditioners, clothes washers, microwave ovens, and cars were estimated as 88.95%, 100.36%, 626.58%, and 31.61%, respectively based on econometric methods. Murray (2013) estimated direct and indirect rebound effects for cost-saving 'green' consumption choices (vehicle fuel and household electricity) by using national survey data in econometric analysis for Australia. It was estimated that the rebound effect was between 4 and 24% for electricity and motor fuel conservation. Chitnis et al. (2013) estimated the combined direct and indirect rebound effects from seven measures that improved the energy efficiency of UK dwellings by means of econometric methods. The study employed quarterly time series data on aggregated UK household consumption expenditure over the period 1964-2009 and found out that the rebound effects was 10% in terms of CO_2 emissions, mainly stemming from an indirect rebound. Chitnis et al. (2014) estimated the direct and indirect rebound effect for domestic energy, vehicle fuel use, and food waste as 0–32%, 25-65%, and 66-106%, respectively, for the UK. National survey data with quasi-experiment methods were used in this study. Chitnis and Sorrell (2015) estimated the total rebound effect 41% for measures that improve the efficiency of domestic gas use, 48% for electricity use and 78% for vehicle fuel use for UK households. Time series data was taken from Consumer Trends, published by the UK Office of National Statistics for 1964–2013.

Freire-González (2017) conducted a study for EU-27 countries' household energy efficiency by means of a hybrid methodology of an econometric estimate, environmental extended I-O analysis and rebound effect-spending models. By using the GDP of all the countries, the rebound effect was calculated as 73.62% while the results of the calculation on half of the countries' GDP was 81.16%. Moreover, it was observed that some countries had more than 100% rebound effect, which was the backfire effect. Freire-González (2017) developed a new method for the calculation of the direct and indirect rebound effect. Raynaud et al. (2016) made a study on impacts of regional energy efficiency program applied in South Europe and provide incentives for reversible heat pumps together with insulation and/or solar thermal for heating water. A survey was conducted with 200 households, which are included in the Programme and by means of the statistical methods, it was concluded that the direct rebound effect was 22% while the indirect rebound effect was 31% for the households. Wang, Han, and Lu (2016) calculated the rebound effect for residential electricity consumption in Beijing. Moreover, the study reviewed the theory of the rebound effect measurement methods namely, a double logarithm energy demand model and an error correction model of the asymmetric demand responses of electricity price changes for the direct rebound effect and a seven-sector environmental energy-input–output (E-I-O) analysis for the calculation of the indirect rebound effect. The results for the long-term direct and indirect rebound effect was calculated as 46%-56% while the short-term direct rebound effect was 24% to 37%.

Freire-González et al. (2017) studied the rebound effect for households in Catalonia by I-O model. The results indicated that direct and indirect rebound effect is between 4.46% and 389.29%. Li, Zhang, and Liu (2016) conducted a study for the relationship between the increase in output of China's industry sector and energy consumption with respect to the rebound effect by means of panel data model for 1994-2012 and found results between 20% and 76%. Zhang et al. (2017) used two-stage AIDS model with data for 2001-2012 at the provincial level on private car usage in China to show that private cars' CO_2 emissions have a partial rebound effect and backfire effect. The direct and indirect rebound effect for each year between 2001 and 2012 was calculated for each province. The direct rebound effect was between -179.82% and 138.2%, the indirect rebound effect was between -62.14% and 155.78% while the total CO_2 rebound was between -321% and 189.38%. Moreover, it was concluded that the rebound effect was increasing. Wu et al. (2016) made a study on Taiwan's industry by means of the supply-driven I-O model and concluded that almost for all the sectors, the indirect rebound effect was higher than the direct rebound effect. Therefore, if the indirect rebound effect would be neglected, the rebound effect would be estimated to be lower than its real value and energy-saving potential would be estimated more than its real value.

Fertner and Große (2016) emphasized that in order to eliminate the rebound effect for compact and resource-efficient urban development, the allocation of the efficiency gains should be planned carefully. Lindeblad et al. (2016) showed that virtual meetings' expected travel and emission reduction would not be achieved because of the rebound effect. However, the impact of the rebound effect would be decreased by effective policies. Lu and Wang (2016) used panel and I-O data from 30 different Chinese cities to build co-integrating equation, a panel error correction model, and an 8-sector E-I-O model for electricity consumption of households and calculated long-term rebound effect as 79% and the short-run rebound effect as 78%. As a result, it was concluded that energy efficiency activities were offset by increasing electricity consumption. Turner and Katris (2017) introduced a new Carbon Saving Multiplier metric by using a demand-driven inter-country I-O model to offer policy-makers more transparent findings. Freire-González (2017) used hybrid analysis of environmental extended I-O analysis and rebound effect-spending modelling for the calculation of the rebound effect for EU-27 countries' energy efficiency by using GDP data and calculated the rebound effect as 73.62%. More than half of the countries had an 81.16% rebound effect while some of the countries had more than 100% rebound effect, which means the backfire effect.

Pui and Othman (2017) studied fuel tax policies for Malaysia and concluded that fuel tax policies could control the rebound effect to some extent. However, it was concluded that emission control could be maintained in the long-term when this policy would be implemented with fuel efficiency development strategies. Li and Lin (2017) made a comparison between heavy and light industry by decomposing the rebound effect into the substitution component and output component and concluded that heavy industry had a more rebound effect compared to light industry. Winebrake and Green (2017) made a study for trucks in the USA. They conducted in-depth interviews with eight different trucking firms. The authors did not calculate the rebound effect but draw qualitative conclusions for the existence of the direct and the indirect rebound effect. Freire-González and Font Vivanco (2017) studied the indirect and direct rebound effect in Spain for about five different natural resources. The data was gathered from Exiobase v.2, which is a multi-regional I-O data base. The method was divided into three parts as the direct rebound effect calculation through price elasticity of demand (logarithmic functional form), the rebound effect-spending model and resource I-O model. The indirect and direct rebound effect was found to be between 64.6%-74.7% for energy, 48%-63% for fossil fuels, 84%-89% for metal ores, 134%-147% for non-metallic minerals and 1191%-1628% for water. Therefore, there was a backfire effect for non-metallic minerals and water. It was concluded that focusing on the indirect effect would be crucial to understand the consequences of the energy policies.

Bjelle, Steen-olsen, and Wood (2018) calculated the rebound effect for different spending pattern scenarios for different household actions. On average, the rebound effect ranged between -172% and 461%. The conclusion of the study was that households should change their rebound effect-spending patterns to achieve carbon footprint reductions. Wen et al. (2018) studied the indirect and direct rebound effect in Chinese households that consisted of 25 provinces in China. Econometric methods, I-O analysis and rebound effect-spending model were used to calculate the rebound effect. The data was obtained from twenty-seven I-O tables, national and provincial energy balance tables, raw energy consumption table and panel data for each province for the years of 2002-2012. The direct rebound effect for each province ranges between 14.12% to 19.98%. The average direct energy effect was calculated as 17.01% and the indirect rebound effect for each province ranged between 22.75% and 164.06%. It was also detected that there are differences between provinces in which Qinghoai was proven to be the most sensitive province because of the fact that 69.23% of its economic sectors had potential to have a backfire effect.

Woodman et al. (2019) conducted a three-year field experiment for 185 high-income households to test the effectiveness of a community environmental group during and after retrofitting to reduce households' energy consumption. The direct rebound effect was estimated as 40% while the indirect rebound effect was not quantified because of a lack of data. Joyce et al. (2019) calculated the environmental rebound effect for ICT according to three different scenarios (reduction in ICT spending, reduction in electricity use, reduction in electricity and an increase in ICT). The first scenario revealed a backfire effect according to different impact measures while others did not show that frequent backfire. The rebound effect for the reduction in electricity use was between 5 and 121% while it was between 2 and 128% for the reduction in electricity use and an increase in ICT. It was also shown that the results differ for Sweden and the EU. Safarzyńska (2018) showed that because of the indirect rebound effect, which was defined as the consumption effect, the likelihood of the rebound effect was higher than the rational-agent model. According to the results, behavioural anomalies' role in environmental policy requires consumption tax to overcome behavioural failure. However, for habit formation where it was less probable for consumers to change their consumption habits, the likelihood of the rebound effect was low. Under a loss aversion situation, rebound effect's probability was depending on the reference consumption. Focusing on the existence of the rebound effect in behavioural models, it was shown that consumers' resistance to adjust their consumption level and less importance they put into reference consumption led to a lower rebound effect.

Inoue and Matsumoto (2019) used the econometric conditional demand analysis model to analyse the reasons of backfire of an energy efficiency program in Japan. While the energy efficiency program was intended to decrease the electricity consumption of the households, significant increases was observed. The authors concluded that the backfire of the policy was due to an increase in electric appliance stocks and size. Upon improvement in their appliances' efficiency, households tend to either buy more appliances or an increase in its size, which results in an increase in their electricity consumption. It was also point out that technological innovation is not merely a source to reduce electricity consumption. Underwood and Fremstad (2018) studied household and urban economies related to embodied CO_2 emissions. Through the household survey data, an econometric technique was used to find the relationship between household CO_2 emissions, expenditure and other socio-economic parameters. The study shed light on the rebound effect, arguing that the rebound effect exists but not really significant in comparison of total net economies. Wang and Nie (2018) investigated the rebound effect of improved efficiency by considering price jump of energy purchase and the zero-cost breakthrough of energy efficiency. Using the Cournot competition model, the impacts of competition on the energy efficiency rebound effect is developed, which explained the influence of price fluctuation on rebound effects. It was found that moderate monopoly and energy price jump is helpful in reducing the energy efficiency rebound effect. Santos et al. (2018) calculated the indirect rebound effect by scenario simulations for electrical appliances and according to the results of three scenarios for Portugal, the indirect rebound effect was between -1.70% and 10.20%.

The combination of both direct and indirect rebound effect is addressed as the total micro-level rebound effects or simply total rebound effects (Hediger, Farsi, and Weber, 2018). Compared to studies solely estimating direct rebound effects, estimation of the total rebound effects appears to be still in its early stages (Druckman et al., 2011). However, as more evidence on the importance of the indirect rebound effects come into the surface, the study on this topic is increasing for the past few years.

Studies on the direct and indirect rebound effect differ from direct rebound effect studies in terms of additional estimation of the indirect rebound effect. The indirect rebound effect exists due to the reduced cost and increased real income due to efficiency improvement which in turn are being "re-spent" to other goods and services. The increasing demand for other goods and services may increase the total energy consumption and/or GHG emissions. Thus, one way to capture this phenomenon is through the "re-spending" effect of income produced by savings on energy consumption (Freire-González, 2011; Sorrell, 2010). There are studies directly related to changes in consumption patterns in households with estimations of the indirect rebound effects (Druckman et al., 2011; Galassi and Madlener, 2018; Underwood and Fremstad, 2018).

The empirical studies in this area vary in terms of geographical coverage, data sources, the cases examined (rebound effect from technical or behavioral changes), level of commodity aggregation, sectoral/economic actor focus (household/industry), methodology and magnitude of the rebound effect (Sorrell, 2010).

In accordance with the studies on the direct rebound effect, total rebound effect studies are also mostly conducted in developed countries. The studies were conducted in Australia (Murray, 2013), Switzerland (Hediger, Farsi, and Weber (2018), Spain (Freire-González and Font Vivanco, 2017), Japan (Mizobuchi, 2008; Inoue and Matsumoto, 2019), United Kingdom (Chitnis et al., 2013**;** Chitnis et al., 2014; Chitnis and Sorrell, 2015; Woodman et al., 2019), Portugal (Santos et al., 2018) and United States (Kratena and Wüger, 2010; Thomas, 2012; Thomas and Azevedo, 2013). In terms of developing countries, the estimation of the total rebound effect was done in China (Li, Zhang, and Liu, 2016; Zhang et al., 2017; Lu and Wang, 2016; Wen et al., 2018) and Taiwan (Wu et al., 2016). Moreover, the geographical coverage of the studies is not only focusing on countries. There are also studies that have regional and city-based studies. For instance, Freire-González (2017) estimated the total rebound effect for EU-27, Joyce et al. (2019) made an estimation for Sweden and EU, Freire-González (2011) and Freire-González et al. (2017) conducted studies in Catalonia, Raynaud et al. (2016) in Southern Europe and Yu, Zhang, and Fujiwara (2013) and Wang, Han, and Lu (2016) conducted studies for Beijing.

The main aim of the studies is typically to estimate the total rebound effect from improved energy efficiency. The studies then revolve around what cases of improved energy efficiency are being examined. Some of the studies focused on the total rebound effect from the side of technological improvement that affects electricity consumption (Wang, Han, and Lu, 2016; Freire-González, 2011; Lu and Wang, 2016). Other studies focus on improved efficiency in transportation (Murray, 2013; Yu, Zhang, and Fujiwara, 2013; Zhang et al., 2017; Mizobuchi, 2008; Nässén and Holmberg, 2009; Chitnis et al., 2014; Chitnis and Sorrell, 2015), in various household's appliances (Yu, Zhang, and Fujiwara, 2013; Inoue and Matsumoto, 2019; Santos et al., 2018**;** Raynaud et al., 2016), in lighting (Mizobuchi, 2008), in ICT (Joyce et al., 2019) and in household heating (Hediger, Farsi, and Weber, 2018; Kratena and Wüger, 2010; Woodman et al., 2019; Brännlund, Ghalwash, and Nordström, 2007).

Studies in this area also differ in terms of sectoral or economic actor focus. The majority of studies revolve around the total rebound effects in the household consumption level in addition to the rebound effect studies on the industrial sector (Li, Zhang, and Liu, 2016; Wu et al., 2016). Freire-González and Font Vivanco (2017) studied the indirect and direct rebound effect in Spain for about five different natural resources and concluded the backfire effect for non-metallic minerals and water. It is also found that focusing on the indirect effect is crucial to understand consequences of the energy policies and if the indirect rebound effect is neglected, the rebound effect would be estimated lower than its real value and energy-saving potential would be estimated more than its real value.

When it comes to the methodological approach, most of the studies have an agreement using the combination of LCA, I-O analysis and econometrics technique. The main aim of the use of these techniques are twofold (Sorrell, 2010): to estimate the energy consumption, carbon/GHG emissions embodied within different goods and services; and to estimate the expenditure and/or price elasticities associated with those goods and services.

While there were only a handful of studies, the findings of the total rebound effects somehow differ (Inoue and Matsumoto, 2019). For instance, Freire-González (2011) estimated the total rebound effect from efficiency improvement that affects electricity consumption in Catalonia. It was found that the short-term and long-term total rebound effects are 56.47% and 65.31% respectively. In the same fashion, Wang, Han, and Lu (2016) estimated the total rebound effect for the case of Beijing. The total short-term rebound effect was found to be around 24% to 37% and the long-term rebound effect was around 46%-56%. Other cases estimate the total rebound effect from improved households heating. Hediger, Farsi, and Weber (2018) estimated the total rebound effects as 33% for the case of Switzerland while Brännlund, Ghalwash, and Nordström (2007) estimated it to be between 12.9 and 16.1%. Backfire effect is also observed in a number of studies (Wen et al., 2018; Freire-González, 2017; Chitnis et al., 2014; Yu, Zhang, and Fujiwara, 2013; Mizobuchi, 2008; Joyce et al., 2019).

The discrepancy of the results was apparent and it mainly depends on the behavior of the households and their spending patterns, which might differ across regions. The specific geographical region might have its own unique magnitude of total rebound effects. It is also worth noting that it was suggested by many works of literature that indirect effects might be larger than direct effects (Freire-González, 2011; Kok, Benders, and Moll, 2006). Thus, for policymaking purposes, estimating the total rebound effect focusing in a targeted geographical area is important to provide meaningful insights for policymakers.

2.3. Economy-wide Rebound Effect

The economy-wide rebound effect is the combination of the direct and indirect rebound effects and mostly it is calculated based on a single country (Sorrell, 2007). Meyer, Distelkamp, and Ingo (2007) used PANTA RHEI, a macro-econometric model for Germany, to estimate economy-wide rebound effect by the data obtained from Wuppertal Institute for the years 1991-2000. It was concluded that there was a strong rebound effect. This study was updated by Meyer, Meyer, and Distelkamp (2012) by means of the same data source and model but the data range of 1995-2004. This study also revealed a strong rebound effect.

Anson and Turner (2009) used energy–economy–environment CGE model for Scottish domestic commercial transport sector on the supply and use of energy. The results showed that total refined oil rebound effect was 36.4% in the short-run while it was 39.2% in the long-run.

Guerra and Sancho (2010) estimated the economy-wide rebound effect by combining the I-O framework and the CGE approach for Spain. According to the results, it was found that the economy-wide rebound effect was between 14.91 and 234.8%.

Topallı and Buluş (2012) estimated the economy-wide rebound effect for energy efficiency in residential buildings as 18%. The time-series data for Turkey's energy consumption for the year 1964-2009 was used with the ARDL model in this study.

Du and Lin (2014) made a study on the economy-wide rebound effect of China by means of an IPAT equation. The data was obtained from the China Statistical Yearbook for 1953-2010. The average rebound effect at three energy pricing stages was calculated as given hereunder.

- Government pricing stage (1979- 1992) – 51.91%
- Coal pricing reform stage (1993-1999) – 25.92%
- Refined oil pricing reform stage (2000-2010) – 25.79%

Yu, Moreno-cruz, and Crittenden (2015) studied the economy-wide rebound effect by using the CGE model for Georgia, USA. Based on the economy-wide impact shocks in different epicenter sectors, which are production sectors, a direct upstream/downstream sector of energy production sectors, a transportation sector or a sector with high production elasticity were compared. The reason behind highly different economy-wide impacts was investigated.

Pfaff and Sartorius (2015) estimated economy-wide rebound effects for non-energetic raw materials in Germany. The study was carried out in the context of a set of material efficiency projects and by means of I-O analysis. The relative rebound effect of individual materials (rocks and minerals, chemical products, ceramics, steel, nonferrous metals, and secondary raw materials) according to final demand, consumption, and investment was calculated. On average, the rebound effect was between 1 and 5% for final demand, consumption, and investment and it was between 2.5 and 10.5% for different materials. There are few studies on resources other than energy in the literature.

Du and Lin (2015) revised the formulation of Shao, Huang, and Yang (2014) based on the IPAT equation and estimated China's economy-wide rebound effect for 1981-2011. The average rebound effect between those years was 43.33%.

Adetutu, Glass, and Weyman-Jones (2015) focused on magnitude and model aspects of the rebound effect by means of data from 55 countries for the years 1980 to 2010. The study showed that 100% energy efficiency improvement would result in a 90% rebound effect and in the long-run, this would end up with a 36% reduction in energy consumption. Koesler, Swales, and Turner (2016) studied international rebound effect by means of the General Equilibrium Model and concluded that there was a rebound effect on the global level. Fan, Luo, and Zhang (2016) calculated the economy-wide rebound effect in China as 16.48% for the years 1995- 2000 and 29.04% for the years 2000-2011. The increase in 2000-2011 showed that although the energy efficiency policies were started to be implemented in those years, the rebound effect was not considered.

Yu, Moreno-cruz, and Crittenden (2015) studied the economy-wide rebound effect in Georgia/USA on the regional level for different sectors and between sectors by using the CGE model. Results indicated that the rebound effect for the construction sector was 3.7% for the non-electricity use and 3.4 % for electricity use; air transport sector had a 53% rebound effect and further processing of petroleum product sector had 162% rebound effect.

Chang (2016) made a study for the eight countries in the South Africa Development Community and identified different rebound effect values for each country. The study used the data for 2005-2009 and the results showed that the rebound effect was varying for different years and for different countries. These results indicated that none of the countries were performing better than others and it was not possible to point a single country as energy innovative.

Li, Zhang, and Liu (2016) calculated the economy-wide rebound effect for 36 Chinese different industrial sectors by employing output distance function on 1998-2011 data as 88.42%. The rebound effect was showing that the effect of the Chinese government's energy efficiency activities had been reducing.

Li and Jiang (2016) used a modified I-O model for the calculation of the economy-wide rebound effect for China's economic sectors for the years 2007-2010. The results showed that the rebound effect was 1.9%, which was decreasing to 1.53% after the cease of the energy supports.

Somuncu and Hannum (2016) presented a MSc thesis on economy-wide rebound effect. They used the CGE approach for estimation of the economy-wide rebound effect for households (energy efficiency and durable goods). The result was 18-19%.

Lu, Liu, and Zhou (2017) studied the economy-wide rebound effect for five different energy types, namely coal, refined petroleum, crude oil and gas, electricity and steam supply and gas supply in 135 Chinese production sectors. It was concluded that energy efficiency improvement in electricity usage had the largest positive effect on GDP and there was no backfire effect. It was recommended to the policymakers that the long-term rebound effect should be taken into consideration.

Yang and Li (2017) worked on the carbon emission rebound effect for 30 provinces of China. Different percentage of rebound effect measures ranging from 10 to 60% was calculated for different regions of China.

Bye, Taran, and Rosnes (2017) calculated the economy-wide rebound effect as 40% for 2030 residential energy efficiency goals of Norway, which were in line with EU goals by means of a multi-sector, CGE model of the Norwegian economy. Wei and Liu (2017) calculated the global rebound effects 70% on energy use and related emissions caused by an energy efficiency improvement for 2040 by CGE.

Wu, Zhang, and Gao (2018) investigated the impact of technical progress and structure of industry on the reduction of carbon intensity in China. The main purpose was not to calculate the rebound effect bur rather to see the effect of technical progress on carbon intensity. However, since the efficiency change was one of the leading factors in technical progress, carbon intensity reduction was not achieved because of the carbon emission rebound effect. The average carbon emission rebound effect from 1998 to 2014 was found as 68.44%. The data was obtained from the China Statistical Yearbook, the China Energy Statistical Yearbook and the China Environmental Statistical Yearbook for 30 provinces of China from 1998 to 2014. It was suggested that the Chinese government should develop policies to decrease the carbon emission rebound effect.

Zhou et al. (2018) focused on decomposing the economy-wide rebound effect into different 135 production sector level rebound effects. Two-stage decomposition and static CGE methods were used to achieve decomposition. The data was obtained from the 2007 I-O Table of China. Five energy-specific categories were stated as coal, crude oil, and natural gas, refined petroleum, electricity and gas supply and it was observed that the rebound effect directly correlated with inter-fuel substitutability. Furthermore, the rebound effect calculation was done for low and high inter fuel substitutability in order to show the difference. The rebound effect with low inter-fuel substitutability for coal, crude oil and natural gas, refined petroleum, electricity and gas supply were respectively -0.4%, 23.7%, 11.9%, -9.3%, 4.3% and with high inter-fuel substitutability, the calculations were 42.9%, 38.5%, 47.1%, 56.5%, 89.7%. The paper concluded that secondary energy resources were exposed to more rebound effect than the primary energy resources.

Borozan (2019) made a study on energy taxes in the EU for residential energy consumption. Quantile panel regression models were employed for the period 2005-2016. Results showed that less energy-consuming EU countries' increase in energy taxes and energy prices had a higher impact on residential energy consumption, so real income and tertiary education rebound was higher compared to more energy-consuming countries. More-energy consuming countries had more educated people but less poverty and the rebound effect was higher for those countries.

Wei, Zhou, and Zhang (2019) developed to reveal properties and key drivers of the rebound effect for energy intensity. Economic growth and energy savings were pointed out as the two targets of the rebound effect and while economic growth was more important for poor developing countries, policymakers were taking energy savings into consideration after the economy becomes richer. The rebound effect for 40 countries was calculated for energy intensity for the data between 1995 and 2009. Results showed that most developing countries had a backfire effect while developed countries like Denmark, Luxembourg, and Taiwan had super conservation effects.

Barkhordar (2019) used a hybrid dynamic general equilibrium model to evaluate the results of the program started by the Iran Government by providing free LED lambs to households. The model was original since it was endogenously calculating useful energy and energy demand that provided for end-use efficiency and useful energy demand. As a result, the economy-wide rebound effect was calculated as 43.8%, which showed that the program was still profitable despite the high rebound effect.

Peng et al. (2019) investigated the impact of excise tax on energy commodities for Jiangsu province of China. The results showed that 5% improvement of energy efficiency would end up with 142% of the rebound effect, backfire, which could be decreased by implying energy excise tax. Static multi-sectoral CGE model was proposed for this study.

Duarte, Sánchez-Chóliz, and Sarasa (2018) used CGE model to estimate Spain's economy-wide rebound effect for three different scenarios (1) Electricity savings in households (2) More efficient transport through vehicles with less fuel need (3) combination of (1) and (2) and the estimation made for the years 2010, 2020 and 2030 separately. The results ranged between 12.05% to 75.39% in all energy use while it ranged between 25.29% to 70.52 in electricity or fuel use. The data was obtained from national Spanish statistics for 2005 and 2015.

Vivanco, Sala, and McDowall (2018) conducted a review study to give guidance to the policy-induced rebound analysis since it was concluded that the rebound effect generally focused on only one resource and ignored linkages between resources. The article also pointed out policy areas vulnerable to the rebound effect.

Somuncu and Hannum (2018) aimed to find out the role of energy theft in determining the amount of the rebound effect. Using Turkey as a case study, the CGE model was developed with and without an energy theft parameter. The authors argued that the interaction between energy theft and energy efficiency was important in providing accurate estimates for the rebound effect in the case where energy theft was prevalent. The results showed that energy theft affects the outcome. The rebound effect was between -1.4% and 3.1% for the service sector and between 0.4% and 2.1% for households without energy theft while it was between -7.9% to -19.7% for the service sector and between 10.4% to 40.7% for households with energy theft.

Wang, Quiggin, and Wittwer (2019) studied the rebound effect of regulations made in Australia about light vehicles fuel standards. CGE was used as a method and also the theoretical framework was provided by ORANI-G model. I-O table of years 2012-2013 and behavior of economic agents were used as the data source. The calculations were done for the year 2025. The direct rebound effect was calculated as between 25% and 29% and the rebound effect for economy-wide was calculated as 49.99%.

Schröder et al. (2019) pointed out that the rebound effect is prone to decrease over time in the circular economy while more goods and services are in line with the circularity and economy is more service-oriented.

Santarius, Walnum, and Aall (2018) made a review on STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model and one of the conclusions of articles was that clear analysis of the environmental rebound effect was limited.

Shao et al. (2019) calculated the energy rebound effect of the overall economy and secondary industry in Shanghai as 93.96% and 73.10%, respectively, based on technological progress. The study used the state-space model with time-varying parameters based on the IPAT identity and the Solow residual approach for the period 1991–2016.

Freire-gonzález (2019) calculated the water rebound effect as 100.47% by means of a dynamic water-economy CGE model for Spain.

As studies with a focus on China, Du et al. (2019) calculated the rebound effect for China's construction sector by means of a static CGE model between 83.20 and 99.22%. The highest rebound, 99.22%, is for natural gas efficiency. Cao et al. (2019) used a combination of the CGE and dynamic Material Flow Analysis models to estimate the economy-wide rebound effect for the Chinese building sector as 74%. Liao and Wang (2019) studied China's energy rebound effect by three elements of the neoclassical production function and the results showed that the energy rebound effect of 54.4% on average was decreasing from 1994 to 2017 according to this paper. Ma and Jiang (2019) calculated China's CO_2 rebound effect by means of dynamic OLS method from each year between 2001 and 2015 and the rebound effect was ranging between -18% and 62%. Deng et al. (2018) focused on the rebound effect for electricity consumption for China by means of a trans-log cost function model with productivity growth equations. The calculated rebound effect was more than 100% for Southwestern China and Central China, -60.39% and −81.47% for Northeastern China and Southern China, respectively. The lowest annual average rebound effect existed in Northwestern China, which was 14.96%.

Wood et al. (2018) used EXIOBASE3 multiregional I-O database for clothing and diet for EU. It was shown that apparel and textiles consumption decrease would lead to a 75% rebound while reducing meat consumption’s rebound was 25% and shift to low-carbon meat (like white meat) was found to lead to a 5% rebound. Hart (2018) used a model which combines income and substitution effects and the rebound effect was 50%, which was a sign of an increase in overall energy efficiency on the global level.

Cheng, Li, and Liu (2018) concentrated on industrial structure and technical progress on carbon intensity in 30 provinces in China. The carbon emissions rebound effect was between 45.18% and 76.89% and it was 68.44% on average by means of a dynamic spatial panel model. Yuldashev, Mirkomilov, and Eshchanov (2019) used CGE model for the simulation of the energy-economy interactions and consequences of a 10% increase in energy efficiency for the transportation sector in China. The results revealed that there was an 89% rebound.

Kulmer and Seebauer (2019) built a CGE model to simulate a 10% energy efficiency improvement in different household groups with particular preferences in Austria. The economy-wide rebound effect was estimated as 65% with a 8-12% direct rebound effect which was a sign of the high effect of the indirect rebound effect for the consumption of fossil fuel. Moreover, results showed that different household groups had different values of the direct rebound effect according to 160 simulation trials.

The economy-wide rebound effect is defined as a rebound effect that focused on the whole economy of a region, country or the global economy. The economy-wide rebound effect was calculated empirically in 37 articles. Most of those studies focused on a single country while Wei and Liu (2017) and Hart (2018) calculated the rebound effect on the global level. In addition, Adetutu, Glass, and Weyman-Jones (2015) and Wei, Zhou, and Zhang (2019) calculated the economy-wide rebound effect for 55 and 40 countries, respectively, while Wood et al. (2018) focused on EU. Chang (2016) focused on the South Africa Development Community (Angola, Botswana, Congo, Mozambique, Namibia, South Africa, Tanzania). The results showed that around one-third of the studies were conducted in China by various researchers. The rest of the studies were spread around countries. The economy-wide rebound effect was calculated three times for Spain (Guerra and Sancho, 2010; Duarte, Sánchez-Chóliz, and Sarasa, 2018; Freire-gonzález, 2019), while it was calculated two times in Germany (Meyer, Distelkamp, and Ingo, 2007; Pfaff and Sartorius, 2015) and Turkey (Topallı and Buluş, 2012; Somuncu and Hannum, 2018) and it was calculated only once for Sweden, Norway, Iran, USA, Austria, and Australia. Since economy-wide rebound effect is a good measure of energy efficiency application in the regional and country level, it can be recommended that economy-wide rebound effect could be studied for many other countries, which are in the stage of industrialization. In this respect, the USA could be considered as a special case regarding its high level of CO_2 emissions. As seen in the literature, there is only one study focusing on the USA and this study is conducted solely for Georgia.

Most of the studies used CGE model for their calculation in Austria, Georgia/USA, Sweden, Turkey, China, Spain, Australia and on the global level. Other than the CGE, I-O analysis was commonly used for those studies. The most frequently studied country was China and the methodologies were very diverse for China.

The magnitude of the economy-wide rebound effect differs between studies. However, it was mostly between 0 and 100%. Backfire effect was observed in six studies (Guerra and Sancho, 2010; Yu, Moreno-cruz, and Crittenden, 2015; Chang, 2016; Freire-gonzález, 2019; Deng et al., 2018; Wei, Zhou, and Zhang, 2019) while super conservation was seen in five studies (Chang, 2016; Lu, Liu, and Zhou, 2017;

Zhou et al., 2018; Wei, Zhou, and Zhang, 2019; Somuncu and Hannum, 2018), so in China and Turkey.

The economy-wide rebound could be mainly divided into two parts namely, energy rebound and emission rebound. However, since it has a broader focus, it is difficult to draw conclusions on the sectors targeted. Most of the studies are on energy consumption in general or on type of energy consumed (coal, electricity, etc.). However, there are four studies that are covering the buildings and construction sector (Kulmer and Seebauer, 2019; Topallı and Buluş, 2012; Bye, Taran, and Rosnes, 2017; Duarte, Sánchez-Chóliz, and Sarasa, 2018; Du et al., 2019; Somuncu and Hannum, 2018; Cao et al., 2019). In addition to buildings, there are several studies related to energy efficiency in the industry. There is also a specific study on clothing and diet (Wood et al., 2018), one in transportation (Yuldashev, Mirkomilov, and Eshchanov, 2019) and another on water (Freire-gonzález, 2019).

2.4. Macroeconomic Rebound Effect

The macroeconomic rebound effect is defined as the combination of economy-wide and indirect effects. There are numerous studies in this area compared to other types of rebound effect.

Barker, Ekins, and Foxon (2007) studied the macroeconomic rebound effect which is defined as the combination of the indirect and economy-wide effects. The effect of policies and programs for the domestic, business, commercial and public, and transport sectors are investigated in this study by means of the rebound effect. By the help of MDM-E3, a sectoral dynamic macroeconomic model of the UK economy and the data for 2000-2010, it was found that the macroeconomic rebound effect arising from UK energy efficiency policies for the period 2000–2010 was around 11% on average across sectors of the economy.

Barker, Dagoumas, and Rubin (2009) analysed transport, residential and services buildings and industrial sectors' of the economic policies for the post-2012 period, 2013–2030, to examine the macroeconomic rebound effect for the global economy. Energy-Environment-Economy Model at the Global level (E3MG), a sectoral dynamic macroeconomic model of the global economy and the data of the International Energy Agency (IEA) between 1993-2002 was used in this study. The direct and macroeconomic rebound effect was calculated to be 31.5% for 2020 and 51.3% for 2030 in total.

Duarte et al. (2016) used CGE model with the data obtained from a social and environmental survey conducted on Spanish households to make an evaluation of the effects of improvements in environmental awareness, and of changes induced by regulations and carbon taxes. The rebound effect was found to be existing for different income groups. It is suggested that the economy should head for more carbon-efficient industries to reduce the rebound effect.

Li et al. (2017) used a multi-sector CGE model for the energy subsidies in China and concluded that the rebound effect was existing and it was larger for electricity compared to primary energies.

Nabernegg et al. (2017) focused on low carbon technologies for energy-intensive industries in Europe, China and India by employing GAINS technology model with a macroeconomic CGE model. According to their findings, the macroeconomic rebound effect's size was 42% and 34% for China and India, respectively. However, there was no rebound effect on Europe.

Song et al. (2018) stated that despite the technological progress in irrigation technology, total use of agricultural water did not decrease in China when it was compared to the past which was an indication of the rebound effect. The provincial panel data of China between 1997 and 2014 was used for this study and the water rebound effect was defined. In order to calculate the macro-scale water rebound effect in this situation, the direct comparison method (the difference between expected and actual water savings from water productivity improvements) was constructed by using the impact of technological progress. The water rebound effect for agriculture was calculated as 61.49%.

Zhang and Lin Lawell (2017) studied the macroeconomic energy rebound effect in China. The two-level nested constant elasticity of substitution production function method was used in order to calculate both the nation-wide and province-level rebound effect. The data (energy consumption, GDP, labor, etc.) was gathered from the China National Bureau of Statistics for the period of 1981 to 2009. The macroeconomic rebound effect was calculated as −14.21%. It was stated that because of the rebound effect, energy efficiency policies might not be useful or even had adverse impact results for short and intermediate run.

Wu et al. (2018) studied the macro-carbon rebound effect in China between the years of 1996-2015. The data was gathered from the China Statistical Yearbook for 30 provinces in China. A new method was used by combining Data Envelopment Analysis and the sequential Malmquist-Luenberger index in order to calculate the carbon rebound effect more precisely. The study concluded that the carbon rebound effect certainly exists in China and it was ranging between 7.4% and 43.8% while stating that the backfire effect and the super conservation effect were existing in some provinces, which led the way to the recommendation of province-specific emission reduction policies. Moreover, the immediate introduction of carbon taxation and carbon trading compatibility mechanisms were pointed out with an increase in R&D investment.

Jin and Kim (2019) proposed a new method for estimating the macroeconomic rebound effect by taking into account other factors of the production and a time series data of economic growth and energy supply, capital stocks, and labor force factors collected for 1971 and 2012 in Korea. The study showed that the rebound effect was higher when the economy was in recession and energy prices were shocked with a rebound effect between 1 and 9%.

Xin-gang, Yuan-feng, and Yan-bin (2019) aimed to investigate the role of Foreign Direct Investment in assuring the energy intensity convergence among provinces in China. The spatial econometric technique was employed to test the energy intensity convergence using the panel data of 30 provinces in China over the period 2005-2014. It was found that the spillover effect of Foreign Direct Investment played an important role in energy intensity convergence. In addition, this Foreign Direct Investment effect on energy intensity was also accompanied by the rebound effect that slowed down the declining energy intensity.

Liu, Li, and Yin (2018) studied the relationships between environmental regulation, technological innovation, and energy consumption in the case of China. The study used econometric panel data analysis of 30 provinces in China. The model results showed that the rebound effect of technological innovation was affecting energy consumption in China.

Rosenbaum (2019) used a Monte-Carlo study and concluded that when there were no macro-economic rebound effects, green growth was more achievable.

It can be stated that there is a limited number of articles which calculated the macroeconomic rebound effect empirically. There are challenges for the calculation of the macroeconomic growth effect. As global economy is an interconnected, complex dynamic and single system, it is beyond the bounds of possibility to make definitive arguments about effect and cause (Gillingham, Jenn, and Azevedo, 2015).

There are seven articles which calculated the macroeconomic rebound effect. Two of those studies (Wu et al., 2018; Jin and Kim, 2019) used Data Envelopment Analysis for the modelling and other two (Barker, Ekins, and Foxon, 2007; Barker, Dagoumas, and Rubin, 2009) used Energy-Environment-Economy Model. However, others used different methodologies like CGE, Gains model, etc.

The type of energy efficiency measure varies between different articles. These areas are domestic, business, commercial and public, and transport sectors, water, transport, residential and services buildings and industrial sectors', energy-intensive industries, energy, macro-carbon, and energy intensity. Therefore, there was various types of macro-level energy efficiency activities focused on the literature.

As it is for many other rebound effect types, China was the country where macroeconomic rebound effect is mostly studied (Nabernegg et al., 2017; Zhang and Lin Lawell, 2017; Wu et al., 2018; Song et al., 2018). Other than China, the macroeconomic rebound effect was calculated for the UK, Europe, China and India, and Korea for a different type of activities.

The magnitude of the macroeconomic rebound effect mostly ranges between 1 to 51.3%. Zhang and Lin Lawell (2017) calculated it as -14%, which means super conservation. Therefore, none of the studies revealed the backfire effect.

2.5. Social Determinants on Rebound Effect

Studies on the rebound effect have been mostly focused on the valuation of the rebound effect by means of different approaches and to develop methodologies for the calculation. The research on the rebound effect corresponding to consumer behavior and social factors was very limited (Wörsdorfer, 2010). However, in many cases, it was emphasized that the rebound effect is mostly stemming from behavioral and social factors. Although socio-psychological research showed that factors like personal norms, beliefs, and attitudes could affect the increase in usage of energy services after energy efficiency implications, these factors were not considered in the rebound effect discussions yet (Peters et al., 2012). Wörsdorfer (2010) argued that the reason behind the occurrence of the rebound effect may not be economic savings. If studies to determine these factors would be conducted, the results of these studies would be a basis for energy efficiency policies.

The studies targeting the rebound effect should focus on the effect of the changing lifestyle of households on energy consumption (Jalas, 2002; Takase, Kondo, and

Washızu, 2006; Mizobuchi, 2008). It was argued that since the lifestyle approaches capture the social aspects of consumption, they could be useful to study the rebound effects (Peters et al., 2012).

Lifestyle concepts was divided into three categories.

1. Social situation defined by socio-demographic variables which are income, education, age, marital status, religion, sex, number of children, etc.
2. The mentality is referring to the motivational element of lifestyles and the socio-psychological concepts of values and attitudes.
3. Performance is defined as the expressive element of lifestyles, which translates the mentality dimension into behavioral patterns. However, it has the risk of tautology for behavioral aspects that should be explained by the lifestyle concept (Peters et al., 2012).

The studies that are focused on the factors that are effective in the rebound effect are given below.

Guerra-Santin and Itard (2010) studied occupants' behavior on energy use for space heating. The data for the study was obtained from a survey which was sent to 7,000 households with a response rate of 5% (313 usable cases). Building characteristics, occupants' behavior, and household characteristics were investigated by means of statistical methods. Presence of elderly, presence of children, education level and income level were the factors used for occupant behavior.

Peters et al. (2012) proposed a theoretical framework on the combination of psychological theories of action and the lifestyle concept to analyze rebound effects. Their work was a part of a research project called REBOUND funded by the German Federal Ministry of Education and Research.

Throndsen and Thomas Berker (2012) conducted a study to examine the cultural and social conditions associated with the household level rebound effects. The aim of the study was to determine favorable conditions that led to a rebound effect by means of empirical and qualitative approaches. The data was collected from 17 households by means of in-depth interviews. These households were the ones who had received funding from Norwegian public energy management enterprise Enova SF and who agreed to go through an in-depth interview that lasted one hour. "Tensions between the Longue durée (resistance against change) and the present" and "Inner-domestic tensions" – negotiations among household members for energy consumption, were identified as the two important socio-cultural factors which produced outcomes that were related to energy consumption.

Wörsdorfer (2010) studied the rebound effect stemming from more energy-efficient washing machines from a theoretical perspective. Social learning was emphasized as an important factor to change consumption patterns in this paper.

Milne and Boardman (2000) showed that low-income houses generally had very low initial temperatures due to financial constraints. If the policies would be designed for higher-income houses which usually have a high initial temperature, it would be more likely that these policies would seem to be successful. However, it should be important to ensure that low-income households have the comfort level with affordable warmth while environmental and policy objectives would be achieved.

Chitnis et al. (2014) estimated the direct and indirect rebound effect for five different income groups. It was observed that for each energy efficiency measure (cavity wall insulation, loft insulation, condensing boiler, tank insulation, CFL lighting, LED lighting, efficient car, household thermostat temperature reduction, car use reduction and food waste reduction), the rebound effect was increasing with decreasing income.

Galvin (2015) studied the effect of gender (female/male commuters to a job) on the rebound effect in Germany. Econometric methods were used to calculate the direct rebound effect for different groups. The data was obtained from the Federal Labor Agency for North-Rhine-Westphalia between 1999 and 2013. It was found that the ratio between female and male rebound effects was between 1.14 and 2.82.

Therefore, the rebound effect for female consumers was higher than the male rebound effect.

Volland (2016) identified the relationship between gas consumption and household and dwelling characteristics as well as income.

Aydin, Kok, and Brounen (2017) identified demographic and dwelling characteristics that have an effect on gas consumption in the Netherlands. It was concluded that tenants had a higher rebound effect compared to homeowners. Moreover, low-income households were showing a higher rebound effect.

Santarius and Soland (2018) constructed a model for how energy efficiency improvements (based on psychological processes) might cause a "motivational rebound effect" or "beneficial effect." Typologies were created in order to categorize and analyse the variables that affect the rebound effect. Despite the commonly conducted studies with simple rational choice models and static assumptions about consumer preferences, this article used psychological theories and ‘motivational rebound elects’ as a new concept. The article suggested that policies should directly take into account human knowledge, motivation, and decision-making.

Liu et al. (2018) revealed that prosocial behavior and the motivational-crowding effect had an immediate influence on the optimal solar subsidy. The rebound effect was defined as the crowding-out effect and according to the results, elasticity for the price of solar panels with respect to the subsidy was 10% which was identified as the rebound effect.

Li and Lin (2018) concluded that the energy rebound effect had a negative effect on the energy-saving performance of the capital-embodied technological progress. Moreover, they showed that energy-savings stemming from technological progress requires energy price cooperation because of the rebound effect.

Safarzyńska and van den Bergh (2018) studied models of vehicle adoption called rational, myopic, habit-oriented and loss-averse consumers with three behavioral models of travel distance, describing rational, habitual and loss-averse drivers by stating that the car industry and electricity generation had dynamic interdependence. It was shown that myopic and loss-averse consumers mostly tend to buy less fuel-efficient cars compared to rational agents. Habitual drivers were prone to commute larger distances than rational ones. Therefore, making estimates based on rational behavior resulted in the lowest level of life-cycle emissions.

Galassi and Madlener (2018) made a study for 3,161 tenants and owner-occupiers of retrofitted buildings in Germany. They used a Discrete Choice Experiment and formed six different hypotheses on the behavior of consumers (opening window, wearing light clothes, etc.). The aim of the study was not to calculate the rebound effect but it was concluded that behavioral reaction to retrofitting varies among cases. Some of them fully neutralized energy savings while others had more negligible effects.

Loi and Ng (2018) investigated socioeconomic factors in Singapore that affected the sensitiveness of households about the consumption of residential electricity. Panel data of six different dwelling type from 29 districts for the years between 2005-2014 were used. Merge of one-way fixed effect and fully modified least squares were used as a method. The rebound effect of price lowering should be less than 48% for every 100% lowering in price. The paper concluded that for many households, the size of the household was a better determinant than price and income. Also, the use of a credit card made people less sensitive to price. Lastly, it was mentioned that the energy usage would increase as people’s awareness increase in energy saving through buying energy-efficient appliances or any price drop in electricity tariffs.

Paul et al. (2019) conducted a literature review for agricultural land and soil management and concluded that there was still a need for further studies on this topic. They also pointed out that the size of different geographical scales and for social-psychological rebound effects should be studied.

Berger and Höltl (2019) conducted case studies in Austria with poor households in Austria and concluded that prebound effect exists for these households. Because of the fact that their consumption was already very low before renovation, there was no room for further reduction.

Oberst, Schmitz, and Madlener (2016) made a study for prosumers' rebound effect and the results showed a very low rebound effect, which means there was no need for additional governmental policies like taxation or subsidies.

Seebauer (2018) focused on the household-level rebound after electric vehicle ownership or insulation. Structural equation modelling was applied to 575 electric car owners and 1,455 households conducted building insulation. Additionally, 111 electric bicycle adopter were involved in the study. The rebound effect was not calculated but explained variance (R^2) in rebound behavior was estimated between 13.2% and 70.1%, which was higher for the indirect rebound. The conclusions drawn were a negative relationship between rebound behavior and pro-environmental values and personal norms for the environment. On the contrary, social norms for environmentally conscious consumption had an increasing effect on the rebound. It was also concluded that low-income and energy-poor households were more subject to rebound.

Wang and Nie (2018) aimed to point out the rebound effects of the efficiency improvement by taking into account the zero-cost breakthrough of energy efficiency and price jump of energy purchase. The paper concluded that energy efficiency improvement may decrease total emissions while increasing energy consumption. It was also stated that under fixed energy price or no price fluctuation conditions, competition increased the rebound effect of energy efficiency improvement.

Santarius, Walnum, and Aall (2018) provides a review article stating that psychological rebound effects should be addressed via sustainability communication. Moreover, sociology and psychology were emphasized as the disciplines that were important for rebound effect research beyond economics.

2.6. Policies Developed for the Rebound Effect

Effectiveness of the energy and climate policies are argued in many studies (Aydin, Kok, and Brounen, 2017; Belaïd, Bakaloglou, and Roubaud, 2018; Freire-González, 2010; Madlener and Hauertmann, 2011). Energy efficiency policies are focusing on technical innovations and technical energy efficiency targets are determined by governments to achieve energy and/or climate goals. As it is mentioned in the Intergovernmental Panel on Climate Change Special Report 2018, technological innovations should be merged with social innovations to maintain the limit of 1.5°C global warming (Coninck and Revi, 2018). Therefore, the rebound effect should be taken into account while setting goals for energy efficiency and forming energy strategies. Technological improvement is not the only important factor for achieving energy efficiency goals, but consumers' behavior is also playing a crucial role in energy efficiency policymaking. For instance, building codes are not the only important parameters that are serving the achievement of energy efficiency goals and policies. As it is seen in the present dissertation results and from Aydin, Kok, and Brounen (2017), enhancement of the building codes or kWh heating required per square meter is not the sole sign of a decrease in energy consumption. There is even the possibility of an increase in energy consumption after energy efficiency improvements (Freire-González, 2010).

Governments aiming at the achievement of energy efficiency policy targets should integrate a consideration of the rebound effect in their estimations or scenarios for energy consumption or for savings through energy efficiency measures to have more realistic and reliable results. Moreover, policies should be developed to overcome positive rebound effect problem stemming from consumer behavior.

Rebound effect may be tackled through different policies that are combined with the existing policies already developed without taking the rebound effect into account.

Energy taxation or carbon taxation is one of these policies (Belaïd, Bakaloglou, and Roubaud, 2018). Households might need energy and CO_2 monitoring platforms to monitor their consumptions and emissions for the achievement of that policy (Yu, Zhang, and Fujiwara, 2013). Monitoring platforms or energy management systems may play an important role in decreasing domestic consumption (Scheepens and Vogtländer, 2018). Moreover, public awareness-raising campaigns to inform consumers about energy efficient and responsible behavior might be organized (Belaïd, Bakaloglou, and Roubaud, 2018; Copiello and Gabrielli, 2017).

Increase in energy prices is recommended as another way of controlling energy consumption (Copiello and Gabrielli, 2017). In this way, it is aimed to direct consumers to act in a more energy-saving manner. Moreover, market-oriented flexible energy pricing was recommended as an effective way to cope with the rebound effect for China (Li and Liu, 2017). Environmental and social costs could be included in the energy supply cost (Copiello and Gabrielli, 2017).

Subsidies as lump-sum payment were used to overcome problems that are faced by low-income households before in Canada. When energy prices were increased in 2000, the Canadian government provided CDN$250 for low-income families which were determined according to the 1999 income declaration. Since low-income households were using less-efficient furnaces, another subsidy policy for low-income households was to buy more efficient furnaces for low-income households. Direct subsidies on the utility price targeting low-income households called targeted lifeline schemes was another policy that was also implemented in the US with other welfare programs (Guertin, Kumbhakar, and Duraiappah, 2003). Transfer payments and social benefits were two additional solutions offered for low-income households (Hache, Leboullenger, and Mignon, 2017). Subsidies for low-income households may increase their welfare for the heating and surplus direct rebound effect. It was applied via the Weatherization Assistance Program in the US but its impact was not clear (Hediger, Farsi, and Weber, 2018). Therefore, if the aim of energy efficiency policies is to decrease energy consumption, targeting low-income households is not very helpful. On the other hand, if the aim of the policies is to increase well-being, health and comfort of this vulnerable group of low-income households, then there is a possibility to have a positive impact (Peters and McWhinnie, 2017).

High-income households cause less rebound effects, while low-income households have stronger rebound effects (Milne and Boardman, 2000; Madlener and Hauertmann, 2011; Peters and McWhinnie, 2017). In addition, Li and Liu (2017) showed that the direct rebound effect was quite high for extra high and low-income groups. As a result, it was recommended that energy efficiency policies could be focused on relatively high-income classes to be more effective (Coyne, Lyons, and McCoy, 2018; Hediger, Farsi, and Weber, 2018). Hache, Leboullenger, and Mignon (2017) offered patrimonial incentives that value green incentives for high-income households. Pricing mechanisms like carbon taxes, energy taxes, and tiered pricing for electricity was recommended for the most developed regions of Norway (Winther and Wilhite, 2014).

Prebound effect and low income are related and this is a sign of fuel poverty. Addressing these vulnerable groups is also important. However, it is not possible for them to engage in a retrofitting activity. Therefore, community energy-scheme run by a voluntary group or a third-sector and possibly legislation driven and local authority approach was recommended for this special group (Galvin and Sunikka-Blank, 2016).

Consumers stop consuming more energy when they reach a certain level of thermal comfort. As a result, deep renovation like highly efficient applications was suggested to overcome the direct rebound effect for low-income households (Hediger, Farsi, and Weber, 2018).

Shared saving contracts for Energy Performance Contracting is defined as a feasible way of mitigating the rebound effect for renters as well as homeowners (Lu, Zhang, and Chen, 2017). This is applicable for the energy service company (ESCO) model.

2.7. Main Results of Literature Review

The studies on the rebound effect showed different estimation results due to the focus of end-use being analysed, methodological approaches that are used, the geographical focus and theoretical framework.

In terms of geographical focus of rebound effect studies, most of the knowledge on the rebound effect is already on developed economies, while only a few studies are focusing on developing economies. As seen, the direct rebound effect is mostly studied in developed countries. According to the results, studies targeting developing countries are very few. Since it was shown that low-income countries tend to have more rebound effects in various studies, developing countries with densely low-income households require a special interest in the rebound effect literature (Baker, Blundell, and Micklewright, 1989; Milne and Boardman, 2000).

The studies in developing economies are thus important as energy rebound can be a serious problem for those countries. One of the main reasons is that the consumption of energy services in developing countries is less saturated than in developed countries. Energy efficiency improvement might have a vital role in developing countries, both contributing to economic development and the reduction of GHG emissions. It was also already assessed in various literature that developing economies need to catch up with developed countries to accomplish sustainable energy development (Fathurrahman, 2016).

As the direct rebound effect for space heating is studied in very few cases for developing countries, the focus on possible reasons for the rebound effect is also lacking in the literature. Most of the studies that focused on the causes of the direct rebound effect are focused on the income factor because of the fact that these studies used available national data. For that reason, factors like education, decision-makers' gender or neighbors' heating habits were not investigated. Surveys were required to gather data on these factors.

Given the diversity of the results in the rebound effect literature, specific rebound effect studies must be incorporated for consideration of energy efficiency or energy conservation policies. The rebound effect can be applied to the technical estimate of energy savings to show more probable energy savings because the technical savings do not give accurate measures.

This dissertation is contributing to the rebound effect literature in several aspects. First, it is mainly based on the data collected directly from the consumers via face-to-face survey in a developing country. Moreover, the reasons behind the gas consumption were investigated by means of the comprehensive survey developed for this study. As a result, it is contributing to the literature by defining the factors on social, demographic and dwelling characteristics. Also, it is concentrating on Turkey as a developing country to calculate direct rebound effect for space heating, which is rarely concentrated on developing countries in previous studies. Third, policy recommendations were drawn for Turkey based on the results obtained.

CHAPTER 3

DATA AND METHODOLOGY

This chapter will discuss the methodological framework of the study. The main aim of the study is to determine whether the rebound effect exists in household space heating in Ankara. Furthermore, the main factors/drivers affecting the rebound effect are investigated.

The study is conducted in several steps (see Figure 3.1). In general, it comprises three steps: data collection, preparation, screening and cleaning, model building, and model pool and analysis. All statistical calculations are done via IBM SPSS® ver. 23 software.

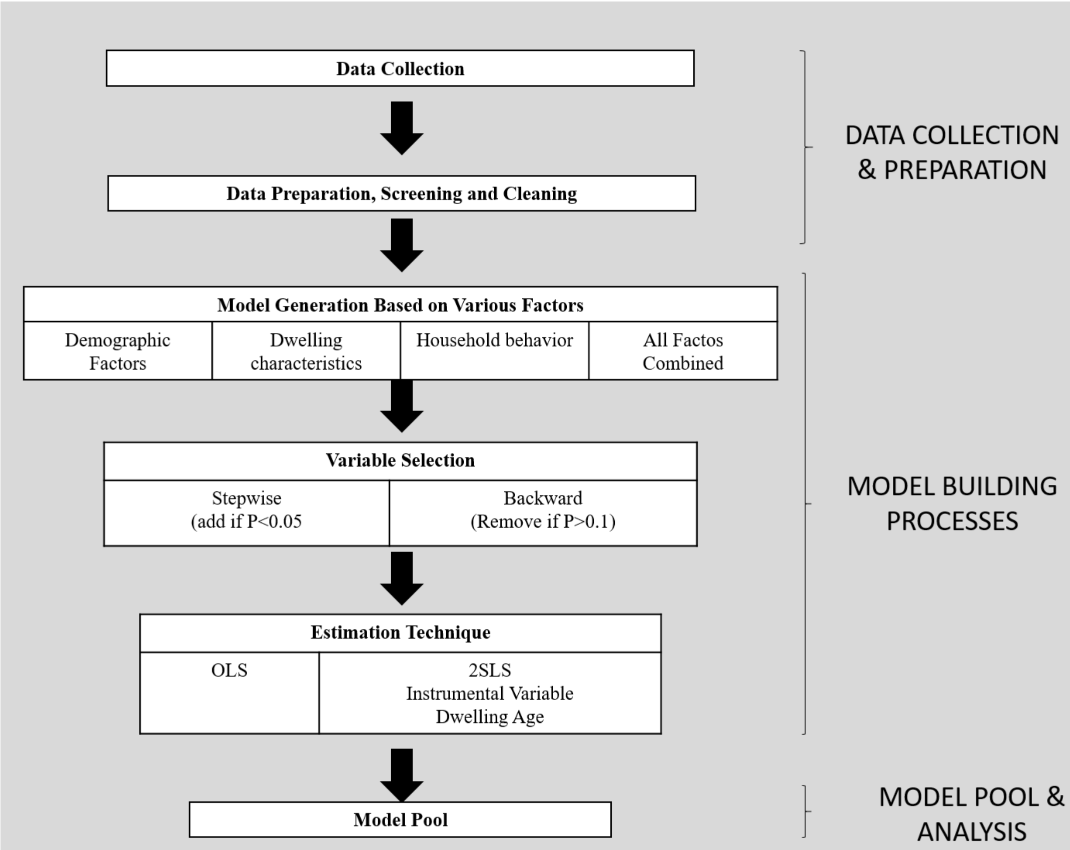


Figure 3.1. Estimation Methodology Flow Diagram

A survey in Ankara related to household heating energy consumption is conducted for the analysis. There are three main sources of data based on (1) Questionnaire, (2) Building energy certificate and (3) Gas consumption.

3.1. Data Collection and Preparation

A survey in Ankara related to household heating energy consumption is conducted for the analysis. There are three main sources of data based on (1) Questionnaire, (2) Building energy certificate and (3) Gas consumption.

The survey of Ankara households covers a total of 317 household data or around 0.02% of the total Ankara households. The total number of buildings being surveyed is 61 apartment buildings. The household was taken from 7 districts out of a total of 25 districts in Ankara. These seven districts are the most densely populated districts in Ankara (Ankara Kalkınma Ajansı, 2017). The survey is conducted by drawing a random sample among households that were retrofitted to improve the heating of the building. The sample size is determined according to the data received from IZODER (Heat Water Noise and Fire Insulators Association). IZODER is responsible for approval of the terms of reference of consumers who receive a loan for insulation from banks in Turkey. The address and contact detail information of the 771 apartments which are approved between May 2011 to April 2017 is provided by IZODER. It is assumed that there are 10 households in each of these apartments, which makes the population size approximately 7,710 inhabitants. The sample size is determined as 308 according to the sample size table of Yazıcıoğlu and Erdoğan (2004) for a 0.05 alpha value. However, to avoid missing data problem, 317 households are surveyed in the study.

Since every apartment has an obligation to demonstrate building energy certificate in the entrance, building energy certificates are obtained during the survey.

Gas consumption data is obtained from Başkent Doğalgaz Dağıtım A.Ş., which is the gas distribution company operating in Ankara.

3.1.1. Questionnaire

The questionnaire is developed under three different groups which are (1) Economic and demographics, (2) Dwelling characteristics, and (3) Household behavior.

Previous studies on the rebound effect for space heating were investigated before the design of the questionnaire and important factors are defined accordingly. In addition, interviews with the households were made to see additional information that would be a significant cause of the rebound effect.

The socio-economic and demographics part of the questionnaire comprises, among others, questions on the size of the households, education, gender as well as the total monthly disposable income of the household. In terms of dwelling characteristics, the questions related to the physical condition of the dwellings were asked. For example, the dwelling size, the position of the dwelling, number of rooms, as well as more directly-related space heating questions, such as the type of boiler used, change of the boiler after the insulation, etc. Lastly, the household behavior area tries to cover the behavioral characteristics of the occupants that might be related to household heating energy consumption. Among others, the questions that are asked are: who is deciding on the heating adjustment, whether occupants wear thick clothes, and whether they are satisfied with the insulation work. The questionnaire is given in Appendix A.

Following the design of the survey, it was conducted to 10 households on the pilot level to see the possible problems and updates needed. Accordingly, the survey was updated to be the more understandable and acceptable version for consumers and to avoid questions that were not favorable and not easy to be answered by households.

3.1.2. Energy Certificate and Gas Consumption

Turkey become an EU candidate in 2005. As a result, Turkey's regulations are started to be adopted according to the EU. "5627 Energy Efficiency Law" is one of the laws that are put in practice in alignment with EU regulations and since it was required to develop a building energy performance regulation within the one-year duration, "Building Energy Performance Regulation" was published on 5th December 2008 in accordance with European Directive 2002/91/EC. The Regulation was put in force in 2009 and it was updated four times since its publication once in 2010, twice in 2011 and lastly in 2017.

The Building Energy Performance Regulation is defining rules and regulations for architecture, insulation, renewable energy integration, co-generation, automation, the mechanical design of the buildings in addition to the energy performance certificate, energy performance calculation procedures, minimum performance criteria and legal status of authorized bodies.

The Energy Identity Certification is defined in the Building Energy Performance Regulation, namely "Building Energy Performance National Calculation Methodology" which was published on 7th December 2010 and amended on 1st November 2017. The Methodology is prepared based on ISO 13790:2008 Energy performance of buildings - Calculation of energy use for space heating and cooling.

The Ministry of Environment and Urbanization authorized certificated experts for the preparation of the Energy Identity Certification for buildings by means of a software called BEP-TR. Moreover, buildings are divided as new and existing buildings according to their construction date. Existing buildings which are in the context of the dissertation are the ones that were built before January 1st, 2011. The certificate is compulsory for all type of buildings.

Energy certificate is the main source of the variable of interest. It is used as a proxy for the energy efficiency of the dwellings. The energy certificate consists of information related to total energy use, the energy intensity of various energy services, CO_2 emissions, and energy label of the building. Energy intensity, which is the quantity of gas in m^3 that is required for heating each m^2 of gross floor area per year for space heating, is used as the proxy of space heating efficiency.

The actual gas consumption is used as the dependent variable of the model. In Ankara, the gas is distributed through a gas distribution company called Başkent Doğalgaz Dağıtım A.Ş. Four-years gas consumption data from 2014 to 2018 for every household is obtained from Başkent Doğalgaz Dağıtım A.Ş.. However, since the questionnaire was conducted in 2018 and the income data is related to 2018, gas consumption data for 2018 is used in the model.

While the focus of the analysis is on residential space heating, the gas consumption data comprises gas consumption for all building energy services (mainly heating and domestic hot water). Therefore, there is a need to isolate the gas consumption related to domestic hot water to have gas consumption for space heating only. To do this, the data from the energy certificate to find the share of gas heating consumption of each of the buildings is acquired. The total gas consumption is assumed to be used for heating and hot water.

After the data was collected, data cleaning and preparation procedure was performed. These steps are related to transforming the data into the variables to be used in the model. The questionnaire results are translated to around fifty different variables that will be used as control variables in the model.

In addition, in this step, the sample with missing data as well as outlying observations are removed (see Figure 3.2). The criteria for removal of the sample are variable with missing gas consumption, irregular gas consumption, and missing energy certificate. Moreover, outlying observations (in terms of the gas consumption variable) are defined as the one with a value more than |4| standard deviation. From the initial 317 collected samples, 15.5% (49 samples) are removed, resulting in a total of 268 samples ready for modelling.

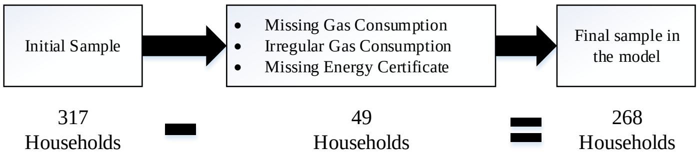


Figure 3.2. Data screening and cleaning

The sample is almost evenly distributed among most populated districts of Ankara as seen in Table 3.1.

Table 3.1. *Distribution of the Sample according to Districts*

Districts	*Surveys*
Altındağ	21
Çankaya	39
Etimesgut	39
Keçiören	51
Mamak	42
Sincan	36
Yenimahalle	40

3.2. Model Building: Rebound Effect Estimation Method

The estimation of the direct rebound effect of this dissertation employs econometric cross-sectional analysis.

In the literature, the direct rebound effect is estimated as (Volland, 2016):

1. Energy efficiency elasticity of demand (Elasticities of energy consumption with respect to energy efficiency)

The elasticity is defined as the changes in energy consumption with respect to changes in energy efficiency. Actual energy saving is equal to the expected saving in the case of perfect elasticity, i.e., there is no rebound effect. In contrast, any deviations imply the departure of realized savings from expected ones. Elasticity smaller than zero, negative unity, means actual saving is larger than the expected one, also known as ‘super conservation’. On the contrary, elasticity larger than negative unity implies a rebound effect, with exception larger than 1 elasticity called as ‘backfire effect’.

2. Energy price elasticity of demand (Elasticities of energy consumption with respect to energy price)

When the individuals are indifferent to the source of a relative change in price, efficiency improvement should have the same effect on energy demand as the price decrease. Thus, energy price elasticity of demand can be a symmetrical measure as efficiency elasticity (Sorrell and Dimitropoulos, 2008). However, many scholars argued that using this definition has many caveats and require very restrictive assumptions (Binswanger, 2001; Sorrell and Dimitropoulos, 2008; Hunt and Ryan, 2014; Chan and Gillingham, 2015). It is mainly argued that fuel price elasticities are overestimated in the case of a single fuel’s multiple usages.

This study employs the first definition of direct rebound effect: efficiency elasticities of demand. The principal method in estimating the rebound effect is to find a best-fit function that maps energy consumption to energy efficiency. The energy intensity is used as the proxy of energy efficiency. Because of the fact that it is difficult to measure energy efficiency, energy intensity is taken as the amount of heat that is required to maintain a certain comfort level (Grossmann et al., 2016).

The first rebound effect is defined as a ratio of changes in energy service consumption to changes in energy efficiency as follows:

$$\eta_{\varepsilon}(S) = \frac{\frac{\partial S}{S}}{\frac{\partial \varepsilon}{\varepsilon}} \quad (1)$$

Here, S is the consumption of energy services and ε is energy efficiency.

Equation (1) could be converted to a differential equation as follows.

$$\eta_{\varepsilon}(S) = \frac{\partial S}{\partial \varepsilon}\frac{\varepsilon}{S} \quad (2)$$

For space heating, the energy service is proportional to energy efficiency and energy consumption (*E*) as follows.

$$S = \varepsilon E \ (3)$$

When equation (3) is substituted into equation (2), the rebound effect would be calculated as shown in equation (4).

$$\eta_{\varepsilon}(S) = 1 + \frac{\partial E}{\partial \varepsilon} \frac{\varepsilon}{E} \ (4)$$

The empirical model that is used to estimate these elasticity variables is as follows:

$$\ln(Q_i) = \beta_0 + \beta_1 \ln(\varepsilon_i) + \sum_{l=3}^{l} \beta_l X_{li} + \gamma_i$$

where,

Q_i = Energy consumption of household *i*

ε_i = Energy efficiency (intensity) of household i

X_{li} = Control variables l (e.g. household size, floor size, etc.) of household *i*

The main goal is to attain the coefficient of β_1. Hence, the direct rebound effect can be estimated as follows:

$$\eta_{\varepsilon}(S) = \eta_{\varepsilon}(E) + 1$$

$\eta_{\varepsilon}(S)$ is the energy efficiency elasticity of the demand for useful work, while $\eta_{\varepsilon}(E)$ is the energy efficiency elasticity of the demand for energy. The $\eta_{\varepsilon}(S)$ is commonly used as a proxy for the rebound effect. The $\eta_{\varepsilon}(E)$ is estimated through the empirical model as β_1. Hence, the rebound effect can simply be estimated as:

$$\eta_{\varepsilon}(S) = \beta_1 + 1$$

In this dissertation, the approach of Aydin, Kok, and Brounen (2017) is followed. The energy service is defined as thermal comfort, in other words, the provision of thermal comfort through heating, and the rebound effect is defined as follows:

$$\tau_G = \partial \ln(H)/\partial \ln(\mu_H)$$

H is the residential heating consumption by households and μ_H is the heating efficiency, which can be defined as follows:

$$\mu_H = H_r/G^*$$

H_r is the amount of reference heating required in a year and obtained from energy certificate while G^* is the gas amount that is necessary to reach to that heating level.

$$H = H_r(G^a/G^*)$$

G^a is the actual gas consumption. As a result, the rebound effect is obtained as follows:

$$\tau_G = \partial \ln\left[H_r\left(\frac{G^a}{G^*}\right)\right]/\partial ln[H_r/G^*]$$

which is: $\tau_G = 1 - \partial \ln(G^a)/\partial ln(G^*)$

The estimation model would be as follows:

$$\ln(G_i^a) = \beta_0 + \beta_1 \ln(G_i^p) + \sum_{j=2}^{j} \beta_j Z_{ji} + \alpha_i + \varepsilon_i$$

α_i and ε_i are the error terms. The β_1 could be defined as:

$$\beta_1 = \partial \ln(G^a)/\partial ln(G^*)$$

As a result, the rebound effect would be equal to $\tau_G = 1 - \beta_1$.

3.2.1. Model Generations Based on Various Factors

In addition to the calculation of the direct rebound effect, it is also aimed to investigate the factors affecting the household gas consumption for space heating. To do so, the variables in each factor (i.e. demography, dwelling characteristics, and household behavior) are developed in a separate model as well as a combination of all. By doing so, the main driver of consumption due to different factors and also the main driver of all of them combined would be found out.

Furthermore, the analysis is expanded to see the different levels of rebound effect in three different levels of household economic groups. To do so, the data is divided into three income levels: low-income, medium-income, and high-income. The grouping of a household is based on TÜİK 2017 data[1] on household disposable income which is distributed to 20% quintiles. Low-income households are determined as the households that have income less than the second quintile (2034 TL per month). While medium-income household has an income between second and fourth quintiles (2034 TL and 4108 TL) and high-income households has income more than the forth quintile.

3.2.2. Variable Selections

The survey data has around 50 variables. Therefore, there is a necessity to eliminate unimportant variables from the final models for the rebound effect estimation. First, variables are put in separate OLS models according to their type (demographic, dwelling characteristics and behavioural factors) and the most important variables are determined for each group. Moreover, the previous literature is used to determine

[1] http://www.tuik.gov.tr/UstMenu.do?metod=temelist

significant factors related to gas consumption. After that, the stepwise and backward selection methods are mainly used for variable selection via SPSS®.

The stepwise selection process works as follows: Variables are entered into the model one by one. The variables showing a significant relationship in the model ($P < 0.05$) are retained, otherwise, it is excluded. The remaining set of variables are the ones showing statistically significant relationship with the dependent variable.

In contrast, the backward selection process works as the following: first, all variables are included in the model. Then, the most insignificant individual (with the highest P-value and $P > 0.1$) variable is dropped. The process continues until all variables in the model show significance relations (i.e. $P < 0.1$) with the dependent variable.

3.2.3. Estimation Technique

In the first step, OLS is used together with the variable selection method mentioned above, to select the variables in the model. In the literature, however, scholars have pointed out that there is a concern of regression-based estimations of the rebound effect in cross-sectional data. It is argued that energy efficiency, which is used as the independent variable, is not exogenous to energy use (Sorrell, Dimitropoulos, and Sommerville 2009). Both are actually determined simultaneously as households pick the dwelling they are staying at (Sorrell and Dimitropoulos, 2008). As a result, there might be other factors affecting households' energy consumption. This is explained as the endogeneity problem stemming from unobserved household characteristics (Aydin, Kok, and Brounen, 2017). Moreover, since our estimation method is depending on engineering predictions of the household energy consumption, it is needed to be careful about a possible error in engineering predictions of the energy efficiency parameter. Several studies showed that engineering methods are overestimating predicted energy consumption (Volland, 2016) and it is assumed that the engineering method has a random measurement error, which needed to be corrected.

In a situation like this, estimators tend to underestimate β_1 and therefore overestimate the rebound effect. It is assumed that non-random measurement error is not included in engineering models and endogeniety problem is addressed. The instrumental variable (IV) approach is used to see the extent of the problem and overcome possible problems on endogeniety and non-random measurement error. Aydin, Kok, and Brounen (2017) and Volland (2016) are followed and dwelling age is used as an instrumental variable for energy efficiency and applied to 2 Stage Least Square (2SLS) estimator to identify the parameters. The dwelling age is assumed to be relevant for determining energy efficiency and affects energy consumption only through energy efficiency.

3.2.4. Model Pool and Analysis

The final set of variables from all models are retained for further analysis. The first analysis is regarding diagnostics test. The diagnostic test is conducted to assess the appropriateness of the model, so the estimated coefficient is not biased. To be appropriate, the model should satisfy assumptions in linear regression model such as linearity, independence of error terms and homoscedasticity. The diagnostic test is conducted by plotting the residuals and predicted values and visually observing the resulting graph. Moreover, specific tests and estimators like Levene's test for homoscedasticity, Pearson correlation for linearity and Durbin Watson statistics for independence, etc. are applied to the models to check the validity of the assumptions.

CHAPTER 4

RESULTS

The results chapter is divided into six parts. The first part is for interpretation of the descriptive statistics for different variables. In the second part, variables on demography, dwelling characteristics, and behavior are separately regressed on dependent variable gas consumption to identify important variables from each group. The third section is on the calculation of the rebound effect by means of different regression methodologies. The fourth section is dedicated to the rebound effect calculation for different income groups. Afterward, diagnostics tests are conducted for regression models. Lastly, questions on consumers behavior and perspective are evaluated and interpreted in the sixth session.

4.1. Interpretation of Descriptive Statistics

Table 4.1 presents the summary statistics for the gas heating consumption and heating intensity. In 2018, a household, on average, consumes 625.02 m^3 gas with the maximum consumption of 2,756.97 m^3 gas and 22.12 m^3 gas as the minimum consumption.

Table 4.1. *Summary statistics for gas heating consumption and heating intensity*

Variables	Mean	Std. Deviation	Maximum
Dependent Variable			
Gas heating 2018 (m^3)	625.02	359.83	2756.97
Independent Variable			
Heating intensity (kWh/m^2-year)	91.13	102.62	737.37
Heating intensity (log)	4.097	0.92	6.60

The complete set of variables are summarized in Table 4.2. The descriptive statistics show that almost one-third of the households are university graduates and while another one third is working. Moreover, 50% of households have at least one member who is a university graduate.

The percentage of the female members is 50%, which means that there is gender balance in the surveyed households.

In terms of low, medium and high income, it is seen that 20% of the households are from the low-income group, 50% is from the medium income group and 30% from the high-income group. This distribution could be considered reasonable. In addition, 72% of households are homeowners.

Overall, 66% of the households are located in the middle floor area while 13% in the basement or bottom and 20% is on the top. These statistics are important because since there is no heating being supplied from the bottom of the roof, the position of the household could affect the rebound effect. Half of the households' neighbors are being heating from both sides. This is consistent with the households located on the middle floor. However, sometimes the neighbors are not heating the whole apartment.

Most of the households (58%) are facing south, which might have a diminishing effect on the rebound effect. The percentage of the households facing north is 35%.

Position of the household could have an effect on the rebound effect as the north facing households need more heating.

Boilers are also important for the energy efficiency of the buildings. Hermetic gas boilers are considered as efficient boilers from the perspective of the first law of thermodynamics. However, condensing boilers are the most efficient ones and they have more than 17% higher efficiency compared to hermetic boilers[2]. 78% of the households in the sample are using hermetic boilers, which are also energy efficient. Moreover, 16% of the households changed their boilers with more efficient ones after insulation, which could have an effect on the rebound effect.

The average months passed after the insulation is around 40 months, which shows there is enough time to estimate the rebound effect.

Behavioral variables show that the average preferred temperature is 22 degree Celsius on average and the temperature change after the insulation is 1 degree Celsius on average according to households.

The decision on heating is taken by female household members in half of the cases. Moreover, in 90% of the cases, it is stated that the heating expenditure is diminished after insulation and 90% of the households are satisfied with the insulation results.

[2] https://www.arcelik.com.tr/sikca-sorulan-sorular/isitma-sogutma-sistemleri/kombi/Hermetik-kombi-ve-yogusmali-kombi-arasindaki-fark-nedir

Table 4.2. *Summary statistics of the variables*

Variables	Mean	Std. Deviation	Minimum	Maximum
Socio-Economic and Demographics:				
Household size	3.08	1.248	1.00	6.00
% younger than 5 years old	0.03	0.08	0.00	0.33
% older than 65 years old	0.15	0.31	0.00	1.00
Average age	43.5	16.69	16.00	85.00
% working	0.29	0.28	0.00	1.00
% female	0.52	0.21	0.00	1.00
% university graduate	0.27	0.31	0.00	1.00
Any university graduate	0.53	0.50	0.00	1.00
income (log)	8.14	0.49	6.21	9.62
Income segregation				
Low income	0.33	0.47	0.00	1.00
Medium income	0.33	0.47	0.00	1.00
High income	0.33	0.47	0.00	1.00
Ownership Type (rent=1)	0.18	0.38	0.00	1.00
Dwelling's Characteristics:				
Building age	13.8	8.23	9.00	48.00
Total No. of Floor	6.34	3.23	3.00	15.00
Apartment floor no	3.33	3.10	-3.00	14.00
Position of the household				
Basement	0.06	0.24	0.00	1.00
Bottom	0.07	0.26	0.00	1.00
Middle	0.66	0.47	0.00	1.00
Top	0.21	0.40	0.00	1.00
Total area	125	32.00	65	287
No. of rooms	4.10	0.63	3.00	6.00
No. of bedrooms	1.97	0.79	1.00	5.00
No. of heater	7.07	1.45	0.00	12.00
Neighbor heating				
Upper	0.22	0.42	0.00	1.00
Below	0.23	0.42	0.00	1.00
Both	0.51	0.50	0.00	1.00
No heating	0.03	0.17	0.00	1.00
Facing direction				
South	0.58	0.49	0.00	1.00
North	0.35	0.48	0.00	1.00

Other	0.13	0.33	0.00	1.00
Boiler type				
Hermetic	0.78	0.42	0.00	1.00
Condensing	0.05	0.22	0.00	1.00
Funnelled	0.17	0.37	0.00	1.00
Age of boiler	8.91	5.75	0.00	33.00
Change boiler after insulation	0.16	0.36	0.00	1.00
Months passed after insulation	40.45	86.72	0.00	128.00
Behavioural Characteristics:				
Average temp preference	22.27	2.90	17.00	45.00
Temperature change after insulation	0.93	0.26	0.00	1.00
Household member taking heating decision				
female	0.47	0.50	0.00	1.00
male	0.16	0.37	0.00	1.00
other	0.37	0.48	0.00	1.00
Education of decision maker	0.21	0.41	0.00	1.00
Reasons effecting heating consideration				
Outside temperature	0.50	0.50	0.00	1.00
Economic factors	0.15	0.36	0.00	1.00
Presence of children in the household	0.13	0.34	0.00	1.00
Other factors	0.22	0.42	0.00	1.00
Whether heating expenditure change	0.91	0.29	0.00	1.00
Dwellers wearing thick clothes inside the house (Yes=1)	0.29	0.46	0.00	1.00
Number of cars owned	0.69	0.57	0.00	3.00
Dwellers using public transportation for saving money (Yes=1	1.07	1.15	0.00	6.00
Smoking at home (Yes=1)	0.44	0.50	0.00	1.00
Whether household satisfied by the insulation	0.89	0.32	0.00	1.00
Number of hours spend at home	0.95	0.12	0.50	1.00

4.2. Identification of the Variables

Regression analysis is conducted for each group of demography, dwelling, and behavioral characteristics according to OLS (backward) estimations. Separate linear regression models are estimated to see important variables for each group and their positive or negative relationship with gas consumption.

Demographic variables showed that household size, income, and average age are significant with a positive t-value, so these parameters have a positive relationship with gas consumption. Therefore, increase in these parameters will increase gas consumption. On the contrary, neighbor heating from both sides (up and down) has a negative and significant relationship with gas consumption. Therefore, it can be concluded that when both neighbors located at the up and bottom of the household are heating, the gas consumption is decreasing.

Regarding dwelling characteristics, the total number of floor and apartment's floor number are the significant variables with a negative t-value while a number of bedrooms, number of the heaters, change of boiler after insulation and average temperature preference are the significant variables that have a positive relationship with gas consumption. The change of gas boilers with a more energy efficient one is increasing efficiency and apparently, could be related to gas consumption. Moreover, as the average temperature increases, the consumption increases.

Behavioral factors that are significant with a negative t-value are outside temperature and economic behavior for the temperature of the household (heating consideration). The reason for these negative values is obvious since a household who has economic concerns for gas consumption would consume less. Moreover, in households where male members are taking the decision for the heating, the number of cars owned by the household and the number of hours spent in the household are the significant variables with positive t-values. Therefore, households that have more cars tend to make more gas consumption.

Table 4.3. *Regression results for demography, dwelling and behavior parameter groups*

Variables	*(1)* *OLS* *Demography*	*(2)* *OLS* *Dwelling*	*(3)* *OLS* *Behavior*
Heating intensity (log)	0.244*** (5.812)	0.285*** (7.256)	0.262*** (6.328)
Household size (log)	0.595*** (5.476)		
income (log)	0.134* (1.7)		
Average age	0.006** (2.3)		
Neighbour heating: both		-0.185** (-2.523)	
Total Number of Floor		-0.056*** (-3.9)	
Apartment floor number		-0.034** (-2.295)	
Number of bedrooms		0.159*** (3.627)	
Number of heater		0.078*** (3.26)	
Change boiler after the insulation		0.251*** (2.621)	
Average temperature preference		0.026** (2.104)	
Household member taking heating decision: male			0.203** (1.995)
Reasons effecting heating consideration: Outside Temperature			-0.394*** (-4.77)
Reasons effecting heating consideration: Economic factors			-0.276** (-2.381)

Number of cars owned			0.29***
			(4.446)
Number of hours spend at home			0.597*
			(1.81)
(Constant)	3.255***	4.173***	4.316***
	(4.649)	(11.536)	(10.601)
R2	0.193	0.384	0.240
Adjusted R2	0.180	0.365	0.222

Notes: The dependent variable is the logarithm of actual gas heating consumption. The t-statistics in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

4.3. Empirical Results

The rebound effect is estimated by the model using OLS backward and OLS stepwise estimations and each followed by 2SLS estimations by taking dwelling age as an instrumental variable. Potential procedure and calculation method of the Energy Performance Certificates may contain a random measurement error (Aydin, Kok, and Brounen, 2017). This means that there could be downward bias in β_1 estimation obtained from OLS. The 2SLS procedure with the dwelling age instrumental variable is applied to eliminate this error. Dwelling age is selected as the instrumental variable because of the fact that it has an effect on gas consumption by only energy efficiency (Volland, 2016).

While using OLS estimations, all the important variables are included in the model. After that, 2SLS is applied to the variables that are significant in OLS models.

The amount of realized gas consumption is the dependent variable and the main independent variable is energy intensity, which is obtained from Energy Identity Certification. This variable will be used for the estimation of the rebound effect. In addition to energy intensity, important variables on demography, dwelling characteristics, and behavior are involved in the model.

The results for OLS (Backward) showed that household size, number of heaters, change of boiler after insulation, male decision-makers and number of cars owned are significant variables with positive t-values. On the other hand, the total number of floor, apartment positioned on the top, taking the outside temperature for heating consideration, hermetic boiler and both of the neighbors heating are the variables that are also significant but have negative t-values. Household's position to be on the top is not significant for the OLS (Stepwise) procedure and also it is not significant for 2SLS (Stepwise). Moreover, neighbor heating below is significant for OLS (Stepwise) procedure while it is not significant for 2SLS (Stepwise).

The rebound effect is 1 minus the coefficient of energy intensity. Therefore, the rebound effect is calculated as around 70% for both OLS (Backward) and OLS (Stepwise) procedures while it is around 48% for 2SLS procedures. Therefore, the rebound effect is significantly decreased with 2SLS estimators. Hence, it is concluded that there is a significant rebound effect for households in Turkey. For instance, according to 2SLS estimations, when the expected efficiency is 50%, the achieved efficiency would be around 25%. We may also conclude that although half of the expected efficiency would be eliminated by the rebound effect, there is still a decrease in gas consumption. Table 4.4 depicts information on OLS estimations via backward and stepwise procedures and by means of the use of an instrumental variable approach which is performed by means of the 2SLS estimation approach.

Table 4.4. *Pooled OLS Estimations and Instrumental Variable Estimations*

	(1)	(2)	(3)	(4)
	OLS Backward	2SLS (1) Dwelling Age	OLS Stepwise	2SLS (3) Dwelling Age
Heating intensity (log)	0.293***	0.518**	0.297***	0.514**
	(8.123)	(2.168)	(8.284)	(2.255)
Household size (log)	0.310***	0.337***	0.309***	0.332***
	(3.953)	(3.795)	(3.941)	(3.811)
Total No. of Floor	-0.063***	-0.077***	-0.064***	-0.077***
	(-5.731)	(-3.979)	(-5.864)	(-4.282)
Position: top	-0.157*	-0.151		
	-1.719	(-1.537)		
Number of heater	0.055**	0.064***	0.053**	0.06**
	(2.36)	(2.396)	(2.335)	(2.361)
Change boiler after insulation	0.298***	0.313***	0.303***	0.316***
	(3.334)	(3.219)	(3.374)	(3.262)
Household member taking heating decision: male	0.311***	0.325***	0.301***	0.316***
	(3.581)	(3.445)	(3.462)	(3.357)
Reasons effecting heating consideration: Outside Temperature	-0.247***	-0.267***	-0.238***	-0.260***
	(-3.82)	(-3.683)	(-3.667)	(-3.562)
Boiler type: Hermetic	-0.213***	-0.171*	-0.215***	-0.173*
	(-2.714)	(-1.799)	(-2.726)	(-1.825)
Neighbour heating: both	-0.191**	-0.109		
	(-2.502)	(0.916)		
Cars owned	0.203***	0.201***	0.214***	0.208***
	(3.525)	(3.248)	(3.691)	(3.334)
Neighbour heating: below			0.163**	0.099
			(2.064)	(0.917)
(Constant)	4.914***	3.924***	4.738***	3.857***
	(18.236)	(3.628)	(18.028)	(4.039)
R2	0.464	0.354	0.459	0.346
Adjusted R2	0.441	0.326	0.438	0.321

Rebound Effect Value	0.707	0.482	0.703	0.486

Notes: The dependent variable is the logarithm of actual gas heating consumption. The t-statistics in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

4.4. Rebound Effect Calculation According to Different Income Groups

There are several studies showing that different income groups show different levels of the rebound effect (Guertin, Kumbhakar, and Duraiappah, 2003; Hache, Leboullenger, and Mignon, 2017; Peters and McWhinnie, 2017; Milne and Boardman, 2000; Madlener and Hauertmann, 2011). The literature on the rebound effect showed that low-income households are showing stronger rebound effect (Peters and McWhinnie, 2017; Milne and Boardman, 2000; Madlener and Hauertmann, 2011). Therefore, it is stated that policies could be designed separately for different income groups to overcome the rebound effect problem. In this dissertation, the households are divided into three different income groups: low, medium and high and rebound effects are calculated separately for each group by means of OLS estimations. As shown in Table 4.5, low and medium-income households are showing higher rebound effect values while high-income households have a relatively lower rebound effect. These results are consistent with the literature. However, there is still a high level of rebound effect for high-income households in Turkey according to the results. Moreover, there is not so much difference between the rebound effect values for low and medium income households.

Table 4.5. *Income Segregated Models*

	(1) Low-Income	*(2) Medium-Income*	*(3) High-Income*
Heating intensity (log)	0.271***	0.298***	0.388***
	(6.313)	(6.499)	(3.627)
Household size (log)	0.291***	0.481***	0.436**
	(3.356)	(3.746)	(2.656)
Neighbour heating: both	-0.23***		
	(-2.816)		
Total Number of Floors		-0.067***	-0.067***
		(-4.411)	(-3.010)
Reason effecting heating consideration: Temperature		-0.739*** (-5.825)	
Reason effecting heating consideration: Children		-0.503*** (-2.95)	
Reasons effecting heating consideration: Economic		-0.626*** (-4.149)	
Number of heaters			0.153*** (3.113)
Decision: male		0.327**	
		2.499	
Months passed after the insulation		-0.001** (-2.056)	
Position: Basement		0.571***	
		(2.714)	
Boiler: Hermetic		-0.365***	
		(-2.909)	
Number of cars owned		0.222**	
		(2.372)	
(Constant)	5.404***	5,517***	3,651***
	(25.715)	(19.553)	(5.873)
R2	0.623	0.522	0.353
Adjusted R2	0.591	0.480	0.319
Rebound Effect	73%	70%	59%

Notes: The dependent variable is the logarithm of actual gas heating consumption.
The t-statistics in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

4.5. Diagnostics Tests

There are five different assumptions to be met in order to perform linear regression analysis. These assumptions are given hereunder.

- Normality: The residuals are normally distributed.
- Homoscedasticity: The variance is homogenous.
- Linearity: There is a linear relationship between the dependent and independent variables.
- Independence: Observations are independent.
- Multicollinearity: There is no high correlation between the independent variables.

The central limit theorem is stating that in an adequate number of sample space (>30), the sampling distributions of means are normally distributed. Since the sample space of this study is 268, normality can be assumed. It is supported by the P-P plots (see Figure 4.1). There is a small deviation from the straight line in each model.

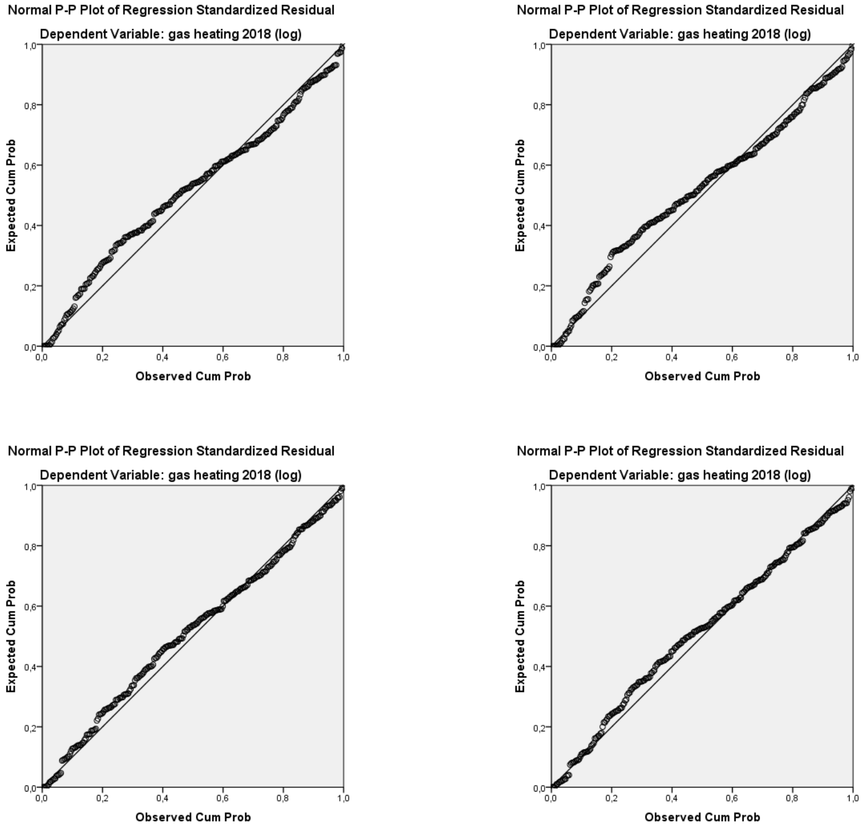
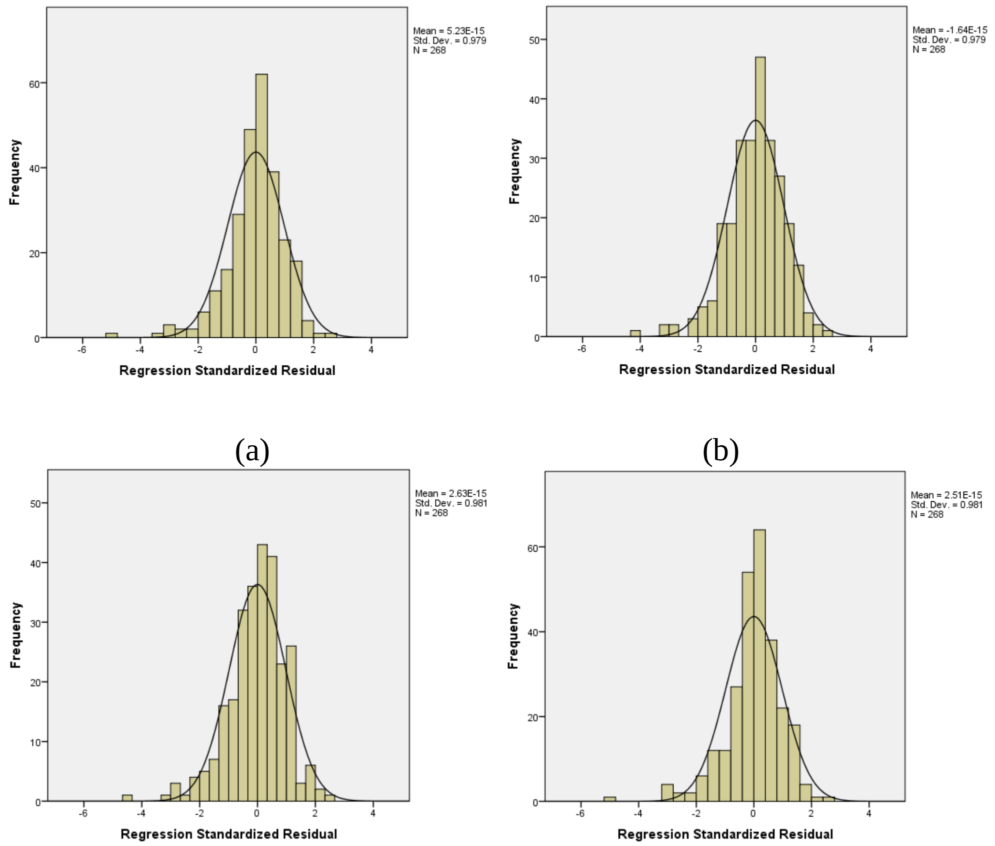


Figure 4.1. Normal P-P Plot of Regression Standardized Residual Dependent Variable: logarithm of gas consumption: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise

The histogram is also used to check whether the error terms have a normal distribution (see Figure 4.2). It is seen that the residuals of all models are normally distributed.



(a) (b) (c) (d)

Figure 4.2. Histogram of residual: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise

Levene's test of equality of error variances is employed to test homoscedasticity. The hypothesis for Levene's test is given below. According to the results, the null hypothesis is not rejected (see Table 4.6,

Table *4.7*, Table 4.8 and Table 4.9). As a result, it is stated that the error variance of the dependent variable is equal across groups for OLS and 2SLS estimations.

H_0: The error variance of the dependent variable is equal across groups.

H_1: The error variance of the dependent variable is not equal across groups.

Table 4.6. *Levene's Test of Equality of Error Variances for OLS Backward*

F	df1	df2	Sig.
1,532	258	9	,249

Table 4.7. *Levene's Test of Equality of Error Variances for OLS Stepwise*

F	df1	df2	Sig.
1,422	260	7	,331

Table 4.8. *Levene's Test of Equality of Error Variances for 2SLS Backward*

F	df1	df2	Sig.
1,462	251	16	,191

Table 4.9. *Levene's Test of Equality of Error Variances for 2SLS Stepwise*

F	df1	df2	Sig.
1,475	251	16	,185

Linearity is tested by Pearson's correlation between the dependent variable and continuous independent variables that are similar in each model. The hypothesis of the test is given below.

H_0: There is no linear relationship between gas consumption and independent variables.

H_1: There is a linear relationship between gas consumption and independent variables.

The null hypothesis is rejected for heating efficiency, household size, the total number of floors, number of heater and number of cars owned according to Pearson's correlation test statistics. Therefore, it is concluded that there is a linear relationship between gas consumption and continuous independent variables.

Table 4.10. *Pearson's Correlation Matrix for Gas Consumption and Independent Variables*

Correlations

		gas heating 2018 (log)	Household size (log)	Total No. of Floor	No. of heater	Cars owned	eff heating (log)
gas heating 2018 (log)	Pearson Correlation	1	,255**	-,350**	,188**	,238**	,299**
	Sig. (2-tailed)		,000	,000	,002	,000	,000
	N	268	268	268	268	268	268

**. Correlation is significant at the 0.01 level (2-tailed).

Independence of the observations assumption is tested via Durbin Watson statistics. When the Durbin-Watson statistics is between 1.5 and 2.5, it is concluded that data is not autocorrelated. As it is seen from Table 4.11, Table 4.12, Table 4.13 and Table 4.14, the data for all the models is not autocorrelated.

Table 4.11. *Durbin Watson Test Results for OLS (Backward)*

Model Summary

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	*Durbin-Watson*
1	,681[a]	,464	,441	,51624	1,763

Table 4.12. *Durbin Watson Test Results for 2SLS (Backward)*

Model Summary

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	*Durbin-Watson*
1	,672[a]	,451	,430	,52150	1,762

Table 4.13. *Durbin Watson Test Results for OLS (Stepwise)*

Model Summary					
Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	*Durbin-Watson*
1	,678[j]	,459	,438	,51760	1,755

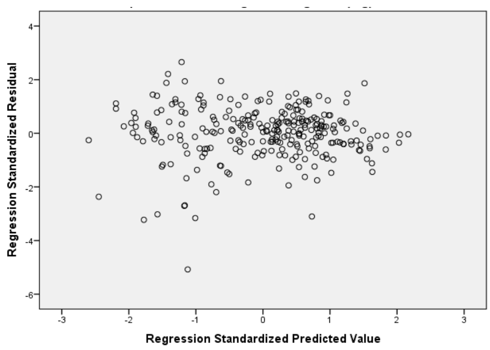
Table 4.14. *Durbin Watson Test Results for 2SLS (Stepwise)*

Model Summary					
Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	*Durbin-Watson*
1	,671[a]	,450	,431	,52086	1,757

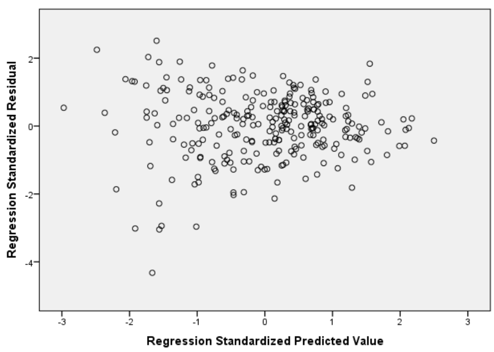
The residual diagnostic is applied to see whether model assumptions are met. Therefore, the aim of the residual analysis is to control whether there is any violation in linearity, independence of error terms and homoscedasticity of the regression model.

Residuals are plotted to the predicted values of each model that is developed. It is shown that the residuals are centered on a horizontal line centered in 0 and there are no systematic positive or negative tendencies (see Figure 4.3). As a result, it can be confirmed that the linearity assumption is met. In addition, the results prove the model to be independent as error terms are randomly distributed within the graph.

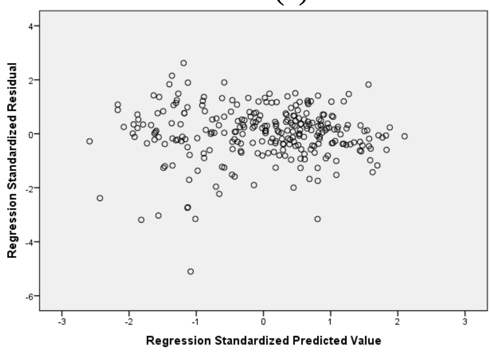
Finally, it can be concluded that the model is homoscedastic. The dots are spread along with the graphs without following a certain pattern (see Figure 4.3). Thus, it could be concluded that the models meet linear regression model assumptions.



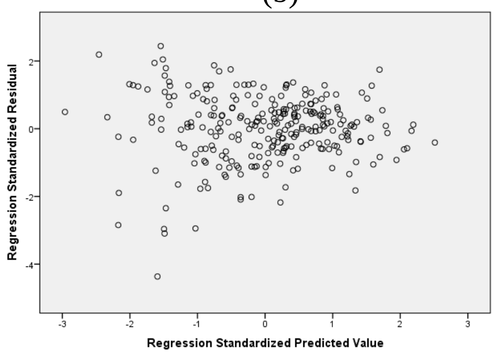
(a)



(b)



(b)



(d)

Figure 4.3. Plot of the residual and predicted value for model: (a) OLS Backward (b) 2SLS Backward (c) OLS Stepwise (d) 2SLS Stepwise

Multicollinearity is tested by means of Variance Inflation Factor (VIF) values. VIF values less than 10 are pointing out that there is no multicollinearity. This result is consistent with the correlation matrix. The correlation matrix shows that there is no high bivariate correlation between independent variables.

Table 4.15. *Multicollinearity statistics*

Backward			Stepwise		
Coefficients					
Model	Collinearity Statistics		Model	Collinearity Statistics	
	Tolerance	VIF		Tolerance	VIF
Household size (log)	.878	1,140	eff heating (log)	.926	1,080
Total No. of Floor	.842	1,187	Household size (log)	.877	1,140
Position: Top	.727	1,375	Total No. of Floor	.820	1,220
No. of heater	.889	1,124	No. of heater	.919	1,088
Neighbour heating: both	.706	1,416	Neighbour heating: below	.901	1,110
Boiler: Hermetic	.944	1,060	Boiler: Hermetic	.936	1,068
Change boiler after insulation	.941	1,063	Change boiler after insulation	.939	1,065
Decision: male	.965	1,037	Decision: male	.967	1,034
Heating consideration: Temp	.956	1,046	Heating consideration: Temp	.948	1,055
Cars owned	.919	1,088	Cars owned	.912	1,096

4.6. Results on Consumer Behaviour

The survey is consisting of questions that could not be involved in the regression model. However, these questions are important for supporting the results obtained from regression models and drawing conclusions about consumers' perspective and opinion about the insulation, the reasons why they have made insulation, etc. In this part, these questions are evaluated and different inferences are made accordingly.

Consumers are surveyed about their opinion regarding the possible results of the insulation. A question on their opinion about whether insulation decreased their gas consumption is asked. It is seen that 75% of the consumers are strongly agreeing and agreeing that insulation decreased their bills and 90% confirmed that gas consumption is changed after insulation (see Figure 4.4). Although this is not consistent with the results on the rebound effect, it could be concluded that despite the rebound effect, there are observable outcomes of the insulation activities. Moreover, consumers are favorable about the insulation activities and they consider it as a useful intervention for their households. However, consumers are not aware of the rebound effect, thus there is an opportunity to further increase efficiency and decrease the gas consumption and CO_2 emissions.

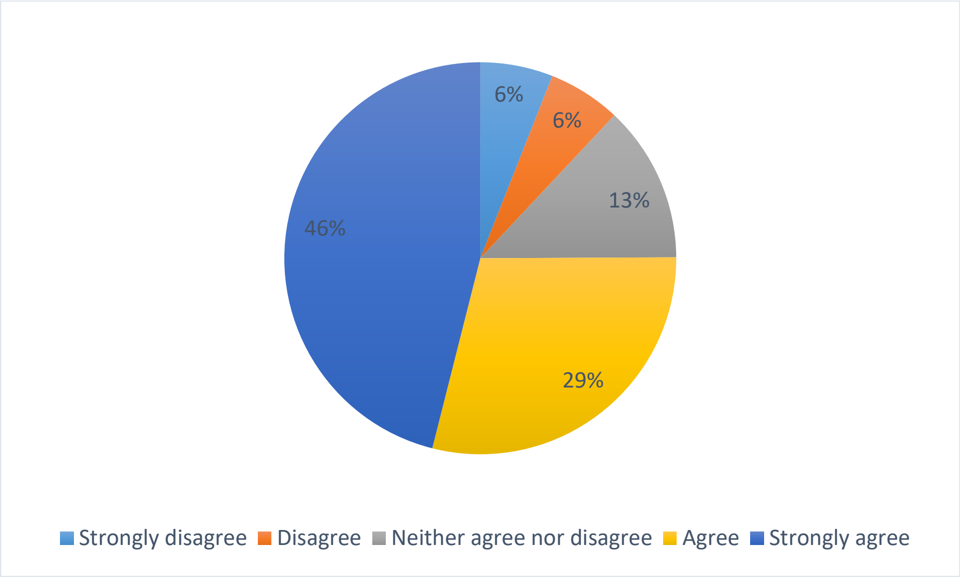


Figure 4.4. Insulation results in a decrease in heating expenditure

Figure 4.5 provides the distribution of the consumers according to their opinion about the possible percentage of the savings after the insulation in heating expenditure. These results are in line with the rebound effect conclusions drawn before. More than half of the consumers are in the opinion that insulation decreased their bills by less than 30%.

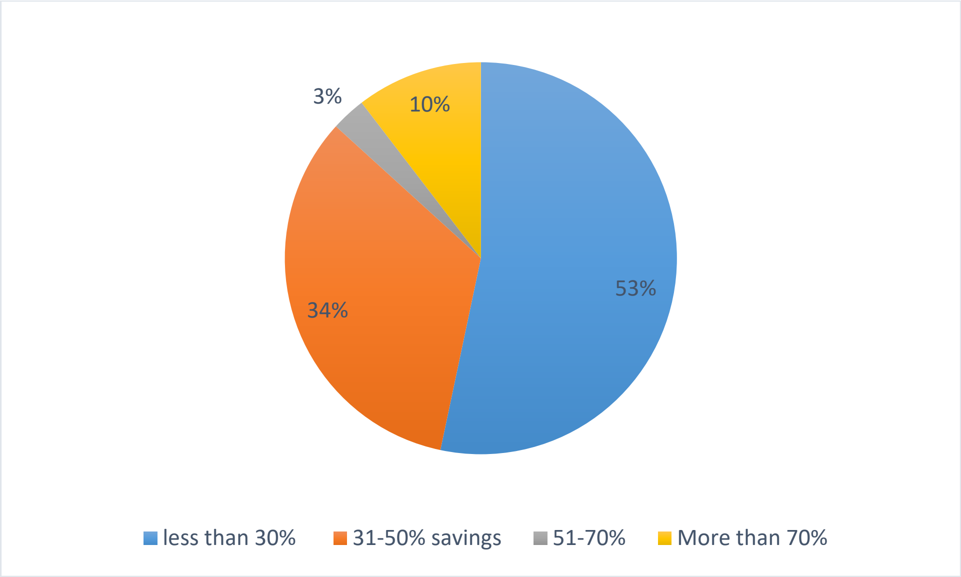


Figure 4.5. Savings from heating expenditure after the insulation

45% of the respondents strongly disagree and disagree that insulation protects the environment. Moreover, 27% of the respondents are indecisive on this issue (see Figure 4.5). Therefore, it can be concluded that consumers are not aware of the possible impact of energy efficiency activities on climate change.

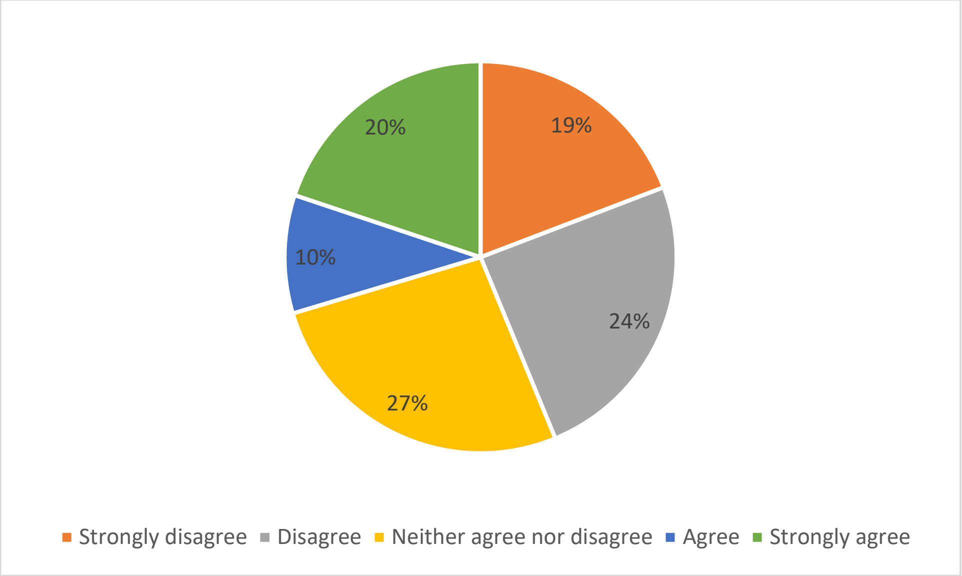


Figure 4.6. Insulation protects the environment

Around 50% of the consumers are regulating their heating according to the outdoor temperature while 16% according to economic consideration and 12% according to children living at home. Moreover, only one-third of consumers are wearing thick clothes. Therefore, it can be concluded that most of the consumers are not cautious about their spending on heating.

CHAPTER 5

POLICY IMPLICATIONS

The Turkish government identified energy saving and efficiency as one of the most crucial pillars of the 2023 national energy policies and strategy objectives[3]. Moreover, it is targeted to develop support schemes to increase energy efficiency in existing buildings in Turkey (Presidency of Turkey 2019). The households in Ankara are showing high magnitude of the rebound effect according to our results. Thus, the rebound effect should be taken into consideration to achieve these energy policy targets.

Recommendations are made to address and overcome the rebound effect for Turkish apartments. First, the rebound effect literature is pointing out the importance of policies for different income groups (Guertin, Kumbhakar, and Duraiappah, 2003; Hache, Leboullenger, and Mignon, 2017; Peters and McWhinnie, 2017; Milne and Boardman, 2000; Madlener and Hauertmann, 2011). It is indicated that low-income households are prone to fuel poverty compared to medium and high-income groups. However, our results showed that low and medium-income groups have almost the same magnitude of rebound effect while the high-income group has a relatively lower rebound effect compared to the low and medium-income group. Thus, it would be suggested that there would be different policies developed for the low and medium-income groups in Turkey. Although the high-income group has relatively less rebound effect, there is still 60% rebound existing for this group, too. For this reason, the high-income group should not be neglected in Turkey to achieve energy efficiency policy goals. Carbon taxes and energy taxes could be effective policies for the high-income group in Turkey.

[3] https://www.enerji.gov.tr/

Information campaigns could be conducted to inform households about the consequences of their inefficient behavior. One of the benefits of the information campaigns is that it would reach to all income groups that seem to be more relevant for Turkey. Moreover, our survey results showed that 75% of the consumers are strongly agreeing and agreeing on insulation decreasing their heating expenditure. Thus, it can be concluded that they are not aware of the losses they have because of the rebound effect. In addition, most of the consumers are not aware of the energy efficiency activities' impact on climate change. Therefore, information campaigns would be very helpful in informing consumers about inefficient behavior and benefits of proper behavior on consumption, the environment and energy security.

As it is shown before, majority of the consumers are in the opinion that the insulation resulted in a decrease in heating expenditure. However, they are not aware of the further decrease that was prevented by the rebound effect. Monitoring and energy management platforms were considered as one of the tools that could be used to overcome the rebound effect problem (Scheepens and Vogtländer, 2018). The households would be aware of their consumption and CO_2 emissions by means of monitoring or energy management platforms. By this way, they can see the gap between actual and expected energy consumption and CO_2 emissions and would develop responsible behavior in order to reduce or eliminate this gap. There are projects that have taken place in the EU to activate consumers via games or phone applications related to energy consumption and energy efficiency to achieve that goal. HIT2GAP[4] is one of these projects aiming at reducing the gap between actual and expected energy efficiency by means of a big data platform. Therefore, it is suggested that similar projects are developed and demonstrated specifically for Turkish households by means of smartphone applications or gamification technologies. The Ministry of Environment and Urbanization put automatic control system obligations for new buildings with central heating systems. However, this obligation is limited and since it is not depending on phone applications or

[4] HIT2GAP project website is http//www.hit2gap.eu.

consumer-friendly systems, its impact might be lower than expected. Therefore, it is suggested to extend these applications to existing buildings with more user-friendly tools.

CHAPTER 6

CONCLUSION AND DISCUSSION

The rebound effect is considered as an important aspect of energy efficiency policies. Technological development is not the only important element for the achievement of these policies. Consumer behavior is an important pillar of the successful achievement of the targets and as it is seen in many studies, the rebound effect is offsetting at least 50% of energy efficiency improvements. For this reason, it is important to understand the reasons behind the rebound effect, the important factors affecting it, and to use this understanding for developing policy measures to decrease or eliminate it.

This dissertation is focused on the direct rebound effect for space heating. For this reason, a face-to-face survey is conducted with 317 households in Ankara. These households are selected from the ones that took insulation measures for their apartments. The aim of the dissertation is to calculate the rebound effect for Turkey and identify factors that have a relationship with gas consumption. Following these studies, policy recommendations are formulated according to the results obtained.

First, demography, dwelling, and behavioral characteristics are regressed with dependent variable gas consumption separately to see the important variables for each group. Demographic variables showed that household size, income, and average age are positively correlated with gas consumption. Increase in these variables would increase gas consumption while neighbors heating from above and below the apartment would decrease gas consumption. Regarding dwelling characteristics, the total number of floors and apartment’s floor number are negatively correlated with gas consumption while the number of bedrooms, number of the heaters, change of boiler after insulation and average temperature preference are positively correlated. Increase in average temperature preference is increasing gas consumption. Lastly, important behavioral factors are identified and it is seen that outside temperature and economic concerns considered for the adjustment of household temperature (heating consideration) has a negative relationship with gas consumption. Therefore, households that consider economic issues for heating would spend less gas. In the case of male members taking the decision for heating, the number of cars owned by the household and the number of hours spent in the household have a positive relationship with gas consumption.

The direct rebound effect is calculated by applying OLS backward and stepwise estimations which are followed by 2SLS estimations for both of the OLS approaches by taking dwelling age as an instrumental variable. It is found that the rebound effect is 70% according to both OLS models and around 50% according to 2SLS estimations. Gas data is obtained from Başkent Doğalgaz Dağıtım A.Ş. operating in Ankara, the energy intensity variable is taken from Energy Identity Certificates and demographic, dwelling and behavior variable data are obtained via the face-to-face survey. Since dwelling age is assumed to have a relationship with energy efficiency only and it is independent of other variables in the model, dwelling age is used as an instrumental variable for 2SLS estimations. Afterward, the rebound effect is calculated for three different income groups: low (73%), medium (70%) and high (59%) income. The results showed that the rebound effect is decreasing from low to high-income groups. However, there is a small difference between these classes, especially between low and medium-income classes.

In addition to the rebound effect calculations, consumers' perspective on different issues are investigated. First, it is shown that most of the consumers are in the opinion that insulation reduced the natural gas bills. It was found that the rebound effect is offsetting half of the energy efficiency gains. However, consumers are still satisfied with the results of the insulation.

During the survey, consumers' perspective on the impact of insulation on the environment is investigated. The results showed that only a quarter of the consumers are in the opinion that insulation helps protect the environment. Therefore, it is concluded that consumers are not aware of the impacts of insulation activities or gas consumption on the environment. Moreover, this result can be interpreted in the way that the reason for consumers to have insulation activities is not mainly depending on their intention to contribute to the prevention of climate change. This interpretation is supported by the results on taking outside temperature to adjust heating that is the most prioritized decision for heating adjustment. It is seen that this consideration is mainly based on a physical factor which is outdoor temperature. Economic considerations and children living in the household are the reasons that are considered in the second place.

One of the main results of this dissertation is to draw policy recommendations according to the results obtained from the rebound effect calculation and the determinants of the gas consumption. As it is seen in the literature, most of the studies are focusing on the relationship between the rebound effect and income. For this reason, we obtained income segregated results of three different models. The result of the rebound effect for three different models from low, medium and high income is slightly different from the literature. The rebound effect is decreasing as the income is increasing. However, it is seen that there is no high difference between the low, medium and high-income groups. As a result, it is recommended that a high-income group should be considered as well as low and medium-income households while policies are formed for energy efficiency in buildings in Turkey.

Moreover, since it is seen that consumers are not very well informed about the direct effect of insulation as an energy efficiency application and the consequences of their inefficient behavior on decreasing energy consumption and achievement of policy targets, information campaigns seem to be very effective ways of coping with the rebound effect for the success of policies for energy efficiency in Turkey.

The results obtained for the rebound effect and the answers received from consumers regarding the effectiveness of the insulation are not consistent according to our inference. Therefore, consumers are not aware of their consumption when they do not have a tool to monitor and manage the energy consumed. There are several pilot projects taking place on these systems and these projects are using gamification to make consumers more actively engaged in energy efficiency activities. As a result, it is recommended to widely conduct these types of projects in Turkey to see the results and effectiveness for Turkish consumers. Moreover, more user-friendly implications like smartphone applications are recommended for the success of these demonstration projects.

The dissertation showed that there is a direct rebound effect for residential apartments in Turkey based on the case of Ankara. Moreover, consumers are not aware of their consumption and real potential for insulation activities. For this reason, additional activities and policies are required to cope with the rebound effect in Turkey. The Turkish government is putting importance on energy security and climate change. Therefore, these recommendations would decrease energy consumption and help maintain energy security and protection of the environment.

REFERENCES

Adetutu, Morakinyo, Antony Glass, and Thomas Weyman-Jones, 2015, Economy-wide Estimates of Rebound Effects: Evidence from Panel Data, *Munich Personal RePEc Archive*.

Adom, Philip Kofi, Charles Barnor, and Mawunyo Prosper Agradi, 2017, Road transport energy demand in West Africa : a test of the consumer-tolerable price hypothesis, *International Journal of Sustainable Energy* 0, 1–22.

Airehrour, David, Jairo Gutierrez, William Liu, and Jinsong Wu, 2016, When internet raised to the things power: Are energy efficiency standards sufficient to curb carbon footprints?, *2015 IEEE Globecom Workshops, GC Wkshps 2015 - Proceedings*.

Ajanovic, Amela, Reinhard Haas, and Franz Wirl, 2016, Reducing CO2 emissions of cars in the EU: analyzing the underlying mechanisms of standards, registration taxes and fuel taxes, *Energy Efficiency* 9, 925–937.

Al Irsyad, M. Indra, and Rabindra Nepal, 2016, A survey based approach to estimating the benefits of energy efficiency improvements in street lighting systems in Indonesia, *Renewable and Sustainable Energy Reviews* 58, 1569–1577.

Alfred, The, P Sloan Foundation, Meredith Fowlie, Michael Greenstone, and Catherine Wolfram, 2015, E2e Working Paper 020 Do Energy Efficiency Investments Deliver ? Evidence from the Weatherization Assistance Program Meredith Fowlie , Michael Greenstone , and Catherine Wolfram Do Energy Efficiency Investments Deliver ? Evidence from the Weatherization A, .

Alvi, Shahzad, Zafar Mahmood, and Shahzada M.Naeem Nawaz, 2018, Dilemma of direct rebound effect and climate change on residential electricity consumption in Pakistan, *Energy Reports* 4, 323–327.

Amjadi, Golnaz, Tommy Lundgren, and Lars Persson, 2018, The Rebound Effect in Swedish Heavy Industry, *Energy Economics* 71, 140–148.

Ankara Kalkınma Ajansı, 2017, İstatisti̇klerle ankara 2017.

Anson, Sam, and Karen Turner, 2009, Rebound and disinvestment effects in refined oil consumption and supply resulting from an increase in energy efficiency in the Scottish commercial transport sector, *Energy Policy* 37, 3608–3620.

Aoyang, H L I, and J Inhua Z Hao, 2018, Rebound effects of new irrigation technologies: The role of water rights, 100, 786–808.

Arrobbio, Osman, and Dario Padovan, 2018, A Vicious Tenacity: The Efficiency Strategy Confronted With the Rebound Effect, *Frontiers in Energy Research* 6, 1–8.

Aune, Finn Roar, Ann Christin Bøeng, Snorre Kverndokk, Lars Lindholt, and Knut

Einar Rosendahl, 2017, Fuel Efficiency Improvements: Feedback Mechanisms and Distributional Effects in the Oil Market, *Environmental and Resource Economics* 68, 15–45.

Aydin, Erdal, Nils Kok, and Dirk Brounen, 2017, Energy Efficiency and Household Behavior: The Rebound Effect in the Residential Sector - Corporate Engagement, *RAND Journal of Economics* 48, 749–782.

Azevedo, Inês M.L., 2014, Consumer End-Use Energy Efficiency and Rebound Effects, *Annual Review of Environment and Resources* 39, 393–418.

Baker, Paul, Richard Blundell, and John Micklewright, 1989, Modelling Household Energy Expenditures Using Micro-Data, *The Economic Journal* 99, 720–738.

Barker, Terry, Athanasios Dagoumas, and Jonathan Rubin, 2009, The macroeconomic rebound effect and the world economy, *Energy Efficiency* 2, 411–427.

Barker, Terry, Paul Ekins, and Tim Foxon, 2007, The macro-economic rebound effect and the UK economy, *Energy Policy* 35, 4935–4946.

Barkhordar, Zahra A., 2019, Evaluating the economy-wide effects of energy efficient lighting in the household sector of Iran, *Energy Policy* 127, 125–133.

Bauer, Gordon, 2018, The impact of battery electric vehicles on vehicle purchase and driving behavior in Norway, *Transportation Research Part D* 58, 239–258.

Baum, Chad M., and Christian Gross, 2016, Sustainability policy as if people mattered: developing a framework for environmentally significant behavioral change, *Journal of Bioeconomics*, 1–43.

Bedoya-Perales, Noelia S., Guilherme Pumi, Angel Mujica, Edson Talamini, and Antonio Domingos Padula, 2018, Quinoa expansion in Peru and its implications for land use management, *Sustainability (Switzerland)* 10, 1–13.

Behl, Peter, Holger Dette, Manuel Frondel, and Colin Vance, 2019, A focused information criterion for quantile regression : Evidence for the rebound effect, *Quarterly Review of Economics and Finance* 71, 223–227.

Belaïd, Fateh, Salomé Bakaloglou, and David Roubaud, 2018, Direct rebound effect of residential gas demand: Empirical evidence from France, *Energy Policy* 115, 23–31.

Berbel, Julio, Carlos Gutiérrez-Martín, and Alfonso Expósito, 2018, Impacts of irrigation efficiency improvement on water use, water consumption and response to water price at field level, *Agricultural Water Management* 203, 423–429.

Berger, Tania, and Andrea Höltl, 2019, Thermal insulation of rental residential housing : Do energy poor households benefit ? A case study in Krems , Austria, *Energy Policy* 127, 341–349.

Bergh, Jeroen C. J. M. van den, 2011, Energy Conservation More Effective With Rebound Policy, *Environmental and Resource Economics* 48, 43–58.

Bitaraf, Hamideh, and Saifur Rahman, 2018, Reducing curtailed wind energy through energy storage and demand response, *IEEE Transactions on Sustainable Energy* 9, 228–236.

Bjelle, Eivind Lekve, Kjartan Steen-olsen, and Richard Wood, 2018, Climate change mitigation potential of Norwegian households and the rebound effect Intergovernmental Panel on Climate Change, *Journal of Cleaner Production* 172, 208–217.

Blair, Roger D, David L Kaserman, and Richard C Tepel, 1984, The Impact of Improved Mileage on Gasoline Consumption, *Economic Inquiry* 22, 209–217.

Borozan, Djula, 2019, Unveiling the heterogeneous effect of energy taxes and income on residential energy consumption, *Energy Policy* 129, 13–22.

Brännlund, Runar, Tarek Ghalwash, and Jonas Nordström, 2007, Increased energy efficiency and the rebound effect: Effects on consumption and emissions, *Energy Economics* 29, 1–17.

Brøgger, Morten, Peder Bacher, Henrik Madsen, and Kim B. Wittchen, 2018, Estimating the influence of rebound effects on the energy-saving potential in building stocks, *Energy and Buildings* 181, 62–74.

Brookes, Leonard, 1979, A low energy strategy for the UK, *Atom* 269, 3–8.

Buhl, Johannes, and José Acosta, 2016, Work less, do less?, *Sustainability Science* 11, 261–276.

Buhl, Johannes, Justus Von Geibler, Laura Echternacht, and Moritz Linder, 2017, Rebound effects in Living Labs : Opportunities for monitoring and mitigating re-spending and time use effects in user integrated innovation design, *Journal of Cleaner Production* 151, 592–602.

Bye, Brita, F Taran, and Orvika Rosnes, 2017, Residential energy efficiency policies: costs, emissions and rebound effects, *Energy*.

Cao, Zhi, Gang Liu, Shuai Zhong, Hancheng Dai, and Stefan Pauliuk, 2019, Integrating Dynamic Material Flow Analysis and Computable General Equilibrium Models for Both Mass and Monetary Balances in Prospective Modeling: A Case for the Chinese Building Sector, . Research-article *Environmental Science and Technology* 53, 224–233.

Chai, Jian, Ying Yang, Shouyang Wang, and Kin Keung Lai, 2016, Fuel efficiency and emission in China's road transport sector: Induced effect and rebound effect, *Technological Forecasting and Social Change* 112, 188–197.

Chang, Ming-chung, 2016, Applying the energy productivity index that considers maximized energy reduction on SADC (Southern Africa Development Community) members, *Energy* 95, 313–323.

Chen, Guangyu, Boqiang Lin, Bin Ye, Guangyu Chen, Boqiang Lin, and Bin Ye, 2018, Is China ' s Manufacturing Industry Efficient ? Evidence from an Energy-Rebound Effect Perspective Is China ' s Manufacturing Industry Efficient ? Evidence from an Energy-Rebound Effect Perspective, *Emerging Markets Finance and Trade* 54, 2245–2257.

Chen, Ko-jung, Ziyang Li, Lu Ta-Ping, Pei-Luen Patrick Rau, and Huang Dinglong, 2018, Influence of Rebound Effect on Energy Saving in Smart Homes, *Cross-Cultural Design Applications in Cultural Heritage, Creativity and Social Development*.

Cheng, Zhonghua, Lianshui Li, and Jun Liu, 2018, Industrial structure, technical progress and carbon intensity in China's provinces, *Renewable and Sustainable Energy Reviews* 81, 2935–2946.

Chitnis, Mona, and Steve Sorrell, 2015, Living up to expectations: Estimating direct and indirect rebound effects for UK households, *Energy Economics* 52, S100–S116.

Chitnis, Mona, Steve Sorrell, Angela Druckman, Steve Firth, and Tim Jackson, 2012, Estimating Direct and Indirect Rebound Effects for UK Households *SLRG Working Paper 02-12*.

Chitnis, Mona, Steve Sorrell, Angela Druckman, Steven K. Firth, and Tim Jackson, 2013, Turning lights into flights: Estimating direct and indirect rebound effects for UK households, *Energy Policy* 55, 234–250.

Chitnis, Mona, Steve Sorrell, Angela Druckman, Steven K. Firth, and Tim Jackson, 2014, Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups, *Ecological Economics* 106, 12–32.

Coninck, Helen de, and Aromar Revi, 2018, IPCC Special Report 2018 - Chapter 4.

Copiello, Sergio, 2016, Building energy efficiency: A research branch made of paradoxes, *Renewable and Sustainable Energy Reviews*, 1–13.

Copiello, Sergio, and Laura Gabrielli, 2017, Analysis of building energy consumption through panel data: The role played by the economic drivers, *Energy & Buildings* 145, 130–143.

Coulombel, N., V. Boutueil, L. Liu, V. Viguié, and B. Yin, 2018, Substantial rebound effects in urban ridesharing: Simulating travel decisions in Paris, France, *Transportation Research Part D: Transport and Environment*, 1–17.

Coyne, Bryan, Sean Lyons, and Daire McCoy, 2018, The effects of home energy efficiency upgrades on social housing tenants: evidence from Ireland, *Energy Efficiency* 11, 2077–2100.

Czepkiewicz, Michał, Jukka Heinonen, and Juudit Ottelin, 2018, Why do urbanites travel more than do others? A review of associations between urban form and long-distance leisure travel, *Environmental Research Letters* 13.

De Borger, Bruno, and Ismir Mulalic, 2012, The determinants of fuel use in the trucking industry-volume, fleet characteristics and the rebound effect, *Transport Policy* 24, 284–295.

De Borger, Bruno, Ismir Mulalic, and Jan Rouwendal, 2016, Measuring the rebound effect with micro data: A first difference approach, *Journal of Environmental Economics and Management* 79, 1–17.

De Zotti, Giulia, Seyyed Ali Pourmousavi Kani, Juan Morales, Henrik Madsen, and Niels Kjolstad Poulsen, 2018, Consumers' Flexibility Estimation at the TSO Level for Balancing Services, *IEEE Transactions on Power Systems* 34, 1918–1930.

Deng, Chun, and Jie Fang Dong, 2016, Coal consumption reduction in Shandong Province: A dynamic vector autoregression model, *Sustainability (Switzerland)* 8, 1–16.

Deng, Chuxiong, Ke Li, Chong Peng, and Feng Han, 2018, Analysis of technological progress and input prices on electricity consumption: Evidence from China, *Journal of Cleaner Production* 196, 1390–1406.

Deng, Gary, and Peter Newton, 2017, Assessing the impact of solar PV on domestic electricity consumption : Exploring the prospect of rebound effects, 110, 313–324.

Dimitropoulos, Alexandros, Walid Oueslati, and Christina Sintek, 2018, The rebound effect in road transport: A meta-analysis of empirical studies, *Energy Economics* 75, 163–179.

Dineen, D, F Rogan, and B.P.O Gallachóir, 2015, Improved modelling of thermal energy savings potential in the existing residential stock using a newly available data source, *Energy* 90, 759–767.

Druckman, Angela, Mona Chitnis, Steve Sorrell, and Tim Jackson, 2011, Missing carbon reductions? Exploring rebound and backfire effects in UK households, *Energy Policy* 39, 3572–3581.

Druckman, Angela, Mona Chitnis, Steve Sorrell, Tim Jackson, and Sussex Energy Group, 2011, Corrigendum to "Missing carbon reductions? Exploring rebound and backfire effects in UK households, *Energy Policy* 49, 3572–3581.

Du, Kerui, and Boqiang Lin, 2015, Comments on 'Using latent variable approach to estimate China's economy-wide energy rebound effect over 1954-2010' by Shuai Shao, Tao Huang and Lili Yang, *Energy Policy* 86, 219–221.

Du, Qiang, Yi Li, and Libiao Bai, 2017, The Energy Rebound Effect for the Construction Industry: Empirical Evidence from China, *Sustainability* 9, 803.

Du, Qiang, Zhe Li, Yi Li, Libiao Bai, Jingtao Li, and Xiao Han, 2019, Rebound effect of energy efficiency in China ' s construction industry : a general equilibrium analysis, *Environmental Science and Pollution Research* 26, 12217–12226.

Duarte, Rosa, Kuishuang Feng, Klaus Hubacek, Julio Sánchez-Chóliz, Cristina Sarasa, and Laixiang Sun, 2016, Modeling the carbon consequences of pro-environmental consumer behavior, *Applied Energy* 184, 1207–1216.

Duarte, Rosa, Julio Sánchez-Chóliz, and Cristina Sarasa, 2018, Consumer-side actions in a low-carbon economy: A dynamic CGE analysis for Spain, *Energy Policy* 118, 199–210.

Dubin, Jeffrey A;, Allen K; Miedema, and Ram V. Chandran, 1986, Price Effects of Energy-Efficient Technologies : A Study of Residential Demand for Heating and Cooling, *The RAND Journal of Economics* 17, 310–325.

Energy Information Administration (EIA), 2016, Transportation Sector Energy Consumption, *International Energy Outlook 2016* 2016, 127–137.

European Commission, 2019, 2018 assessment of the progress made by Member States towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive as required by Article 24(3) of the Energy Efficiency Directive 2012/27/EU.

European Environment Agency, 2009, Greenhouse gas emissions from transport Executive summary, , 1–13.

Fan, Ruguo, Ming Luo, and Pengfei Zhang, 2016, A study on evolution of energy intensity in China with heterogeneity and rebound effect, *Energy* 99, 159–169.

Fathurrahman, Fahman, 2016, Measuring the sustainability of energy development in emerging economies, *International Journal of Global Environmental Issues* 15, 315.

Fertner, Christian, and Juliane Große, 2016, Compact and Resource Efficient Cities? Synergies and Trade-offs in European Cities, *European Spatial Research and Policy* 23, 65–79.

Figge, Frank, and Andrea Stevenson Thorpe, 2019, The symbiotic rebound effect in the circular economy, *Ecological Economics* 163, 61–69.

Figus, Gioele, Karen Turner, Peter Mcgregor, and Antonios Katris, 2017, Making the case for supporting broad energy e ffi ciency programmes: Impacts on household incomes and other economic benefits, *Energy Policy* 111, 157–165.

Foell, Wesley K., 2019, A two-century analysis of household energy transitions in Europe and the United States: From the Swiss Alps to Wisconsin, *Energy Research and Social Science* 54, 96–112.

Fowlie, Meredith, Michael Greenstone, and Catherine Wolfram, 2018, DO

ENERGY EFFICIENCY INVESTMENTS DELIVER ? EVIDENCE FROM THE WEATHERIZATION ASSISTANCE PROGRAM, *The Quarterly Journal of Economics*, 1597–1644.

Freire-gonzález, Jaume, 2019, Does Water Efficiency Reduce Water Consumption ? The Economy-Wide Water Rebound Effect, , 2191–2202.

Freire-González, Jaume, 2010, Empirical evidence of direct rebound effect in Catalonia, *Energy Policy* 38, 2309–2314.

Freire-González, Jaume, 2011, Methods to empirically estimate direct and indirect rebound effect of energy-saving technological changes in households, *Ecological Modelling* 223, 32–40.

Freire-González, Jaume, 2017, Evidence of direct and indirect rebound effect in households in EU-27 countries, *Energy Policy* 102, 270–276.

Freire-González, Jaume, 2017, A new way to estimate the direct and indirect rebound effect and other rebound indicators, *Energy* 128, 394–402.

Freire-González, Jaume, and David Font Vivanco, 2017, The influence of energy efficiency on other natural resources use: An input-output perspective, *Journal of Cleaner Production* 162, 336–345.

Freire-González, Jaume, Jaume Lez, David Font Vivanco, and Ignasi Puig-Ventosa, 2017, Economic structure and energy savings from energy efficiency in households, *Ecological Economics* 131, 12–20.

Frondel, Manuel, Jörg Peters, and Colin Vance, 2007, Identifying the Rebound Theoretical Issues and Empirical Evidence from a German Household Panel, *Ecological Economics* 66, 153–160.

Frondel, Manuel, Nolan Ritter, and Colin Vance, 2012, Heterogeneity in the rebound effect: Further evidence for Germany, *Energy Economics* 34, 461–467.

Frondel, Manuel, and Colin Vance, 2018, Drivers' response to fuel taxes and efficiency standards: evidence from Germany, *Transportation* 45, 989–1001.

Fukui, Hideki, and Chikage Miyoshi, 2017, The impact of aviation fuel tax on fuel consumption and carbon emissions: The case of the US airline industry, *Transportation Research Part D: Transport and Environment* 50, 234–253.

Galassi, Veronica, and Reinhard Madlener, 2017, The Role of Environmental Concern and Comfort Expectations in Energy Retrofit Decisions, *Ecological Economics* 141, 53–65.

Galassi, Veronica, and Reinhard Madlener, 2018, Shall I open the window? Policy implications of thermal-comfort adjustment practices in residential buildings, *Energy Policy* 119, 518–527.

Galvez, Pablo, Petr Mariel, and David Hoyos, 2014, *Estimating the Direct Rebound Effect in the Residential Energy Sector : An Application in Spain*.

Galvin, Ray, 2014, Estimating broad-brush rebound effects for household energy consumption in the EU 28 countries and Norway : some policy implications of Odyssee data, *Energy Policy* 73, 323–332.

Galvin, Ray, 2015, Integrating the rebound effect: accurate predictors for upgrading domestic heating, *BUILDING RESEARCH &INFORMATION* 43, 710–722.

Galvin, Ray, 2015, The ICT / electronics question : Structural change and the rebound effect, *Ecological Economics* 120, 23–31.

Galvin, Ray, 2015, The rebound effect , gender and social justice : A case study in Germany, *Energy Policy* 86, 759–769.

Galvin, Ray, 2016, Rebound effects from speed and acceleration in electric and internal combustion engine cars : An empirical and conceptual investigation, *Applied Energy* 172, 207–216.

Galvin, Ray, 2017, How does speed affect the rebound effect in car travel ? Conceptual issues explored in case study of 900 Formula 1 Grand Prix speed trials, *Energy* 128, 28–38.

Galvin, Ray, and Andreas Gubernat, 2016, The rebound effect and Schatzki's social theory: Reassessing the socio-materiality of energy consumption via a German case study, *Energy Research and Social Science* 22, 183–193.

Galvin, Ray, and Minna Sunikka-Blank, 2016, Quantification of (p)rebound effects in retrofit policies - Why does it matter?, *Energy* 95, 415–424.

Garcia, Oscar Garay, C. Els Daalen, Emile Chappin, Bas van Nuland, Iman Mohammed, and Bert Enserink, 2017, Assessing the Residential Energy Rebound Effect by Means of a Serious Game, *Simulation Gaming Applications for Sustainable Cities and Smart Infrastructures*.

Gately, Dermot, 1992, Imperfect Price-Reversibility of U . S . Gasoline Demand : Asymmetric Responses to Price Increases and Declines, *Energy Journal* 13, 179–207.

Georges, Emeline, Bertrand Cornelusse, Damien Ernst, Vincent Lemort, and Sébastien Mathieu, 2017, Residential heat pump as flexible load for direct control service with parametrized duration and rebound effect, *Applied Energy* 187, 140–153.

Ghoddusi, Hamed, and Mandira Roy, 2017, Supply elasticity matters for the rebound effect and its impact on policy comparisons, *Energy Economics* 67, 111–120.

Ghosh, Neal K, and Michael F Blackhurst, 2014, Energy savings and the rebound effect with multiple energy services and efficiency correlation, *Ecological*

Economics 105, 55–66.

Gillingham, Kenneth, Alan Jenn, and Inês M L Azevedo, 2015, Heterogeneity in the response to gasoline prices : Evidence from Pennsylvania and implications for the rebound effect, *Energy Economics* 52, S41–S52.

Goldberg, Pinelopi Koujianou, 1996, the Effects of the Corporate Average Fuel Efficiency Standards, *Journal of Industrial Economics* 46, 1–33.

Grant, Don, Andrew K. Jorgenson, and Wesley Longhofer, 2016, How organizational and global factors condition the effects of energy efficiency on CO2 emission rebounds among the world's power plants, *Energy Policy* 94, 89–93.

Greene, David L., 1992, Vehicle use and fuel economy: how big is the "rebound" effect?, *Energy* 13, 117–143.

Greene, David L., James R Kahn, and Robert C Gibson, 1999, Fuel Economy Rebound Effect for U.S. Household Vehicles, *The Energy Journal* 20, 1–31.

Greening, Lorna A., David L. Greene, and Carmen Difiglio, 2000, Energy efficiency and consumption - the rebound effect - a survey, *Energy Policy* 28, 389–401.

Grossmann, Doreen, Ray Galvin, Julika Weiss, Reinhard Madlener, and Bernd Hirschl, 2016, A methodology for estimating rebound effects in non-residential public service buildings: Case study of four buildings in Germany, *Energy and Buildings* 111, 455–467.

Guerra-Santin, Olivia, and Laure Itard, 2010, Occupants' behaviour: Determinants and effects on residential heating consumption, *Building Research and Information* 38, 318–338.

Guerra, Ana Isabel, and Ferran Sancho, 2010, Rethinking economy-wide rebound measures: An unbiased proposal, *Energy Policy* 38, 6684–6694.

Guertin, Chantal, Subal C. Kumbhakar, and Anantha K. Duraiappah, 2003, Determining Demand for Energy Services : Investigating income- driven behaviours.

Hache, Emmanuel, Déborah Leboullenger, and Valérie Mignon, 2017, Beyond average energy consumption in the French residential housing market: A household classification approach, *Energy Policy* 107, 82–95.

Hamamoto, Mitsutsugu, 2019, An empirical study on the behavior of hybrid-electric vehicle purchasers, *Energy Policy* 125, 286–292.

Hart, Rob, 2018, Rebound, directed technological change, and aggregate demand for energy, *Journal of Environmental Economics and Management* 89, 218–234.

Haughton, Jonathan, and Soumodip Sarkar, 1996, Gasoline Tax as a Corrective Tax: Estimates for the United States, 1970-1991, *The Energy Journal* 17, 103–126.

Havas, Lisa, Julie Ballweg, Chris Penna, and Digby Race, 2015, Power to change: Analysis of household participation in a renewable energy and energy efficiency programme in Central Australia, *Energy Policy* 87, 325–333.

Hediger, Cécile, Mehdi Farsi, and Sylvain Weber, 2018, Turn It Up and Open the Window: On the Rebound Effects in Residential Heating, *Ecological Economics* 149, 21–39.

Henly, John, Henry Ruderman, and Mark D Levine, 1988, Energy Saving Resulting from the Adoption of More Efficient Appliances : A Follow-up, *The Energy Journal* 9, 163–170.

Hens, Hugo, Wout Parijs, and Mieke Deurinck, 2010, Energy consumption for heating and rebound effects, *Energy and Buildings* 42, 105–110.

Herring, Horace, and Robin Roy, 2012, Technological innovation , energy efficient design and the rebound effect, *Technovation* 27, 194–203.

Hill, Jason, Liaila Tajibaeva, and Stephen Polasky, 2016, Climate consequences of low-carbon fuels: The United States Renewable Fuel Standard, *Energy Policy* 97, 351–353.

Holck, Nina, Igor Sartori, Magnus I Vestrum, and Helge Brattebø, 2017, Using a segmented dynamic dwelling stock model for scenario analysis of future energy demand : The dwelling stock of Norway 2016 – 2050, *Energy & Buildings* 146, 220–232.

Holzmann, Angela, and Erwin Schmid, 2018, Consumer behaviour in the residential heating sector in Austria : Findings from a bottom-up modelling approach, *Energy & Buildings* 158, 486–493.

Inglesi-lotz, Roula, 2018, Decomposing the South African CO2 emissions within a BRICS countries context : Signalling potential energy rebound effects, *Energy* 147, 648–654.

Inoue, Nozomu, and Shigeru Matsumoto, 2019, An examination of losses in energy savings after the Japanese Top Runner Program?, *Energy Policy* 124, 312–319.

Jalas, Mikko, 2002, A time use perspective on the materials intensity of consumption, *Ecological Economics* 41, 109–123.

Jin, Taeyoung, and Jinsoo Kim, 2019, A new approach for assessing the macroeconomic growth energy rebound effect, *Applied Energy* 239, 192–200.

Johansson, Olof, and Lee Schipper, 1997, Measuring the Long-Run Fuel Demand of Cars Separate Estimations of Vehicle Stock , Mean Fuel Intensity , and Mean Annual Driving Distance, *Journal of Transport Economics* 31, 277–292.

Jones, Clifton T., 1993, Another Look at U.S. Passenger Vehicle Use and the ’ Rebound ’ Effect from Improved Fuel Efficiency, *The Energy Journal* 14, 99–110.

Joyce, P. James, Göran Finnveden, Cecilia Håkansson, and Richard Wood, 2019, A multi-impact analysis of changing ICT consumption patterns for Sweden and the EU: Indirect rebound effects and evidence of decoupling, *Journal of Cleaner Production* 211, 1154–1161.

Julien Walzberg, Thomas, Nicolas Merveille, and Mohamed Cheriet, 2018, An agent-based model to evaluate smart homes sustainability potential, *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC* 2017-Octob, 1–7.

Kemp, Deanna, Sandy Worden, and John R. Owen, 2016, Differentiated social risk: Rebound dynamics and sustainability performance in mining, *Resources Policy* 50, 19–26.

Khazzoom, J Daniel, 1980, Economic Implications of Mandated Efficiency in Standards for Household Appliances, *Source: The Energy Journal* 1, 21–40.

Kim, Seung-Nam, 2017, Is telecommuting sustainable? An alternative approach to estimating the impact of home-based telecommuting on household travel, *International Journal of Sustainable Transportation* 11, 72–85.

Koesler, Simon, Kim Swales, and Karen Turner, 2016, International spillover and rebound effects from increased energy efficiency in Germany, *Energy Economics* 54, 444–452.

Kok, Rixtmethods, René M J Benders, and Henri C. Moll, 2006, Measuring the environmental load of household consumption using some methods based on input-output energy analysis: A comparison of methods and a discussion of results, *Energy Policy* 34, 2744–2761.

Kratena, Kurt, and Michael Wüger, 2010, The Full Impact of Energy Efficiency on Households' Energy Demand.

Kulmer, Veronika, and Sebastian Seebauer, 2019, How robust are estimates of the rebound effect of energy efficiency improvements? A sensitivity analysis of consumer heterogeneity and elasticities, *Energy Policy* 132, 1–14.

Labidi, Etidel, and Tahar Abdessalem, 2018, An econometric analysis of the household direct rebound effects for electricity consumption in Tunisia, *Energy Strategy Reviews* 19, 7–18.

Langbroek, Joram H.M., Joel P. Franklin, and Yusak O. Susilo, 2018, How would you change your travel patterns if you used an electric vehicle? A stated adaptation approach, *Travel Behaviour and Society* 13, 144–154.

Leard, Benjamin, Joshua Linn, Virginia Mcconnell, and William Raich, 2015, Fuel Costs, Economic Activity, and the Rebound Effect for Heavy-Duty Trucks.

Lenzen, Manfred, and Christopher J. Dey, 2002, Economic, energy and greenhouse emissions impacts of some consumer choice, technology and government outlay options, *Energy Economics* 24, 377–403.

Li, Guo, Jiasen Sun, and Zhaohua Wang, 2018, Exploring the energy consumption rebound effect of industrial enterprises in the Beijing–Tianjin–Hebei region, *Energy Efficiency*.

Li, Hong, Qin Bao, Xusheng Ren, Yuantao Xie, Jingzheng Ren, and Yingkui Yang, 2017, Reducing rebound effect through fossil subsidies reform: A comprehensive evaluation in China, *Journal of Cleaner Production* 141, 305–314.

Li, Jianglong, Aijun Li, and Xuan Xie, 2018, Rebound effect of transportation considering additional capital costs and input-output relationships: The role of subsistence consumption and unmet demand, *Energy Economics* 74, 441–455.

Li, Jianglong, and Boqiang Lin, 2017, Rebound effect by incorporating endogenous energy efficiency : A comparison between heavy industry and light industry, 200, 347–357.

Li, Jianglong, Hongxun Liu, and Kerui Du, 2019, Does market-oriented reform increase energy rebound effect? Evidence from China's regional development, *China Economic Review* 56, 101304.

Li, Ke, and Zhujun Jiang, 2016, The impacts of removing energy subsidies on economy-wide rebound effects in China: An input-output analysis, *Energy Policy* 98, 62–72.

Li, Ke, and Boqiang Lin, 2018, How to promote energy efficiency through technological progress in China ?, *Energy* 143, 812–821.

Li, Ke, Ning Zhang, and Yanchu Liu, 2016, The energy rebound effects across China's industrial sectors: An output distance function approach, *Applied Energy* 184, 1165–1175.

Li, Xuehui, and Jianghua Liu, 2017, Direct rebound effect for urban household in China — an empirical study, *Energy Efficiency*.

Li, Yi, Yan Luo, Yingzi Wang, Laili Wang, and Manhong Shen, 2017, Decomposing the decoupling of water consumption and economic growth in China's textile industry, *Sustainability (Switzerland)* 9, 1–17.

Liao, Maolin, and Yingjie Wang, 2019, China's energy consumption rebound effect analysis based on the perspective of technological progress, *Sustainability (Switzerland)* 11.

Lin, Boqiang, Yufang Chen, and Guoliang Zhang, 2017, Technological progress and rebound effect in China's nonferrous metals industry : An empirical study, *Energy Policy* 109, 520–529.

Lin, Boqiang, and Hongxun Liu, 2015, A study on the energy rebound effect of

China ’ s residential building energy efficiency, *Energy & Buildings* 86, 608–618.

Lin, Boqiang, and Ruipeng Tan, 2017, Estimating energy conservation potential in China’s energy intensive industries with rebound effect, 156.

Lin, Boqiang, and Peng Tian, 2016, The energy rebound effect in China’s light industry: A translog cost function approach, *Journal of Cleaner Production* 112, 2793–2801.

Lin, Boqiang, and Xuan Xie, 2015, Factor substitution and rebound effect in China’s food industry, *Energy Conversion and Management* 105, 20–29.

Lin, Boqiang, and Hongli Zhao, 2016, Technological progress and energy rebound effect in China’s textile industry: Evidence and policy implications, *Renewable and Sustainable Energy Reviews* 60, 173–181.

Lin, Borong, Zhe Wang, Yanchen Liu, Yingxin Zhu, and Qin Ouyang, 2016, Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China ’ s hot summer e Cold winter climate region, *Building and Environment* 101, 9–18.

Lin, Jing, and Boqiang Lin, 2020, Energy & Buildings The actual heating energy conservation in China : Evidence and policy implications, *Energy & Buildings* 190, 195–201.

Lindeblad, Peter Abrahamsson, Yuliya Voytenko, Oksana Mont, and Peter Arnfalk, 2016, Organisational effects of virtual meetings, *Journal of Cleaner Production* 123, 113–123.

Liu, Hongxun, Kerui Du, and Jianglong Li, 2019, An improved approach to estimate direct rebound effect by incorporating energy efficiency: A revisit of China’s industrial energy demand, *Energy Economics* 80, 720–730.

Liu, Hongxun, and Boqiang Lin, 2016, Incorporating energy rebound effect in technological advancement and green building construction: A case study of China, *Energy and Buildings* 129, 150–161.

Liu, Jingru, Xin Sun, Bin Lu, Yunkun Zhang, and Rui Sun, 2016, The life cycle rebound effect of air-conditioner consumption in China, *Applied Energy* 184, 1026–1032.

Liu, Shen, Gregory Colson, Na Hao, and Michael Wetzstein, 2018, Toward an optimal household solar subsidy: A social-technical approach, *Energy* 147, 377–387.

Liu, Weisheng, Ying Liu, and Boqiang Lin, 2018, Empirical analysis on energy rebound effect from the perspective of technological progress d a case study of China’s transport sector, *Journal of Cleaner Production* 205, 1082–1093.

Liu, Yulin, Zhihui Li, and Xingmin Yin, 2018, Environmental regulation, technological innovation and energy consumption—-a cross-region analysis in China, *Journal of Cleaner Production* 203, 885–897.

Llorca, Manuel, and Tooraj Jamasb, 2017, Energy efficiency and rebound effect in European road freight transport, *Transportation Research Part A* 101, 98–110.

Loi, Tian Sheng Allan, and Jia Le Ng, 2018, Analysing households' responsiveness towards socio-economic determinants of residential electricity consumption in Singapore, *Energy Policy* 112, 415–426.

Lu, Linyi, Manhong Shen, Yan Luo, Laili Wang, Jie Shen, and Yi Li, 2018, Water environmental stress, rebound effect, and economic growth of China's textile industry, *PeerJ* 6, e5112.

Lu, Milin, and Zhaohua Wang, 2016, Rebound effects for residential electricity use in urban China: an aggregation analysis based E-I-O and scenario simulation, *Annals of Operations Research*, 1–22.

Lu, Yingying, Yu Liu, and Meifang Zhou, 2017, Rebound effect of improved energy ef fi ciency for different energy types : A general equilibrium analysis for China, *Energy Economics* 62, 248–256.

Lu, Yujie, Nan Zhang, and Jiayu Chen, 2017, A behavior-based decision-making model for energy performance contracting in building retrofit, *Energy & Buildings* 156, 315–326.

Lunacek, Monte, Mark Ruth, Wesley Jones, and Fei Ding, 2018, Understanding the Impact of Electric Water Heater Control on the Grid, *IEEE Power and Energy Society General Meeting* 2018-Augus, 1–4.

Lütolf, Philipp, Marc Scherer, Olivier Megel, Martin Geidl, and Evangelos Vrettos, 2018, Rebound effects of demand-response management for frequency restoration, *2018 IEEE International Energy Conference, ENERGYCON 2018*, 1–6.

Ma, Xuejiao, and Qichuan Jiang, 2019, How to balance the trade-off between economic development and climate change?, *Sustainability* 11, 1–30.

Madlener, Reinhard, and Maximilian Hauertmann, 2011, Rebound Effects in German Residential Heating : Do Ownership and Income Matter ? Institute for Future Energy Consumer Needs and Behavior (FCN).

Makov, Tamar, and David Font Vivanco, 2018, Does the Circular Economy Grow the Pie? The Case of Rebound Effects From Smartphone Reuse, *Frontiers in Energy Research* 6, 1–11.

Matos, Fernando J.F., and Francisco J.F. Silva, 2011, The rebound effect on road freight transport: Empirical evidence from Portugal, *Energy Policy* 39, 2833–2841.

Mayo, John W., and John E. Mathis, 1988, The effectiveness of mandatory fuel efficiency standards in reducing the demand for gasoline, *Applied Economics* 20, 211–219.

Menon, Balagopal G., 2017, Empirical evidence of direct rebound effect in Indian two-wheeler sector, *Energy Efficiency* 10, 1201–1213.

Meyer, Bernd, Martin Distelkamp, and Marc Ingo, 2007, Material efficiency and economic-environmental sustainability. Results of simulations for Germany with the model PANTA RHEI, *Ecological Economics* 63, 192–200.

Meyer, Bernd, Mark Meyer, and Martin Distelkamp, 2012, Modeling green growth and resource efficiency : new results, *Mineral Economics* 24, 145–154.

Milne, Geoffrey, and Brenda Boardman, 2000, Making cold homes warmer: The effect of energy efficiency improvements in low - income homes, *Energy Policy* 28, 411–424.

Mishina, Yoshinori, and Yasunori Muromachi, 2017, Are potential reductions in CO2 emissions via hybrid electric vehicles actualized in real traffic? The case of Japan, *Transportation Research Part D: Transport and Environment* 50, 372–384.

Miyoshi, Chikage, and Hideki Fukui, 2018, Measuring the rebound effects in air transport: The impact of jet fuel prices and air carriers' fuel efficiency improvement of the European airlines, *Transportation Research Part A: Policy and Practice* 112, 71–84.

Mizobuchi, Kenichi, 2008, An empirical study on the rebound effect considering capital costs, *Energy Economics* 30, 2486–2516.

Mizobuchi, Kenichi, and Kenji Takeuchi, 2019, Rebound effect across seasons: evidence from the replacement of air conditioners in Japan, *Environmental Economics and Policy Studies* 21, 123–140.

Moshiri, Saeed, and Kamil Aliyev, 2017, Rebound effect of efficiency improvement in passenger cars on gasoline consumption in Canada, *Ecological Economics* 131, 330–341.

Muñoz, Ivan, Francisco Portillo, Sabina Rosiek, Francisco J. Batlles, Javier Martínez-Del-Río, Iñaki Acasuso, Valentina Piergrossi, Marco De Sanctis, Silvia Chimienti, and Claudio Di Iaconi, 2019, Prospective environmental and economic assessment of solar-assisted thermal energy recovery from wastewater through a sequencing batch biofilter granular reactor, *Journal of Cleaner Production* 212, 1300–1309.

Murray, Cameron K., 2011, Income dependent direct and indirect rebound effects from 'green' consumption choices in Australia, *Munich Personal RPEC archive, MPRA Paper No. 34973, Munich.*

Murray, Cameron K., 2013, What if consumers decided to all 'go green'? Environmental rebound effects from consumption decisions, *Energy Policy* 54, 240–256.

Nabernegg, Stefan, Birgit Bednar-friedl, Fabian Wagner, Thomas Schinko, Janusz Cofala, and Yadira Mori Clement, 2017, The Deployment of Low Carbon Technologies in Energy Intensive Industries : A Macroeconomic Analysis for Europe, China and India, *Energies* 10, 1–26.

Nässén, Jonas, and John Holmberg, 2009, Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden, *Energy Efficiency* 2, 221–231.

Nesbakken, Runa, 1998, Residential Energy Consumption for Space Heating in Norwegian Households A Discrete-Continuous Choice Approach.

Nesbakken, Runa, 2001, Energy Consumption for Space Heating : A Discrete - Continuous Approach, *The Scandinavian Journal of Economics* 103, 165–184.

Niemierko, Rochus, Jannick Töppel, and Timm Tränkler, 2019, A D-vine copula quantile regression approach for the prediction of residential heating energy consumption based on historical data, *Applied Energy* 233–234, 691–708.

Nilsson, Andreas, Magnus Bergquist, and Wesley P. Schultz, 2016, Spillover effects in environmental behaviors, across time and context: a review and research agenda, *Environmental Education Research* 4622, 1–17.

Oberst, Christian A, Hendrik Schmitz, and Reinhard Madlener, 2016, Are Prosumer Households That Much Different ? Evidence from Stated Residential Energy Consumption in Germany Christian A . Oberst , Hendrik Schmitz and Reinhard Madlener December 2016 Revised March 2018 Institute for Future Energy Consumer Needs and Behav.

Odeck, James, and Kjell Johansen, 2016, Elasticities of fuel and traffic demand and the direct rebound effects : An econometric estimation in the case of Norway, *Transportation Research Part A* 83, 1–13.

Ouyang, Xiaoling, Beiying Gao, Kerui Du, and Gang Du, 2018, Industrial sectors' energy rebound effect: An empirical study of Yangtze River Delta urban agglomeration, *Energy* 145, 408–416.

Pakusch, Christina, Gunnar Stevens, Alexander Boden, and Paul Bossauer, 2018, Unintended effects of autonomous driving: A study on mobility preferences in the future, *Sustainability (Switzerland)* 10, 1–22.

Paul, Carsten, Anja-Kristina Techen, James Scott Robinson, and Katharina Helming, 2019, Rebound effects in agricultural land and soil management: Review and analytical framework, *Journal of Cleaner Production* 227, 1054–1067.

Peng, Jiao Ting, Yuan Wang, Xiang Zhang, Yanmin He, Masashi Taketani, Rui Shi, and Xiao Dong Zhu, 2019, Economic and welfare influences of an energy excise tax in Jiangsu province of China: A computable general equilibrium approach, *Journal of Cleaner Production* 211, 1403–1411.

Peters, Anja, Marco Sonnberger, Elisabeth Dütschke, and Jürgen Deuschle, 2012, Theoretical perspective on rebound effects from a social science point of view – Working Paper to prepare empirical psychological and sociological studies in the REBOUND project.

Peters, Bianca, and Stephanie F. McWhinnie, 2017, On the rebound: estimating direct rebound effects for Australian households, *Australian Journal of Agricultural and Resource Economics* 62, 65–82.

Pfaff, Matthias, and Christian Sartorius, 2015, Economy-wide rebound effects for non-energetic raw materials, *Ecological Economics* 118, 132–139.

Pohl, Johanna, Lorenz M. Hilty, and Matthias Finkbeiner, 2019, How LCA contributes to the environmental assessment of higher order effects of ICT application: A review of different approaches, *Journal of Cleaner Production* 219, 698–712.

Poon, Ivan, 2015, Incorporation of rebound effect into energy efficient measures cost-benefit analysis model, *IEEE International Conference on Building Efficiency and Sustainable Technologies*, 90–94.

Portal, Márcio Telles, and Luis Laureano, 2017, Does Brazilian allowance for corporate equity reduce the debt bias? Evidences of rebound effect and ownership-induced ACE clientele, *Research in International Business and Finance* 42, 480–495.

Presidency of Turkey, Presidency of Strategy and Budget, 2019, The Eleventh Development Plan (2019-2023).

Pui, Kiew Ling, and Jamal Othman, 2017, Economics and environmental implications of fuel ef fi ciency improvement in Malaysia : A computable general equilibrium approach, 156.

Puller, Steven L., and Lorna A. Greening, 1999, Household adjustment to gasoline price change : an analysis using 9 years of US survey data, *Energy Economics* 21, 37–52.

Qiu, Lu-yi, and Ling-yun He, 2017, Are Chinese Green Transport Policies Effective ? A New Perspective from Direct Pollution Rebound Effect , and Empirical Evidence From the Road Transport Sector, *Sustainability* 9, 1–11.

Raynaud, Maxime, Dominique Osso, Bernard Bourges, Bruno Duplessis, and Jérôme Adnot, 2016, Evidence of an indirect rebound effect with reversible heat pumps: having air conditioning but not using it?, *Energy Efficiency* 9, 847–860.

Rosenbaum, Eckehard, 2019, Rebound effects and green growth – An examination of their relationship in a parsimonious equilibrium input-output-framework, *Journal of Cleaner Production* 225, 121–132.

Rosenow, Jan, and Ray Galvin, 2013, Evaluating the evaluations : Evidence from energy efficiency programmes in Germany and the UK, *Energy & Buildings* 62, 450–458.

Ruzzenenti, Franco, 2018, The Prism of Elasticity in Rebound Effect Modelling : An Insight from the Freight Transport Sector, *Sustainability* 10, 1–13.

Safarzadeh, Soroush, and Morteza Rasti-Barzoki, 2019, A game theoretic approach for assessing residential energy-efficiency program considering rebound, consumer behavior, and government policies, *Applied Energy* 233–234, 44–61.

Safarzyńska, Karolina, 2018, Integrating behavioural economics into climate-economy models: some policy lessons, *Climate Policy* 18, 485–498.

Safarzyńska, Karolina, and Jeroen C.J.M. van den Bergh, 2018, A higher rebound effect under bounded rationality: Interactions between car mobility and electricity generation, *Energy Economics* 74, 179–196.

Santarius, Tilman, and Martin Soland, 2018, How Technological Efficiency Improvements Change Consumer Preferences: Towards a Psychological Theory of Rebound Effects, *Ecological Economics* 146, 414–424.

Santarius, Tilman, Hans Jakob Walnum, and Carlo Aall, 2018, From Unidisciplinary to Multidisciplinary Rebound Research: Lessons Learned for Comprehensive Climate and Energy Policies, *Frontiers in Energy Research* 6, 1–10.

Santos, Ricardo S., J. C.O. Matias, and Antonio Abreu, 2018, *Energy Efficiency in Buildings by Using Evolutionary Algorithms: An Approach to Provide Efficiency Choices to the Consumer, Considering the Rebound Effect*.

Santos, Ricardo S., J. C.O. Matias, Antonio Abreu, and Francisco Reis, 2018, Evolutionary algorithms on reducing energy consumption in buildings: An approach to provide smart and efficiency choices, considering the rebound effect, *Computers and Industrial Engineering* 126, 729–755.

Sarr, Mare, and Tim Swanson, 2016, Will Technological Change Save the World? The Rebound Effect in International Transfers of Technology, *Environmental and Resource Economics*.

Saunders, Harry D., 2014, Toward a neoclassical theory of sustainable consumption: Eight golden age propositions, *Ecological Economics* 105, 220–232.

Scheepens, Arno E., and Joost G. Vogtländer, 2018, Insulation or smart temperature control for domestic heating: A combined analysis of the costs, the eco-costs, the customer perceived value, and the rebound effect of energy saving, *Sustainability (Switzerland)* 10, 1–24.

Schleich, Joachim, Bradford Mills, and Elisabeth Dütschke, 2014, A brighter future? Quantifying the rebound effect in energy efficient lighting, *Energy Policy* 72, 35–42.

Schröder, Patrick, Magnus Bengtsson, Maurie Cohen, Paul Dewick, Joerg Hoffstetter, and Joseph Sarkis, 2019, Degrowth within – Aligning circular economy and strong sustainability narratives, *Resources, Conservation and Recycling* 146, 190–191.

Seebauer, Sebastian, 2018, The psychology of rebound effects: Explaining energy efficiency rebound behaviours with electric vehicles and building insulation in Austria, *Energy Research & Social Science* 46, 311–320.

Shao, Qing Long, and Beatriz Rodriguez-Labajos, 2016, Does decreasing working time reduce environmental pressures? New evidence based on dynamic panel approach, *Journal of Cleaner Production* 125, 227–235.

Shao, Shuai, Longfei Guo, Mingliang Yu, Lili Yang, and Dabo Guan, 2019, Does the rebound effect matter in energy import-dependent mega-cities ? Evidence from Shanghai (China), *Applied Energy* 241, 212–228.

Shao, Shuai, Tao Huang, and Lili Yang, 2014, Using latent variable approach to estimate China's economy-wide energy rebound effect over 1954-2010, *Energy Policy* 72, 235–248.

Small, K, and K van Dender, 2004, A study to evaluate the effect of reduced greenhouse gas emissions on vehicle miles traveled., *Department of Economics, University of California, Irvine.*

Small, Kenneth A, and Kurt Van Dender, 2007, Fuel Efficiency and Motor Vehicle Travel : The Declining Rebound Effect, .

Somuncu, Tugba, and Christopher Hannum, 2016, Can energy efficiency save energy? An economy-wide rebound effect simulation for Turkey, *Enerday 2016*.

Somuncu, Tugba, and Christopher Hannum, 2018, The rebound effect of energy efficiency policy in the presence of energy theft, *Energies* 11, 1–28.

Song, Jianfeng, Yanan Guo, Pute Wu, and SHikun Sun, 2018, The Agricultural Water Rebound Effect in China, *Ecological Economics* 146, 497–506.

Sorrell, Steve, 2007, *The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency UK Energy Research Centre*. Vol. 42.

Sorrell, Steve, 2010, Mapping rebound effects from sustainable behaviours: key concepts and literature review *SLRG Working Papers*.

Sorrell, Steve, and John Dimitropoulos, 2008, The rebound effect: Microeconomic definitions, limitations and extensions, *Ecological Economics* 65, 636–649.

Sorrell, Steve, John Dimitropoulos, and Matt Sommerville, 2009, Empirical estimates of the direct rebound effect : A review, *Energy Policy* 37, 1356–1371.

Sorrell, Steve, and Lee Stapleton, 2018, Rebound effects in UK road freight transport, *Transportation Research Part D: Transport and Environment* 63, 156–174.

Stapleton, Lee, Steve Sorrell, and Tim Schwanen, 2017, Peak car and increasing rebound : A closer look at car travel trends in Great Britain, *Transportation Research Part D* 53, 217–233.

Steren, Aviv, D Rubin, and Stav Rosenzweig, 2016, Assessing the rebound effect using a natural experiment setting : Evidence from the private transportation sector in Israel, 93, 41–49.

Su, Yu Wen, 2019, Residential electricity demand in Taiwan: Consumption behavior and rebound effect, *Energy Policy* 124, 36–45.

Sun, Bixuan, 2018, Heterogeneous direct rebound effect: Theory and evidence from the Energy Star program, *Energy Economics* 69, 335–349.

Sunikka-blank, Minna, Ray Galvin, Minna Sunikka-blank, and Ray Galvin, 2012, Introducing the prebound effect- the gap between performance and actual energy consumption - Minna Sunikka-Blank and Ray Galvin.pdf, , 37–41.

Taiebat, Morteza, Samuel Stolper, and Ming Xu, 2019, Forecasting the Impact of Connected and Automated Vehicles on Energy Use: A Microeconomic Study of Induced Travel and Energy Rebound, *Applied Energy* 247, 297–308.

Takase, Koji, Yasushi Kondo, and Ayu Washizu, 2005, An analysis of sustainable consumption by the waste input-output model, *Journal of Industrial Ecology* 9, 201–219.

Takase, Koji, Yasushi Kondo, and Ayu Washizu, 2006, An analysis of consumers' behavior by the waste input-output model: Environmental impact of income and time use, *Journal of Life Cycle Assessment, Japan*.

Teli, D., T. Dimitriou, P. A B James, A. S. Bahaj, L. Ellison, and A. Waggott, 2016, Fuel poverty-induced 'prebound effect'' in achieving the anticipated carbon savings from social housing retrofit', *Building Services Engineering Research & Technology* 37, 176–193.

Thomas, Brinda A., 2012, Energy Efficiency and Rebound Effects in the United States, .

Thomas, Brinda A., and Inês L. Azevedo, 2013, Estimating direct and indirect rebound effects for U.S. households with input-output analysis Part 1: Theoretical framework, *Ecological Economics* 86, 199–210.

Throndsen, William, and Thomas Berker, 2012, Households On The Rebound Factors Increasing and Decreasing Rebound Effects in Norwegian Households, .

Topallı, Nurgün, and Abdülkadir Buluş, 2012, The Rebound Effect : Empirical

Evidence from Turkey, *Sosyal Bilimler Dergisi*, 29–38.

Turner, Karen, 2012, 'Rebound' effects from increased energy efficiency: a time to pause and reflect.

Turner, Karen, and Antonios Katris, 2017, A 'Carbon Saving Multiplier' as an alternative to rebound in considering reduced energy supply chain requirements from energy efficiency?, *Energy Policy* 103, 249–257.

Underwood, Anthony, and Anders Fremstad, 2018, Does sharing backfire? A decomposition of household and urban economies in CO2emissions, *Energy Policy* 123, 404–413.

van den Brom, Paula, Arjen Meijer, and Henk Visscher, 2019, Actual energy saving effects of thermal renovations in dwellings—longitudinal data analysis including building and occupant characteristics, *Energy and Buildings* 182, 251–263.

Vivanco, David Font, René Kemp, and Ester Van Der Voet, 2015, The relativity of eco-innovation : environmental rebound effects from past transport innovations in Europe, *Journal of Cleaner Production* 101, 71–85.

Vivanco, David Font, Serenella Sala, and Will McDowall, 2018, Roadmap to rebound: How to address rebound effects from resource efficiency policy, *Sustainability (Switzerland)* 10, 1–17.

Vivanco, David Font, and Ester Van Der Voet, 2014, The Remarkable Environmental Rebound Effect of Electric Cars: A Microeconomic Approach, *Environmental Sicence&Technology* 48, 12063–12072.

Volland, Benjamin, 2016, Efficiency in Domestic Space Heating: An Estimation of the Direct Rebound Effect for Domestic Heating in the U.S., *IRENE Working Paper* 16.

Walker, Author I O, and Franz Wirl, 1993, Irreversible Price-Induced Efficiency Improvements : Theory and Empirical Application to Road Transportation, *The Energy Journal* 14, 183–205.

Wang, Chan, and Pu yan Nie, 2018, How rebound effects of efficiency improvement and price jump of energy influence energy consumption?, *Journal of Cleaner Production* 202, 497–503.

Wang, H., D. Q. Zhou, P. Zhou, and D. L. Zha, 2012, Direct rebound effect for passenger transport: Empirical evidence from Hong Kong, *Applied Energy* 92, 162–167.

Wang, H., P. Zhou, and D. Q. Zhou, 2012, An empirical study of direct rebound effect for passenger transport in urban China, *Energy Economics* 34, 452–460.

Wang, Jiayu, John Quiggin, and Glyn Wittwer, 2019, The rebound effect of the Australian proposed light vehicle fuel efficiency standards, *Economic Analysis and*

Policy 61, 73–84.

Wang, Qingsong, Zhenlei Gao, Hongrui Tang, Xueliang Yuan, and Jian Zuo, 2018, Exploring the Direct Rebound Effect of Energy Consumption: A Case Study, *Sustainability* 10, 259.

Wang, Shaojian, Jingyuan Zeng, and Xiaoping Liu, 2019, Examining the multiple impacts of technological progress on CO 2 emissions in China : A panel quantile regression approach, *Renewable and Sustainable Energy Reviews* 103, 140–150.

Wang, Xiaolei, and Boqiang Lin, 2016, Impacts of residential electricity subsidy reform in China, *Energy Efficiency*, 1–13.

Wang, Xiaolei, Xiaohui Wen, and Chunping Xie, 2018, An evaluation of technical progress and energy rebound effects in China's iron & steel industry, *Energy Policy* 123, 259–265.

Wang, Zhaohua, Bai Han, and Milin Lu, 2016, Measurement of energy rebound effect in households : Evidence from residential electricity consumption in Beijing , China, *Renewable and Sustainable Energy Reviews* 58, 852–861.

Wang, Zhaohua, and Milin Lu, 2014, An empirical study of direct rebound effect for road freight transport in China, *Applied Energy* 133, 274–281.

Weber, Sylvain, and Mehdi Farsi, 2014, Travel Distance and Fuel Efficiency: An Estimation of the Rebound Effect using Micro-Data in Switzerland, *Working paper 14-03*, 1–22.

Wei, Taoyuan, and Yang Liu, 2017, Estimation of global rebound effect caused by energy ef fi ciency improvement, *Energy Economics* 66, 27–34.

Wei, Taoyuan, Jinjin Zhou, and Hongxia Zhang, 2019, Rebound effect of energy intensity reduction on energy consumption, *Resources, Conservation and Recycling* 144, 233–239.

Wen, Fenghua, Zhengke Ye, Huaidong Yang, and Ke Li, 2018, Exploring the rebound effect from the perspective of household: An analysis of China's provincial level, *Energy Economics* 75, 345–356.

Werner, Piotr, 2015, The Rebound Effect of Information and Communication Technologies Development in the European Union, *Applied Spatial Analysis and Policy* 8, 409–423.

West, Jeremy, Mark Hoekstra, Jonathan Meer, and Steven L. Puller, 2017, Vehicle miles (not) traveled: Fuel economy requirements, vehicle characteristics, and household driving, *Journal of Public Economics* 145, 65–81.

West, Sarah E, 2004, Distributional effects of alternative vehicle pollution control policies, *Journal of Public Economics* 88, 735–757.

Wheaton, William C, 1982, The Long-Run Structure of Transportation and Gasoline, 13, 439–454.

Winebrake, James J., and Erin H. Green, 2017, Environmental policy, decision making, and rebound effects in the U.S. trucking sector, *Research in Transportation Business & Management* 23, 54–63.

Winebrake, James J., Erin H. Green, Bryan Comer, Chi Li, Sarah Froman, and Michael Shelby, 2015, Fuel price elasticities for single-unit truck operations in the United States, *Transportation Research Part D: Transport and Environment* 38, 178–187.

Winther, Tanja, and Hal Wilhite, 2014, The use of heat pumps in Norwegian homes : Accounting for the comfort rebound effect .

Wood, Richard, Daniel Moran, Konstantin Stadler, Diana Ivanova, Kjartan Steen-Olsen, Alexandre Tisserant, and Edgar G. Hertwich, 2018, Prioritizing Consumption-Based Carbon Policy Based on the Evaluation of Mitigation Potential Using Input-Output Methods, *Journal of Industrial Ecology* 22, 540–552.

Woodman, Nicholas, Thomas Rushby, Clare Saunders, Rebecca Wallbridge, Patrick James, Nicholas Bardsley, Milena Büchs, Graham Smith, and Anastasios Papafragkou, 2019, Domestic thermal upgrades, community action and energy saving: A three-year experimental study of prosperous households, *Energy Policy* 127, 475–485.

Wörsdorfer, Julia Sophie, 2010, Consumer needs and their satiation properties as drivers of the rebound effect, *Group*, 29.

Wu, Feng, Qian Zhang, and Xing Gao, 2018, Does water-saving technology reduce water use in economic systems? A rebound effect in Zhangye city in the Heihe River Basin, China, *Water Policy* 20, 355–368.

Wu, Kuei Yen, Jung Hua Wu, Yun Hsun Huang, Szu Chi Fu, and Chia Yon Chen, 2016, Estimating direct and indirect rebound effects by supply-driven input-output model: A case study of Taiwan’s industry, *Energy* 115, 904–913.

Wu, Liangpeng, Ye Chen, Mohammad Reza, and Wenjie Liu, 2018, Estimation of China ’ s macro-carbon rebound effect : Method of integrating Data Envelopment Analysis production model and sequential Malmquist-Luenberger index, *Journal of Cleaner Production* 198, 1431–1442.

Xin-gang, Zhao, Zhang Yuan-feng, and Li Yan-bin, 2019, The spillovers of foreign direct investment and the convergence of energy intensity, *Journal of Cleaner Production* 206, 611–621.

Yang, Lisha, and Li Jianglong, 2017, Rebound effect in China Evidence from the power generation sector, .

Yang, Lisha, and Zhi Li, 2017, Technology advance and the carbon dioxide emission in China – Empirical research based on the rebound e ff ect, *Energy Policy* 101, 150–161.

Yang, Qian Ru, Kun Zhang, Xiao Xia Yuan, and Qiao Mei Liang, 2019, Evaluating the direct rebound effect of China's urban household energy demand, *Energy Procedia* 158, 4135–4140.

Yazıcıoğlu, Yahşi, and Samiye Erdoğan, 2004, *SPSS Uygulamalı Bilimsel Araştırma Yöntemleri* (Detay Yayıncılık).

Yu, Biying, Junyi Zhang, and Akimasa Fujiwara, 2013, Evaluating the direct and indirect rebound effects in household energy consumption behavior: A case study of Beijing, *Energy Policy* 57, 441–453.

Yu, Xuewei, Juan Moreno-cruz, and John C Crittenden, 2015, Regional energy rebound effect : The impact of economy-wide and sector level energy ef fi ciency improvement in Georgia , USA, *Energy Policy* 87, 250–259.

Yuldashev, Oybek, Mirkhon Mirkomilov, and Bahtiyor Eshchanov, 2019, *Testing 'Rebound Effect' in the Transportation Sector: Empirical Evidence from China Journal of Transport Economics and Policy*.

Zhang, Jiangshan, and C. Y.Cynthia Lin Lawell, 2017, The macroeconomic rebound effect in China, *Energy Economics*.

Zhang, Shanshan, and Boqiang Lin, 2018, Investigating the rebound effect in road transport system: Empirical evidence from China, *Energy Policy* 112, 129–140.

Zhang, Shanshan, and Boqiang Lin, 2018, Investigating the rebound e ff ect in road transport system : Empirical evidence from China, 112, 129–140.

Zhang, Yue-Jun, Zhao Liu, Chang-Xiong Qin, and Tai De Tan, 2017, The direct and indirect CO2 rebound effect for private cars in China, *Energy Policy* 100, 149–161.

Zhang, Yue-jun, Zhao Liu, Si-ming Zhou, Chang-xiong Qin, and Huan Zhang, 2018, The impact of China's Central Rise Policy on carbon emissions at the stage of operation in road sector, *Economic Modelling* 71, 159–173.

Zhang, Yue-jun, and Hua-rong Peng, 2017, Exploring the direct rebound effect of residential electricity consumption : An empirical study in China, *Applied Energy* 196, 132–141.

Zhang, Yue-Jun, Hua-Rong Peng, Zhao Liu, and Weiping Tan, 2015, Direct energy rebound effect for road passenger transport in China: A dynamic panel quantile regression approach, *Energy Policy* 87, 303–313.

Zhou, Meifang, Yu Liu, Shenghao Feng, Yang Liu, and Yingying Lu, 2018, Decomposition of rebound effect : An energy-specific , general equilibrium analysis in the context of China, *Applied Energy* 221, 280–298.

Zink, Trevor, and Roland Geyer, 2017, Circular Economy Rebound, *Journal of Industrial Ecology* 21, 593–602.

Zolnik, Edmund J., 2016, Inducing Demand by Expanding Road Capacity: Controlling for the Rebound Effect, *Annals of the American Association of Geographers* 106, 837–852.

Zolnik, Edmund J., 2018, Effects of additional capacity on vehicle kilometers of travel in the U.S.: Evidence from National Household Travel Surveys, *Journal of Transport Geography* 66, 1–9.

APPENDICES

A. Questionnaire

Bu araştırma ODTÜ İşletme Bölümü öğretim üyelerinden Prof. Dr. Ramazan SARI tarafından yürütülen TÜBİTAK destekli bir çalışmadır. Anket yoluyla gerçekleştirilecek çalışmanın amacı yalıtım yaptırılan konutlarda yaşayan kişilerin ısınma/ısıtmaya dönük alışkanlıkları ve davranış özellikleri; bunu etkileyen bina/hane özellikleri ve yalıtım sonrasında olası farklılaşan alışkanlıkları, davranışları ve harcama özellikleri hakkında bilgi almaktır. Çalışma kapsamında toplanan veriler sadece bilimsel araştırma ve yazılarda kullanılacak derlenen kişi ve aile bilgileri gizli tutulup, kesinlikle paylaşılmayacaktır. Sorulara objektif ve samimi cevaplar vermeniz araştırmadan sağlıklı sonuçlar alınabilmesi açısından büyük önem taşımaktadır.

Anketimize katıldığınız için teşekkür ederiz.

*****Yalıtımdan önce de aynı hanede ikamet edilmesi ve doğalgaz ile ısınılması anketin uygulanması için koşul sorularıdır.**

Demografik Bilgiler

1. Katılımcının Cinsiyeti **Kadın ( )** **Erkek ( )**
2. Yaşınız…………
3. En son bitirdiğiniz okul?, Terk ise belirtiniz…………………………………..
4. Hanenin toplam geliri………………………
5. Hanehalkı kiracı mı yoksa ev sahibi mi? **Kiracı ( )** **Ev Sahibi ( )**
6. Kaç yıldır bu evde yaşıyorsunuz?...............
7. Sizin dışınızda hanede kaç kişi yaşamakta……………
8. Anketör yaşayanların yaş-eğitim-çalışma durumlarını sor!!!

Anne-Baba-Çocuk-Kaynana vs. Cinsiyet Önemli!!	Yaş	Eğitim	Çalışma Durumu (çalışıyor-çalışmıyor-emekli-öğrenci)

1.			
2.			
3.			
4.			
5.			
6.			
7.			

Konutun Özellikleri

9. Konutunuzun yaşı ………………

10. Konutun tipi **Apartman Dairesi ( )** **Müstakil ( )**

11. Toplam kat sayısı ……………….

12. Apartman dairesi ise bulunduğu kat ……….. Anketör Dikkat!!! Bilgiyi destekleyen seçenek işaretlensin **Kot ( ) , Zemin ( ) , Çatı Katı ( )**

13. Evinizin hakim yönü/cephesi …………………………………………
(Güney, Güney-Batı gibi)

14. Evinizin ısıtma sistemi…………………………………………….(Kombili vb.)

15. Evinizin toplam alanı ……………………..**m^2**

16. Evdeki oda sayısı ………… (Örneğin: 2+1, 3+1 vs.)

17. Yatak odası olarak kullanılan oda sayısı ………………

18. Evde bulunan petek sayısı…………

19. Apartman ise hanenin alt ve üst katında ısıtma yapılıyor mu?	**20.** Yalıtım sonrası ısıtmada değişiklik oldu mu nerede oldu? (örneğin alt kata ısıtmanın durdurulması)
☐ Sadece alt katta ☐ Sadece üst katta ☐ Alt ve üst katta ☐ Isıtma yapılmıyor	☐ Sadece alt kattaki hane ☐ Sadece üst kattaki hane ☐ Alt ve üst kattaki hane

21. Isı yalıtımı evinizin/binanızın hangi bölüm veya bölümlerinde yapılmıştır?

- ☐ Dış cephesinde mantolama
- ☐ İç cephesinde mantolama
- ☐ Çatısında
- ☐ Penceresinde
- ☐ Zemininde
- ☐ Diğer

Davranışsal Özellikler

22. Ortalama oda sıcaklığı nedir? ……..

23. Oda sıcaklığı yalıtım sonrasında değişti mi?

- ☐ Evet
- ☐ Hayır

24. Değiştiyse yaklaşık kaç derece değişti? ……………

25. Kışın ısıtma yapılan zamanlarda pencerelerinin açık olduğu süre

Yatak Odası	Oturma Odası
☐ Her zaman kapalı	☐ Her zaman kapalı

☐ 0 – 1 ☐ 1-2 ☐ 2-3 saat açık ☐ 3 saatten fazla süre açık	☐ 0 – 1 ☐ 1-2 ☐ 2-3 saat açık ☐ 3 saatten fazla süre açık

26. Isı kontrol yöntemi

- ☐ Radyatörlerde elle kontrol
- ☐ Elle thermostat kontrolü
- ☐ Programlanabilir thermostat
- ☐ Diğer ……………………………….

27. Yalıtım yaptırdıktan önceki ısı ayarı? ………………..

28. Yalıtım yaptırdıktan sonraki ısı ayarı? ....

29. Yalıtımdan sonra kombinin tipi değiştirildi mi?

- ☐ Evet Hangileri? ………………..
- ☐ Hayır

30. Kombinin tipi………………

31. Kombinin yaşı ....

32. Kombi/ısıtıcı ısı ayarı **(birden fazla işaretlenebilir)**

Soğuk günlerde	Sıcak günlerde

☐ En yüksek sıcaklıkta o En yüksek sıcaklıkta kullanım saati….. ☐ Orta sıcalıkta o Orta sıcaklıkta kullanım saati…… ☐ En düşük sıcaklıkta o En düşük sıcaklıktaki kullanım saati…..	☐ En yüksek sıcaklıkta o En yüksek sıcaklıkta kullanım saati….. ☐ Orta sıcalıkta o Orta sıcaklıkta kullanım saati…… ☐ En düşük sıcaklıkta o En düşük sıcaklıktaki kullanım saati…..

33. Yalıtım için yaptığınız masraf tutarı? .... (Dairenin yada müstakil evin toplam harcaması/apartmanın toplam harcaması)

34. Radyatörlerin kapatıldığı odalar var mı?

- ☐ Evet Hangileri ve bu odaların alanı ne kadar? ………………..
- ☐ Hayır

35. Yalıtım sonrasında evin ısısını değiştirmenize neden olan bir gelişme yaşandı mı? (çocuk sahibi olunması, evde yaşlı bir bireyin yaşamaya başlaması türünden)

- ☐ Evet (Açıklama: ………………………………….….)
- ☐ Hayır

36. Cevap evet ise . Değişiklikten (çocuk sahibi olmak gibi) sonra radyatörlerin kullanımı

oturma odası	yatak odası	banyolar	girişteki
☐ 5 saatten az	☐ 5 saatten az	☐ 5 saatten az	☐ 5 saatten az

☐ 6-18 saat ☐ 19 saatten fazla	☐ 6-18 saat ☐ 19 saatten fazla	☐ 6-18 saat ☐ 19 saatten fazla	☐ 6-18 saat ☐ 19 saatten fazla

37. Isıtma yapılan zamanlarda evde en az bir kişinin bulunma süresi

Haftaiçi	**Haftasonu**
☐ Sabah ☐ Öğlen ☐ Akşam ☐ Gece	☐ Sabah ☐ Öğlen ☐ Akşam ☐ Gece

38. Ev sıcaklığına kim karar veriyor?

………………………………………..(ortak da karar verilebilir)

39. Kararın verilmesinde ilk üç nedeni 1 den başlayarak sıralayınız.

- ☐ Evde küçük çocuk olduğu için
- ☐ Evde yaşlı olduğu için
- ☐ Evde evcil hayvan bulunması
- ☐ Doğalgaz kart limiti olduğu için
- ☐ Maliyet sebebiyle-Faturalar
- ☐ Hava sıcaklığı
- ☐ Diğer ……………………………………………………

40. Evinizin/binanızın yalıtım yapılmadan önce ve sonraki durumunu düşünerek aşağıdaki ifadeleri değerlendirmeniz beklenmektedir.

	1 **Kesinlikle Katılmıyorum**	**2**	**3** **Ne Katılıyorum Ne Katılmıyorum**	**4**	**5** **Tamamen Katılıyorum**	**6** **İlgim-Bilgim Yok**

Isı yalıtımı faturaları düşürmüştür.						
Isı yalıtımı ile ısınma alışkanlıklarımda değişiklik olmuştur.						
Isı yalıtımı enerji/yakıt tasarrufu sağlamıştır						
Isı yalıtımı binaya bakım sağlamış, değerini arttırmıştır						
Isı yalıtımı ile ses yalıtımı sağlanmıştır.						
Isı yalıtımı ile doğa korunmaktadır.						

41. Isı yalıtımı sonrasında evinizin toplam ısıtma maliyetindeki ortalama tasarruf oranı nedir?

- ☐ Tasarruf sağlamadım
- ☐ %30 den az tasarruf sağladım
- ☐ %31 ile %50 arası

- ☐ %51 ile%70 arası
- ☐ %70 den fazla

42. Evde kalın giyinildiği olur mu?

- ☐ Evet
- ☐ Hayır

43. Evde sigara kullanılıyor mu?

- ☐ Evet
- ☐ Hayır

44. Evde sahip olunan özel araç sayısı

- ☐ Bulunmuyor
- ☐ 1
- ☐ 2
- ☐ 3 ve üzeri

45. Evde tasarruf amaçlı toplu taşıma kullanan kişi sayısı……………….

46. Kanuni zorunluluk olmasaydı yalıtım yaptırmayı yine de düşünür müydünüz?

- ☐ Evet
- ☐ Hayır

47. Yalıtım yaptırma tarihi (ay/yıl) ……………….

48. Yalıtım katsayısı …………………………. (mümkünse öncelikle yöneticiden alalım)

49. Doğalgaz abone numarası ……….

50. Evinizin ısınması, ısıtılması ve ısınma alışkanlıklarınızla ilgili ayrıca belirtmek istediğiniz birşeyler bulunuyor mu?

51. Enerji kimlik belgesi

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name	: Yılmaz, Zehra İlknur
Nationality	: Turkish (TC)
Date and Place of Birth	: 16 March 1984, Ankara
Phone	: +90 535 301 35 50
E-mail	: e132879@metu.edu.tr

EDUCATION

Degree	**Institution**	**Year of Graduation**
MS	Ankara University Statistics	2012
BS	METU Statistics	2007
High School	Kalaba Anadolu High School, Ankara	2002

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2007-Present	TÜBİTAK	Senior Expert

FOREIGN LANGUAGES

Advanced English, Beginner Italian, Beginner Spanish, Beginner German

PUBLICATIONS

HOBBIES

Fitness, Zumba, Succulents, Travelling, Reading