Efficient Consumption of Energy: the role of energy mix

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Abstract:

The promotion of energy efficiency policies is an important objective for both the International Energy Agency (IEA) and the Energy Information Administration (EIA). Based on the EIA report (1995), energy efficiency is an essential component of energy resources in nations. Improving energy efficiency helps nations to manage their energy resources. Unfortunately, according to the EIA report, there is not any defensible measurement for energy efficiency, so this concept is vague.

The most common indicator for energy efficiency has been the economic-thermodynamic indicator. This indicator is the inverse of energy intensity which is defined as the ratio of energy use to GDP. Changes in energy intensity are a function of several factors such as economic structural changes, technical changes, and climate changes. Therefore, the energy intensity may not be a reliable indicator of energy efficiency. This thesis is going to illustrate energy efficiency based on the productive efficient consumption of energy. Productive efficient consumption of energy describes energy efficiency according to the level of energy inefficiency which is the distance between the actual demand for energy and the productive/optimal demand for energy. Demonstrating the effect of energy mix on the efficient consumption of energy, first in 28 OECD countries, second in the residential sector of Australia and New Zealand, and finally in selected OPEC countries relatively is the key objective of this paper.

This thesis is going to utilize the Stochastic Frontier Analysis (SFA) as an approach; however, most of this thesis has tackled the energy intensity with the Decomposition Methods. Stochastic Frontier Analysis will estimate the inefficiency level according to the distance between actual demand and the optimal demand. Productive efficient demand is considered as an optimal demand in this thesis. Furthermore, tow SFA models, which are namely; Battese, G. E. and T. J. Coelli (1992) (BC92), and True Fixed Effect (TFE) models, will be utilized in the different chapters of this thesis. In the third paper, the relationship between energy consumption of OPEC countries and their population has been estimated based on Product Generation Dematerialization (PGD).

Overall, this thesis demonstrates that increasing the consumption of renewable energy resources or decreasing in the consumption of fossil fuel energy resources is associated with

an increase the energy efficiency. Therefore shifting towards the dominant energy resource may raise energy efficiency. Since the third essay is about OPEC countries and OPEC countries rely mainly on fossil fuels, we estimate the efficient consumption of energy after removing the renewables variables from estimation. Moreover, we illustrate the relationship between energy consumption and population in the selected OPEC countries. In the third paper, we conclude that firstly, Saudi has the highest and Iran has the lowest energy inefficiency; averagely; secondly, Algeria, Indonesia, Iran, Saudi Arabia have experienced 34%, 56%, 30%, and 45% materialization over the selected period of time; respectively.

To:

My beloved Parents and my husband

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I. Chapter One

Introduction

Total global consumption of energy is more than 370 exajoules (EJ)[1]. Fossil fuels account for approximately 95% of this amount of energy: 44% petroleum, 26% natural gas, 25% coal, 2.5% hydroelectric power, 2.4% nuclear power, and 0.2% non-hydro renewable energy (Chow, Kopp et al. 2003). Efficient consumption of energy can help to save money, and reduce emissions; therefore, efficiency is usually called as "first fuel." Middle East, India, and China which are the major economic powerhouses, are expected to account for 8%, 15%, and 36% of energy usage growth in the next two decades; respectively. However, the US is expected to account for only two percent. Hence, efficient consumption of energy has been one of the main aims of worldwide (ESMAP 2017).

The overall goal of this Ph.D. thesis is to explore the impact of a range of variables on the use of energy, and subsequently; on the efficient use of energy. Essays in this thesis contribute to the field of energy economics, and Frontier Analyses (FA) modeling. The first essay addresses the effect of energy mix on the efficient consumption of energy in selected OECD countries with utilizing the Stochastic Frontier Analysis (SFA) models. The second essay is focused on the role of energy mix on the efficient residential energy consumption in New Zealand, and Australia with using SFA models. Finally, removing the energy mix variables to estimate efficient consumption of energy according to the SFA models; Product Generation Dematerialization (PGD) is used to demonstrate the role of dematerialization on energy consumption in selected OPEC countries. The main issue addressed in these three essays is finding whether the mix of energy resources has an impact on the efficient consumption of energy.

Background

Since the Industrial Revolution, fossil fuels have been a major source of energy around the world. This source of energy has provided more than 80% of the whole primary energy in the world. The main merit of fossil fuel is controllability of its extraction in contrast with other sources of energy, such as renewable energy resources. Fossil fuels are a stock resource

[1] 350 quadrillion British thermal units (Btus).

which can be extracted at the required rate; however, renewable energy, particularly wind and solar, are mainly a flow type of energy whose rate of flow cannot be controlled. There are several other advantages of fossil fuels, such as high energy density, high energy return on Energy Invested (ERoEI), low cost, ease of transport, distribution, and combustion, and high flexibility for conversion to different forms of secondary energy. While this energy resource has several advantages, countries will not be able to rely merely on this source of energy (Ishida 2013), because of environmental problems caused by fossil fuel consumption and increasing relative. Thus, countries have started to focus on energy efficiency.

After the first oil shock in 1973, countries are paying more attention to energy efficiency. Geller, Harrington et al. (2006), have shown that OECD countries could consume approximately 49% less energy than the amount which could be utilized without improving energy efficiency in 1998. Energy efficiency is a generic term which can be described from two points of view. First, from a thermodynamic point of view, efficiency is defined as the maximum amount of work that can be generated by energy, or a system (Dincer, Hussain et al. 2004). Thus, energy efficiency from the thermodynamic point of view is defined as the ratio of the output of a process to energy input (Tsatsaronis 2007). The second point of view is economic, output-oriented, which is defined as producing more output with the same amount of inputs; and input-oriented, which refers to producing a given amount of output using a minimum amount of input. An improvement in the sustainable use of energy and a reduction in greenhouse gas emissions are two benefits of energy efficiency. Since the economic point of view has been utilized to evaluate the energy efficiency of various economic activities at different level's of aggregation, such as sectoral, national, or international (Patterson 1996), this point of view will be applied to the energy efficiency concept in this thesis.

There are four indicators to estimate efficient consumption of energy. Efficient consumption of energy can be quantified using: 1: thermodynamic indicators, 2: physical-thermodynamic indicators, 3: economic indicators, and 4: economic-thermodynamic indicators. Thermodynamic measurements are according to the thermodynamic point of view which is the ratio of useful output into the energy inputs. Some of the thermodynamic indicators are solely simple ratios; some of them are sophisticated measures. The thermodynamic indicator is calculated based on the "state function" of the process. As the "state function" for each process is different from others, the thermodynamic indicators provide an unique measurement of efficiency for the given process. Physical-thermodynamic indicators are hybrids which utilize thermodynamic units of input and physical units of output. Utilizing a physical unit of output has an advantage because the required end-use unit of output is encapsulated in the physical unit of output. So, this indicator provides an opportunity to consider the end-use units of output in the estimation of energy efficiency. Economic indicators calculate output and inputs based on their monetary values. Economic-thermodynamic indicators are hybrids too. These indicators use the thermodynamic units of inputs and the market price of outputs. Energy intensity, in fact, is the inverse of economic-thermodynamic indicators which is identified by Patterson (1996) (Fouquet 2013).

Almost all of the efficiency measures utilize energy intensity (Filippini and Hunt 2012). Energy intensity, which is expressed as the ratio of energy consumption to GDP, is the most common proxy for energy efficiency. However, since intensity incorporates many factors, it is a function of several factors such as the structure of the economy, climate, and technology. These factors make measuring energy intensity complicated. For instance, while the energy intensity of IEA members has decreased by 1.6% per year on average over 1990-2009, this progress is not merely because of new policies aimed at improving the efficiency of consumption. It can be because of changes in several factors; such as technical and structural change.

Based on International Energy Agency (IEA) 2014:

"Energy efficiency is high on the political agenda as governments seek to reduce wasteful energy consumption, strengthen energy security and cut greenhouse gas emissions. However, the lack of data for developing proper indicators to measure energy efficiency often prevents countries from transforming declarations into actions."

Therefore this study measures energy efficiency by demonstrating the level of inefficiency in this thesis. The lowest level of inefficiency is represented by the highest level of energy efficiency. The level of energy inefficiency is estimated by the distance between the actual demand of energy and the optimal (productive efficient) demand of energy. Actual demand for energy is an annual demand for a particular category of energy consumer. Optimal demand for energy is defined as the productive efficiency demand of energy. Thus, whenever the actual demand of energy for the particular energy consumer is equal to the optimal demand of energy which is derived from an economic model of optimal behavior of firms and households, the energy consumer consumes energy at the efficient level.

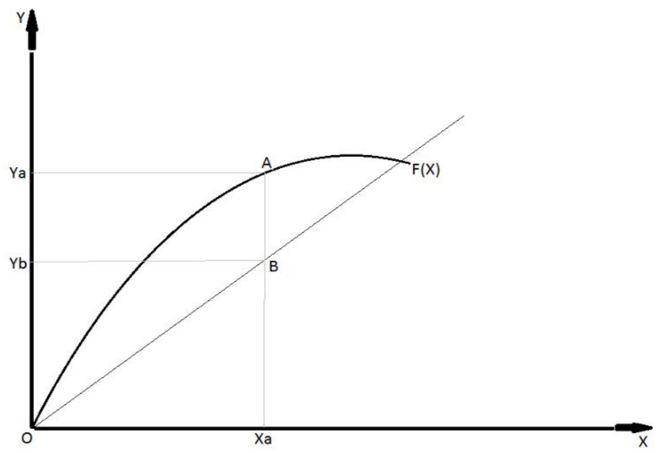
In the first and second essays, due to the diversity of energy resources which are utilized in OECD countries, we emphasize energy mix variable in our estimation of productive efficient energy consumption.

In the third essay, due to dominating consumption and supply of fossil fuels in the OPEC members, we remove the energy mix variables in our estimation of energy efficiency. Moreover, the PGD indicator is chosen to display the role of population and energy use. The role of the population will be figured out by estimating the changes in the consumption of energy relative to changes in population.

Productive efficiency

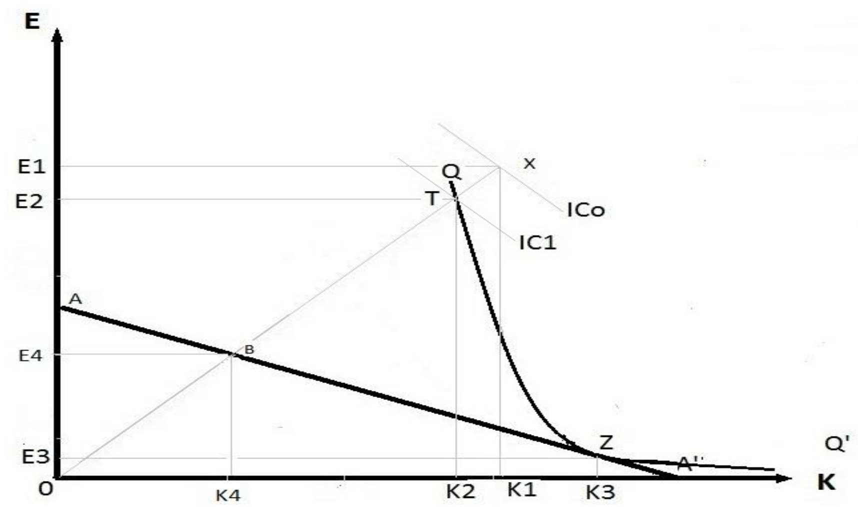
Productive efficiency aims to minimize the consumption of inputs for the production of a given amount of output with a given level of technology whose improvement decreases inputs without any changes in the amount of output and technology (Farrell 1957). Productive efficiency can be improved using both obsolete and modern technologies.

Graph (1) shows the production frontier for one input (x) and one output (y). The production frontier F(x) illustrates the current production technology to attain the maximum level of output. Point A (X_a, Y_a) is on the frontier, but the point B (X_a, Y_b) is below the frontier. As it can be seen, points A and B both utilize (X_a) units of input, although at point B output is lower. Therefore, technical efficiency is the ratio of OY_b to OY_a (comparing the current output with the frontier output).



Graph 1: Production frontier

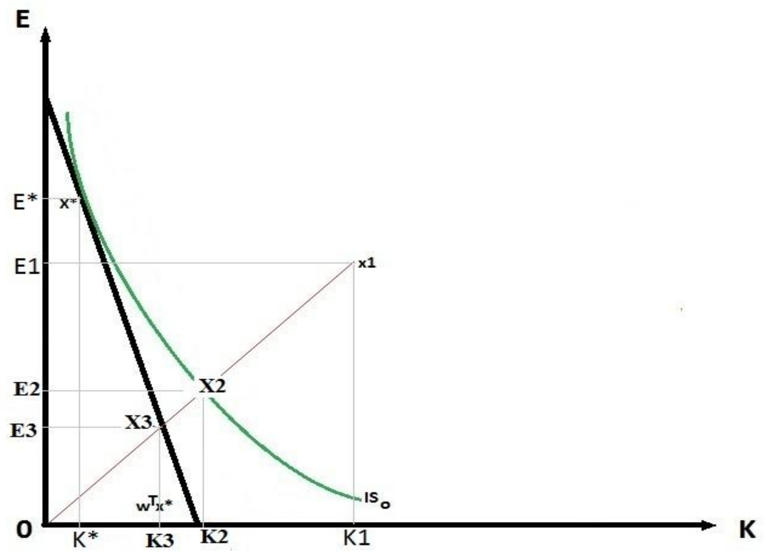
In graph (2) the firm uses two inputs, E (energy) and K (capital), faces prices (r_e) and (r_k) respectively, to produce the given amount of output (QQ'). The iso-quant curve (QQ') represents the minimum combination of inputs to produce (QQ'). (AA') is the iso-cost line so, the cost is C=r_e.E + r_k.K with a slope of (-$\frac{r_k}{r_e}$). Assuming cost minimisation; the tangent of isoquant curve (QQ') and iso-cost line (AA'), is best practice for the firm. $MRS_{k,e}$ is a rate at which capital can be substituted for energy. This rate defined by the ratio of the marginal products of capital to the marginal products of energy, so $MRS_{k,e}$= $\frac{MP_k}{MP_e}$. Therefore, the tangent point is where $\frac{MP_k}{MP_e}$= $\frac{r_k}{r_e}$.



Graph 2: Productive efficiency

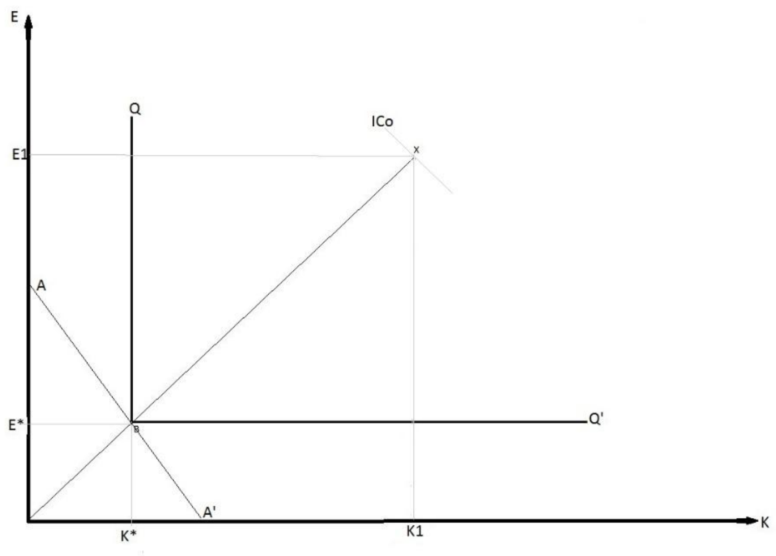
Assume a firm is operating at X, using inputs (K1, E1) amount of inputs to produce QQ'. The firm's iso-quant curve is (QQ'), and the iso-cost line is (AA'), so the firm is neither on its iso-quant curve nor on the iso-cost line. If the firm reallocated its inputs mix from (X) to (T); which is on QQ', the amount of its output does not change, but the amount of its inputs decrease to the (K2, E2). The point (T) is technically efficient. Koopmans (1951) defended point (T) as a technical efficient point if and only if a decrease in any input components of (T) is not possible for producing the same amount of output. The problem with point (T) is that it is not a cost minimum. Going from point (T) to the point (B), which is on the iso-cost line, results in a decrease in inputs (K4, E4), and also decreasing in the amount of cost. Point (B) is the allocative efficient point of the firm (farrell 1957). The firm which is at point (B) can increase its output without increasing its cost. Moving to the point Z= (K3, E3), where the tangent of iso-quant curve equals the slope of the iso-cost line, is the productive efficient point. At (Z) output does not change from X, but the inputs combination is efficient. Point (Z) is both technical and allocative efficient point (Farrell 1957). As can be seen, efficient consumption does not only mean a decrease in consumption. For example, in this graph, after moving from point (X) to the point (Z) the amount of energy decreases, but the amount of capital consumption of firm increases; thus, in this graph energy is substituted with capital with the rate of $\frac{r_k}{r_e}$. Hence, point (Z) is a productive efficient point which is the product of both technical and allocative efficiency (Farrell 1957).

Graph (3) shows another situation where the firm is at point X1= (K1, E1) then relative to productive efficiency X*= (K*, E*). In this case, (K1-K*) capital is substituted with (E1-E*) amount of energy. This substitution can happen when the cost of energy is relatively less than the cost of capital. For example, when a firm applies a new technology, such as, a renewable source of energy, which causes lowers cost. As mentioned, the substitution rate depends upon the marginal productivity of capital to the marginal productivity of energy which should be equal to the slope of the iso-cost line at the productive efficiency point.



Graph 3: Productive efficiency

Graph (4) illustrates the productive efficient demand of inputs using the Leontief production function. This type of function implies a fixed proportion of inputs required to produce its output; substitution is not feasible. In other words, the inputs in this function are strictly complementary. In this situation reaching the productive efficient point B= (K*, E*) requires a decrease in both inputs capital and energy in fixed proportions along the vector (OX). Thus, in this case, substitution between capital and energy is not possible, the only efficient subset is at point B=(E*, K*). Assuming the firm is at X= (K1, E1) with the (QQ') amount of output, the productive efficient point of the firm is B= (K*, E*) which shows minimum required inputs for the (QQ') amount of output. It is obvious, in all these cases; the productive efficient point is cost minimizing.



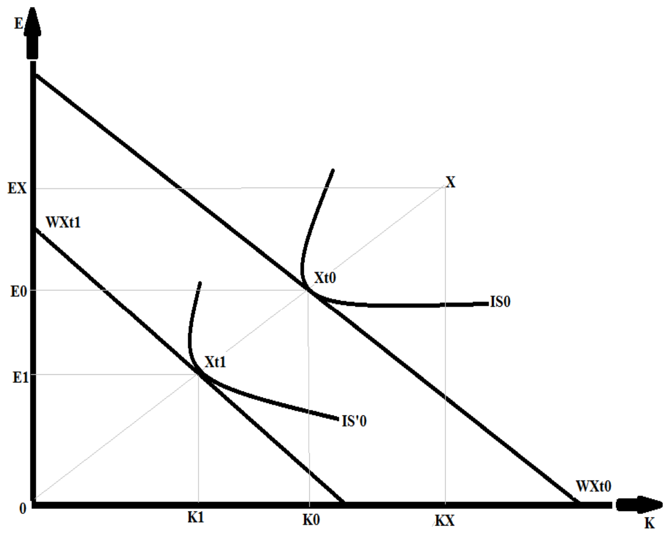
Graph 4: Production efficiency in Leontief function

In the first and third essays, we are going to estimate the production function according to cost minimizing. The second essay is about the residential sector. Based on the basic framework of household production theory, households demand market 'goods'; such as energy as an input of their production processes to produce the 'commodities.' The commodity will appear as an argument in the household's utility function. Hence, in the first stage, households behave as a firm; households minimize their production cost (Filippini 1999).

In the second essay, based on the household production theory, we are going to estimate the productive efficient consumption of energy subject to minimizing the cost.

Technical change

As noted above, productive efficient consumption of inputs is a consequence of an underlying increase in efficient use of inputs for a given level of output (technical efficiency) with minimizing the cost (allocative efficiency) in the given level of technology. Therefore, changing in the amount of inputs due to reaching productive efficiency is different from the changing in the amount of inputs due to technological progress. Decreases in inputs, and cost of production, after technical progress, is due to increasing the productivity of inputs which causes shifts from an iso-quant curve to another one. So even without any change in relative prices, the cost of producing a given level of output changes. Technical change can be neutral and non-neutral. Neutral technical change occurs when the marginal rate of substitution over the expansion path is not dependent on technology change. Therefore, after the technical change, the isoquant of a given output shifts to the right or the left-hand side. Neutral technology change is divided into the Hicks- neutral, Harrod-neutral, and Solow-neutral. Hicks-neutral technical progress happens when technological change does not affect one input differently from the way which it affects the other one. In the other words, Hicks-neutral technical change only influences the aggregate production function. Harrod-neutral technology improvement happens when the ratio of capital into output does not change, so that the progress is in order to efficient consumption of the other input, such as labor or energy. Capital-augmenting technology is called Solow-neutral technical progress. This technology improvement decreases the energy-capital ratio which is capital saving. Overall, technology change affects the iso-quant (Fouquet 2013). Graph (5) describes progressive technology change with the (ISo) iso-quant curve and (WXto) iso-cost line. Technology before progressive technology implementation is represented by t0; t1 is the situation after technical changes. The productive efficient point of the firm in the (t0) situation is Xt0 (E0, K0). Assume (t1) is progressive Hicks- neutral technology change with the linear expansion path (the marginal rate of substitution does not change along expansion path). New technology shifts the iso-quant curve to left hand side to the (IS'o). The new productive, efficient point is Xt1.



Graph 5: Technology change

Frontier analysis approach can be used to estimate of productive efficiency. This approach can be applied to production, distance, cost, and inputs demand functions. For the estimation of production and distance functions, information of all inputs (not only energy) and outputs is required. Furthermore, to estimate cost and input demand functions, output and input prices are also required. Since one input frontier demand function, approximately, provides us the level of inefficiency with a measure of the distance between the actual demand of inputs and the productive efficient demand of inputs, the three essays in this thesis estimate an input frontier demand function (Filippini and Hunt 2013).

So far, productive efficiency has been demonstrated using capital and aggregate energy as inputs; for example, Filippini (1999), and Farsi, Filippini et al. (2005). However, there are many variables that might affect the energy consumption of each energy consumer; for example, one consumer may consume the special type of energy more than others. Thus, each type of energy may cause a change in productive efficiency. Consequently, technical efficiency, and allocative efficiency, of energy consumer will be change.

Technical progress

Since prices, technical progress, and economic structure influence energy intensity over time (Hang and Tu 2007, Ma and Stern 2008) controlling for their effects are necessary in order to demonstrate the production efficient consumption of energy. Technical change can cause a shift in demand. It is usual for a decrease in demand to be defined as a result of technical progress, but it can lead to an increase in demand for energy (Fouquet 2013).

Technology change has two impacts on energy demand. Firstly, changing technology can affect prices. Although technical change (equal-factor-augmenting) may not affect prices, most types of technical change affect prices. Price changes can capture one part of the technical change. Autonomic effect of technical change can also affect the demand for energy. This effect can be captured by using either deterministic dummy variables or Underlying Energy Demand Trend (UEDT). The studies which utilize the (UEDT) have claimed that deterministic time dummy variables cannot estimate the precise price elasticity of energy demand (rebound effect), so the autonomic effect of technical progress is not clear (Hunt, Judge et al. 2003). Although some studies utilize the UEDT to capture the technical effect, there is no evidence to reject the use of a deterministic time dummy variable (Adeyemi and Hunt 2007). This thesis is going to utilize deterministic time dummy variables to capture the effect of technical progress. Therefore, the effect of technology change is going to be captured using price and deterministic time dummy variables.

The rebound effect is a concept based on technical improvement, and it is defined as the systemic response of a firm to new technology which increases the efficiency of energy use. When energy required for particular activity decreases, the cost of using energy services also decreases. Thus, producers supply more of that particular energy (A Greening, Greene et al. 2000). Furthermore, according to Khazzoom (1980), the result of these reductions may increase demand for that energy service too. Consequently, there is a decrease in energy demand, but not as much as expected (Khazzoom 1980).

Equation 1: $$-\gamma_{pe}(S) = -\frac{\partial \ln(s)}{\partial \ln(pe)} \qquad \gamma = \text{price elasticity of demand}$$

Frondel and Vance (2011), defined the rebound effect as the price elasticity of the demand for particular energy (S) with respect to energy price (pe). For example, consider a firm that has experimented with Hicks-neutral technical progress. Consumption of both inputs (capital and energy) decreases; consequently, the cost of production decreases too. Demand for products increases, and then firms use more inputs. Thus, inputs consumption, after technical progress, decrease but less than expected.

Technical change, in this thesis, encompasses exogenous technical progress and changes in other important exogenous factors, such as changes in consumer tastes and changes in social norms. Thus, technical change can either decrease or increase the energy demand.

Rebound effect vs. frontier and efficiency measurement

The rebound effect arises from a reduction in the expected gains from new technologies that increase the efficiency of energy use because of behavioral and other responses — however, frontier and efficiency measurement concern productive efficiency. Productive efficiency is based on technical and allocative efficiency. Technical efficiency means using fewer inputs for a given level of output given the level of technology. Allocative efficiency includes technical efficiency with cost minimization.

Therefore, the rebound effect is different from the productive efficiency which is utilized as the methodology in this thesis.

Frontier and efficiency measurement

Frontier and efficiency measurement was initiated by Koopmans (1951) and Debreu (1951) who explain technical efficiency and productive efficiency respectively. Farrell (1957) extended their work by defining an overall computational framework for productive efficiency which is a combination of technical and allocative efficiency. Efficiency measurement is divided into parametric, nonparametric, and semi-parametric approaches. Envelopment estimator is the nonparametric perspective. Two of the most common models of envelopment estimator are Free Disposal Hull (FDH) and data envelopment analysis (DEA). The difference between FDH and DEA is the convexity of reference technology. Two most common models of DEA are DEA-CCR and DEA-BCC that the model's name is according to their introducers. The DEA-CCR model was introduced by Charnes, Cooper, and Rhodes in 1978[2], and also the DEA-BCC is introduced by Banker, Charnes, and Cooper (1984)[3] that

[2] Charnes, A., et al. (1978). A Data Envelopment Analysis Approach to Evaluation of the Program Follow through Experiment in US Public School Education, Carnegie-Mellon Univ Pittsburgh Pa Management Sciences Research Group.

[3] Banker, R. D., et al. (1984). "Some models for estimating technical and scale inefficiencies in data envelopment analysis." Management science **30**(9): 1078-1092.

these models can be either Constant Returns to Scale (CRS) or variable returns to scale (VRS).

The parametric form of production frontier was introduced by Aigner and Chu (1968). One of the differences between the nonparametric and parametric perspectives is the form of relationship between output and inputs of the process. The parametric approach is based on frontier regression which usually assumes an algebraic relationship between inputs and output; however, the non-parametric approach does not assume any assumption. According to Zhou, Ang et al. (2012), assuming the algebraic relationship makes underlying energy efficiency more accurate than when there is not an assumption. On the other hand, the non-parametric approach does not include a stochastic component for error term. It means that the non-parametric approach is deterministic. Whereas, the error term of the parametric approach has stochastic and non-stochastic parts (Jacobs 2001). Since this thesis is going to analyze the energy efficiency for all sectors of countries, the stochastic part of the error term has a crucial role in some sectors such as agriculture. Thus, omitting this part of error term decreases the accuracy of estimation. Thus, the parametric approach is better for economic interpretation between the output and the particular input (Florens and Simar 2005). The semi-parametric approach is a combination of parametric and nonparametric approach which is not widely utilized in the empirical studies (Haghiri 2013). The parametric approach is chosen between the parametric, non-parametric, and semi-parametric in this thesis.

The parametric approach can have a deterministic production function or the stochastic one. Aigner, Lovell et al. (1977), introduced SFA by adding the stochastic part to the probabilistic frontier production. Pooled, Random, Fixed, True Random, and True Fixed effect are mostly common models for stochastic frontier analysis. The difference between the Aigner frontier production function and the previous functions is error term. This error term is divided into two components; randomness out of the control of the firm, and the randomness under the control of the firm.

SFA is described as:

Equation 2: $$Y_i = F(X_i; \beta) \cdot exp(V_i) \cdot exp(U_i)$$

Equation 3: $$Exp(V_i) + exp(U_i) = error\ term$$

Y_i= goal attainment or observed scalar output of individuals i= 1, 2, ….

X_i= vector of N inputs.

β= vector of parameters.

$\beta X'$= deterministic part of frthe ontier.

V_i= is a stochastic part of the error term. This part of the error term captures effects which are not under the control of firm, such as a drought. Thus, it is never zero.

U_i= is the other component of error term which is not stochastic. Therefore, it can be controlled by firms.

TE_i= technical inefficiency.

Equation 4:

$$TE_i = \frac{(observed\ output)}{(frontier\ or\ productive\ efficient\ output)} = Exp\ (-U_i)$$

The exp ($-U_i$) term is inefficiency, because firms or other producers are able to use this capacity, so with using this capacity, the firms can reach the maximum goal attainment. Therefore, (TE_i) is between one and zero.

(TE_i) = 1 efficient process and output on the frontier.

(TE_i) <1 inefficient process and output is below of frontier.

Thus, the (U_i) term by itself should be a non-negative term (U_i)>0. So, the higher inefficiency is decreasing, the higher level of production. Therefore, the changes in the technical inefficiency cause less or more efficient process.

Since the thesis aim is to estimate the consumption of energy and the level of inefficient consumption of energy for countries according to their source of energy, estimating the coefficients of the demand function, when countries consume minimum energy for a given amount of output is considered as the goal attainment of stochastic frontier analysis.

Motivation

Energy efficiency improvement is one of the main goals for both International Energy Agency (IEA) and the Energy Information Administration (EIA) (Filippini and Hunt 2012); because the role of energy efficiency is reducing in the consumption of energy and carbon emissions; subsequently. The common proxy to estimate the efficient consumption of energy is energy intensity (Filippini and Hunt, 2012). Pasquier and Saussay (2012), illustrate the energy intensity of OECD countries from 1990 to 2009; ten countries are described briefly as follow:

New Zealand

The energy intensity of New Zealand's economy decreased 1.0% per year on average over the period of 1990 to 2009. A large proportion of this saving energy happened from 2001 to 2007. In 2009, due to the high percentage of energy-intensive sectors in New Zealand's economy, energy intensity was higher than the IEA average. New Zealand policy was aimed at decreasing energy intensity. It was the first non-EU country to introduce a carbon emissions trading (ETS) scheme to reduce carbon emissions for activating its potential in the energy efficiency.

Greece

From 1990 to 2009, there was an insignificant decline in the energy intensity of Greece. It was due to Total Final Consumption (TFC) of energy in this country increasing from 1990 to 2008. This enhancement in TFC of energy is a result of the strong economic growth of Greece during that period. After that period, Greece experienced depression in its economy, as a result of which, TFC decreased. Therefore, the energy intensity of Greece has decreased over the estimated period (1990-2009), but not by a lot.

Japan

Energy intensity decreased by about 0.7% between 1990 and 2009. It should be noted that Japan's energy efficiency improved by 30% over the last 30 years (until 2011). Japan has one of the lowest total primary energy supply (TPES) per GDP. Low TPES is a result of energy conservation in various sectors, which improves intensity. According to the IEA improving energy intensity is mainly due to changes in its economic structure.

Australia

Energy intensity decreased by 1.7% per year over the period 1990-2009. Australia's cheap energy and its energy-intensive industries result in Australia's energy intensity being higher than the IEA average. Decreases in the contribution of industry to GDP relative to the service sector, the energy intensity of Australia decreased. Therefore, reduction in energy intensity of Australia is derived from changes in economic structure.

Germany

Germany's energy intensity reduction was 1.8% per year over the estimated period (1990-2009). From early 1970, the first oil shock, Germany's government began to implement energy efficiency policies. The reduction of Germany's intensity in the period 1990 to 2009 is mostly related to those policies.

Slovakia

The Slovakia Republic had the highest decline in energy intensity among the IEA countries between 1990 and 2009 (4.6% per year). Slovakia's strategies for conserving energy began in 1990 and were completed by 2006. Of interest, is that Slovakia, as well as Germany, improved its intensity not only by changes in its economic structure but also with taking progressive energy efficiency strategies.

United Kingdom

Energy intensity declined by 2.3% per year over the 1990 and 2009 period. The United Kingdom's energy intensity was significantly less than average OECD intensity during the period of 1973 to 2004. Progress in reducing the energy intensity of the United Kingdom accelerated with a better understanding of the energy efficiency in the mitigation of climate change.

United States

Energy intensity decreased by 1.6% between 1990 and 2009 in the United state. Strategies to control the energy consumption of the country began in 1973 (the first oil shock). From that time to 2013 the economic output of the United States had threefold increase; whereas, the energy consumption of the United States has increased only by 50 percent. It should be mentioned that progress in reducing the rate of intensity in the United States was not constant; for example, from early 1970 to 1980 the rate was higher than 1980 to 1990 because of changing gasoline demand during that period (Goodman 2013).

Italy

Energy intensity declined over the estimated period and was equal to the average decline in the IEA member countries over the period 1990-2009. The energy intensity of Italy compared to IEA members has been traditionally low and stable since early 1980.

Spain

Energy intensity of Spain was below the IEA average over period 1990-2009 and decreased by 0.4% per annum.

The above review shows that energy intensity is decreasing in the selected countries. Improvements in intensity came about from changes in several factors, such as the structure of the economy, climate, and technical changes. For example, from the IEA 25 recommendations report, the low energy intensity of Japan is derived from a change in its economic structure. By way of contrast, the decrease in the energy intensity of Germany was due to the implementation of energy efficiency policies. EIA (1995) reports[4]:

"Energy efficiency is a vital component of the Nation's energy strategy. One of the Department of Energy's missions [is] to promote energy efficiency to help the Nation manage its energy resources. The ability to define and measure energy efficiency is essential to this objective. In the absence of consistent, defensible measures, energy efficiency is a vague, subjective concept that engenders directionless speculation and confusion rather than insightful analysis. The task of defining and measuring energy efficiency and creating statistical measures as descriptors is a daunting one."

Therefore, this report confirms the problems of energy efficiency measurement (Filippini and Hunt 2013).

On the other hand; coal, oil, gas, geothermal, and other renewables are energy resources that can support economic activity. Stern (2004) indicates that changing the input (energy) mix when the scale of output and technology are held constant, causes a movement along the isoquants of the production function. Moreover; The Ministry of Economic Development (MED) claims that quality diversity causes different outcomes (Bill 2011). Therefore, utilizing different types of energy, such as oil, gas, geothermal, and other renewables, may affect energy efficiency.

Estimation of efficient energy consumption should comprehensive and based on an extensive analysis of the factors driving demand.

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[4] Series, D. E. C. (1995). "Measuring Energy Efficiency in the United States' Economy: A Beginning." US DOE, Energy Information Administration.

International Energy Agency (IEA) 2017 demonstrated that having reliable indicators on how energy is consumed is a key consideration for monitoring and informing the effectiveness of energy efficiency (IEA 2017).

First essay: The impact of renewables on productive efficient consumption of energy in OECD economies:

The first essay will estimate the impact of renewable energy resources, and structural economic changes on energy efficiency in 28 OECD countries with utilizing SFA methodology between 1975 and 2011. Recently, the Ministry of Business (2011) (MBIE)[5] refers to the Logarithmic Mean Divisia Index (LMDI) which is based on a relationship between energy demand and fuel switching (Ministry of Business 2011):

ΔEnergy= Δactivity+ Δstructure+ Δfuel switching+ Δefficiency

Where:

Δenergy is defined as the change in the demand for energy.

Δactivity is defined as the change in the level of production or the size of sector as is measured by Gross Domestic Product (GDP).

ΔStructure represents the change in the economic structure of a country, for example; shifting from an intensive energy industry to a less energy-intensive industry.

Δ Fuel switching means switching from low to high energy quality; for instance, renewables are categorized as high energy quality, and any type of coal is categorized as low energy quality.

ΔEfficiency means changes in energy intensity. According to Ministry of Business (2011) report, changes in the type of energy can have a direct effect on the demand for energy. To date, the direct relationship between energy demand and types of energy has been shown, and many articles describe the effect of fuel switching on the energy intensity.

Ma and Stern (2008) studied the energy intensity trend in China. They have described the effect of inter-energy changes on the energy intensity of China according to LMDI. They asserted that the effect of energy mix on China's energy intensity is not significant.

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[5] Ministry of Economic Development (MED) was replaced with Ministry of Business, Innovation and Employment (MBIE) in2012.

Energy efficiency trends in Australia show the impact of energy mix on real energy intensity too. Real energy intensity affects energy consumption because of its energy mix impact, and the technical effect. In this study, energy mix changes are shown to have a substantial effect on energy end-use efficiency improvement (Wilson, Trieu et al. 1994). Tedesco and Thorpe (2003) looked at the energy mix effect on energy intensity in Australia. They found that decreasing energy intensity was the mainly the result of the energy mix effect. Shahiduzzaman and Alam (2013) described the impact of energy mix on aggregate energy intensity. Aggregate energy intensity includes structural effects while real energy intensity excludes this effect. They also conclude that the effect of energy switching on aggregate energy intensity in Australia is not significant. Thus, according to these articles, energy mix has an impact on either aggregate or real energy intensity.

Thus, energy switching has a direct effect on energy intensity too. Based on LMDI, there is a direct relationship between changes in energy intensity and the demand of energy. Therefore, different energy resources have direct and indirect effects on energy demand.

Countries, according to accessibility, quality, and types of resources, have utilized their dominant source of energy. Therefore, the dominant energy differs across countries.

Furthermore, based on the LMDI, there is a direct relationship between economic structural changes and changes in energy demand. Hence, economic structural changes have an impact on productive, efficient energy demand, subsequently; on efficient consumption of energy. This essay tests the hypothesis that "The impact of renewables on productive efficient consumption of energy in OECD economies."

Second essay: The impact of renewables on productive efficient consumption of energy in the end-uses sector (residential sector of Australia and New Zealand has chosen as the case study):

Final energy consumption is usually divided into the three sectors; industry, service, and others. Building energy consumption is one of the crucial parts of 'others' (Perez-Lombard, Ortiz et al. 2008). Building energy consumption is divided into the domestic (residential) and non-domestic (commercial) energy consumption. The global contribution from both residential and commercial buildings towards energy consumption has risen from 20% to 40% in developed countries which has exceeded the industrial and transportation sectors

(Perez-Lombard, Ortiz et al. 2008). According to Zhang (2004), residential energy consumption a major component of final energy consumption for countries. Residential energy consumption in this essay is defined as the energy used in private households and apartments, such as energy used for space and water heating, cooling, lighting, cooking and the use of appliances. Personal transport is not included in estimates of residential energy consumption.

People in developing countries rely on traditional biomass fuels for daily energy needs. These resources account for more than 90% of households energy consumptions in many developed and developing countries (van der Kroon, Brouwer et al. 2013). Using traditional biomass fuels have negative effects on health, environment, and human productivity (Heltberg 2005). The transition toward more efficient, and cleaner forms of energy is needed to overcome the negative impacts of using fossil fuels. A common model for describing household energy choices is the “energy ladder.”

The energy ladder assumes households move to more sophisticated energy forms as their income rises (Hosier and Dowd 1987). Fuel switching is a central concept in the energy ladder modeling. Fuel switching refers to moving up to the new fuel and simultaneously moving away from the fuel used before (Heltberg 2005). Energy resources on the ladder are in order according to the cleanliness, ease of use, cooking speed, and quality (van der Kroon, Brouwer et al. 2013). Cleveland and Ruth (1998), claimed that different energy types are different in terms of ability to do work per heat equivalent. Hence, different energy types have different quality; for example, electricity is categorized as high-quality energy, and coal is categorized as the low-quality energy.

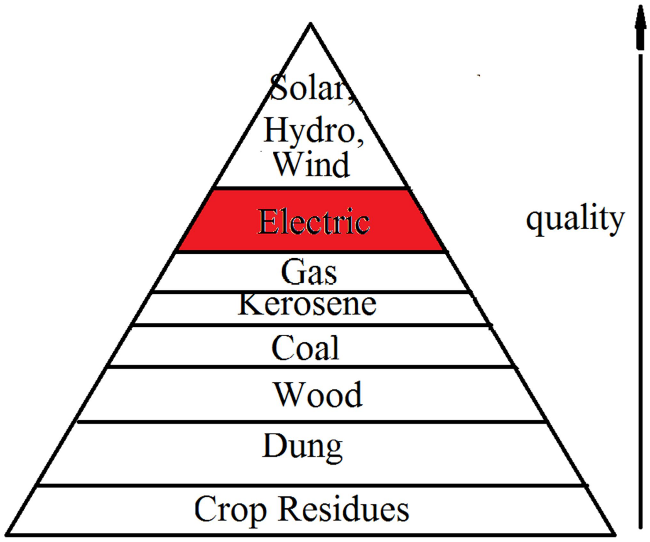

Figure 1: Energy Ladder Model[6]

The main source of energy in the residential sector, in both Australia and New Zealand, is electricity. Most of the Australian electricity is generated by fossil fuels; while, electricity in New Zealand is generated mainly by renewables. Hence, electricity in these two countries is generated with different energy resources with different quality. Therefore, the second essay tests the hypothesis of "The impact of renewables on productive efficient consumption of energy in the end-uses sector (residential sector of Australia and New Zealand has chosen as the case study)."

Third essay: Estimating the productive efficient consumption of fossil fuels in OPEC countries, and demonstrating the effect of dematerialization on fossil fuels consumption:

The Organization of the Petroleum Exporting Countries (OPEC) was founded in Iraq, after the agreement signing by five countries; namely, Iraq, Islamic Republic of Iran, Kuwait, Saudi Arabia, and Venezuela in September 1960. Qatar (1961), Indonesia (1962), Libya (1962), the United Arab Emirates (1967), Algeria (1969), Nigeria (1971), Ecuador (1973), Gabon (1975), Angola (2007) and Equatorial Guinea (2017) were joined the OPEC's members later. According to the estimation in 2016, 81.5% of the world's proven crude oil reserves are located in the OPEC countries (OPEC, 2016).

[6] Electricity in energy ladder model is generated by fossil fuels.

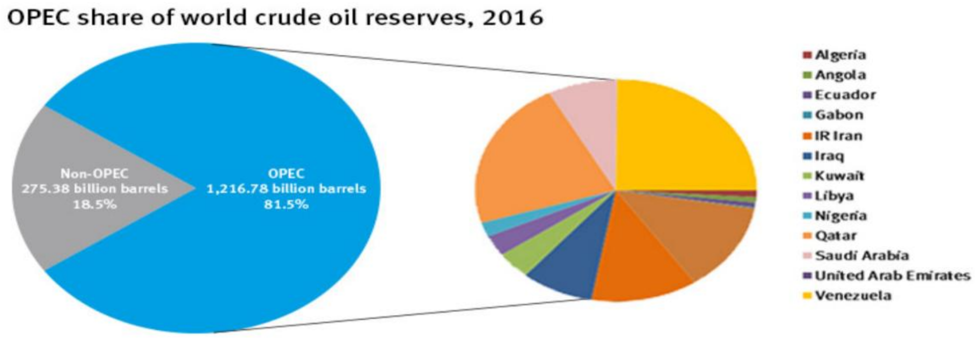

Figure 2: OPEC crude oil reserves

Adetutu (2014), demonstrated that CO_2 emissions from fossil fuels consumption have increased by 440% between 1970 and 2010. This rise occurred when OPEC counties energy consumption rose by 685% during the same period. OPEC countries mostly consume fossil fuels. Therefore, it is clear that the trajectory of energy consumption in the OPEC members' countries has crucial implications for global warming. To tackle the global warming problem, policymakers and governments around the world need to understand the level of efficient consumption of energy in order to restricting energy consumption in oil-exporting developing countries.

You can see the CO_2 emissions trends in the selected OECD countries[7]:

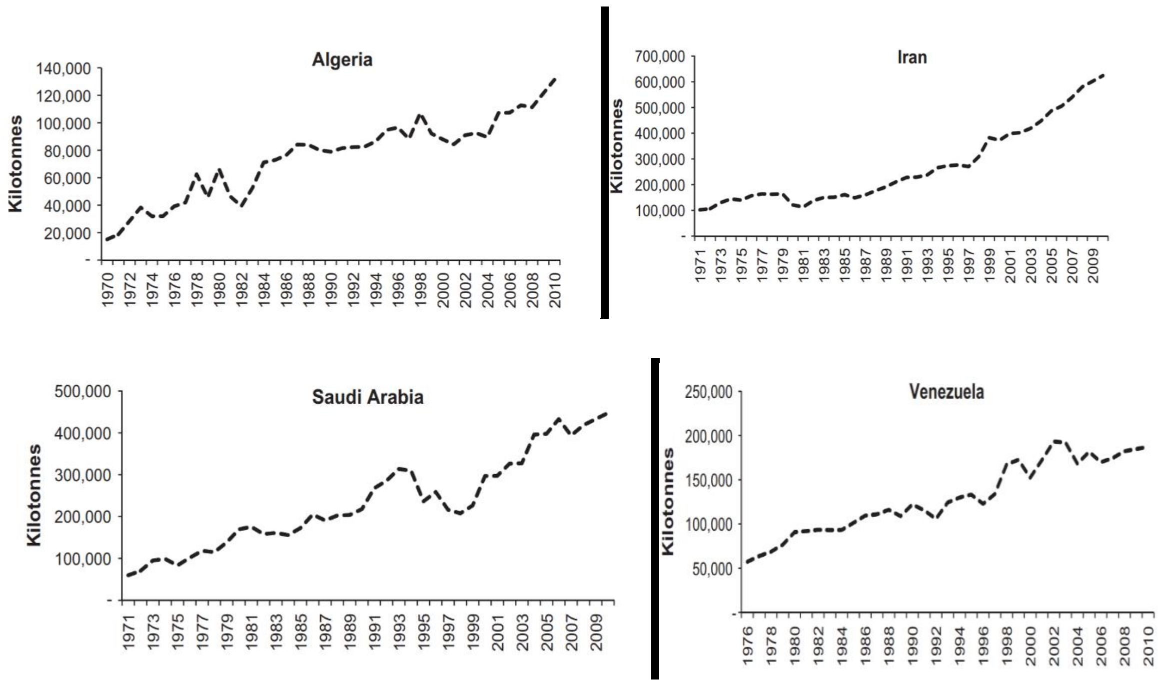

Figure 3: Historical CO_2 emissions trends

[7] Adetutu, M. O. (2014). "Energy efficiency and capital-energy substitutability: Evidence from four OPEC countries." Applied Energy **119**: 363-370.

Energy intensity is the most common indicator used to measure energy efficiency in OPEC countries. The higher energy intensity means more energy used to generate one unit of energy-gross domestic product (GDP) (Al□Rashed and León 2015). In this chapter, we will estimate the efficient consumption of energy with SFA modeling. Since OPEC countries mainly utilize fossil fuels (Secretariat 2014), the energy mix variables will be removed from the estimation.

Over the last 25 years, the largest share of growth in population has been in the Middle East, Africa, and India. The population of all OPEC countries is expected to grow by 316 million in this period, and 81% of the global population is expected to be in developing countries by 2040 (Secretariat 2014). Energy intensity merely expresses per capita energy consumption; it does not reflect changes of consumption by a single indicator; such as population (Ziolkowska and Ziolkowski 2011). Figure (4) illustrates the relationship between energy consumption, CO_2 emissions, and population (Perez-Lombard, Ortiz et al. 2008). Product Generational Dematerialization (PGD) indicator shows the role of population in the consumption of energy with measuring changes in energy consumption relative to changes in the population. The third essay tries to test the hypothesis of "Estimating the productive, efficient consumption of fossil fuels in OPEC countries, and demonstrating the effect of population on fossil fuels consumption".

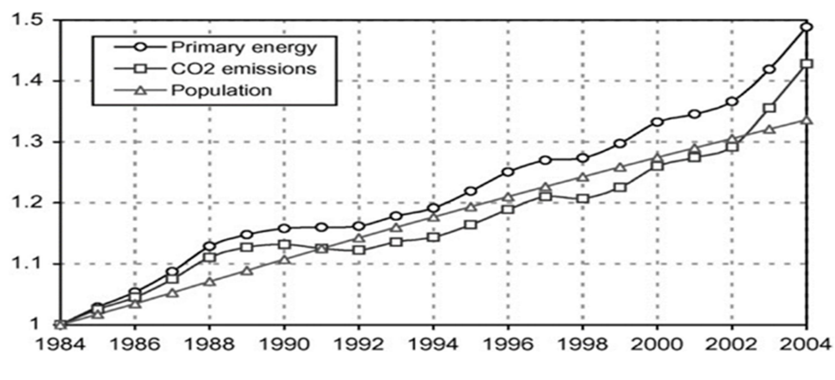

Figure 4: the relationship between energy consumption, CO_2 emissions, and population

Structure of the thesis:

The structure of this thesis is shown in figure (5). Followed by a general introduction in chapter one; Chapter 2, chapter 3 and chapter 4 are empirical chapters directed at understanding the effect of energy mix on productive efficient consumption of energy with considering renewables (OECD economies as the case study), with considering renewables in end-uses (in residential sector), and without considering renewables (OPEC countries as the case study). Each chapter includes an introduction, a review of the relevant literature, methodology, data, results, and conclusion. Finally, chapter 5 provides a general conclusion, the discussion of limitations and directions for future research.

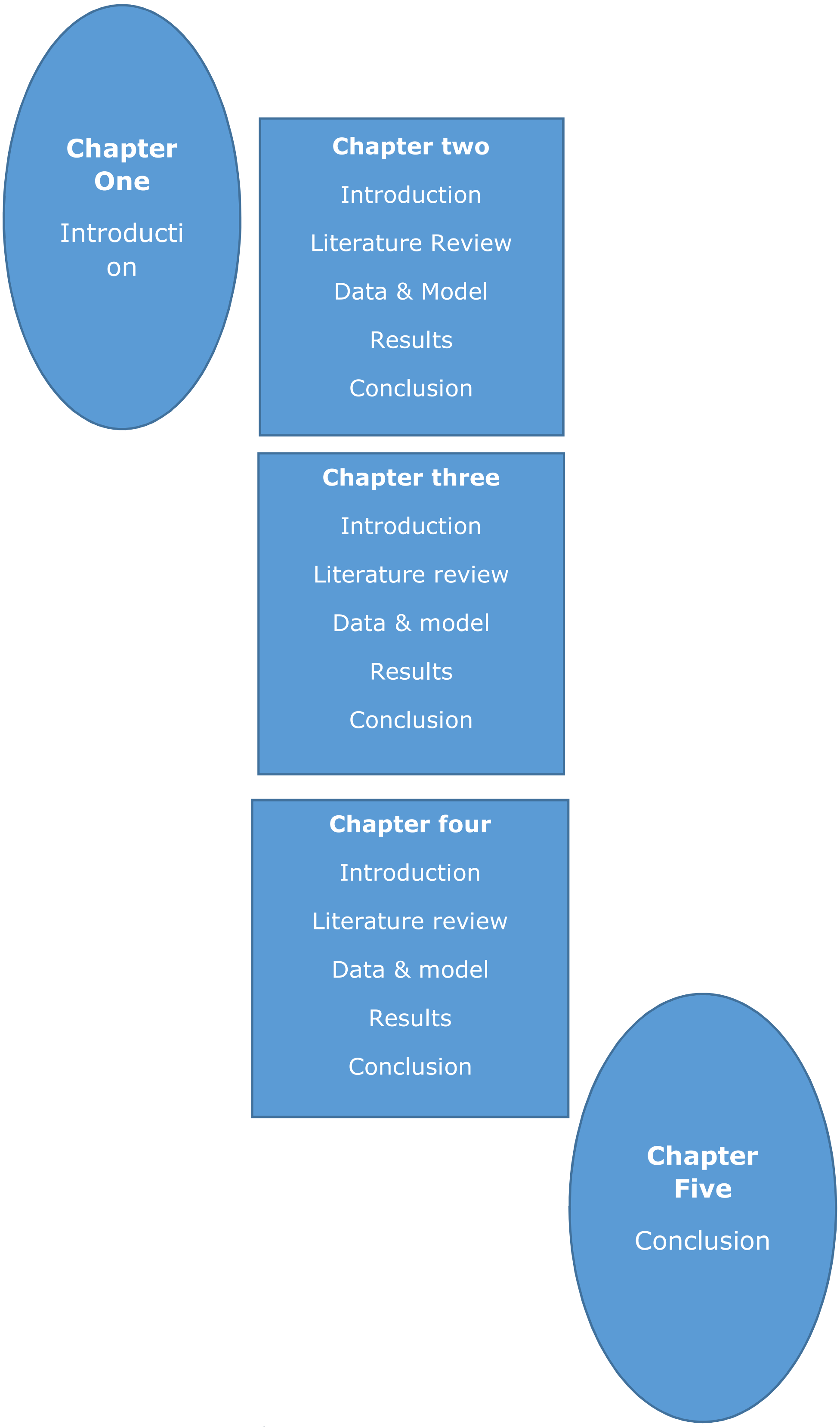

Figure 5: Thesis Structure

II. Chapter 2:

The impact of renewables on productive efficient consumption of energy in OECD economies[8]:

Estimating the impact of different energy resources on the efficient consumption of energy is important, due to the quality diversity of energy resources. Energy resources with higher quality can generate more production (Cutler, 2000). In this chapter, we utilize SFA modeling to estimate whether using high-quality energy resources, such as; renewables in countries has any effect on the efficient consumption of energy. Section 1 introduces the existing gap in the efficient consumption of energy estimation, Section 2 indicates existing researches about energy efficiency, and energy intensity, Section 3 explains the methodology, Section 4 describes the data and the empirical model, Section 5 presents the results, and finally, the summary and conclusions are provided in Section 6.

Introduction

Energy consumption is closely aligned with economic growth, and it is the largest contributor to greenhouse gas emissions (Seneviratna and Long 2018) (Pirlogea 2013). In 2008, 83% of anthropogenic greenhouse gas emissions were associated with energy use (IEA 2010). Hence, improvements in energy efficiency yield a double dividend viz. contributing to growth and a reduction in greenhouse gas emissions (Shahiduzzaman and Alam 2013).

Energy efficiency is a generic term which can be described as output-oriented, producing more output with the same amount of inputs; and input-oriented, producing a given amount of output using a minimum amount of input.

Energy intensity, defined as the ratio of energy use to GDP, is commonly used as an indicator for energy efficiency (Stern, 2012). It is well recognized that two issues arise from this definition. First, ideally, differences in the diversity of primary energy supply should be accounted for when deriving an estimate for the numerator, especially when undertaking cross-country studies. It is highly plausible that countries with similar estimates of total

[8] An earlier version of the essay was presented at the (the 34th USAEE/IAEE North American Conference, Tulsa)(Moshrefi & Sharp, 2016).

energy use have quite different profiles of energy type. A further complication arises from the fact that not all energy sources are of equal productivity (Stern 2012). Second, GDP is a summary measure of economic activity. Again, countries with similar levels of GDP are likely to differ in terms of their economic structure. Therefore, in order to gain greater insights into energy efficiency, we must control for differences in the energy mix and economic structure.

A person in developing countries utilizes 32 million Btus of energy on average, per year. However, a person in developed countries consumes nearly 210 million Btus of energy on average, per year. Whereas, per-capita renewable energy consumption rate never exceed 100,000 Btus in developing countries, annually (Chow, Kopp et al. 2003). According to the US Energy Information Administration's (EIA) report in 2010; consumption of renewable energy has been rising at a rate of 2.6% annually, in the world (Pao and Fu 2013).

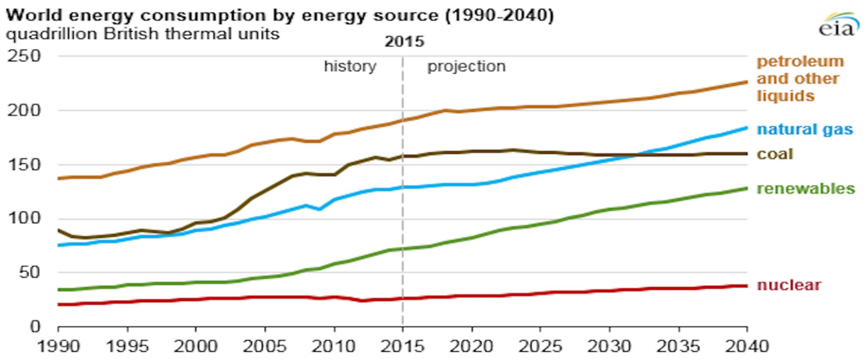

Figure 6: World energy consumption

Because the Kyoto Protocol has been signed by most OECD[9] countries to reduce the greenhouse emissions, their supply of renewable energy resources has been increased, from 1990 (Shafiei and Salim 2014).

Austria, Canada, Belgium, Denmark, Germany, France, Greece, Ireland, Iceland, Italy, the Netherlands, Luxembourg, Norway, Spain, Portugal, Sweden, Turkey, Switzerland, the United States, and the United Kingdom have signed the Convention on the Organisation for Economic Co-operation and Development in 14th of December 1960. Japan, Finland, Australia, New Zealand, Mexico, the Czech Republic, Hungary, Poland, the Republic of Korea, and Slovakia became OECD members subsequently (IEA 2001).

Building strong economies for its members, improving efficiency, expanding free trade, and contributing to development in industrialized as well as developing countries are the main objectives of OECD countries (OECD 2011).

[9] Organisation for Economic Co-operation and Development.

Moving economies in a higher level of resource productivity and the more efficient use of energy resources can lead countries to have more dynamic and competitive economies. This chapter investigates the relationship between the share of renewable energy resources and efficient consumption of energy, after controlling the energy mix in selected OECD countries.

Literature review

The relationship between fuel[10] mix and energy intensity has been investigated in several studies such as; Wilson, Trieu et al. (1994) in Australia's manufacturing sector, Ma and Stern (2008), in China, and Shahiduzzaman and Alam (2013), in Australia. Most find that economic structure is a determinant of energy intensity. Fuel mix was affected energy intensity, but the degree of this influence varies across countries.

Substantial improvements in energy efficiency occurred at a time when domestic oil prices rose sharply suggesting that relative energy prices are a key influence in observed gains in energy efficiency. These results provide insights for parametric analysis seeking to estimate causal linkages between the variables of interest, such as the price of energy and economic structure, and energy intensity (Greening, Davis et al. 1997).

Filippini and Hunt (2011) used stochastic frontier analysis (SFA) to estimate the causal relationship between energy efficiency and explanatory variables, such as changes in economic structure, technology, and climate for 29 OECD countries between 1978 and 2006. Using panel data for 48 US states over the period 1995-2007 Filippini and Hunt (2012), used SFA to estimate residential energy efficiency for 48 US states. By controlling for a range of economic variables and other factors, such as heating degree days, they concluded that energy intensity is not necessarily a good indicator of energy efficiency. The authors' draw similar conclusions using a SFA energy demand approach to estimate energy efficiency for 49 US states over the period 1995-2009(Filippini and Hunt 2013). The studies by Filippini and Hunt highlight the insights gained from using SFA energy demand models; first as an indicator of efficiency and second when it comes to informing energy policy.

Apergis, Aye et al. (2015), used data envelopment analysis (DEA) to estimate energy efficiency in 20 OECD countries from 1985 to 2011. They conclude that the level of energy efficiency is high in selected OECD countries, but this level is decreasing over time. EU

[10] Fuel is defined as an energy end-use in this essay.

countries were found to have the highest level of energy efficiency. Capital-intensive economies were more energy efficient than labor-intensive economies.

Zhou and Ang (2008) illustrated energy efficiency for economy-wide using a non-parametric approach (DEA) for 21 OECD countries from 1997 to 2001. The difference between their study and previously proposed DEA models for energy efficiency performance is that they consider the undesirable part of the output (e.g., pollution) simultaneously with its desirable part (e.g., industrial production). They concluded that precise energy efficiency estimation requires the inclusion of the undesirable part of the output.

Zhou, Ang et al. (2012), also estimated energy efficiency performance for 21 OECD countries in 2001. This study measured economy-wide energy efficiency according to using Stochastic Frontier Analysis (SFA). Because SFA includes statistical noise, they conclude that SFA provides more accurate estimates of energy efficiency than the non-parametric approach.

Stern (2012) used SFA to investigate trends in energy efficiency in 85 countries over the period 1971 to 2007. He found that the most influential factors to be total factor productivity (TFP) and the ratio of the exchange rate to purchasing power parity (PPP). Furthermore, he showed that energy efficiency in developed countries, and China and India, has improved over time.

Although both Filippini and Hunt (2011) and Stern (2012) both estimate energy efficiency trends in countries, there are some differences in approach. Filippini and Hunt base their analysis on the demand function whereas Stern's paper is based on the production function. Therefore, Filippini and Hunt's paper is contingent on energy price given the economic environment. In contrast, Stern's paper tries to uncover the impact of differences in the economic environment.

We summarise the above findings using the following Logarithmic Mean Devisia Index (LMDI) that shows the relationship between energy demand, economic structure, fuel switching, and energy intensity.

Equation 5: $\Delta \text{Energy demand} = \Delta \text{Activity} + \Delta \text{Structure} + \Delta \text{Fuel Switching} + \Delta \text{Energy intensity}$

Where:

ΔEnergy demand is the change in energy demand.

ΔActivity is the change in the level of production, as measured by the gross domestic product (GDP).

ΔStructure represents the change in economic structure; for example, shifting from intensive to the less energy-intensive industry.

Δenergy Switching or energy mix refers to changes in the quantity of end use, for example, switching from coal to hydro.

ΔEnergy intensity is used as a measure of energy efficiency.

Obviously, the availability of usable energy resources; demand; and, the economic, environment, and geopolitical context differ across countries (Armaroli and Balzani 2011). Bearing these factors in mind, we are interested in whether the share of renewable energy sources has an impact on energy efficiency. Renewable sources include: geothermal, hydro, solar photovoltaics, solar thermal, solid biomass, wind, and renewable municipal waste and ocean sources. The share of renewable energy resources at two points in time,1990 and 2011, for OECD listed countries[11] show that the share of renewable sources of energy decreased in six countries: Australia, Korea, Mexico, Norway, Turkey, and the US; and, increased in the remaining 22 countries. The question arising from this observation is whether higher levels of energy efficiency are associated with a shift towards a higher share of primary energy originating from renewable sources?

Given that numerous countries have adopted policies aimed at promoting renewable sources of energy the focus of our research is on whether different energy types, controlling for a range of economic variables, have an effect on energy efficiency.

Approaches, such as index decomposition analysis (IDA) and frontier analysis (FA) have been proposed in order to overcome the problems associated with the use of energy intensity as an indicator of energy efficiency. The energy efficiency indicator as used in IDA is created according to a bottom-up approach (Boyd & Roop, 2004). On the other hand, FA provides an estimate of energy efficiency according to the distance between the actual demand of energy and the best practice frontier of energy use (Farrell 1957). The parametric form of FA (SFA) is chosen in this essay because the non-parametric model does not include statistical noise (Zhou and Ang 2008), and there is no algebraic form between output and inputs (Filippini and Hunt (2012), Zhou, Ang et al. (2012), and Hu and Wang (2006)). We adopt the framework used by Filippini and Hunt and specifically allow for the share of renewable resources.

[11] Australia, Austria, Belgium, Canada, CZ, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak, Sweden, Switzerland, Turkey, UK, US.

To the best of our knowledge, this essay is the first study that includes changes toward a higher share of renewables in countries and energy efficiency, using SFA. The objective of this essay is to provide empirical estimates of the impact of the different energy types on the efficient consumption of energy resources in 28 OECD countries. The essay is organized as follows: Section 2 explains the methodology. Section 3 describes the data and empirical model. Section 4 presents the results. Finally, the summary and conclusions are provided in Section 5.

Methodological framework

Energy efficiency is measured by the difference between productive efficient energy demand and actual demand. Productivity is defined as the ratio of output to inputs which is the inverse of energy intensity. In other words, we estimate the efficiency of energy consumption at a given level of productivity. Based on this, we test the hypothesis whether energy mix affects the efficient consumption of energy, under the assumption that all countries seek to minimize their use of energy with respect to a given level of output. The stochastic frontier model is denoted as follows:

Equation 6:

$$y_{i,t} = f(X_{i,t}; \beta).\exp\{v_{i,t} - u_{i,t}\} \; i = 1, ..., N \;\; t = 1, ..., T$$

Where: y_{it} is observed final energy consumption by country i in year t; X_{it} is the $1\times$ K vector of explanatory variables which are associated with the energy consumption of countries; and β represents a K $\times$ 1 vector of unknown parameters to be estimated. The error term has two components. The first component is stochastic v_{it} and assumed to have an independent and identical normal distribution with zero mean and constant variance, i.e., iid~ N (0, δ_v^2). The second component u_{it} is not stochastic and is assumed to be a one-sided normal distribution with the non-negative random variables, which represent technical inefficiency, i.e. $u_{it} \sim N^+(0, \delta_u^2)$.

Five models are commonly used in SFA; the pooled, random effect, fixed effect, true random effect (TRE), and true fixed effect (TFE). Both TRE and TFE models include time-invariant group specific variables designed to capture heterogeneity and the time-variant technical inefficiency term (u_{it}) (Greene 2005). Both TFE and TRE models are considered in this essay and the pooled model (Aigner, Lovell, & Schmidt, 1977) was estimated for the purpose of comparison.

Unobserved heterogeneity bias, resulting from a possible correlation between explanatory variables and the technical inefficiency term, is addressed by defining the technical inefficiency term u_{it} as a function of the explanatory variables (Mundlak 1978).

Equation 7: $U_i = AX_i\pi + \tau_i$ *Equation 8:* $AX_i = \frac{1}{T}\sum_{T=1}^{T} X_{it}$

$\tau_i \sim iid\ (0, \delta_\delta^2)$

Where: X_i represents the vector of explanatory variables of demand, AX_i is an average vector of all explanatory variables, and the π is an unknown coefficient. When π=0 there is no correlation between the inefficient term and explanatory variables.

Equation (6) is readily incorporated into equation (5) and the parameters in equation (5) are estimated using the maximum likelihood method. After estimating the productive efficient demand of energy, the level of energy inefficiency of countries is obtained according to the conditional mean of the efficiency term E (U_{it}| U_{it}+V_{it}) (Jondrow, Knox Lovell et al. 1982). The level of energy inefficiency is expressed as:

Equation 9: $$EF_{it} = \frac{f(X_{it}.\beta).exp(v_{it})}{y_{it}} = exp(-\widehat{u_{it}})$$

Where $EF_{i,t} \in [0,1]$; a score of one indicates no inefficiency in energy consumption.

Data and empirical models

We use an unbalanced panel data set for 28 OECD countries between 1975 and 2011. Data are drawn from the following sources: International Energy Agency (IEA) - GDP, population, aggregate energy demand, and domestic primary supply of energy resources; World Bank - value added for industry and service sectors; OECD - area size; and, climate dummy variables are based on the classification proposed by Kottek, Grieser et al. (2006).

Variables

With energy consumption as the dependent variable, we use the price of energy, GDP, population, area size, industrial sector share of GDP, the service sector share of GDP, and climate as regressors. Time dummy variables are used to capture the exogenous effect of technical progress, changes in consumer tastes and social norms. Technical progress is recognized as having an endogenous, and exogenous, impact on energy demand. The endogenous impact of technical progress is captured through price. It is assumed that different rates of technological innovation countries are captured by the inefficiency term (Filippini and Hunt 2012).

As the impact of energy mix on productive efficient demand is of primary importance in this essay; energy resources with the highest level of consumption in countries are included in the energy mix. The primary supply of energy resources are; coal, crude oil, gas, geothermal, hydro, oil products (oil products include naphtha, white spirit and SBP, lubricants, bitumen, paraffin waxes, and petroleum coke), nuclear[12], and renewable municipal waste. Renewable municipal waste consists of products that are combusted directly to produce heat and/or power and comprises waste produced by households, industry, hospital, and tertiary sector that are collected by local authorities for incineration at specific installations (IEA 2008), solar photovoltaics, solar thermal, solid biomass, and wind. Total primary supply is defined as sum of all primary supply of energy resources in countries, namely; coal, crude oil, gas, geothermal, hydro, oil products, nuclear, renewable municipal, solar photovoltaics, solar thermal, solid biomass, wind, peat, heat, tide, wave, and ocean sources(Moshrefi and Sharp 2015).

Table 1: Variable measurement

Variables	**Measurement**
Final energy consumption	Million tonnes oil equivalent (Mtoe).
Domestic primary supply	Kilo tonnes (Kt).
Energy consumer price index (CPI)	Real energy prices (2010-100) at PPP.
Annual GDP per Capita	Billions 2005 USD using PPPS.
Industry value added	Percentage of GDP.
Service Sector value added	Percentage of GDP.
Climate classification[13]	A, tropical weather; B, dry weather; C, mild mid-latitude weather; and E, polar.
D_t	Time dummy variables.
Area size	Squared kilometers.
Population	All persons annually.

[12] Due to nuclear energy can generate electricity without any greenhouse gas emissions; such as carbon dioxide, it is categorized as the clean energy resource (Hsiao, 2013).

[13] According to the Koppen classification; A, tropical weather; B, dry weather; C, mild mid-latitude weather; and E, polar one Kottek, M., et al. (2006). "World map of the Koppen-Geiger climate classification updated." Meteorologische Zeitschrift **15**(3): 259-263.

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Table 2: Descriptive statistics for key variables

Variables	Mean	Std. Dev.	Min	max
Final energy consumption	115645.8	257909.3	2213.68	1581622
Wind	159.3443	744.9712	0	12113.79
Solar thermal	62.14103	217.3382	0	1972.536
Solar photovoltaics	18.78575	128.7051	0	2408
Hydro	2362.474	5702.136	0	32681.12
Geothermal	586.5168	1980.844	0	15650.9
Renewable municipal	193.6357	569.7636	0	4095.181
Coal	36549.27	87132.98	54.431	558411.6
Crude	70574.77	153356.4	0	921892.6
Gas	34590.38	90010.42	0	594784
Oil products	-1297.893	13468.56	-115557	56174.32
Nuclear	15383.25	35283.62	0	218630.5
CPI (Price)	60.84787	28.06941	0	131.5
Industrial value-added	31.6771	6.144834	12.93014	61.59483
Service value added	64.21803	8.992673	31.60943	86.77441
GDP	99.6929	36.4326	23.10094	251.7267
Population	3.82e+07	5.35e+07	358950	3.14e+08
Area size	1250403	2766057	2586	9984670

Empirical model

The empirical model is described by equation (9) and estimated in natural log form:

Equation 10:

$$D_{i,t} = \beta + \beta^{p} P_{i,t} + \beta^{shi} SHI_{i,t} + \beta^{she} SHE_{i,t} + \beta^{gdp} GDP_{i,j} + \beta^{rpop} Rpop_{i,t} + \beta^{em} EM_{i,t} + \beta^{t} D_{t} + \beta^{c} D_{c} + v_{i,t} + u_{i,t}$$

Where:

i = 1,…,28 denotes country; t = 1,…,36 denotes year.

$D_{i,t}$ = aggregate energy demand.

$P_{i,t}$ = energy consumer price index.

$SHI_{i,t}$ = industrial sector value added as a percentage of GDP.

$SHE_{i,t}$ = service sector value added as a percentage of GDP.

$GDP_{i,t}$ = gross domestic product per capita.

$Rpop_{i,t}$ = population density (people per sq.km of land).

$EM_{i,t}$ = energy mix, the ratio of primary supply of different energy resources to total primary supply.

D_t = time dummy variables[14].

D_c = climate categorical variables.

$v_{i,t}$ = stochastic component of the error term.

$u_{i,t}$ = non-random component of the error term.

The level of energy efficiency (EF) according to the conditional mean of efficiency term E (U_{it}| U_{it}+ V_{it}) (Jondrow, Knox Lovell et al. 1982) is expressed as:

Equation 11: $$EF_{it} = \frac{D^{\wedge}_{it}}{D_{it}} = e\,(-\widehat{u_{it}})$$

$D^{\wedge}_{it}$= the frontier demand of energy (optimal).

D_{it}= the actual demand of the energy in the county (i) at the year (t).

Results

The Wu-Hausman test endorses the use of TFE. Due to the uniform correlation between dependent and independent variables, the distribution of U_{it} in the TFE model is assumed to be exponential. The distribution is half-normal in the pooled model.

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[14] As estimating price and income elasticities are not the purpose of this essay, this essay does not use Structure Time Series Model (STSM) to show Underlying Energy Demand Trend (UEDT) (Dimitropoulos*, J., et al. (2005). "Estimating underlying energy demand trends using UK annual data." Applied Economics Letters **12**(4): 239-244.
).

Spearman's test was applied to find whether there is a correlation among GDP, service value added, and industrial value added. Correlation between GDP and industrial value added was not significant. However, the correlation between service value added and GDP was significant, and service value added was dropped from the model. There is no significant correlation between price and primary energy supply. Taking advantage of Spearman's test that shows no correlation among price and primary energy supply and final energy consumption, the TFE model is estimated with lagged price as an instrumental variable.

Log-likelihood and AIC indicators are utilized to choose the best model. Since there is a uniform correlation between depended variables and independent variables, the positive log-likelihood is acceptable. Moreover, the positive log-likelihood should be accompanied by a negative AIC. Consequently, the true fixed effect model without an instrument variable (TFE model without lags), which has the best log-likelihood and AIC, is chosen to estimate energy inefficiency.

Results are presented in Table 3. Service value added is dropped out of the energy demand equation because of the correlation between service value added and GDP. The pooled model did not converge without service value added and is not reported. All coefficients of TFE model with two lags have the same sign as coefficients in TFE model without any lag, except GDP.

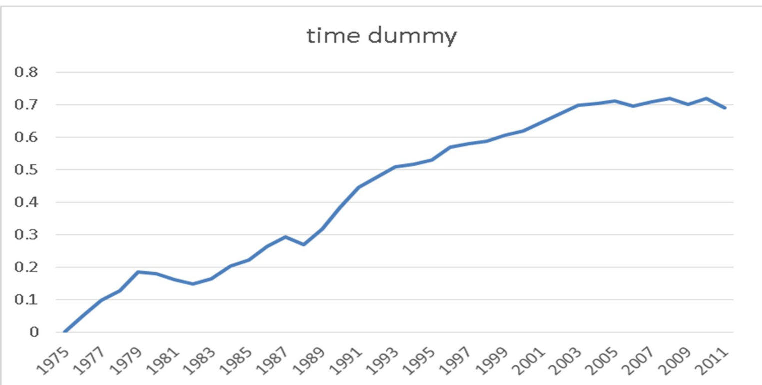
Most of the energy variable parameter estimates, using the TFE model without lags, are significant and negative, with the exception of solar thermal. Price, industrial value added, GDP, and the ratio of population to the area, are significant with expected signs.

Negative energy coefficients in the TFE model without lags illustrate whenever the primary supply of each energy resource increases over the period, final energy consumption decreases, with the exception of renewable solar thermal. Industrial value-added positive and significant. Final energy consumption of countries rises by 0.02% and 0.004% respectively with a 1% increase in the industrial value added and population density.

The negative coefficient for GDP demonstrates that 1% growth in GDP causes a 0.001% decrease in final energy consumption. We attribute the negative sign to changes in economic structure, notably to growth in the size of the service sector. As can be seen from Table 3, the price coefficient is negative and significant. If the price of energy increases by 1%, the demand of energy decreases by 0.0013%. The lambda coefficient is 3.64, which shows that the contribution of the one-sided error component is relatively high and the effect on the inefficiency term is positive and significant.

Population density is significant and positive. Some authors, for example, Karathodorou, Graham et al. (2010), and Mindali, Raveh et al. (2004) found a negative relationship between energy demand and density. However, in our essay the relationship between density and energy demand is positive. The reason for this difference is the definition of population density. In Karathodorou, Graham et al. (2010) and Mindali, Raveh et al. (2004), population density increases due to decreases in the area size (population constant); in contrast, in this thesis, the population density increases with the number of people holding area constant. Therefore, the positive sign of population density is acceptable.

Time dummy variables capture the effects of both technical progress and other exogenous changes; such as consumer taste, in countries over time (Hunt, Judge et al. 2003). However, in Filippini and Hunt (2011) the time dummy variables capture the effect of technical progress, expectations of changes in international oil price, and changes in awareness of climate change. Our results show all of the time dummy coefficients are significant and positive. The positive sign shows that after holding the effect of energy price constant, the effect of exogenous factors; such as consumer taste, outweigh the effect of technical progress (Sa'ad 2011). As a result, the positive sign for time dummy variables is acceptable. One of the climate dummy variables is significant with the expected sign[15]. Graph (6) shows the estimated time dummy coefficient relative to the year 1975. Lambda, the ratio of the variance of the inefficiency term to the variance of the stochastic term, illustrates the relative contribution of efficiency (U_{it}) and stochastic (V_{it}) parts of the error term. Lambda is significant with the expected sign.



Graph 6: Estimated time dummy coefficients

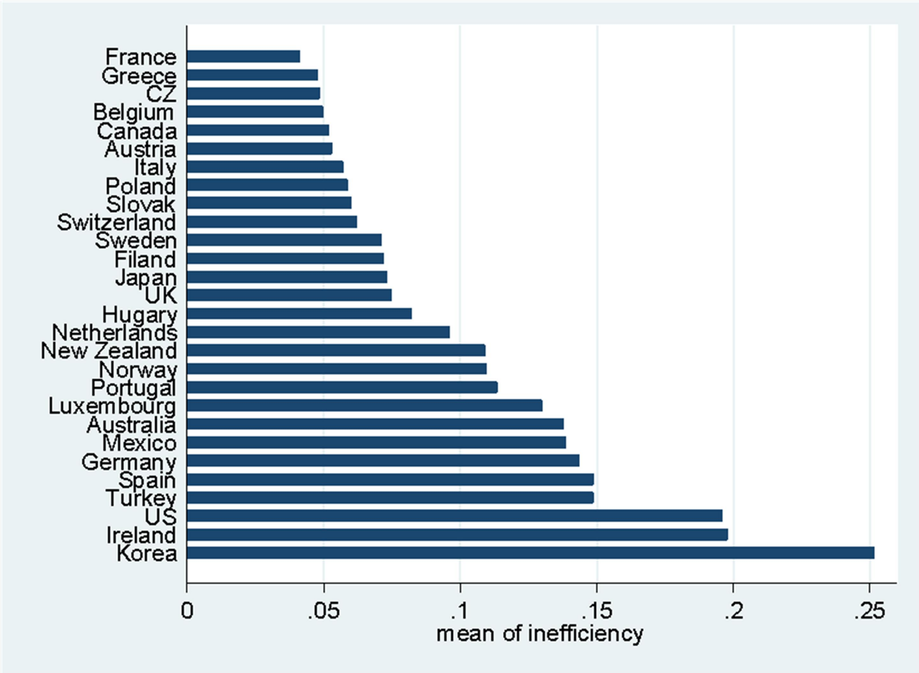
[15] Table A.2 climate dummy variables is in the appendix.

Table 3: Estimated coefficient (t-value in parentheses)

Variables	TFE (without lags)	TFE (with two lags)
Wind	1.215	3.626
	(0.69)	(1.63)
Solar thermal	37.34***	12.14
	(5.10)	(1.32)
Solar photovoltaics	-15.45	-24.85**
	(-1.83)	(-2.89)
Hydro	-2.446*	-3.276***
	(-2.30)	(-7.39)
Geothermal	0.453	0.538
	(0.42)	(1.88)
Biomass	-5.079*	-5.660
	(-2.16)	(.)
Coal	-2.219*	-2.262***
	(-2.06)	(-10.27)
Crude oil	-2.286*	-2.745***
	(-2.19)	(-15.37)
Gas	-1.736	-1.877***
	(-1.66)	(-8.83)
Oil products	-1.999	-2.329***
	(-1.92)	(-13.09)
Nuclear	-2.425*	-2.788***
	(-2.21)	(-12.95)
Renewable municipal	-18.04***	-13.59***
	(-6.05)	(-4.61)
Industrial value-added	0.0282***	0.0360***
	(9.22)	(8.15)
GDP	-0.00151*	0.00265***
	(-2.53)	(3.41)
Price	-0.00136***	-0.000128
	(-3.72)	(-0.37)
RPOP	0.00483***	0.00511***
	(5.22)	(5.09)
Lambda	3.64***	5.59***
	(0.009)	(0.019)
Log-likelihood	890.42	596.74
AIC	-1616.84	-1033.49

Note: ***, **, and * coefficient are significantly different from zero at the 99%, 95%, and 90% confidence level respectively.

Graph (7) shows mean energy inefficiency over the period 1975-2011; ranging from Korea the highest and France the lowest.



Graph 7: Mean energy inefficiency

Table 4 shows the ranking of energy efficiency for OECD countries with the mix of energy resources included in the model. By way of contrast the ranking reported by Filippini and Hunt (2011), which does not account for energy mix, is shown in column three. Comparison of rankings shows the position of 14 countries increasing and 14 decreasing relative to the "without energy mix" ranking. Australia, Mexico, Norway, Turkey, and the USA have a decreasing share of renewables.

Table 4: Average Energy Efficiency Scores and Rankings

Country	**Efficiency-Rank(with energy mix)**	**Efficiency-Rank(without energy mix)***
Australia	21	2
Austria	6	9
Belgium	4	16
Canada	5	3
CZ	3	18
Finland	12	8
France	1	3
Germany	23	20
Greece	2	22
Hungary	15	12
Ireland	27	24
Italy	7	9
Japan	13	11

Korea	28	29
Luxembourg	20	19
Mexico	22	21
Netherlands	16	5
New Zealand	17	25
Norway	18	6
Poland	6	26
Portugal	19	28
Slovakia	9	12
Spain	24	27
Sweden	11	14
Switzerland	10	1
Turkey	25	22
UK	14	7
US	26	16

* Source: (Filippini and Hunt 2011)[16]

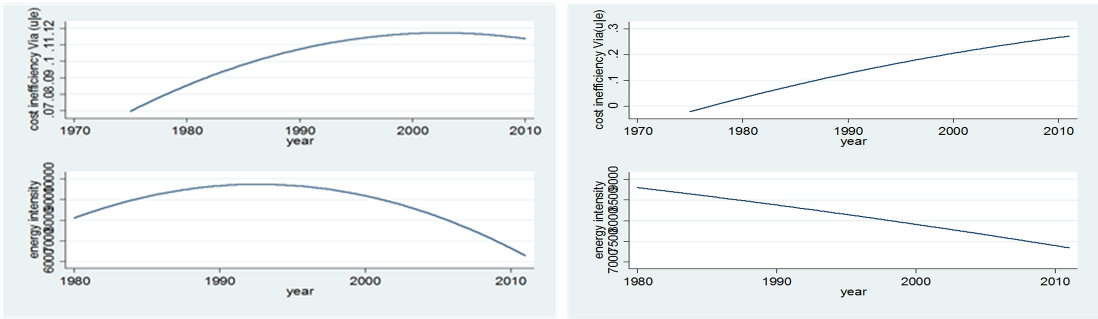
The ranking of Australia, Belgium, Norway, Poland, CZ, and Greece have been changed dramatically after the inclusion of energy mix. Moreover, the share of renewable energy is lower than fossil fuels. In the case of Norway, although the contribution of hydro is high during the time period, the share of renewable energy resources in 2011 is lower than in 1990[17].

Energy intensity and energy inefficiency

We now turn to a comparison of energy intensity and energy inefficiency. First, we note that Spearman's rank correlation coefficient implies that energy intensity and energy inefficiency are independent. Energy intensity and energy inefficiency graphs for Australia and New Zealand are used to illustrate that energy intensity cannot be a reliable indicator for energy efficiency[18].

[16] Filippini, M. and L. C. Hunt (2011). "Energy Demand and Energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach." Energy Journal **32**(2): 59-80.

[17] Energy efficiency and energy mix graphs for all countries are reported in the appendix.
[18] In some countries, such as Slovakia, Portugal, Germany, and Canada, the energy intensity and energy inefficiency graphs are similar.



New Zealand Australia

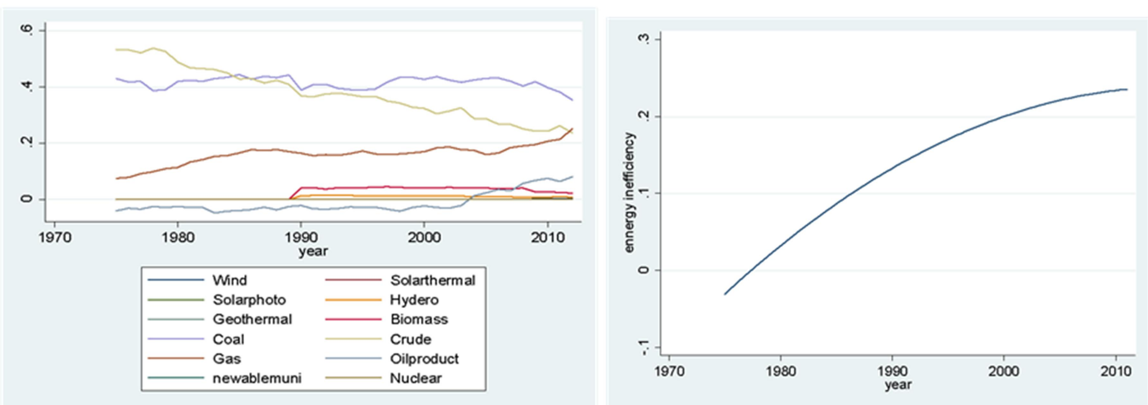
Graph 8: Energy inefficiency and energy intensity

Energy inefficiency and energy mix

In this section, we demonstrate the energy inefficiency graph according to the energy mix graphs for countries Australia and New Zealand.

Australia

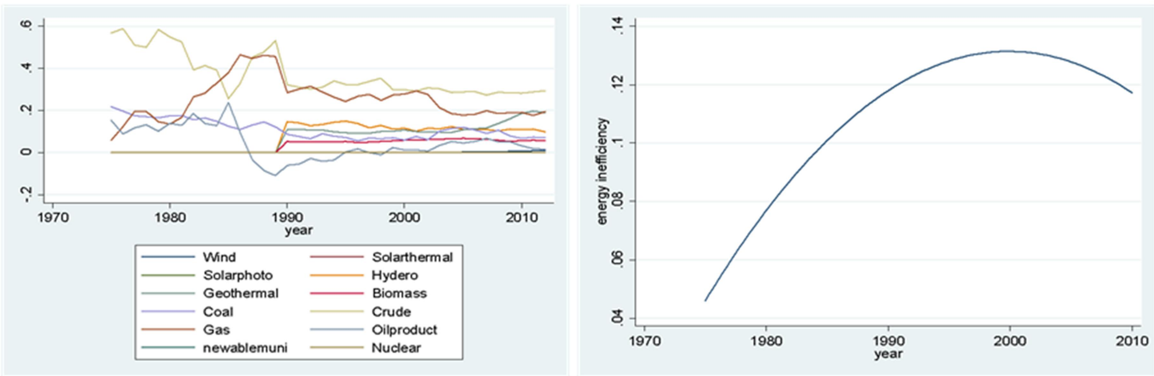
AS it can be seen, crude oil was the main source of energy until 1987, due to a dramatic fall, from 1987; coal replaced crude oil as a main source of energy. Natural gas is another energy resource which has a sharp increase over the estimated period. Primary supply of oil products is increasing between 1975 and 2011. Furthermore, there are two main renewable energy resources in Australia; biomass, and hydro. The primary supply of both of them is decreasing. The amount of other renewable energy resources is negligible compared to fossil fuels. Therefore, the primary supply of fossil fuels is increasing; however, the primary supply of renewable energy resources is decreasing. As a result, energy inefficiency in Australia is increasing.



Graph 9: Australia energy mix & energy inefficiency

New Zealand

The main source of energy in New Zealand is crude oil. The primary supply of crude oil had a sharp decrease from 1975 to 1985. Then its amount soared until 1989. Consequently, after a slight decrease, it remains almost constant over the rest of the estimated period. Natural gas primary supply increased between 1975 and 1989, and then it decreases. The primary supply of coal has a gradual decline during the estimated period. The primary supply of oil products also has a slow fall from 1975 to 2011. Furthermore, the primary supply of renewable energy resources is significantly high, especially geothermal. Primary supply of geothermal is increasing sharply from 1990 to 2011. According to the fuel mix graph of New Zealand, the primary supply of fossil fuels is decreasing. Also, the primary supply of all renewable energy resources is increasing. Thus, although energy inefficiency of New Zealand is increasing from 1975 to 2002, this rise is with decreasing slope, and then it decreases.



Graph 10: New Zealand energy mix & energy inefficiency

Summary and Conclusion

Building on Filippini and Hunt (2012) this essay shows that renewable energy consumption affects energy efficiency. In the majority of OECD countries (except Italy, Finland, Sweden, and Slovakia) increases in the primary supply of renewable energy resources, or decreases in the primary supply of fossil fuel energy resources are associated with an increase the energy efficiency. In particular comparisons of energy inefficiency and energy intensity emphasize the unreliability of energy intensity indicator because only three countries (Portugal, Germany, and Canada) out of 28 have some degree of similarity between their energy intensity and energy inefficiency. The estimated model provides evidence that shifting toward renewable energy resources, as the primary supply of energy, is associated with an increase in energy efficiency.

Consumption of fossil fuels, in most countries, seems to be cheaper than renewable energy resources. However, environmental externalities (greenhouse emissions) and energy security are associated with reliance on fossil fuels. In addition, based on the IEA report in 2013, the number of subsidies worldwide for consuming fossil fuels was $548 billion in 2013 which is over four times the value of subsidies to renewable energy resources (IEA 2013). Thus, there are considerable merits associated with policies aimed at shifting toward the consumption of renewable energy resources.

Appendix (A)

Time dummy estimated coefficient:

Table A.1 time dummy variables

year	TFE (without lags)	TFE (with two lags)
1975	0	0
	(.)	(.)
1976	0.0506	0.778**
	(1.65)	(3.21)
1977	0.0976***	0.764**
	(3.31)	(3.19)
1978	0.128***	0.851***
	(4.40)	(3.49)
1979	0.186***	0.957***
	(6.32)	(3.92)
1980	0.180***	0.910***
	(6.23)	(3.68)
1981	0.160***	0.854***
	(5.34)	(3.51)
1982	0.147***	0.840***
	(4.65)	(3.44)
1983	0.164***	0.884***
	(5.05)	(3.57)
1984	0.203***	0.909***
	(6.22)	(3.70)
1985	0.222***	0.940***

	(6.59)	(3.90)
1986	0.263***	1.003***
	(7.73)	(4.06)
1987	0.292***	1.016***
	(8.30)	(4.15)
1988	0.270***	1.063***
	(7.25)	(4.36)
1989	0.316***	1.111***
	(8.77)	(4.45)
1990	0.384***	1.141***
	(8.49)	(4.72)
1991	0.446***	1.221***
	(9.66)	(5.03)
1992	0.476***	1.255***
	(10.56)	(5.23)
1993	0.508***	1.326***
	(10.46)	(5.38)
1994	0.516***	1.325***
	(10.64)	(5.36)
1995	0.530***	1.330***
	(11.38)	(5.47)
1996	0.569***	1.379***
	(12.09)	(5.67)
1997	0.580***	1.392***
	(12.15)	(5.72)
1998	0.586***	1.391***
	(12.20)	(5.73)
1999	0.606***	1.414***

	(11.97)	(5.78)
2000	0.620***	1.432***
	(11.98)	(5.83)
2001	0.646***	1.446***
	(12.06)	(5.88)
2202	0.672***	1.462***
	(12.38)	(5.83)
2003	0.697***	1.492***
	(12.62)	(6.04)
2004	0.702***	1.492***
	(12.68)	(6.09)
2005	0.710***	1.497***
	(12.98)	(6.08)
2006	0.696***	1.444***
	(12.75)	(5.89)
2007	0.709***	1.460***
	(12.78)	(5.96)
2008	0.718***	1.436***
	(12.61)	(5.86)
2009	0.700***	1.463***
	(11.77)	(5.98)
2010	0.718***	1.475***
	(11.84)	(6.07)
2011	0.690***	1.428***
	(10.70)	(5.88)

Climate dummy estimated coefficient:

Table A.2 climate dummy variables

variables	TFE (without lags)	TFE (with two lags)
Da	3.586	1.044
	(.)	(.)
Db	2.385*	2.830***
	(2.02)	(19.76)
Dc	-1.762	-0.395
	(-1.74)	(-1.15)
Dd	0.127	1.604***
	(0.91)	(8.87)
De	-0.915	0.881
	(.)	(.)

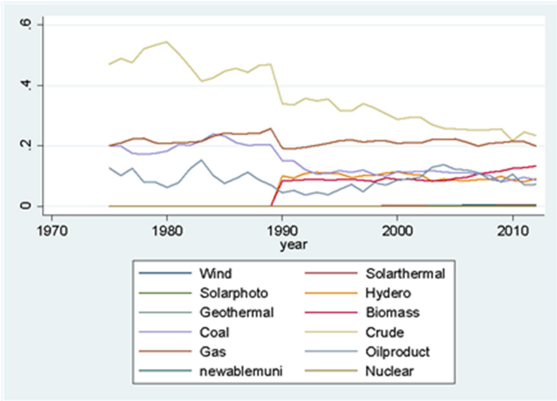
Fig. An energy inefficiency and energy mix graphs

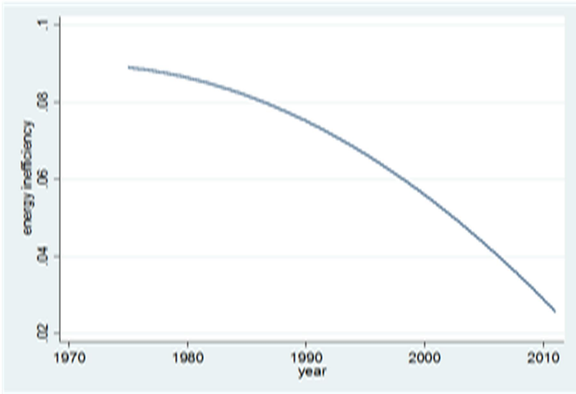
Energy inefficiency and energy mix

Austria

The energy mix graph of Austria illustrates the primary supply of crude oil was going down considerably from 1975 to 1998. This decline is continued from 1998 to 2011, but with the slight slope. Amount of primary supply of natural gas goes up over the estimated period. The third main energy resource is coal. The primary coal supply also drops between 1975 and 2011. Besides, the primary supply of oil products was decreasing until 1991, from 1991, whose amount increases. Moreover, in Austria the primary supply of renewable energy resources is significant. Primary supply of biomass and hydro are increasing sharply overestimated period. According to the energy mix graph of Austria, the inefficiency of

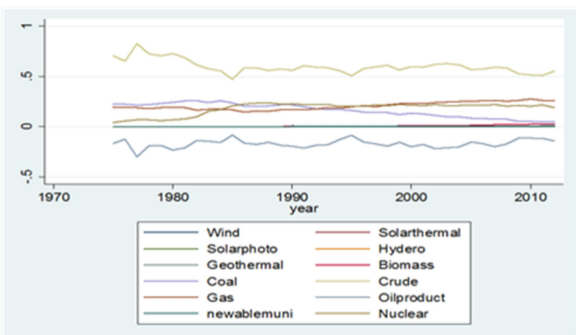
Austria decreased from 1975 to 2011. The energy inefficiency graph in Austria also shows a similar result.

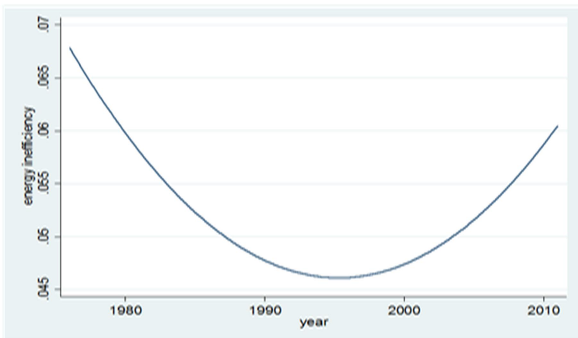




Belgium

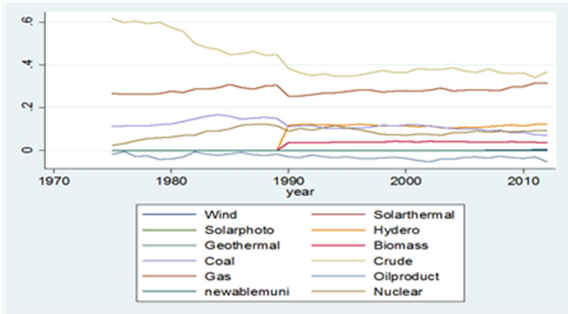
Crude oil is the main source of energy in Belgium. Primary supply of crude oil decreased slightly between 1975 and 1995; then it began to increase. The second main source of energy was coal until 1992 when, natural gas was replaced as the second main source of energy. Coal primary supply remained almost constant until 1992; then it goes down. The amount of primary supply of natural gas stayed at the same level until 1992, from 1992, it is increasing over the rest of the estimated period. In addition, the amount of primary supply of renewable energy resources is negligible. Consequently, the inefficiency graph of Belgium shows the expected result. Belgium’s inefficiency graph reached its lowest amount in 1995, then it increases.

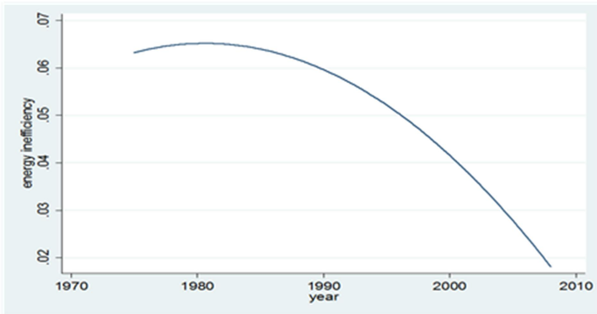




Canada

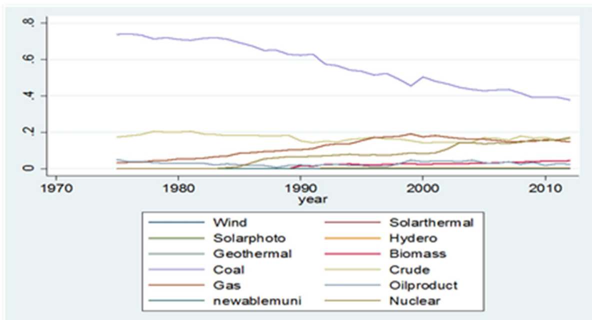
While there is a sharp decline in the amount of primary supply of crude oil until 1990, from 1990, it remains almost constant. The second main source of energy in Canada is natural gas whose amount of primary supply is increasing over the estimated period. As can be seen, from 1975 to 1990 the third main source of energy in Canada was coal, but from 1990 hydro is replaced coal as the third source of energy. Furthermore, the amounts of other renewable energy resources increase sharply over the estimated period. Therefore, the renewable energy resources make up a high proportion of total primary supply of energy in Canada. In sum, the energy inefficiency of Canada is decreasing between 1975 and 2011.

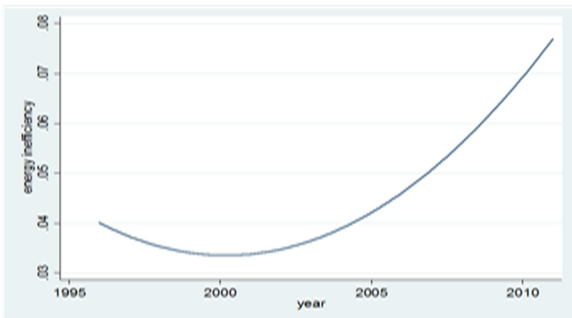




CZ

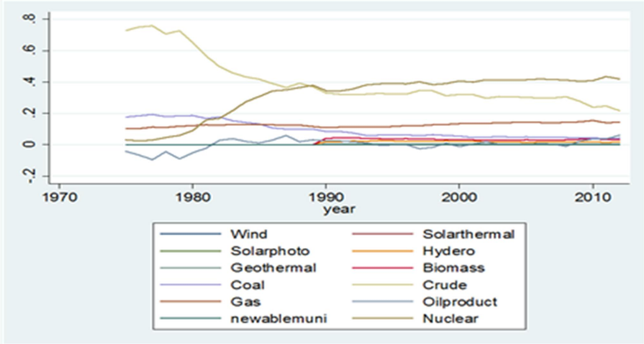
The primary coal supply constitutes a significant proportion of total primary energy supply in CZ which had a sharp decrease from 1975 to 2000. After 2000, coal primary supply stays at the same level. There is a slight decrease in the amount of crude oil until 1992, after 1992, crude oil experiences a slow upward trend. Natural gas primary supply increased from 1975 to 1999; then it decreases slightly. Even though the primary supply of renewable energy resources is increasing over the estimated period, the total amount of them compared to the fossil fuels is significantly low, except biomass. Based on the fuel mix graph description, it can be concluded that CZ's inefficiency met its lowest amount in 2000.

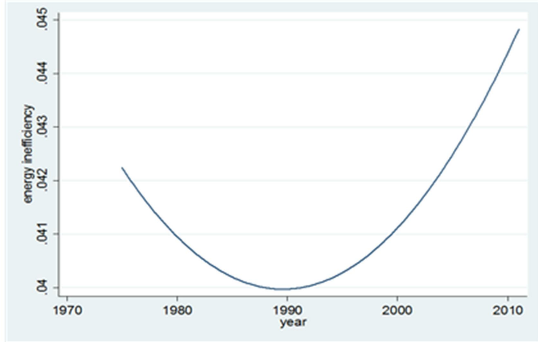




France

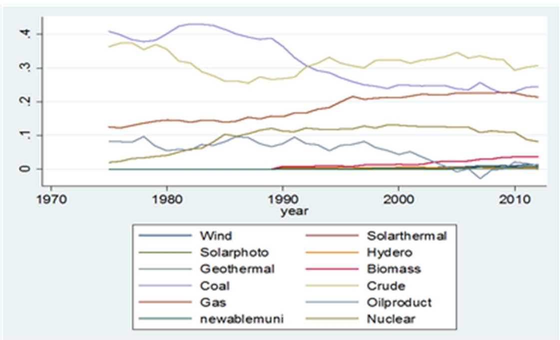
The main source of primary supply in France was crude oil until 1990, and its amount is decreasing, after 1990, nuclear is replaced crude oil, and its amount was increasing. From 1990, the primary supply of crude oil and nuclear remains almost constant. Natural gas is replaced coal after 1985. Primary supply of natural gas is improving over the estimated period. Although, the primary supply of renewable energy resources is increasing over the estimated period, its proportion is significantly low compared to fossil fuels. Thus, the inefficiency graph of France confirms the same result.

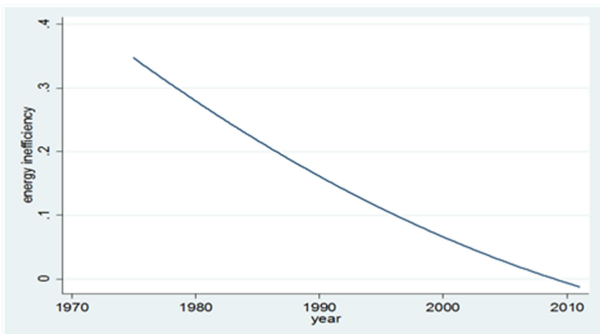




Germany

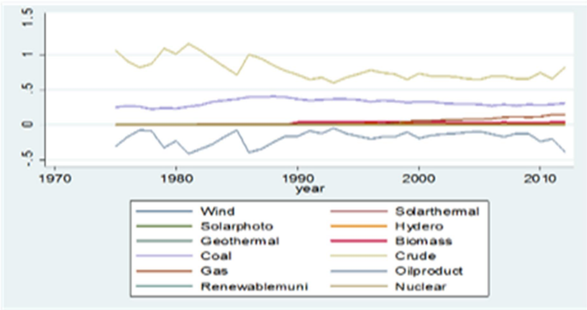
Coal was the main source of energy until 1992, from 1992 crude oil is replaced coal as the main source of energy in Germany. The primary supply of coal was increasing moderately from 1975 to 1992, from 1992; its primary supply has a dramatic decline until 2011. The amount of crude oil dramatically decreased from 1975 to 1990, and then increased until 2004, finally the primary supply of crude oil falls. The amount of primary supply of natural gas is increasing over the estimated period. Oil products primary supply decreases from 1975 to 2011. Primary supply of nuclear was rising until 2008, from 2008 its amount has a slight drop. Furthermore, the amounts of renewable energy resources are increasing. Biomass is the main source of renewable energy resources in Germany. Biomass primary supply is increasing over the estimated period, but before 2004, it increased more rapidly. Overall, according to the energy mix graph, energy inefficiency in Germany decreases from 1975 to 2011.

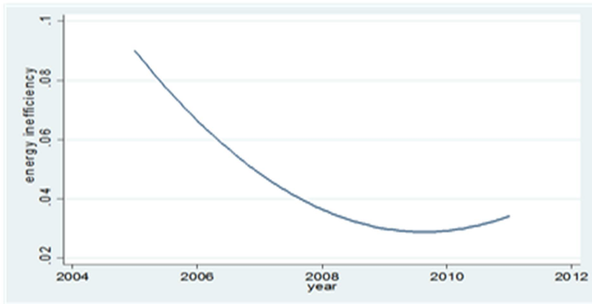




Greece

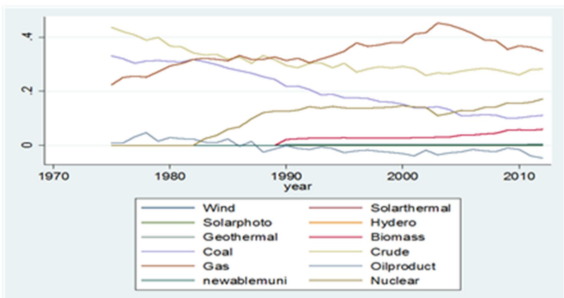
Crude oil is the first source of primary supply in Greece. The amount of primary supply of crude oil decreases slightly from 1975 to 2011. The second source of energy in Greece is coal. Coal primary supply was increasing between 1975 and 1986, and then from 1986, it began to decline. Natural gas primary supply is increasing over the estimated period. Besides, although the amounts of renewable energy resources are negligible, they are increasing over the estimated period. Therefore, the energy inefficiency in Greece is going down over the estimated period.

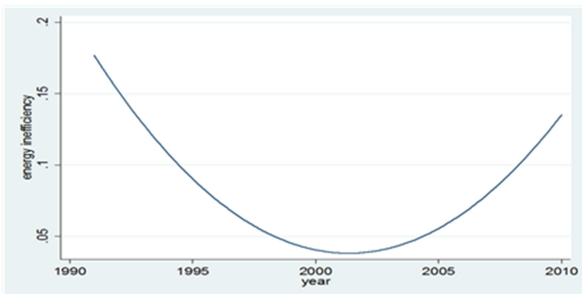




Hungary

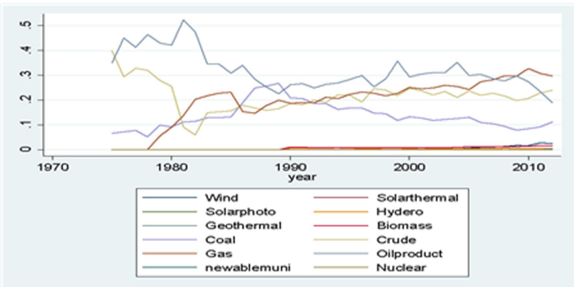
The main source of energy was crude oil until 1986; from 1986 natural gas replaced it as the main source of energy. Crude oil primary supply decreased considerably until 2002, and then it increases slightly. Primary supply of natural gas increases sharply over the estimated period. Coal and oil products are other energy resources in Hungary. Coal primary supply dropped dramatically until 2002, and then it stays almost constant. Nuclear is increasing during the selected period of time, and it was replaced coal in 2002. Primary supply of oil products had a moderate decrease until 2002, and then it increases slightly. Moreover, without considering biomass, the renewable energy resources account for a significantly low proportion of total primary energy supply in Hungary, but their amounts are increasing. Biomass primary supply increases moderately over the estimated period. As a result, energy inefficiency in Hungary was decreasing from 1975 to 2002, and then it increases slightly.

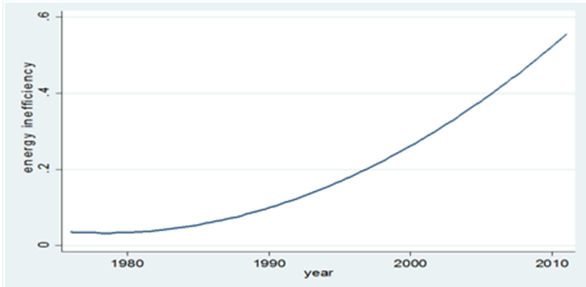




Ireland

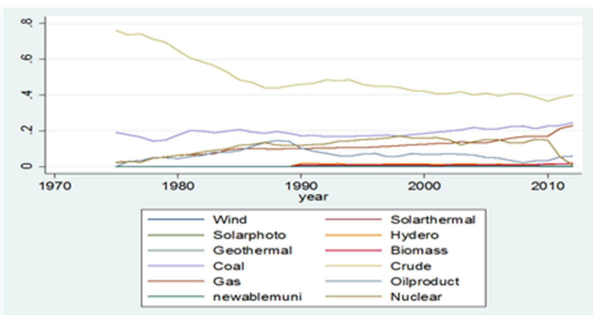
The main source of energy in Ireland is oil products. The primary supply of oil products dropped dramatically until 1989, from 1989, whose amount increases moderately. Crude oil primary supply decreased considerably from 1975 to 1984, from 1984, the primary supply of crude oil rises. Natural gas primary supply grows over the estimated period. Primary supply of coal went up until 1989 and then declines. Nuclear is another source of primary supply in Ireland. Primary supply of nuclear went down sharply between 1975 and 1982, and then it rises. Moreover, the primary supply of all types of renewable energy resources is significantly low over the estimated period. Hydro's primary supply has a slight fall over the estimated period. As a result, energy inefficiency in Ireland reached its lowest point in 1988.

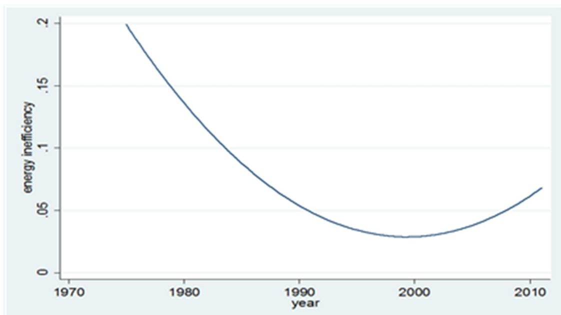




Japan

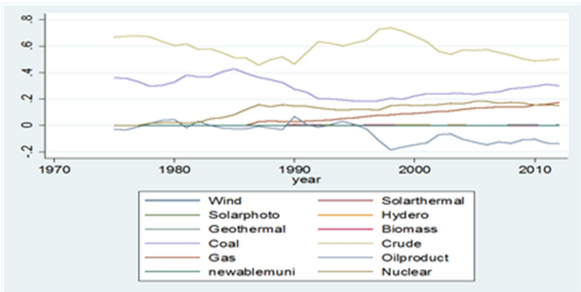
Crude oil is the first main source of energy in Japan which dropped significantly from 1975 to 2000; then it remains almost constant. The second main source of energy is coal. Primary supply of coal decreased until 1994, and then it goes up. Natural gas primary supply is increasing over the estimated period. Primary supply of nuclear was increasing until 2010; in 2010 its amount sharply decreases. Oil product's primary supply falls rapidly from 1975 to 2011. On the other hand, the amounts of renewable energy resources are too low compared to fossil fuels. Therefore, energy inefficiency in Japan is decreasing from 1975 to 1998, and then it increases.

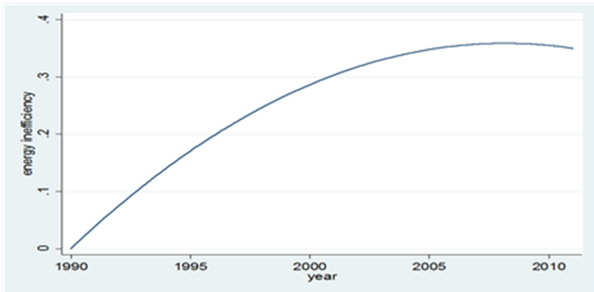




Korea

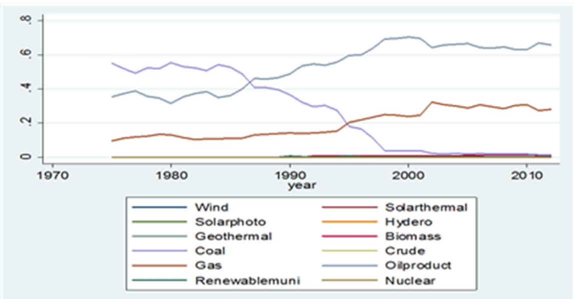
Primary supply of fossil fuels (crude oil, coal, and natural gas) is increasing over the estimated period. However, the amounts of renewable energy resources are significantly low in Korea. Primary supply of nuclear is also increasing. Therefore, energy inefficiency of Korea increases dramatically between 1975 and 2011 which confirms the inefficiency graph of Korea.

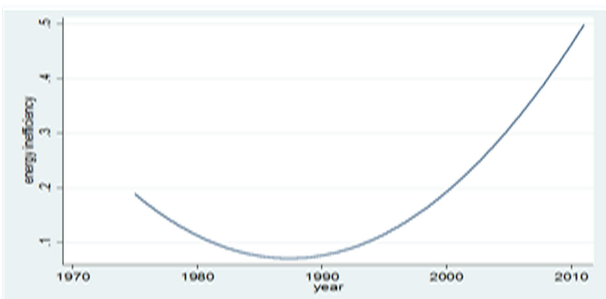




Luxembourg

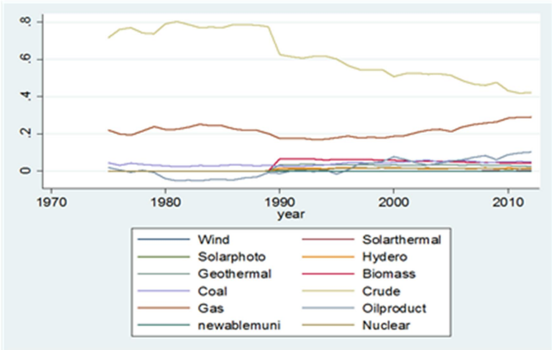
The main source of primary supply in Luxembourg was coal until 1986, after 1986, whose primary supply went down considerably. From 1986, the oil products are the main source of energy which grows sharply. The third main source of primary supply is natural gas which remained constant until 1996, and then it increases dramatically. It should be mentioned that renewable energy resources account for a significantly low proportion of total primary supply of energy resources in Luxembourg. According to the energy mix graph, the energy inefficiency graph is increasing from 1987 to 2011.

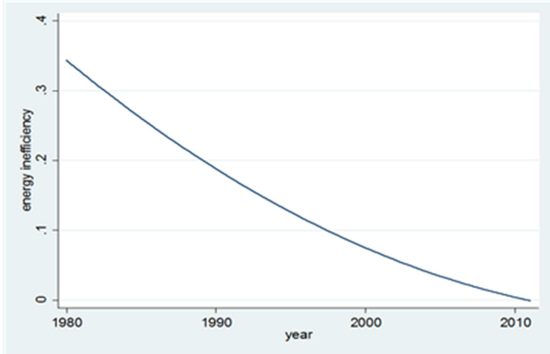




Mexico

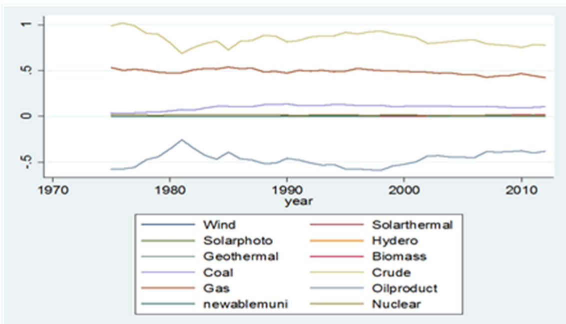
The main source of energy in Mexico is crude oil. Crude oil primary supply has a dramatic fall from 1975 to 2011. Natural gas is the second main source of energy in Mexico. Natural gas had a slight downward trend between 1975 and 2003, from 2003, it increases slightly. Besides, the primary supply of renewable energy is significantly high. The amount of all renewable energy resources increases over the estimated period; except biomass. Hence, the energy inefficiency of Mexico decreases over the estimated period.

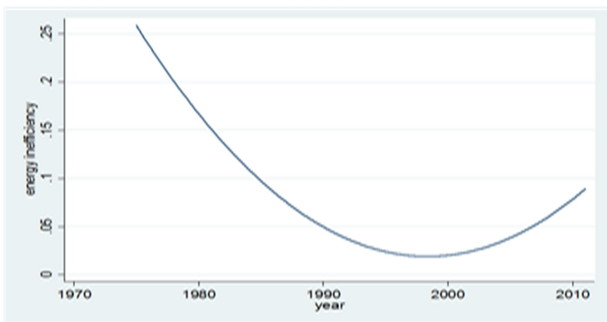




Netherlands

Crude oil is the main source of energy in the Netherlands. Crude oil primary supply decreases slightly from 1975 to 2011. Natural gas and coal are the second and third source of energy in Netherland respectively. Their amounts of primary supply remain almost stable over the estimated period. Oil products are the other source of energy in the Netherlands. Primary supply of oil products was decreasing between 1975 and 1997, and then from 1997, it increases. Furthermore, the amount of primary supply of renewable energy resources is negligible. As a result, the energy inefficiency of the Netherlands decreased from 1975 to 1997, and then it increases slightly.

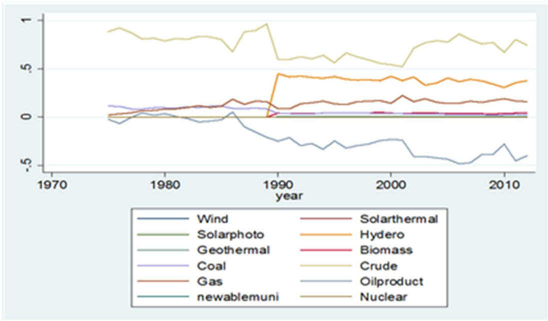


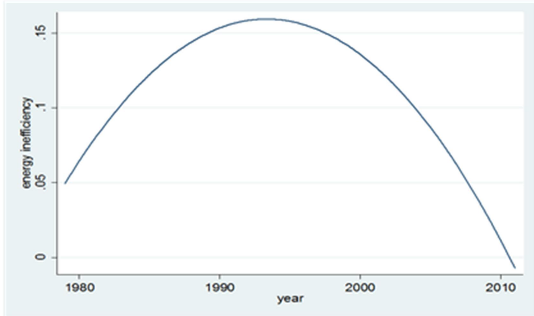


Norway

The main source of energy in Norway is crude oil. Primary supply of crude oil decreased sharply from 1975 to 1996. From 1996, it increases. Natural gas primary supply is increasing gradually over the estimated period. The amount of primary supply of coal decreases between 1975 and 2011. Moreover, the primary supply of renewable energy resources is increasing from 1990 to 2011, especially hydro. The primary supply of hydro is significantly high in

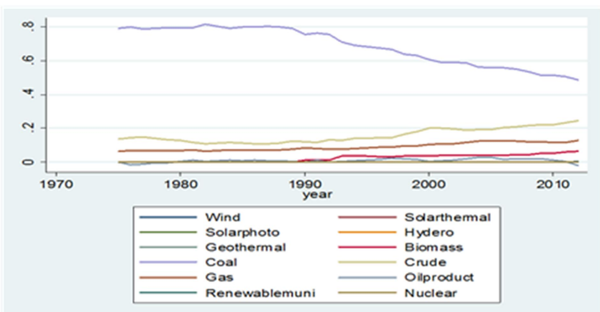
Norway so that it replaced natural gas as the second main source of energy from 1990. In sum, energy inefficiency in Norway reached its highest point in 1994.

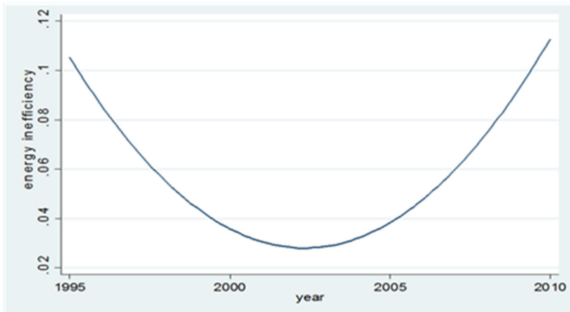




Poland

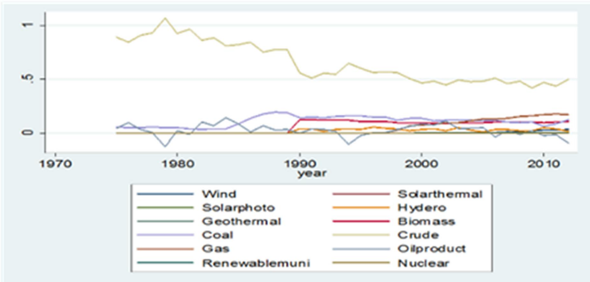
The main source of primary supply is coal in Poland. Primary supply of coal had a considerable decline from 1975 to 2002, after 2002, it decreases, but with a slow slope. The second source of primary energy supply is crude oil. The amount of primary supply of crude oil remained almost constant from 1975 to 1996, and then it increases. The other source of energy is natural gas in Poland. The primary supply of natural gas is increasing over the estimated period. On the other hand, the primary supply of renewable energy resources is significantly low compared to fossil fuels, except biomass. Biomass primary supply remains almost constant over the estimated period. Hence, the energy inefficiency in Poland decreases from 1975 to 2002; then it increases (it can be seen from the energy inefficiency graph).

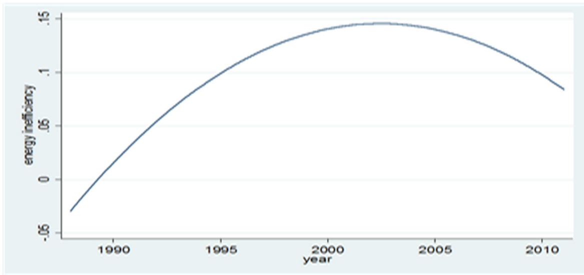




Portugal

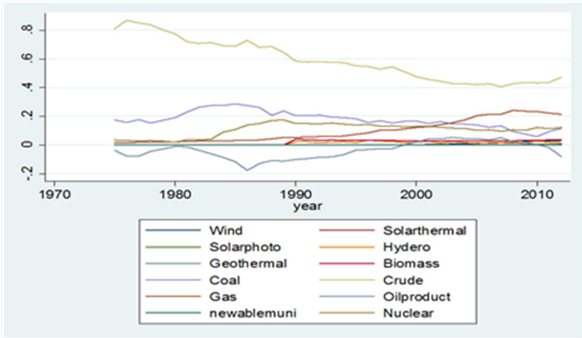
The main source of energy in Portugal is crude oil. Primary supply of crude oil decreased slightly until 2002, after 2002, it increases moderately. Coal is the second main source of energy in Portugal. Although the primary supply of coal is falling over the estimated period, its slope of decline is different. After 2002, it decreases with the deeper slope. The other source of fossil fuel is oil products in Portugal. The primary supply of oil products increased until 2002; then it began to decrease. Furthermore, the amount of primary supply of renewable energy resources is significant. Biomass is the main source of renewable energy in Portugal. Primary supply of biomass was decreasing from 1990 to 2002, and then it increases slightly. Hydro is the other source of renewable energy which is consumed significantly. The primary supply of hydro remains almost constant over the estimated period. In sum, the energy inefficiency of Portugal reached its highest point at 2002.

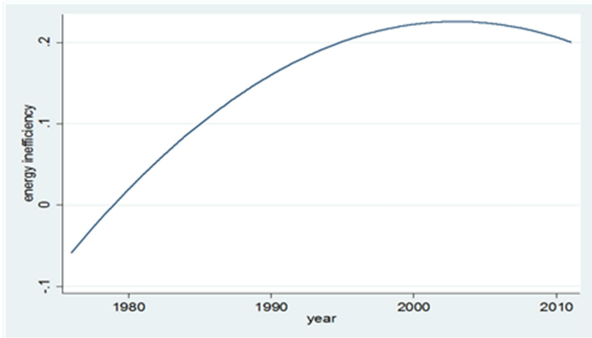




Spain

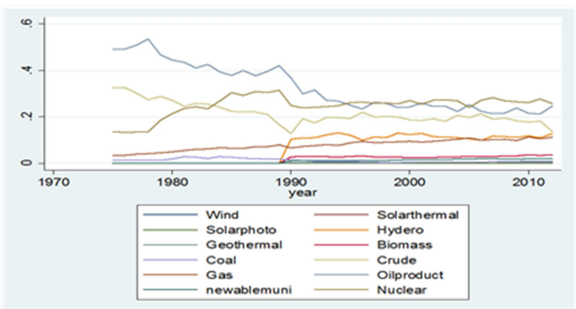
Crude oil is the main source of primary energy supply in Spain over the estimated period. Primary supply of crude oil goes down rapidly between 1975 and 2011. The second source of primary supply was coal until 2003. Primary supply of coal increased slightly between 1975 and 1990, and then it began to decrease. The other source of primary energy supply is natural gas. Natural gas had a dramatic growth from 1975 to 2003, and then it stays almost at the same level. Oil products is another primary resource in Spain. Nuclear primary supply increased from 1975 to 2000, and then its amount stays constant. The primary supply of oil products increased until 2003, and then it decreases. Moreover, the amounts of primary supply of renewable energy resources are not high compared to fossil fuels in Spain. Biomass has the highest amount of primary supply among renewable energy resources. Primary supply of biomass decreased slightly from 1990 to 2003, and then it increases. Wind is the other main source of renewable energy resources in Spain. Primary supply of wind is increasing over the estimated period, but after 2003, it increases more rapidly. Thus, it can be concluded that energy inefficiency of Spain increased with the slow slope until 2004, and then it began to decrease slightly.

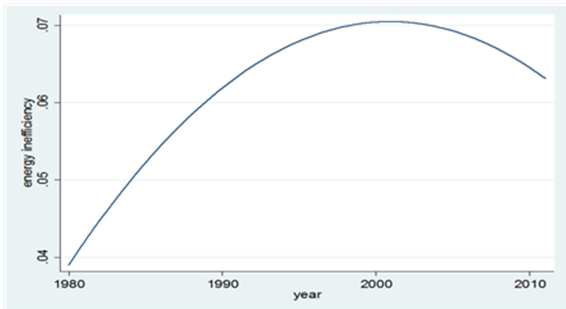




Switzerland

Oil products and crude oil are first and second main energy resources in Switzerland respectively. Oil products primary supply had a dramatic drop from 1975 to 1990, and then it remains constant. On the other hand, crude oil primary supply decreased until 1990, and then it increases slightly. Primary supply of nuclear was rising until 1990, and then it remains stable. Natural gas primary supply is increasing over the estimated period. Moreover, the primary supply of renewable energy resources is significantly high; especially hydro. Based on the energy mix graph, the energy inefficiency graph of Switzerland is describable. Energy inefficiency of Switzerland increased with the slow slope until 2000, and then it began to decrease.

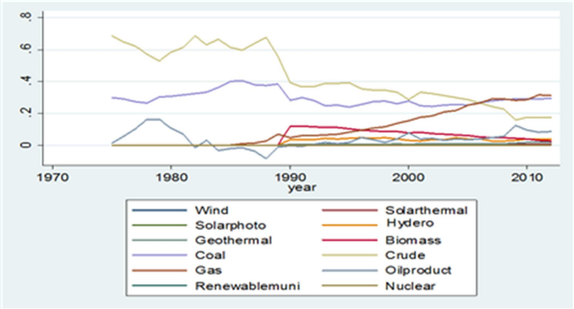


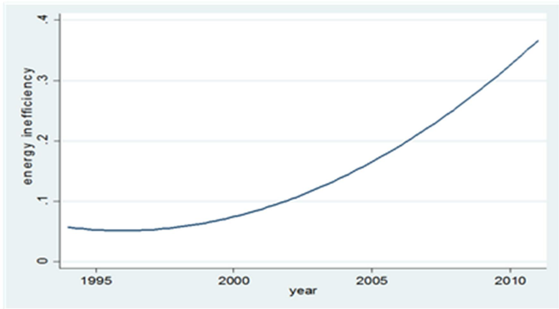


Turkey

Crude oil primary supply has a dramatic fall from 1975 to 1995; then its decline is continued with the slow slope. Coal primary supply reaches its highest point in 1986, from 1986, the primary supply of coal is decreasing, but from 1998, its decline is with the slower slope. Natural gas is increasing sharply over the estimated period. Although the primary supply of biomass and hydro are significant, their amount is decreasing over the estimated period.

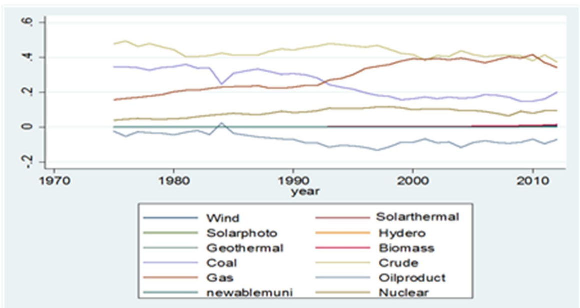
Consequently, the energy inefficiency of Turkey is increasing from 1995 according to the energy mix graph.

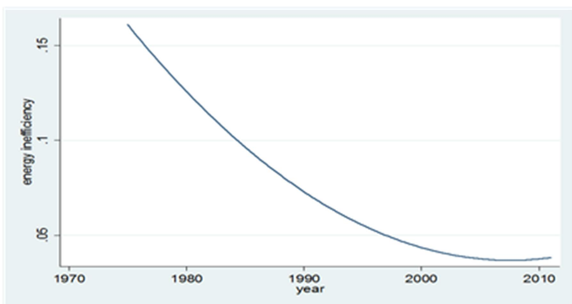




United Kingdom

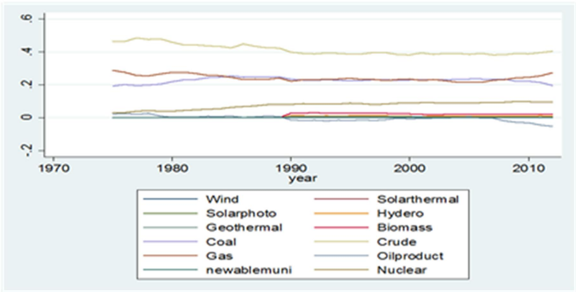
Crude oil accounts for the main source of total primary energy supply over the estimated period for the United Kingdom. The amount of primary energy supply of crude oil decreases slightly. The second main source of energy was coal until 1994, due to the dramatic decline, from 1994 natural gas is replaced as the second source of energy in the United Kingdom. Natural gas primary supply goes up considerably between 1975 and 2011. Oil products primary supply is decreasing over the estimated period. Furthermore, the primary supply of renewable energy resources is significantly low compared to fossil fuels. Nuclear primary supply is increasing slightly. On the other hand, these low amount of renewable energy resources are increasing; while, the primary supply of fossil fuels is decreasing over the estimated period. As a result, energy inefficiency in the United Kingdom is decreasing.

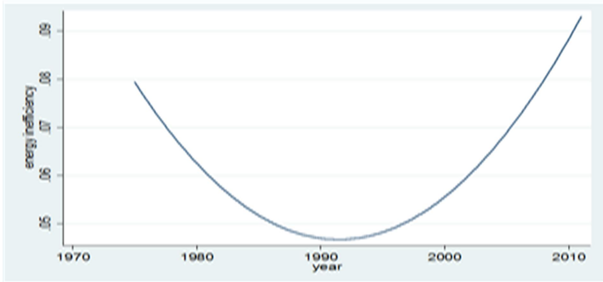




United States

With paying attention to the energy mix graph, it can be seen that before 1991 primary energy supply of crude oil and natural gas were decreasing slightly, but from 1991 they are increasing gradually over the estimated period. Moreover, the amount of coal primary supply increased moderately before 1991, after 1991, it decreases slightly. Primary supply of nuclear is rising. On the other hand, the primary supply of renewable energy resources is significantly low. Also, their amounts are decreasing over the estimated period. Thus, the energy inefficiency of the United States reached its lowest point at 1991.





III. Chapter 3:

The impact of renewables on productive efficient consumption of energy in the end-uses sector; a residential sector of Australia and New Zealand has chosen as the case study:

Energy inefficiency in selected OECD countries was estimated in the last chapter. In this chapter, we will demonstrate the effect of energy mix on residential energy use. Energy inefficiency will be estimated using SFA. This chapter is organized as follows. Section 1 introduces energy consumption in the residential sector. Section 2 reviews the literature on energy consumption in the residential sector and identifies the research gap. Section 3 explains the methodology. Section 4 describes the data and empirical model. Section 5 presents the results, and finally, the summary and conclusions are provided in Section 6.

Introduction

Residential energy consumption accounted for 23% and 35% of global total final energy consumption in 2011and 2014 in OECD countries, respectively (Indicators 2014). Residential energy consumption includes all energy used in private households and apartments, such as energy used for space and water heating, cooling, lighting, cooking and the use of appliances. Personal transport is not included in estimates of residential energy consumption.

Global residential energy consumption has been increasing since 1990 because the percentage of people, with access to electricity has increased dramatically (Roser 2019). Global residential carbon dioxide (CO_2) emissions per capita were 0.71 tonnes in 1995 and increased by 4% in 2011. Therefore, researchers have realized that carbon emission from residential energy consumption might be a new growth source of carbon emissions (Weber and Perrels (2000); Bin and Dowlatabadi (2005); Druckman and Jackson (2009)). The amount of carbon emissions associated with residential use more than tripled from 1950 to 2009 ((EIA) 2011). Emissions per capita in non-OECD countries were four times higher than in OECD countries in 2011. This difference can be attributed to the lower carbon intensity energy mix of OECD countries, due to a higher share of renewable energy resources.

The residential sector in Australia is the second largest user of energy, and this sector is responsible for around seven tonnes of GHG emissions each year (Strategies, Harrington et al. 2008). Emissions from residential energy consumption in Australia account for about one-fifth of Australian emissions. Since 1990, Australian energy consumption has remained relatively stable. Also, the expectation is that it will decline in the residential sector by 6% by 2020. The main energy end use in the residential sector of Australia are heating and cooling appliances. Most Australian total energy is sourced from fossil fuels. The main source of energy in the residential sector of Australia is electricity. The contribution of electricity to total residential energy consumption in Australia is expected to increase until 2020. Australian electricity is mainly generated from fossil fuels (86%). The second main source of energy used in the Australian residential sector is natural gas (Strategies, Harrington et al. 2008). While the percentage of renewable energy resources in the Australian residential energy consumption increased between 2010 and 2012, the share of those resources is not significant (Statistics 2014).

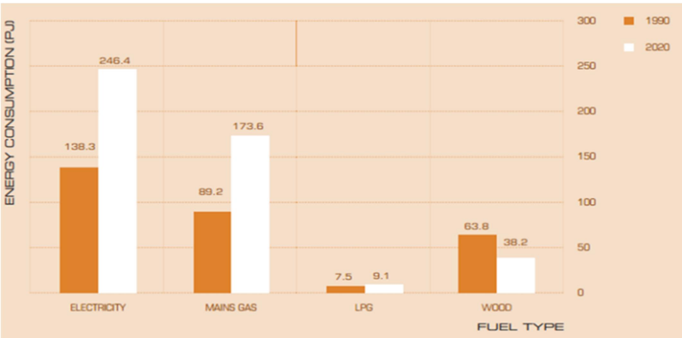


Figure 7: Australia Residential Energy End-Use

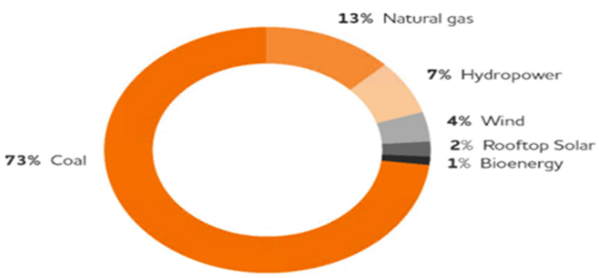


Figure 8: Electricity generation Australia

The New Zealand Emissions Trading Scheme (ETS), introduced in 1990, is aimed at decreasing emissions while maintaining economic productivity (Environment 2015). Thirteen percent of total energy consumption in New Zealand is attributable to the residential sector (Energy 2017). The main source of energy for residents is electricity: 69% of total residential energy consumption. BRANZ reports that electricity consumption in the residential sector grew dramatically from 1945 (Isaacs, Camilleri et al. 2006). Around 80% of New Zealand's electricity is generated from renewable energy resources such as hydro, geothermal and wind.

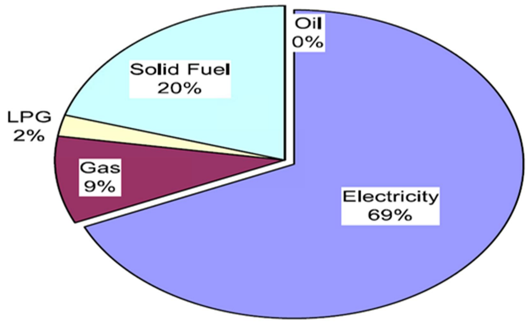


Figure 9: New Zealand Residential Energy End-Use

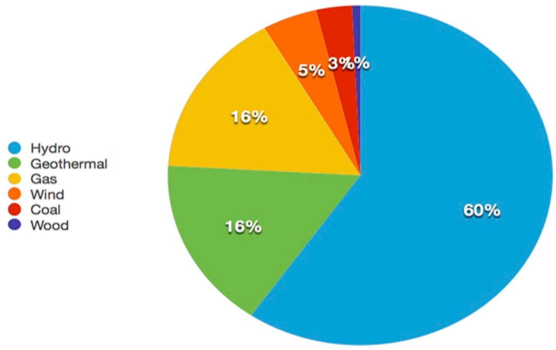
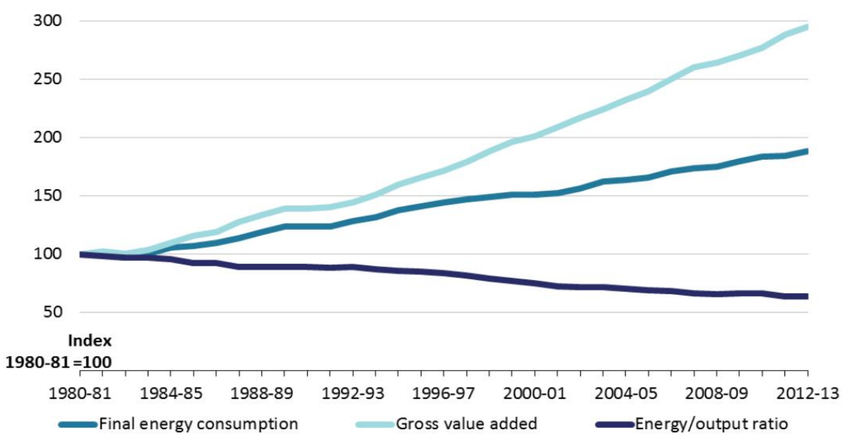
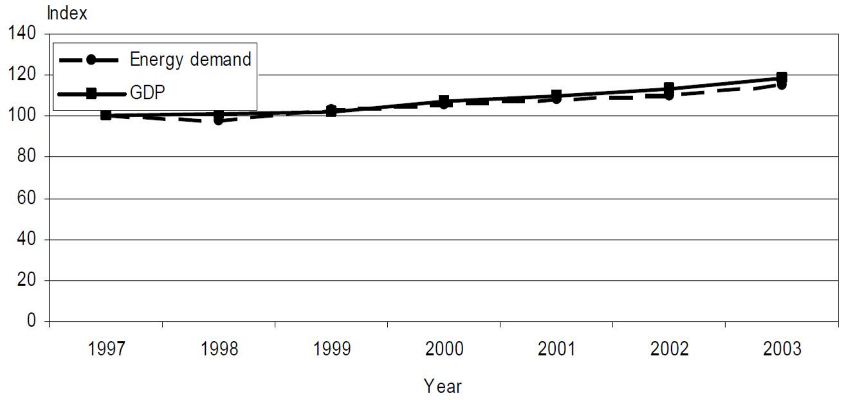


Figure 10: Electricity generation New Zealand

It is insightful to compare economic growth and energy use in Australia and New Zealand. Since the mid-1980s, the Australian economy is consuming energy at a lesser rate than its economic growth (Stanwix, Pham et al. 2015). However, economic growth and energy consumption growth in New Zealand move together (Brown-Santirso and Thornly 2006). One of the highest energy users in both countries is households.



Graph 11: Australia energy consumption and gross value added[19]



Graph 12: NZ energy consumption and GDP

In the first essay, we demonstrated the effect of the energy mix on the efficient consumption of primary energy resources. Countries that consume more renewable energy resources as their source of primary energy are more energy-efficient. Moreover, renewable energy resources have lower emissions. This essay focuses on the residential sector. As Australia and New Zealand are completely different in terms of energy use in their residential sectors, this essay estimates the efficient consumption of energy in the residential sector, controlling for types of energy resources.

Literature review

There are many studies that estimate residential energy consumption. The effective factors for residential energy consumption can generally be categorized as contextual and behavioral. Contextual factors; such as climate conditions, building attributes, energy system and appliances of the building, technical progress, location of buildings, and energy prices (Estiri 2016). Behavioral factors include household characteristics namely; household income, size, ethnicity, and education level.

Nesbakken (1999) demonstrated the relationship between energy price and residential energy consumption in Norway. Energy price is inelastic, and also it is negatively correlated with residential energy consumption. Results show that the energy price elasticity in Norway is -0.24, -0.57, -0.33, and -0.53 in the years 1990, 1993, 1994, and 1995; respectively. Moreover, he estimated the income elasticies for those four years in both long-run and short-run. Income is also inelastice, but it is positively correlated with energy consumption in Norway. The

[19] Gross Value Added (GVA) + taxes on products - subsidies on products = GDP

elasticity of income in short-run is 0.04, 0.01, 0.01, and 0.01 in years 1990, 1993, 1994, and 1995; respectively. The long-run elasticity of income in long-term is 0.21, 0.28, 0.21, and 0.15 in years 1990, 1993, 1994, and 1995; respectively. He noted that differences in the price and income elasticities from year to year are because the energy demand model of his study was linear. Accordingly, the elasticities are not constant. Increasing the residential building's size is associated with higher residential energy consumption (Kaza (2010); Kelly (2011)). Single-family residences or separate houses consume more energy than multifamily buildings (Baxter, Feldman et al. 1986). In addition; newer homes tend to utilize energy less than older ones (Brounen, Kok et al. 2012). Although some studies Brandon and Lewis (1999) showed that increases in household income have a positive effect on the energy consumption of households. Others believe that the impact of income on households energy consumption is complex due to the influence of household income on housing characteristics (Kelly 2011). Kelly (2011), illustrated that the complex effect of income on energy consumption is due to reciprocal causality between dwelling energy efficiency and dwelling energy consumption. Households with high income utilize technology for efficient consumption of energy (indirect effect of income on energy consumption). However, they tend to have a larger floor area; hence, they need more energy for heating (direct effect of income on energy consumption). Yin, Zhou et al. (2016), investigated the future Residential Electricity Consumption (REC) trend and their effective factors for China using the REC model between 2005 and 2010. They estimated the price and income elasticities for the short- and long-term in both rural and urban areas of China. Then, they compared their results with previous studies in other countries. They concluded that the price elasticity of electricity is an effective factor with the negative sign on REC in both rural and urban areas. The short-term price elasticity is -0.4, and -0.6 for urban, and rural areas; respectively. Moreover, the long-term price elasticity is -1.2, and -1.5 for urban and rural areas; respectively. The effect of income elasticity was insignificant in a rural area of China, but it is significant (although small) in the urban area. The relationship between electricity consumption and income is demonstrated as the inverted 'U' pattern. It means that income has a positive effect on electricity demand; however, its impact is decreasing as the income rises. Yin, Zhou et al. (2016), compared their results with previous studies and found that people who are living in China are more sensitive to price change than people in other countries, especially in rural area. However, income elasticity in China is smaller than in other countries.

Table 5: The most effective factors in residential energy consumption

Factor	Effect	Source
Housing size	Increasing housing size, more energy consumption	Brounen, Kok et al. (2012) Ewing and Rong (2008) Kaza (2010) Kelly (2011) Shimoda, Asahi et al. (2007)
Housing type	Detached dwellings, more energy consumption	Aydinalp, Ugursal et al. (2003) Aydinalp, Ugursal et al. (2002) Baxter, Feldman et al. (1986)et Ewing and Rong (2008) Santin, Itard et al. (2009) Santamouris, Kapsis et al. (2007)
Housing age	Older homes, more energy consumption	Ewing and Rong (2008) Santin, Itard et al. (2009) Hirst, Goeltz et al. (1982)
Household size	Increasing household size, more energy consumption	Aydinalp, Ugursal et al. (2002) Druckman and Jackson (2009) Kelly (2011)
Income	Complex	Steemers and Yun (2009) Van Raaij and Verhallen (1983)
Education	Less education, more energy consumption	Estiri (2016)

The relationship between contextual factors and residential energy consumption has been investigated in several studies. Biying, Zhang et al. (2012) estimated the correlation between residential location choice and energy consumption behavior in 775 households in Beijing in 2010. Household energy consumption is defined as total energy consumption which is used directly within the household and for personal transport. Behavioral mechanisms are defined as the effect of residential environment characteristics on household energy consumption. First, households locate themselves in neighborhoods; then their energy consumption is based on neighborhood characteristics. Using Mixed MNL–MDCEV (Multiple Discrete-Continuous Extreme Value) models Biying, Zhang et al. (2012) found that there is a correlation between residential location choice and the household's energy consumption. According to this correlation, accessibility to the subway/ bus station has a negative impact on the energy consumption of the household. Thus, land-use policies can influence residential energy consumption patterns. Based on the land-use policy, developing residential facilities and public transport in a neighborhood can effectively increase a household's energy-saving behavior. Estiri (2016) illustrated the possible difference between energy consumption of city-dwellers and suburban households for 12,083 households of US in 2009; 5313 of those households were located in cities. The rest of the households were located in suburban areas. Comparing energy consumption between suburban and city households shows that city dwellers consume 23.7% energy in their home less than suburbanites. Furthermore, he concludes suburbanites use 11% more household per capita energy use[20] than city dwellers. However, city dwellers are living in houses that have 22% higher energy intensity.

Farahbakhsh, Ugursal et al. (1998) examined the characteristics of the Canadian housing stock to determine the effect of energy efficiency technology on the residential energy demand, using the Canadian Residential Energy End-use Model (CREEM). In this essay, residential dwellings were divided into the five major types: single-detached, single-attached, apartments (less than five stories), high rise apartments and mobile homes. In the end, they emphasized that the main contributor to residential energy consumption in all five major types was space heating, so upgrading thermal technology and improving heating system efficiency could greatly decrease residential energy consumption. Upgrading Canadian houses is an effective factor in residential energy savings.

Rushdi (1986) utilized a translog cost function to estimate the own- and cross-price elasticities among different types of energy resources in South Australia from 1960 to 1982. The non-unitary elasticity and unitary elasticity of substitution assumptions between any two different energy resources were estimated in this study. He concluded that, on average, 70% of the expenditure of South Australian households was on electricity, 20% on gas and 10% on oil. He mentioned that expenditure on other energy resources, such as solar and wood, had not been into the account. He found the own-price elasticity of energy resources was large and significant. The own-price elasticity of electricity, gas, and oil are -0.68, -1.53, and -1.05; respectively. Furthermore; he claimed that gas and oil are not substituted for energy resources, and found that electricity was a substitute energy resource for both gas and oil. Hu, Yan et al. (2016) illustrated the amount of energy consumption related to space heating in the urban residential areas of China. According to the Building Energy Research Centre of Tsinghua University (BERC) (BERC, 2015) building energy consumption in China is comprised of four subsectors; namely, heating energy use in northern China, public and commercial building energy use, rural residential energy use, and urban residential building energy use. Energy consumption of Hot Summer and Cold Winter zones (HSCW) of urban residential building areas of China is significantly increased. Therefore, they utilized the bottom up model to estimate space heating energy consumption in the HSCW. They said that the total primary energy consumption in HSCW of China was 13.4 million tonne of coal equivalent (tce) in 2013 which is included 32 billion kwh of electricity, and 0.27 million m^3

[20] energy use divided by household size

of natural gas. This energy consumption is still increasing. They concluded that the high energy consumption of the HSCW area is due to the age of building in this area. The old residential buildings consume more than 70% of total energy. Gram-Hanssen (2011), and Ruderman, Levine et al. (1987) examined the effect of different residential appliances on energy consumption. Gram-Hanssen (2011) demonstrated whether or not the energy efficiency of appliances and houses are more important than user practices for reducing a households' energy consumption. He chose Denmark from 1980 to 2004 for his case study. The bottom-up model was utilised as the methodology. The residential energy consumption was modelled on the type of building, size and year of building, a number of members of the household, income level of household, age and education level of inhabitants. He found that heating energy consumption was more related to the energy efficiency of the building, such as building size and year of construction. Therefore, small and new buildings consume less energy for the heating purpose. However, electricity consumption for lighting and appliances depends more upon users' practices, such as the number and size of appliances. He concluded that users' practices are as important as efficiency of technology for the purposes of reducing a household's energy consumption. Ruderman, Levine et al. (1987) analysed the quantitative behaviour of the market to improve the energy efficiency in residential appliances such as heating and cooling equipment. They believed that the quantitative evaluation of market decisions about energy efficiency is one of the important factors to forecast the residential energy consumption. The market behaviour is characterized by two quantities; the market discount rate and the payback period. They conclude that the payback periods of investing in improving household appliances' energy efficiency have more effect on energy efficiency than the discount rate.

Different ethnicities vary in their consumption of energy. However, no research has investigated the effect of different ethnicities on energy consumption (Ewing and Rong 2008). Higher education decreases in residential energy consumption directly (Estiri 2016).

Even though previous studies estimated residential energy consumption with a wide range of variables, they neither consider the effect of different types of energy on residential energy consumption.

Ministry of Business (2011), indicated that some types of energy provide the same level of output, with more highly efficient use in applications. This report confirmed that there is a relationship between energy types and energy consumption in transport, business, and residential sectors in New Zealand. Stern (2004) presented that shifting in energy use from the use of fossil fuels to the utilizing the higher quality energy has an effect of the level of economic activities. Series (1995) informed that one of the effective factors on residential energy consumption is different energy resources. Energy ladder model assumes households to improve their energy use corresponding rise in their income. The energy resources on the energy ladder are in order according to the cleanliness, ease of use, cooking speed, and quality (van der Kroon, Brouwer et al. 2013).

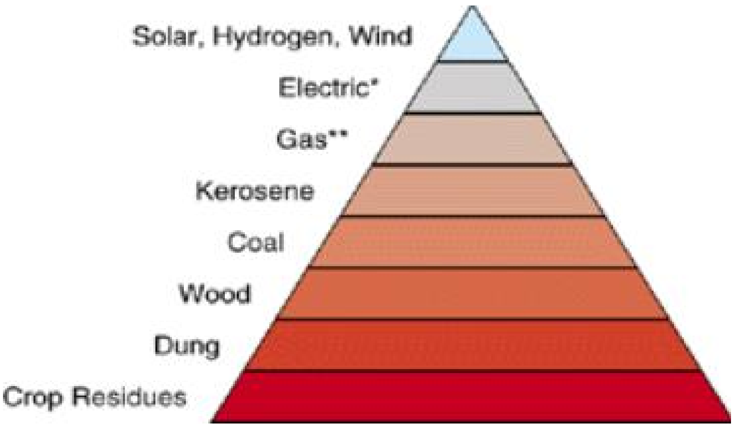


Figure 11: Energy ladder

Furthermore, there is extensive literature on residential energy efficiency. The research to date has been concerned more about energy efficiency improvements in the building (technology improvements) than with considering the contextual and behavioral factors. Schranck (2013) presented residential energy efficiency in Washington, relating to the Home Automation System (HAS) in the US. He was concerned about residential energy efficiency in home automation technology rather than on reducing in residential energy consumption. He found that residential energy use in the US accounted for 54% of total building energy consumption. Therefore, associating HAS with building management systems, and building automation and control networks can help to improve residential energy efficiency. Suter and Shammin (2013) demonstrated a small-scale of experimental design to estimate the return of three types of energy efficiency treatments from autumn, 2006 to spring, and 2011 in residential energy consumption of US. They utilized three different data resources in this essay: 1. Monthly billing records of natural gas consumption of each home; 2. temperature and humidity records of homes, and 3. Monthly billing records of electricity consumption for each home. The three experimental treatments used were the programmable thermostat, attic insulation, and provision of financial incentives. They estimated natural gas to be the main source of residential energy consumption in the US. The results show that programmable thermostats by themselves do not reduce energy consumption significantly, but after pairing that with financial incentives, the largest reduction happens. Also, financial incentives cause households to decrease their indoor temperatures by 4.3 degrees. Haas and Schipper (1998) estimated the households' energy demand for OECD countries between 1972 and 1992, to show whether or not irreversible improvements in technology are a major reason for the mild growth in the households' energy demand after the drop in oil prices in 1985. The residential energy consumption is estimated according to the price of energy, income, heating degree days and energy intensity. They utilized price and income elasticity to obtain the following conclusions. Firstly, when the price of energy is rising, the price elasticity is different from when the price of energy is falling. Secondly, the main effective parameter for forecasting and describing the demand of energy is technical efficiency. Thirdly, when indicators of technical efficiency are included in estimating energy demands, the income elasticity is higher. The authors mentioned that energy intensity meant technical efficiency.

To the best of my knowledge, this study is the first study that includes residential demand of energy resources and energy efficiency with considering different energy resources. The objective of this study is to estimate the effect of different energy resources on efficient energy consumption in the residential sector.

Methodological framework

Series (1995) suggests four different energy intensity measures applicable as indicators for energy intensity; million Btus[21] per household, million Btus per building, thousand BTUs per square foot, and million Btus per household member. These indicators measure energy intensity based on the ratio of energy consumption to the household, building, and floorspace. Residential energy demand is affected by behavioral and structural changes. Main behavioral changes are family size, income, and thermostat setting. Structural changes include building age, location, and energy mix. Although behavioral and structural changes affect all four residential energy intensity indicators, changes affect some indicators more than others. Furthermore, none of the residential energy intensity indicators does not reflex the effect of different climate change. Therefore, the report claims that the energy intensity indicators are imperfect for the residential sector. Since, the choice of indicator for energy efficiency in the

[21] British Thermal Unit

residential sector depends on the questions asked, data, and energy resources availability (Series 1995).

In order to overcome these problems, some approaches have been proposed; such as Frontier Analysis (FA), and Index Decomposition Analysis (IDA). IDA is a bottom-up framework which is used to create energy efficiency indicators ((Boyd and Roop 2004), and (Zhou and Ang 2008)). Based on parametric (SFA)[22] and non-parametric (DEA)[23] estimation of the energy used; the level of energy efficiency is calculated as the difference between optimal energy use and actual energy one.

Subbiah, Pal et al. (2017) demonstrated that residential energy demand is derived from both active and passive energy usage.

Equation 12: $E_{total} = E_{active} + E_{passive}$ $E =$ *residential energy consumption*

Active residential energy consumption means energy consumed by appliances; such as washer, dryer, vacuum cleaner, TV, and microwave.

Passive residential energy consumption refers to energy consumption that is housing unit specific; such as wall area, floor area, and heating fuel types.

DEA and SFA methods were introduced in the late 1970s to estimate the efficiency of organizational units. Units utilize the same set of inputs to produce the same set of outputs; such as branches of banks, and schools. Thus, for a given amount of inputs in units, there are maximum values of output. Maximum output values are measured with the production frontier (Read 1998).

Therefore, it is possible to use the basic framework of household production theory to estimate the efficiency of household energy demand. Based on this theory; households (organizational units) purchase "goods" on the market which serve as inputs that are used to produce the "commodities" (outputs) which appear in the household's utility function. Therefore, the aggregate residential energy demand is an input demand function ((Deaton and Muellbauer 1980), and (Filippini and Hunt 2012)).

Although, both SF and DEA methods have been utilized as an efficiency measurement method for several years, they rely on different assumptions. DEA does not have any random noise, and inefficiency distribution terms; also, there is no production function form in DEA.

[22] Stochastic Frontier Analysis
[23] Data Envelopment Analysis

Since SF method imposes behavioral changes on the production function form, and the distributional changes in the error term (Read 1998); the SF method is chosen to estimate the residential energy efficiency in this essay.

Efficient consumption of energy in this essay is measured by the difference between the optimal (productive-efficient) consumption of energy and actual energy consumption in the residential sector. Accordingly, we test the hypothesis - whether different energy resources have an impact on residential energy demand efficiently - on the assumption that households want to minimize their use of input (energy) with respect to any given level of output (energy services). Therefore, the difference between the actual amount of input (households used) and cost-minimizing input (optimal amount) represents the inefficient consumption of input. The stochastic frontier model is denoted as follows:

Equation 13:

$$y_{i,t} = f(X_{i,t};\beta).\exp\{v_{i,t} - u_{i,t}\} \quad i=1,...,N \quad t=1,...,T$$

Where: $y_{i,t}$ is aggregate residential energy demand for country i in year t, $X_{i,t}$ is $1\times$ K vector of explanatory variables which are associated with residential energy consumption of countries, and β represents a K × 1 vector of unknown parameters to be estimated. The error term has two components. The first component $v_{i,t}$ is stochastic and is assumed to have an independent and identical normal distribution with zero mean and constant variance, i.e., iid~ N (0, δ_v^2). The second component $u_{i,t}$ is not stochastic and is assumed to be a one-sided normal distribution with the non-negative random variables, which represent technical inefficiency, i.e., $u_{i,t}$~ $N^+(0,\delta_u^2)$.

Since the time-invariant nature of inefficiency term is questionable; also, the panel data which is used is not large, Battese and Coelli (1992) (BC92) and Battese and Coelli (1995) (BC95) models of Stochastic Frontier Analysis (SFA) are used in this research (Federico Belotti, Silvio Daidone (SFA using STATA) 2012).

In both BC92 and BC95 models, inefficiency term is a function of time:

Equation 14: $u_{it} = u_i(exp(-\eta\ (t-T)))$ $i= 1,2,...., N$ $t=1,2,...., T$

u_{it}, is assumed to be a iid nonnegative truncated normal distribution (u_i~ iid N^+ (μ , σ_u^2)). η is unknown parameters to be estimated. BC95 adopts the two-stage approach: the first stage estimates the time-varies stochastic frontier function; the second stage specifies the regression model for the inefficiency term (Battese and Coelli, 1995). Thus, the inefficiency term in BC95 model is an iid nonnegative truncated normal distribution where ($u_{it} \sim N^{+}$ (μ_{it}, σ_u^2)) (ÖZGEN 2011):

Equation 15: $$\mu_{it} = \delta_0 + \sum_{h=1}^{H} \delta_h Z_{hit}$$

Z_{hit}, is the h^{th} exogenous variable which is expected to affect inefficiency by means of its distributionμ_{it}. δ_h (h= 1,2,…, H) are parameters of the slope to be estimated. These exogenous variables can be either positive or negative. Negative parameters show that the variables of parameters improve the inefficiency; in contrast, positive signs imply these variables diminish the efficiency.

It should be noted that both BC92 and BC95 models are estimated using a maximum likelihood model. After estimating the optimal (productive efficient) residential energy consumption, the level of residential energy inefficiency is calculated on the conditional mean of the efficiency term E (U_{it}| U_{it} +V_{it}) (Jondrow). Therefore, the level of inefficiency is:

Equation 16: $$EF_{it} = \frac{f(X_{it}.\beta).exp(V_{it})}{y_{it}} = exp(\widehat{u_{it}})$$

Data and empirical models

To study the level of residential energy inefficiency, we utilize a balanced panel data set for two countries, Australia, and New Zealand from 1994 to 2012. The residential sector in Australia mainly utilizes fossil fuels whereas the main energy resource in the residential sector of New Zealand is renewables. Hence, we have chosen New Zealand, and Australia to compare their residential energy efficiency, and to illustrate the effect of the different energy mix. The average size of households, the energy intensity, and share of different house types[24], residential building consents and ethnicities are from the Australian Bureau of Statistics[25] (ABS) and New Zealand Statistics. Aggregated residential energy consumption, real residential energy price, real disposable personal income in US dollars as at 2010, residential energy demand for resources, population density growth index in 2001 and area size are taken from an OECD data set[26]. The population is obtained from World Bank data

[24] As the share of single-family detached house is more than others in both countries, single-family detached house has been chosen in this essay as the relevant measurement to be used.
[25] Statistics, A. B. o. from www.abs.gov.au.

[26] sets, O. d. from https://data.oecd.org.

set. Finally, Heating Degree Days (HDD) and Cooling Degree Days (CDD) are collected from the Degree Days website[27].

Variables

We use aggregate residential energy consumption[28] as the dependent variable and the price of energy, income, population, area size, HDD and CDD of Australian and New Zealand cities, single-family detached home, building consents[29] and the average size of households as regressors. In this essay, time dummy variables are utilized to capture the exogenous[30] effect of technical progress during the estimated period. The variables of interest in this essay are different residential energy resources. The residential consumption of energy resources is geothermal, wind, hydro, solar, coal and natural gas.

Table 6: Variable measurements

Variables	**Measurement**
Total residential energy consumption	TeraJoule (TJ)
Residential energy resources	TeraJoule (TJ)
Residential energy price	Real index for households
Disposable income	Thousand Million 2010 USD constant PPPS
Population	All persons annually
Area size	Squared kilometers
HDD & CDD	Degree Days climate data center[33]
Household sizes[31]	The number of residents in the occupied private dwelling
House types[32]	The number of single-family detached houses
Population density growth	Population growth density index: 2001=100
Building consents	The actual value of total residential buildings
Time variable	Years categorized

Table 7: Descriptive statistics for key variables

Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
Total residential energy consumption	224358.6	170070.2	51309.28	438671.8
Geothermal	146.8158	148.8828	0	310

[27] BiZEE. from http://www.degreedays.net/.

[28] Aggregated residential energy is defined as the sum of the residential demand of energy resources annually in a country, namely: wood, LPG, natural gas, geothermal, wind, hydro, solar, coal, oil, and biogas

[29] To capture the effect of age of building

[30] Price captures the endogenous effect of technical progress

[31] This data set excludes 'visitors only'

[32] A single-detached or separate house has been chosen as the house type.

[33] http://www.degreedays.net

Wind	585.8055	737.018	1.185911	2,325.765
Hydro	16840.94	12,734.22	3180.795	34,062.07
Gas	65833.08	61,525.05	4454	150,800
Coal	782.4203	374.4339	66.57	1,609.15
Population	10,002.86	10,183.94	4.337	22,728.25
Population growth	1.230211	.3964685	.525	2.061
Price	88.0706	13.80868	66.86513	111.7407
Single houses	79.53395	1.829345	77.07	82.5
Household size	2.668684	.0828927	2.4	2.8
Income	25,258.43	4,773.134	17,816.67	35,207.85
Area	3,975,897	3,760,767	264,944	7,686,850
Building consent	2.53e+09	2.75e+09	1.48e+07	7.61e+09
Time	10	5.550749	1	19

Empirical model

The empirical model is estimated in natural log form:

Equation 17: $D_{i,t} = \beta + \beta^{p} P_{i,t} + \beta^{i} I_{i,t} + \beta^{rpop} POP_{i,t} + \beta^{em} EM_{i,t} + \beta^{cdd} CDD_{i,t} + \beta^{hdd} HDD_{i,t} + \beta^{bc} BC_{i,t} + \beta^{ht} SH_{i,t} + \beta^{hhs} HHS_{i,t} + \beta^{t} T_{t} + v_{i,t} + u_{i,t}$

Equation 18: $U_{it} = \delta_0 + \delta_1 T_{it}$[34]

Where:

i= 1, 2 denotes country t= 1,2, 3, …, 18 denotes year

$D_{i,t}$= Aggregate residential energy consumption

$P_{i,t}$= Residential energy price

$I_{i,t}$= Disposable income

$POP_{i,t}$= Population growth density (growth of people per sq.km of land)

$EM_{i,t}$= Energy mix, residential energy resources

$CDD_{i,t}$= Cooling Degree Days

[34] Linear change of inefficiency term, such as cultural effects with respect to time

$HDD_{i,t}$= Heating Degree Days

$BC_{i,t}$= Building consents

$SH_{i,t}$= Single houses

$HHS_{i,t}$= Household size

T_t[35]= Years categorised[36]

$v_{i,t}$= stochastic component of the error term

$u_{i,t}$= non-random component of the error term

The level of Energy Efficiency (EF) in the residential sector in both BC92 and BC95 models are estimated according to the conditional mean of efficiency term E ($U_{it}| U_{i,t} + V_{i,t}$) (Jondrow et al. 1982) is expressed as:

Equation 19: $$EF_{i,t}= \frac{\widehat{D_{i,t}}}{D_{i,t}} = e(-\widehat{u_{i,t}})$$

$\widehat{D_{i,t}}$= the efficient residential energy demand (optimal)

$D_{i,t}$= the actual residential energy demand in the country (i) in the year (t)

Results

Spearman's test was applied to find whether there is a correlation among income, population, building consent, house types, and household size. There is no significant correlation among incomes, building consents, house types, and household types. However, the correlation between population and incomes was significantly high (0.71), so the population variable was dropped from the model. To capture the effect of the population; the population density growth is utilized.

After estimating residential energy consumption according to the model BC (95) (equations 5&6), the coefficient of T1 has a value of one, and the other T coefficients have a value of zero; thus, the model should be specified with BC92 (Battese and Coelli 1995). Although, according to the Spearman's test, there is no significant correlation between residential

[35] Hicksian neutral technology effect

[36] The primary purpose of this thesis is not to estimate price and/or income elasticities. Therefore, the years categorised has been utilised to capture the exogenous effect of technical progress.

energy consumption, and income, the BC92 model is estimated with lagged income as an instrumental variable for the purpose of comparison.

Using Log-likelihood and AIC indicators help us to find the best model. Since the model log-likelihood of this essay is positive, the AIC should be negative. Consequently, after estimating the log-likelihood and AIC for the models, the BC92 model with the instrumental variable is chosen to estimate the residential energy inefficiency.

Results are shown in Table (8). The sign of all coefficient of the BC92 model with lag and without lag is the same, except cooling degree days in Brisbane.

Table 8: Estimated coefficient (t-value in parentheses)

Variables	**BC92 without lag**	**BC92 with lag**
Income	1.077*** (3.38)	8.82e-08*** (16.09)
Price	-0.000276*** (-9.87)	-0.000337*** (-40.30)
Building consent	-1.82e-12*** (10.53)	-1.44e-12*** (20.39)
Geo	-0.0000945** (-2.94)	-0.0000381** (2.80)
Wind	-0.0000179*** (24.31)	-0.0000155*** (42.26)
Hydro	-0.000000367*** (-7.24)	-9.03e-08** (-3.13)
Solar	-109353.3*** (-10.89)	-56796.0*** (-10.49)
Gas	-0.000000303*** (-6.66)	-0.000000343*** (-13.26)
Coal	0.000000570*** (15.87)	0.000000428*** (22.07)
Single houses	0.00151*** (16.71)	0.00157*** (52.65)
Household size	0.0628*** (30.56)	0.0587*** (60.42)
CDD Canberra	0.00128*** (6.96)	0.000261** (2.62)
CDD Perth	-0.000427 (-1.32)	-0.00100*** (-8.29)
CDD Adelaide	0.000222*** (4.24)	0.000566*** (19.44)
CDD Brisbane	-0.000724*** (23.85)	0.000728*** (48.75)
CDD Melbourne	0.00102*** (-3.73)	0.000267 (1.95)
CDD Sydney	-0.000848*** (-19.30)	-0.00102*** (-46.24)
CDD Auckland	0.00112*** (-15.54)	0.000786*** (-19.73)

CDD Hokitika	0.000457*** (7.97)	0.000413*** (17.59)
CDD Dunedin	0.000304*** (9.86)	0.000421*** (24.63)
CDD Wellington	0.000274*** (8.73)	0.000132*** (7.62)
CDD Christchurch	0.000189*** (11.45)	0.0000955*** (10.56)
HDD Canberra	-0.000385*** (8.16)	-0.000138*** (5.80)
HDD Perth	0.00184*** (-7.62)	0.000241 (-1.67)
HDD Adelaide	-0.000349** (2.64)	-0.000944*** (13.78)
HDD Brisbane	-0.00210*** (-10.38)	-0.000888*** (-7.45)
HDD Melbourne	-0.000386** (2.77)	-0.000632*** (-7.10)
HDD Sydney	0.00290*** (9.65)	0.00110*** (6.33)
HDD Auckland	-0.00484*** (19.05)	-0.00405*** (32.44)
HDD Hokitika	-0.000904*** (11.79)	-0.000661*** (18.51)
HDD Dunedin	-0.000737*** (9.27)	-0.00108*** (31.42)
HDD Wellington	-0.00983*** (-28.96)	-0.00897*** (-55.32)
HDD Christchurch	-0.00134*** (10.06)	-0.00172*** (30.06)
Population growth	0.00246*** (4.62)	0.00113*** (5.28)
Time effect	-0.000994*** (-11.20)	-0.000427*** (-9.90)
Gamma	0.656* (-0.06)	0.940* (-0.05)
Log-likelihood	308.9790	331.2593
AIC	-541.9581	-586.5186

Note: ***, **, and * coefficients are significantly different from zero at the 99%, 95%, and 90% confidence levels respectively.

Table (8) shows that all the energy variables in both the BC92 with lag and without lag models are significant with expected signs, except gas. Natural gas is directly used in the residential sector; for instance, in cooking, or water heating. For using coal, the first step is combusting coal and converts it to the usable energy for households (Busch and Gimon 2014). Also, price, income, population growth, household size, and single houses are significant with the expected sign in both models. All the weather variable[37] parameter

[37] The base temperature to calculate CDD and HDD is 18^{0}C ~ 65^{0}F

estimates, using the BC92 with and without lag models, are significant with the expected sign, with the exceptional CDD in Brisbane in the BC92 with the lag model. The time effect variable in both models is negative and significant.

Coefficient interpretation for BC92 with lag:

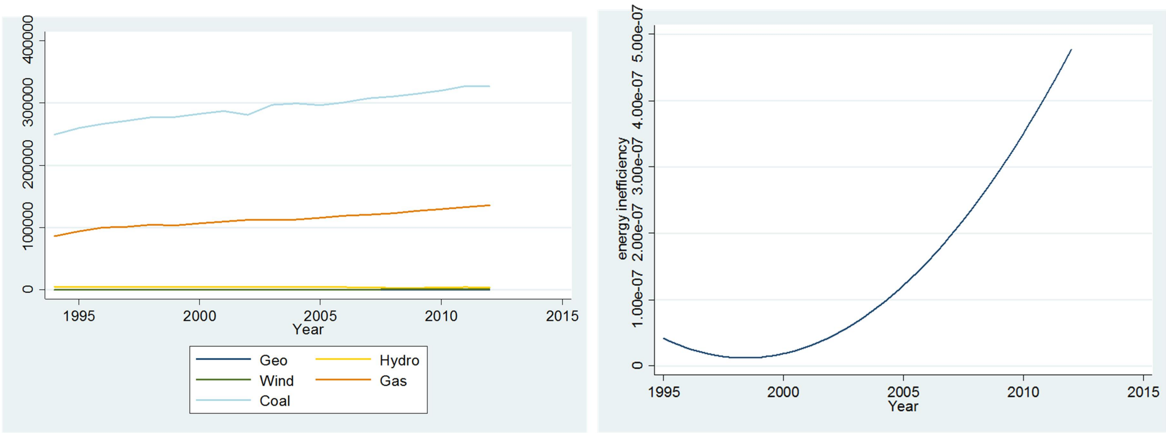
The negative coefficient of renewable energy resources illustrates that when renewable energy consumption in a residential sector increases over the period, final residential energy consumption decreases. The positive coefficient of coal shows that increases in residential consumption of coal enhance final residential energy consumption. Income and building consent coefficients are significant with expected sign. Residential energy consumption of the countries rises by 8.82e-08 with a 1% increase in the income and drops by 1.44e-12 with a 1% increase in the building consent[38]. If the price of energy increases by 1%, the demand for residential energy decreases by 0.000337%. Population growth density is significant and positive. This essay has held the area size constant during the population growth. Therefore, the positive sign of population growth density is acceptable. The time-fixed effect is used to capture the effects of technical progress during the selected period. It shows that during that period, due to the technical progress in residential buildings, residential energy consumption decreases. Heating Degree Days and Cooling Degree Days variables for all cities[39] in both countries are significant with the acceptable sign; expect the CDD variable in Brisbane. As can be seen, the gamma coefficient is 0.94; also, it is statistically significant with the positive sign. It indicates that the component of the inefficiency term overcomes the component of the stochastic term.

Residential energy inefficiency and energy mix

[38] It includes the total approval for new residential buildings, and for alteration and renovation of old residential buildings.

[39] Airport stations are chosen as the best weather stations in terms of location and accuracy (Degree Days.net).

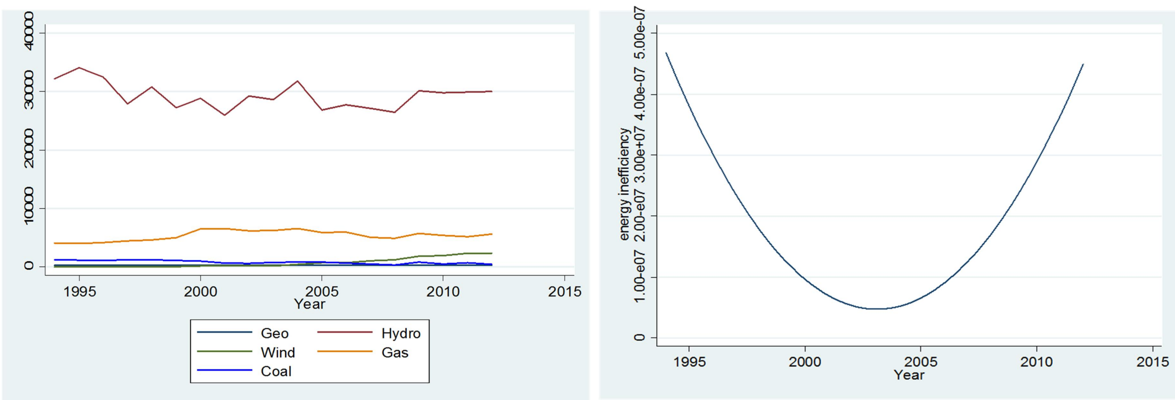
Australia



Graph 13: Australia energy mix & energy inefficiency

A graph (13) displays residential energy consumption and residential energy inefficiency in Australia from 1994 to 2012, respectively. From the graphs, it is clear that fossil fuel is the main source of energy, and its consumption is increasing over the selected period. Moreover, consumption of renewable energy resources is negligible compared to fossil fuels in the residential sector of Australia. Overall, the inefficient consumption of energy in the residential sector is rising.

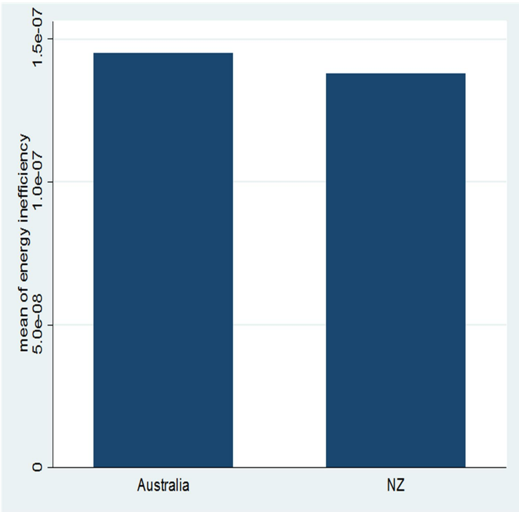
New Zealand



Graph 14: NZ energy mix & NZ energy inefficiency

A Graph (14) shows the residential energy consumption & residential energy inefficiency in New Zealand from 1994 to 2012, respectively. It can clearly be seen that the main source of energy is hydro. Hydro consumption dropped in 2004 and then remains almost constant. The second main source of residential energy consumption in New Zealand is gas. Although consumption of gas showed a slight increase in 2000, it decreased gradually until 2007, when it rose again. Coal fell gradually between 1994 and 2005, since when it is increasing. As a result, residential energy inefficiency reached its lowest level in 2004.

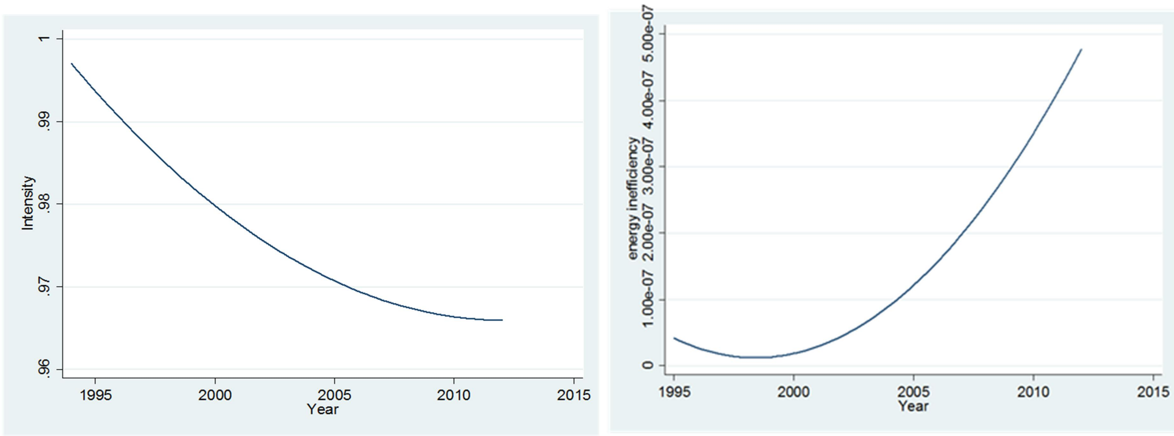
Graph (15) shows the mean residential energy inefficiency over the period 1994-2012 for Australia and New Zealand.



Graph 15: mean energy inefficiency

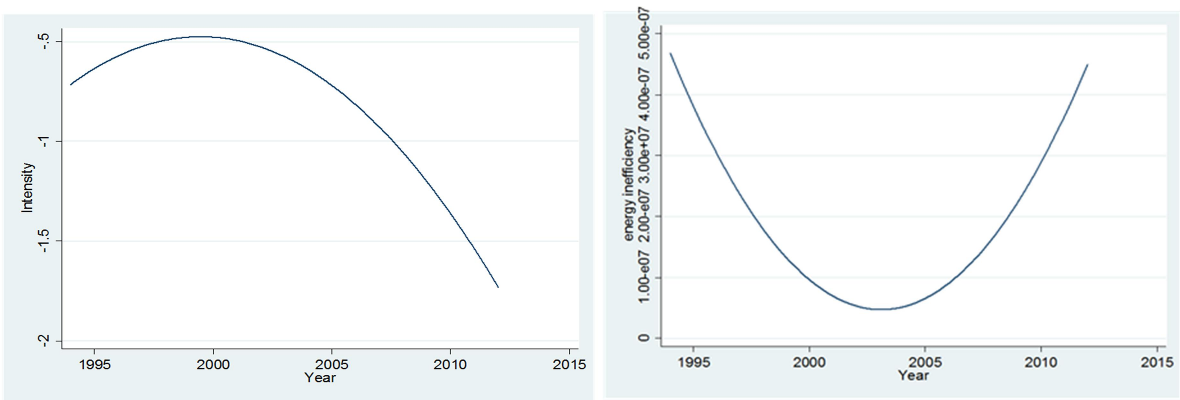
Residential energy inefficiency and residential energy intensity

The study will be more interesting if we compare the level of residential energy inefficiency with the residential energy intensity in Australia and New Zealand. First, we emphasize that Spearman's rank correlation coefficient implies that residential energy inefficiency and residential energy intensity are independent. Energy inefficiency and energy intensity graphs for Australia and New Zealand are drawn for the purpose of comparison.



Graph 16: Australia energy inefficiency &energy intensity

As we can see, residential energy intensity of Australia is decreasing over the selected period; however, the level of residential energy intensity in Australia is increasing.



Graph 17: New Zealand energy inefficiency &energy intensity

The trend of residential energy intensity is different from the trend of the level of residential energy inefficiency in New Zealand.

Summary and conclusion

Australian Bureau of Statistics (ABS)[40] (2015) has been released a report about family and household projection from 2011 to 2036 in Australia. According to this report, both the number of families and households will increase until 2036. The number of households is projected to grow from 8.42 million to 12.57 million by 2036. Stats NZ[41] (2013), reports that

[40] Statistics, A. B. o. (2015). "Households in Australia source data." from https://aifs.gov.au/facts-and-figures/households-australia/households-australia-source-data.

[41] NZ, S. (2013). "National Family and Household Projections." from www.stats.govt.nz.

the number of households and families will grow by an average of 1.1 percentages per year from 2013 to 2038. The number of households is projected to increase from 1.65 million in 2013 to 2.2 million by 2038 in New Zealand.

Residential sector in Australia and New Zealand is one of the largest sectors in terms of energy consumption; also, consumption of energy in this sector will continue to grow due to increasing the number of households. Therefore, the more reliable estimation of energy efficiency can help the policymakers in the future.

This research analyses the level of residential energy efficiency for two Australia and New Zealand countries; as opposed to relying on simple energy intensity indicators; such as ‘energy per building’ and ‘energy per capita.’ The approach combines frontier analysis and energy demand modeling and focuses on the effect of different energy types in order to estimate productive efficient residential energy consumption. As you can see from graph 3, due to the negligible amount of renewable energy resources in the residential sector of Australia, residential energy inefficiency is increasing from 1997. On the other hand, graph 4 shows that the main source of residential energy in New Zealand is renewable energy resources. Because of decreasing in the amount of hydro consumption over the estimated period, residential energy inefficiency reached its lowest point in 2004. Overall, because the main source of residential energy consumption in New Zealand is renewable energy resources, the residential energy inefficiency in New Zealand is less than the residential sector in Australia; on average. After comparisons of residential energy intensity and the level of residential energy inefficiency; this study has found that energy intensity indicator is not a reliable proxy for estimating efficient consumption of energy in end-uses; such as a residential sector. The estimated model confirms that shifting toward the consumption of renewable energy resources, as the main energy resources for the residential sector, causes an increase in the inefficient consumption of energy.

In general, the limitation of this study is the lack of data set on socio-demographic characteristics; such as the level of household education, household ethnicities, and household religious affiliation in Australia, and New Zealand. Future studies with capturing the impact of all socio-demographic characteristics on residential energy consumption may result in a more accurate and reliable result for further research. Moreover, estimating the productive efficient consumption of energy in other end-use sectors in Australia, and New Zealand; such as transportation is another area of research for the future.

IV. Chapter 4:

Estimating the productive efficient consumption of fossil fuels in OPEC countries, and demonstrating the effect of dematerialization on fossil fuels consumption:

We have assessed the effect of energy mix on aggregate energy consumption of OECD countries; and the residential sector in Australia, and New Zealand. Energy inefficiency was estimated using SFA. In this chapter, we are going to focus on OPEC countries. OPEC members entirely rely on fossil fuels. Thus, this chapter will provide estimates of inefficient consumption of energy using SFA. In addition, we explore the role of population in energy consumption. This essay is organized as follows. Section 1 introduces energy consumption, energy intensity, and inefficient consumption of energy in OPEC countries. Section 2 explains the methodology. Section 3 contains a literature review. Section 4 describes the data and the empirical model. Section 5 presents the results. The summary and conclusions are provided in Section 6.

Introduction

The literature points to a relationship between economic growth and energy consumption. According to this relationship, if causality flows from energy to income, economic growth can be affected by a reduction in the consumption of energy. However, if we consider that causality flows from income to energy, the relationship between economic growth and energy consumption is less (Squalli 2007). The most empirical literature is based on positive causality, but some studies underline the negative causality (Wolde-Rufael 2005). The negative causality shows that there is bidirectional causality between energy consumption and economic growth. Therefore, increasing energy consumption has a direct effect on economic growth, that economic growth also decreases energy consumption (Erdal, Erdal et al. 2008). Soytas and Sari (2003) indicated that although there are different directions of causality among countries, reducing energy consumption damages economic growth. The relationship between real GDP and energy consumption expands to include greater carbon emissions. In fact, carbon emissions mostly arise from energy use. Policies that focus only on reducing energy consumption as a solution to the problem of carbon emissions do not account for the adverse effect on economic growth (Soytas and Sari (2003); Soytas and Sari (2009); Apergis and Payne (2010). Switching to renewable energy resources can be a satisfying solution to reducing GHG emissions and sustaining economic growth. However, some countries rely entirely on fossil fuels to satisfy energy demand; such as members of OPEC[42] (Secretariat 2014). Therefore; for these countries improving the efficient consumption of fossil fuels has become crucial.

After signing an agreement in 1960, Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela were the founding members of OPEC. Later, Qatar, Libya, Indonesia, the United Arab Emirates, Algeria, Nigeria, Ecuador, Gabon, Angola, and Equatorial Guinea joined OPEC. The primary goal of OPEC, as stated in its official website, is to "co-ordinate and unify petroleum policies among member countries, in order to secure fair and stable prices for petroleum producers; an efficient, economic and regular supply of petroleum to consuming nations, and a fair return on capital to those investing in the industry". OPEC has been one of the leading players in the global energy market. Since its member countries hold a large percentage of world reserves, these countries mainly consume fossil fuels. Energy consumption of seven OPEC members are described briefly below Birol (2010):

Overview of some OPEC countries

Saudi Arabia

Saudi Arabia has considerable natural gas and crude oil. In 2007, the Saudi Arabian Oil Company (Aramco) estimated its reserves at 259.9 billion barrels, equal to 24% of the world's total reserves. The Ghawar oil field, which is in the Al-Ahsa Governorate, is the world's largest oil field. In 2014, the total proven natural gas reserves in Saudi Arabia were 8,488.9 billion cubic meters (bcm). This ranked Saudi Arabia as having the third-largest natural gas reserves in the Middle East. Moreover, Saudi Arabia was the world's eighth-largest natural gas supplier and the fifth largest consumer of natural gas (Council 2016). The American Energy Information Administration (EIA) indicated that Saudi Arabia was also the largest oil consumer in the Middle East (NEWS 2017).

[42] Organization of the Petroleum Exporting Countries.

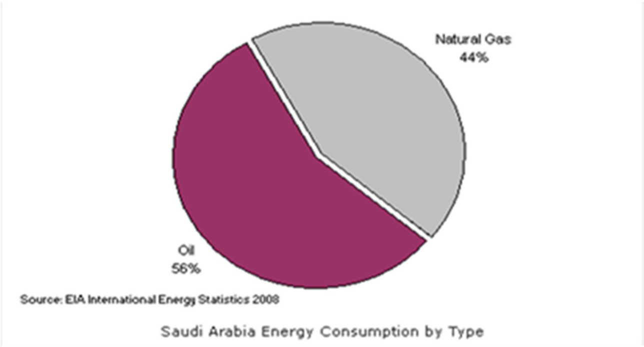


Figure 12: Saudi Arabia: energy consumption by type

Algeria

Natural gas (50.4%) and crude oil (49.5%) are, respectively, the two main energy resources in Algeria. This nation has the third-largest shale gas resource globally and has the third-largest crude oil reserves in Africa (EIA 2016). A total of 143,764-kilo tonnes of oil equivalent (ktoe) or 5.7050166e+12 British thermal units (Btu) of energy was produced in Algeria in 2014. It was the world's fifth-largest exporter of natural gas in 2009. It was also the world's seventh-largest exporter of oil products in 2008. Algeria's total energy consumption in 2010 was about 31,500 ktoe (1.250021e+12 Btu) while its energy consumption had grown to 38,543 ktoe (1.5295099e+12 Btu) by 2013 (Pedia 2017). These data are shown in Figure (13).

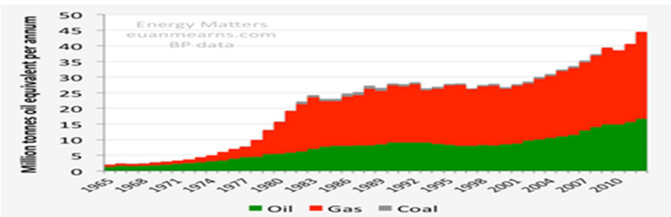


Figure 13: Algeria energy consumption by type

Iran

Iran has the world's second-largest natural gas reserves and the third-largest oil reserves (Yazdan, Behzad et al. 2012). Iran's energy consumption has grown rapidly over the last thirty years (about 6 percent per year). Iran's energy consumption was 9.6 quadrillion British thermal units (Btu) in 2012. Oil and natural gas accounted for 98% of its total energy consumption in 2012 (EIA 2014). Energy consumption has risen by more than 50% in Iran during the last ten years. The main reasons for this rapid growth are: first, the economic growth of Iran was 5% annually, averaged over the last 40 years; secondly, its population has grown by about 2% and, finally, it has low domestic energy prices (Moshiri 2013). The 2012 numbers are demonstrated in Figure (14).

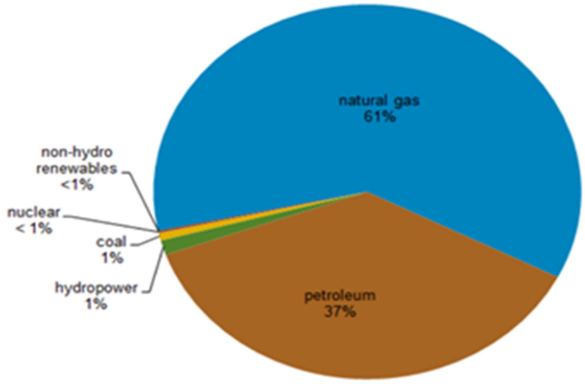


Figure 14: Iran energy consumption by type, 2012

Indonesia

Based on the Indonesian Ministry of Energy and Mineral Resource's statistics, coal, crude oil, and natural gas are its main energy resources. This makes Indonesia the fifth-largest global coal producer (BP 2016). Although Indonesia has significant potential for renewable energy resources, its share of those resources in its energy mix consumption is below 5% (Tharakan 2015). These are shown in Figure (15).

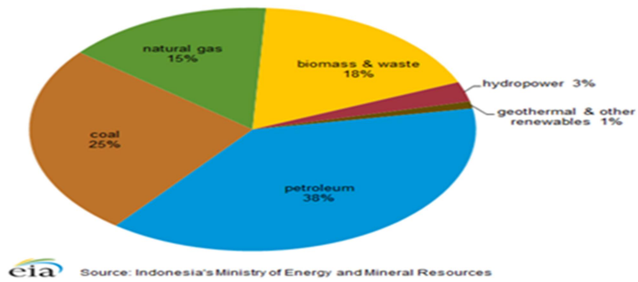


Figure 15: Indonesian energy consumption by type, 2012

Kuwait

Kuwait is one of the founder members of OPEC. Its main energy resources are crude oil and natural gas. Energy exports grew by 16% from 2004 to 2008, so it became the ninth-largest oil producer in 2009 globally. Birol (2010) reported 60% of the world's oil was produced by 10 countries in 2009; Russia (13%), Saudi Arabia (12%), US (8%), Iran (5%), China (5%), Canada (4%), Mexico (4%), Venezuela (3%), Kuwait (3), and United Arab Emirates (3%).

Primary energy use in Kuwait was 1.198e+6 Btu which equates to 426,518 Btu per million persons.

Iraq

Iraq's economy depends on its energy sector: oil exports accounted for 95% of government income and 70% of its GDP in 2011. Iraq has 13th-largest proven gas reserves, and fifth-largest proven oil reserves. Iraq's energy consumption is dominated by oil and natural gas, as shown in figure (16). Although its energy consumption had quadrupled from 1980 to 2010, its rate of growth had been much less than elsewhere in the Middle East (IEA 2012).

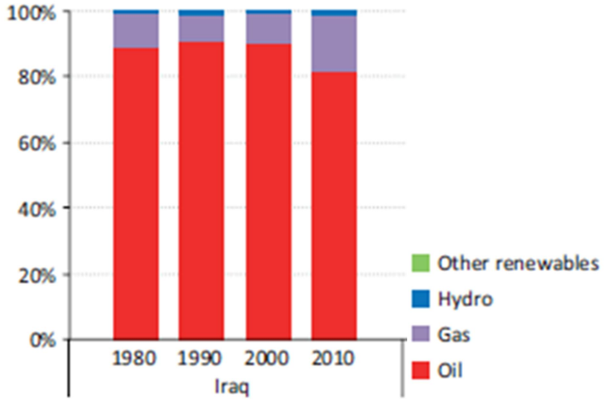


Figure 16: Iraq's energy consumption by type, 2012

Venezuela

Venezuela is another of the world's largest exporters and producers of crude oil and is, therefore, an important player in the global oil market. Proven oil reserves of Venezuela were the largest in the world in 2014. Its total energy consumption was 3.3 quadrillion British thermal units (Btu) in 2014. Oil, natural gas and hydroelectric power represent most of the total energy consumed in that country, as shown in figure (17). Most of the proven oil reserves are in the Orinoco River Basin and are equal to 220.5 billion barrels (EIA 2015).

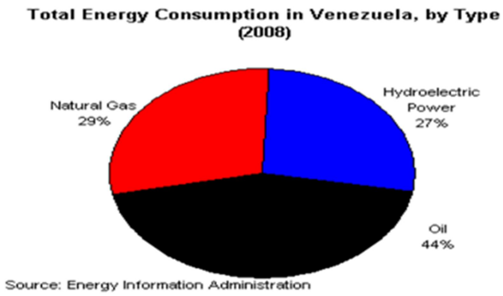


Figure 17: Venezuela energy consumption by type, 2008

Energy intensity

Energy intensity, calculated as units of energy consumption per unit of GDP, is a common indicator of energy efficiency. Energy intensity is commonly used by the members of OPEC (Al□Rashed and León 2015). Rich fossil fuel resources, along with policies encouraging energy use, such as fuel subsidies, are the major reasons for the inefficient use of energy in many OPEC nations (Mahadevan and Asafu-Adjaye 2007). Therefore, energy intensity in all OPEC countries is high compared to other countries ((Hino 2016), (Yazdan, Behzad et al. 2012)).

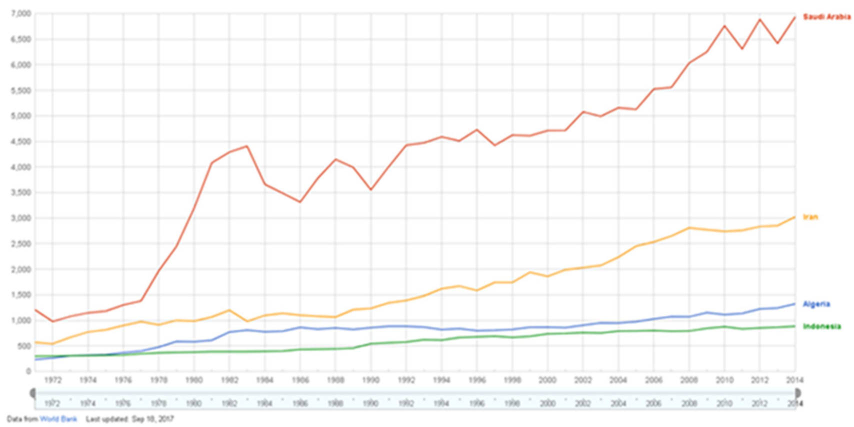
Iran has one of the highest energy intensity around the world; its energy intensity is three times higher than the world average and two-and-a-half times higher than the Middle Eastern average. Furthermore, Iran's energy intensity is still rising. Yazdan, Behzad et al. (2012) noted that Saudi Arabia is ranked as having the greatest energy consumption per capita in the Middle East and it too does not utilize energy efficiently. Saudi's energy intensity was 4.1 in 2014, which was four times more than the UK (UK's energy intensity was 1, and Germany's energy intensity was measured at 1.2) (Hino 2016). Indonesia's energy intensity was 565 toe[43] per GDP, which was four times higher than the average of OECD countries (139 toe) as was Malaysia's energy intensity (439 toe) in the year 2011. The Indonesian Government targeted a decrease of one percentage point per annum in its energy intensity until 2025 (Tharakan 2015). Algeria's energy intensity was six toe/mda[44], which was equal to 0.411 per $1000 of its GDP in 2007, twice as high as the average OECD nation's energy intensity. The relationship between Algeria's consumption of energy in the industrial sector and its value-added worth in the industrial sector shows that energy intensity had increased by 2.45% per annum between 2003 and 2007 (Borodinecs 2015).

43 Tonne of Oil Equivalent.
44 Total Oil Equivalent/Million Algeria Dinars (toe/mda).

Table 9: Selected countries by energy intensity per GDP [45]

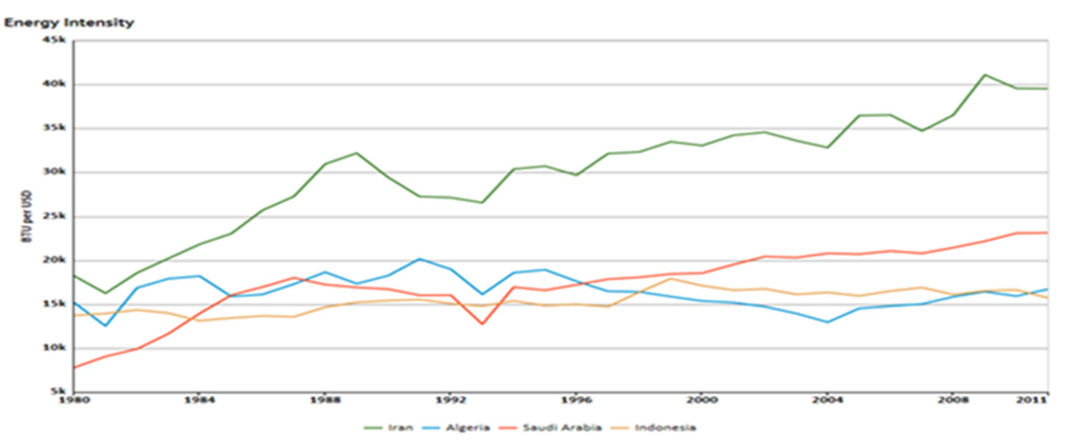
Country	**1971**	**2001**
Algeria	0.24	0.59
Indonesia	0.97	0.7
Iran	0.42	1.0
Kuwait	0.2	0.6
Nigeria	2.3	2.9
Saudi Arabia	0.13	0.8
United Arab Emirates	0.14	0.64
Venezuela	0.4	0.7

Sari and Soytas (2009) showed that Saudi Arabia was the largest per capita energy consumer among OPEC countries and that Venezuela ranked second. Moreover, Saudi Arabia, Algeria, and Indonesia are, respectively, the three largest carbon dioxide emitters. On the other hand, Iran is the most developed country among the OPEC countries (Al□Rashed and León 2015). On this basis, Algeria, Indonesia, Iran, and Saudi Arabia have been chosen as a case study for consideration in this essay.



Graph 18: Energy consumption per capita

45 It is published Mehrzad Zamani 2005.



Graph 19: Energy Intensity of Saudi Arabia, Algeria, Iran, and Indonesia

As we have mentioned, energy intensity is one of the common indicators for energy efficiency in OPEC countries; however, there have been extensive studies about the negative aspects to energy intensity. Al□Rashed and León (2015) illustrated that nation which consumes waste and biomass as their energy inputs do not have precise aggregated energy consumption data. Aggregating biomass and waste energy data with conventional energy resources is problematic. Hence these nations have underestimated energy intensity. Pagá and Gürer (1996) mentioned that GDP is a monetary indicator; so, dollar exchange rate's fluctuations distort the energy intensity for the purpose of cross- country comparisons. They said that although the purchasing power parity (PPP) can help to alleviate this distortion, it causes the other distortions; such as artificially decreasing the energy intensity of developing countries which are not efficient. Also, they claimed that GDP cannot entirely reflect the physical output of nations. Therefore, energy intensity cannot be an accurate indicator for energy efficiency. Finding a reliable indicator of energy efficiency has become an essential issue for policymakers. Filippini and Hunt (2011) proposed the alternative way to estimate the economy-wide of the energy inefficiency. They utilized frontier estimation and energy demand modeling.

Energy efficiency in selected OPEC countries:

The frontier function of energy demand is estimated, controlling for GDP, energy price, and countries specific effects. Aggregate energy demand for the four selected OPEC countries is:

Equation 20: $D_{it} = P_{i,t} + GDP_{i,t} + SHI_{i,t} + SHA_{i,t} + D_t + D_c + A_i + RD_{i,t} + SHE_{i,t} + POP_{i,t} + U_{i,t} + V_{i,t}$

i= 1, 2, 3, and 4 denotes country t= 1,2, 3, …, 41 denotes year

$D_{i,t}$= aggregated energy consumption per capita.

$P_{i,t}$= consumer price index.

GDP_{it}= gross domestic product per capita.

$SHI_{i,t}$= industrial sector value added as a percentage of GDP.

$SHA_{i,t}$= agricultural value added as a percentage of GDP.

$SHE_{i,t}$= service value added as a present of GDP.

A_i= area size.

D_t= time dummy variables.

D_c= climate dummy variables.

$RD_{i,t}$= resource depletion.

$POP_{i,t}$= Population.

$U_{i,t}$= non-random component of the error term.

$V_{i,t}$= stochastic component of the error term.

The balance panel log functional form of the above equation is:

Equation 21: $D_{i,t} = \beta + \beta^{p} P_{i,t} + \beta^{gdp} GDP_{i,t} + \beta^{shi} SHI_{i,t} + \beta^{sha} SHA_{i,t} + \beta^{she} SHE_{i,t} + \beta^{rpop} RPOP^{46}{}_{i,t} + \beta^{t} D_t + \beta^{c} D_c + \beta^{rd} RD_{i,t} + u_{i,t} + v_{i,t}$

The level of Energy Efficiency (EF) is estimated according to the conditional mean of efficiency term E ($U_{i,t}$| $U_{i,t}$+$V_{i,t}$) (Jondrow, Knox Lovell et al. 1982) is:

Equation 22: $EF_{i,t} = \frac{\widehat{D_{i,t}}}{D_{i,t}} = e\ (\widehat{-u_{i,t}})$

$\widehat{D_{i,t}}$ = optimal energy consumption

$D_{i,t}$= the actual energy consumption in the country (i) in the year (t)

Energy consumption is estimated according to the True Fix Effect (TFE) model with $u_{i,t} \sim$ iid $N^{+}(0,\ \delta_u^2)$, and $v_{i,t}$~N $(0,\delta_v^2)$.

[46] Population density (people per sq.km of land).

Table 10: Estimated coefficient (t-value in parentheses)

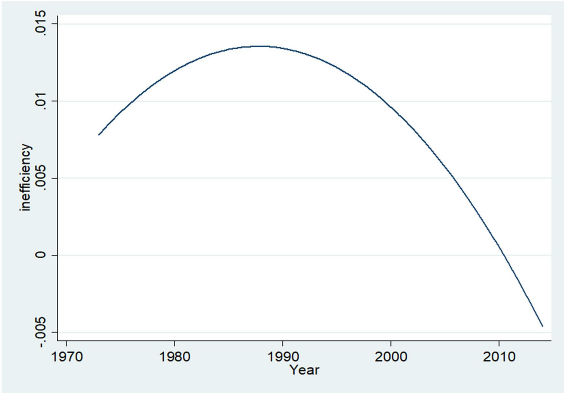
Variables	TFE
Agriculture value-added	0.00259*** (3.47)
GDP	5.02e-15*** (-5.16)
Service value-added	-0.000443*** (7.16)
Industrial value-added	0.000291*** (-3.69)
Price	-0.000163*** (-10.62)
Db[47]	-0.0470 (0)
Dc[48]	-0.0808*** (-5.73)
Population density[49]	0.000000526*** (-9.94)
Resource depletion	2.53e-13*** (-6.81)
Lambda	4.02*** (0.0006)

After applying the Wu-Hausman test, True Fixed Effect (TFE) model is chosen. Due to the uniform correlation between dependent and independent variables, the distribution of U_{it} in the TFE model is assumed to be exponential.

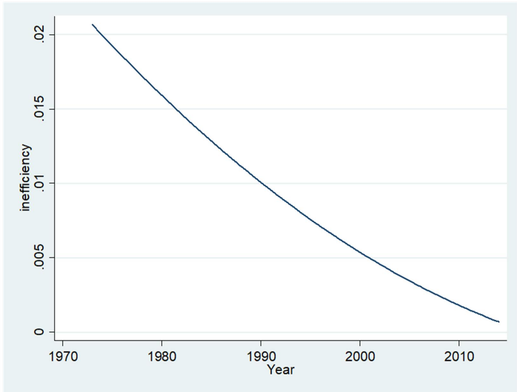
Results are presented in Table (10). Most of the variables are significant with expected signs, except dry climate variable. Aggregated fossil fuels' consumption of countries increases by 0.00259, 5.02e-15, and 0.000291 with a 1% rise in agricultural value-added, industrial value-added, and GDP; respectively. The negative sign of service value-added shows that whenever service value-added increases by 1% aggregated fossil fuels consumption decreases by -0.000443. If the price of energy increases by 1%, the demand of fossil fuels decreases by -0.000163. Since increasing in population density in this thesis means increase in the number of people after holding area size constant, the positive sign of population density is acceptable. If depletion of energy resources rises by 1% aggregated fossil fuels consumption increases by 2.53e-13. Time dummy variables capture the effects of both technical progress and other exogenous changes; such as consumer taste, in countries over time (Hunt, Judge et

47 Dry climates
48 Temperate climates
49 Population per Area (sq.km of land)

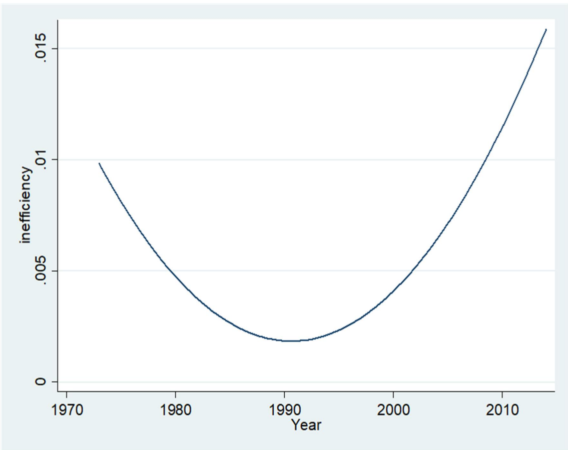
al. 2003). Most of the time variable coefficients[50] are positive and significant. The coefficient of Lambda illustrates that the relative contribution of efficiency (U_{it}) and stochastic (V_{it}) parts of the error term. Lambda is significant with the expected sign.



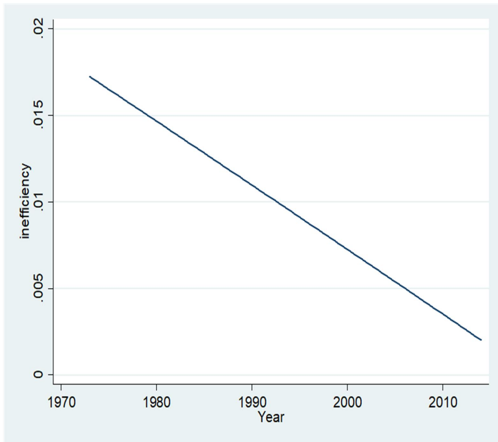
Algeria



Indonesia



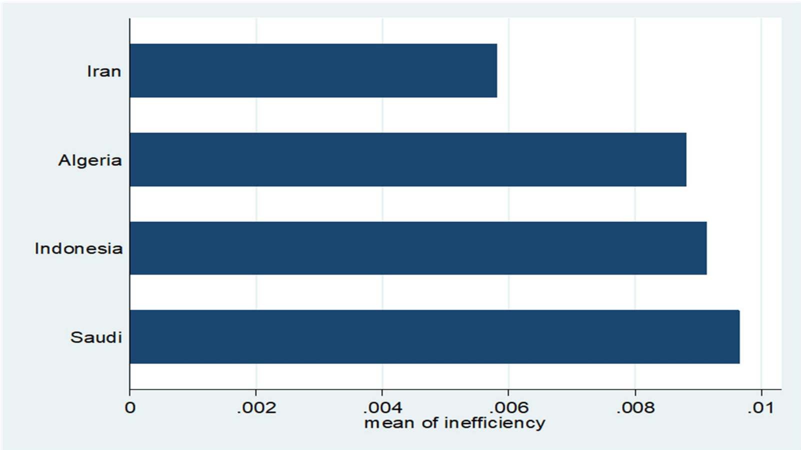
Iran



Saudi

Graph 20: Energy Inefficiency graphs

[50] Table A.1 time dummy variables in Appendix.



Graph 21: Average of inefficient consumption of energy

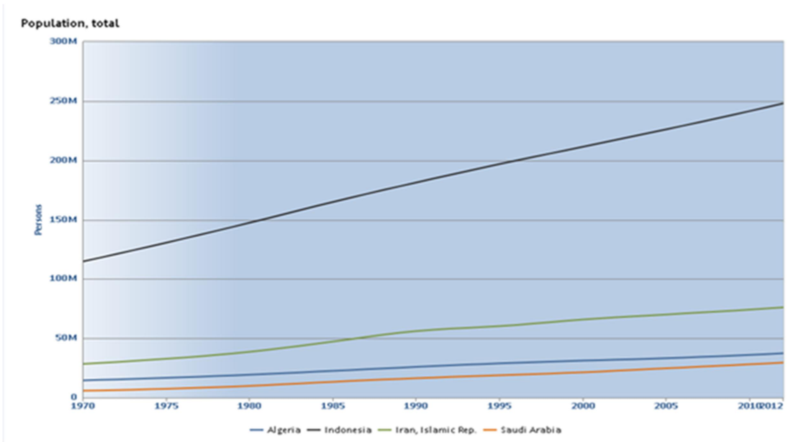
Although inefficient consumption of energy in Iran is increasing, the average level of inefficient energy consumption per capita of Iran is the lowest one among those four selected OPEC countries (Graph (21)). Also, according to the graph (19), Iran has the highest energy intensity among Algeria, Indonesia, and Saudi Arabia.

As can be seen from the graph (20); inefficient consumption of energy in Algeria, Indonesia, and Saudi is decreasing; except in Iran. On the other hand; graph (19) shows that the energy intensity in all four selected OPEC countries is increasing over the time period. Malenbaum (1978), introduced the dematerialization concept which illustrates the intensity of material/ energy use. Bernardini and Galli (1993) defined the dematerialization as a reduction in raw material/energy intensity of economic activities. They measured dematerialization as the ratio of the consumption of material/energy in the gross domestic product (GDP).

Population as for the effective factor in energy consumption, subsequently on economic growth is mentioned in many studies. Such as, Moshiri (2013) asserted the main reasons for Iran's energy consumption growth are economic growth, population growth, and the subsidized local energy market. Furthermore, Asif and Muneer (2007) claimed that there is a close relationship between modernization, population growth, and urbanization, and global energy demand in developed and emerging economies.

Population growth in selected OPEC countries

It is anticipated that the gross global population will increase to 9 billion between 2015 and 2040. It is estimated that the greatest increase in global population will be in the Middle East and Africa. The population of all OPEC countries is expected to grow by 316 million in this period, and 81% of the global population is expected to be in developing countries by 2040. Furthermore, over the last 25 years, the largest share of growth in population has been in the Middle East, Africa, and India (Secretariat 2014). The population trends in Algeria, Indonesia, Iran, and Saudi Arabia are shown in Graph (22). As it is obvious from the Graph 5, Indonesia has the greatest population - and the greatest increase.



Graph 22: Population trends in Algeria, Indonesia, Iran and Saudi Arabia

Dematerialization and energy intensity cannot provide a measurement to demonstrate the dynamic energy consumption changes per capita. Due to this limitation of the dematerialization theory, it should not be used as an empirical forecasting tool in the area of resource policies. In this essay, we utilize Product Generational Dematerialization (PGD) indicator to reflect changes in energy consumption by population (Ziolkowska and Ziolkowski 2011).

Although energy consumption is likely to rise faster than the population growth, globally, energy intensity cannot reflect the impact of population growth on GDP. Therefore, we also need to consider population growth as it affects OPEC countries; PGD indicator is used to fill this gap. The PGD indicator measures changes in energy consumption relative to changes in the population. In the other worlds, PGD indicator combines two indicates; consumption of energy and its changes which are expressed in relative values, and changes in population (Ziolkowska and Ziolkowski 2011) .

Since OPEC countries mostly consume fossil fuels and estimating the level of energy efficiency, as done in chapters two and three, while considering the share of renewables is not possible. Therefore, after estimating the level of inefficient consumption of energy in selected

OPEC countries, we utilize the Product Generational Dematerialization (PGD) indicator to demonstrate the role of the population on energy consumption of OPEC members. The PGD indicator measures changes in energy consumption relative to changes in the population. The objective of this study is to reflect the effect of population changes on the consumption of energy in selected OPEC countries.

Methodological framework

There are several approaches and models that we can utilize to assess dematerialization processes. Cleveland and Ruth (1998) indicated that among the existing indicators, none of them is wide-spread as a global tool. Hence, researchers seek to find more effective indicators for evaluating dematerialization processes.

Product generational dematerialization (PGD) was introduced by Ziolkowska and Ziolkowski (2010) to analyze the dynamics of two factors; simultaneously. PGD indicator expresses percentage changes in material consumption and the simultaneous percentage changes in population over the selected time period. Hence, it provides a common measurement for the purpose of comparison. The PGD indicator is used for macroeconomic comparisons and raw material dematerialization, simultaneously. It is a useful indicator of the following issues: 1: environmental efficiency analyses; 2: evaluating whether the environmental policy was effective or not in the selected time periods; 3: facilitating the creation of energy and development, and sustainable environmental policies; 4: demonstrating the pace of introducing resources into the economic systems, and 5: managing scenarios and trends analysis during crises.

The ‘Generational’ term of this indicator refers to the ‘analyzed population.' There are five steps to measure the PGD indicator: 1. Define the product; 2. Calculate the dynamic effects in production (consumption); 3. Define the demographic situation; 4. Calculate the dynamic effects in the demographic situation, and 5. Calculate the outcome’s ratio of demographic and production dynamics. Dynamic effects are measured by comparing the given value in a given year with the value in the previous year (Ziolkowska and Ziolkowski 2010).

Therefore, PGD indicator in this essay is estimated as a difference between the dynamics of population and the dynamics of energy consumption in selected countries over selected time periods (Ziolkowska and Ziolkowski 2011).

Equation 23: $PGD = \Delta \text{ world population } (\Delta P) - \Delta \text{ country production } (\Delta C)$

PGD: Product Generational Dematerialization.

ΔP: ratio (changes) of the population between two years.

ΔC: ratio (changes) of product consumption between two years.

Production refers to the total consumption of energy which has been described earlier, and the demographic situation refers to the populations of the selected OPEC countries.

Generational dematerialization is defined to occur when an increase in population is greater than the increase in energy consumption. When an increase in population is equal to the increase in energy consumption, it shows a balance. And when an increase in population is less than the increase in energy consumption, it shows generational materialization. Therefore, the negative value of the PGD indicator denotes the materialization; while, the positive value of the indicator indicates the dematerialization of the process.

Literature review

Despite the diversity in the definition of dematerialization, the main idea of this concept is the same. Gałecki (2010) illustrated the dematerialization concept as a quantitative reduction of natural resources. Sun (2001) defined dematerialization/materialization as the real change of energy consumption in one year if this change is less/more than the trend based on the given base-year changes, over a selected period. Further, dematerialization can also be defined as the result of recycling (Høyer and Næss 2001). Høyer and Næss (2001) asserted that higher dematerialization happens with a higher recycling rate. In contrast to that point of view, Høyer (1997) said that recycling means using the same resources again and again. Obviously, it is not environmentally neutral because it needs a high level of energy use; for example in the transportation sector. Therefore, recycling can be recognized as dematerialization in the scale of the process. Ekins (2002), and Grübler (2003) claimed that dematerialization is a result of increasing productivity of natural resources.

Some authors believe that dematerialization results from the transition of an economy to a service economy. Carolan (2004) wrote about the ecological materialization, especially regarding ‘productivist’ orientation. He mainly focused on how things are produced and emphasized that there was a shift in production and consumption, which is not undeniable, in the last two decades; for instance, the digital revolution. Due to the digital revolution, fewer resources are consumed than traditional forms of production. Hence, we call it the "dematerialization" of consumption, and production. Kander (2005), analyzed whether shifting into a service economy affords dematerialization of production; consequently, there was an environmental improvement for Sweden's economy from 1870 to 1970. He claimed that dematerialization occurred when there was an improvement in the productivity of resources in manufacturing and other secondary industries, which was not due to the structural shift towards a service sector.

Ziolkowska and Ziolkowski (2010), and (2011) claimed that the traditional dematerialization indicators show the improvement in the product efficiency without reflecting the dynamics of the achieved improvements in regards to the population (generation) growth. Hence, they introduced the use of the PGD to measure the scale of change in the use of natural resources versus the scale of change in population. Ziolkowska and Ziolkowski (2011), used the PGD indicator for global crude oil dematerialization between 1972 and 2010. The result showed that although the global population is increasing, dematerialization of crude oil is raised, globally. Also, Ziolkowska and Ziolkowski (2010), claimed that there is 1% materialization for the global energy sector.

The following studies used the PGD indicator to estimate the level of energy efficiency.

Ackah, Alabi et al. (2016) examined the efficiency of renewable energy consumption using the PGD indicator in 10 African countries between 1971 and 2012. They estimated the renewable energy consumption per capita according to the GDP per capita, carbon emissions, energy resource depletion, human capital development, and price. After estimating renewable energy consumption, they measured the PGD indicator. Results show that four out of ten African countries have experienced materialization in renewable energy consumption over the estimated period. They concluded that energy prices, economic growth, energy resource depletion, and carbon emissions significantly impact on consumption of renewable energy.

Ziolkowska and Ziolkowski (2015) illustrated a new perspective on the efficient consumption of energy in the transport sector of 27 European Union (EU) countries from 2000 to 2010 by using the PGD indicator. Results show that increases in the energy consumption of the transport sector were greater more than increases in the population (materialization tendency) in the EU-27 between 2000 and 2007.

Energy efficiency consumption in selected OPEC countries

Moshiri (2013), demonstrated the effects of energy price reform on energy efficiency in Iran. He indicated that the energy intensity in Iran was also high because of long-term subsidized energy prices. The Iranian government undertook energy price reform in February 2010 for managing energy consumption. The target of this reform was to decrease subsidies. Reducing the subsidies led to energy prices rising by 90 percent over five years. He concluded that lower energy subsidies but did not have a clear impact on the energy intensity of Iran.

Sabetghadam (2006) listed eight indicators for sustainable energy in Iran, namely; per capita carbon emissions, most significant energy-related local pollutants, households with access to electricity, clean energy investment, resilience to external impacts, the burden of energy investments, energy intensity, and a ratio of final energy consumption to GDP. Energy intensity in his paper was calculated as the ratio of energy consumption to the real GDP. According to this indicator, the energy intensity was 12.1, 20.6, and 22.6 in 1980, 1990, and 2003 respectively. He concluded that Iran was consuming energy inefficiently.

Banaeian and Zangeneh (2011) illustrated energy efficiency in the production of corn in ten provinces [51] of Iran by utilizing a Data Envelopment Analysis (DEA) approach between 2001 and 2007. They also calculated energy use efficiency, energy productivity, specific energy, and net energy [52] gain in corn production. They concluded that total energy consumption and average technical efficiency in corn production were 52.57, and 90.26% in the period 2001-2007, respectively. They found that energy use in the production of corn was not efficient in Iran.

Mohammadi, Rafiee et al. (2011) estimated the energy efficiency of farmers in kiwifruit production by utilizing Data Envelopment Analysis (DEA) approaches in Mazandaran- Iran. They concluded that 3687.62 from total energy input in kiwifruit could be saved without reducing production, on average. Moreover, they found that of the 86 considered farmers, 62.79% were technically efficient.

[51] Isfahan, Elam, Lorestan, Hamadan, Kermanshah, Kerman, Qazvin, Fars, Sistine & Baluchistan and Khuzestan.

[52] Energy output- energy input.

Dincer, Hussain et al. (2004) illustrated the energy and exergy used in all private and public sectors of Saudi Arabia from 1990 to 2001. They defined exergy from the thermodynamics point of view; namely, exergy is defined as the maximum amount of work that can be produced from a system or energy when it comes to equilibrium with considering environmental conditions. They then compared the energy and exergy efficiency of six sub-sectors together in 2000: commercial, streets, governmental, hospitals, mosques and charitable associations. They concluded that the government sub-sector was the most exergy efficient while hospitals were the most energy efficient sub-sectors. Moreover, Dincer, Hussain et al. (2004) estimated the energy and exergy efficiency in three sub-sectors of the transport section: air, road, and marine. They concluded that the road sub-sector was the most efficient while the air and marine sub-sectors operated at the same level in terms of efficient consumption of energy.

Wolde-Rufael (2005) investigated the long-term relationship between real gross domestic product (GDP) per capita and the energy consumption per capita for 19 African countries from 1971 to 2001. He concluded that in some African countries such as Algeria, Egypt, Democratic Republic of Congo and Ghana, energy consumption was significantly and positively related to their respective GDP. He also found that there was causality running from economic development to energy consumption in Algeria, Ghana, Democratic Republic of Congo, the Ivory Coast, and Egypt. Economic growth in these countries led to greater use of energy.

There is extensive literature on energy efficiency in the OPEC countries. The research to date has been concerned more about the efficiency/intensity of energy resources. To the best of my knowledge, this is the first study that indicates the role of population in energy consumption of OPEC countries. The objective of this study is to analyze energy consumption changes in OPEC countries relative to population changes according to the PGD indicator.

Data and empirical models

To estimate the impact of structural changes on energy efficiency according to PGD indicator, we use a balance panel data set for Algeria, Indonesia, Iran, and Saudi Arabia to estimate energy consumption from 1973 to 2014. Then, we describe the relative changes in estimated energy efficiency and population. Data are taken from the World Bank[53]: industrial value added, service value added, agriculture value added, GDP, aggregated fossil fuels consumption, population, energy price, and resource depletion[54]. Finally, climate dummy variables are based on the classification proposed by Kottek, Grieser et al. (2006). Population age groups and area size data are according to the knoema[55] open data resource.

Variables

We utilize the aggregate fossil fuel consumption as the dependent variable and the price of energy, industrial value added, and service value added, agriculture value added, GDP, resource depletion and climate classification as regressors. The exogenous effect [56]of technical progress is captured by time dummy variables during the selected period. Population and industrial value-added are the variables of interest in this essay.

Table 11: Variable Measurements

Variables	**Measurement**
Aggregate fossil fuels consumption	Kg of oil equivalent.
GDP	Billion current US dollar.
Industrial value added	Percentage of GDP.
Agriculture value added	Percentage of GDP.
Service value added	Percentage of GDP.
Population	All persons annually.
Consumer Price Index (CPI)	Real prices (2010-100).
Resource depletion	Current US dollar.
Climate classification	A, tropical weather; B, dry weather; C, mild mid-latitude weather; and E, polar weather.
Year	Time dummy variables.
Area size	Squared kilometers.

[53] WordBank World Bank Open Data - World Bank Group.

[54] Energy depletion is the ratio of the stock energy resources value into the remaining reserve lifetime.

[55] knoema (2011). World Data Atlas.

[56] Price captures the endogenous effect of technical progress.

Table 12: Descriptive statistics for key variables

Variables	Mean	Std. Dev.	Min	max
Aggregated fossil fuels consumption	1795.587	1767.167	89.7533	6937.009
GDP	1.84e+11	1.96e+11	8.72e+09	9.18e+11
Industrial value added	48.81208	9.900748	25.3855	83.1276
Agriculture value added	9.410989	5.028645	.7913606	24.12156
Service value added	41.70058	7.510845	16.03687	58.87084
Population	7.32e+07	7.28e+07	6714095	2.55e+08
Consumer price index	48.53097	43.67144	.2008868	250.8293
Resource depletion	1.46e+10	2.00e+10	1.08e+07	1.15e+11
Area size	204687.8	24166.87	174515	238174

Empirical Model

The estimated energy consumption proceeds as:

Equation 24: $D_{i,t}= F\ (GDP_{i,t}, SHI_{i,t}, SHE_{i,t},\ SHA_{i,t}\ , POP_{i,t}, P_{i,t}, RD_{i,t},\ D_t, D_c)$

The model is estimated in natural log form:

Equation 25: $D_{it}= \beta^{gdp}\ GDP_{i,t}\ + \beta^{shi}\ SHI_{i,t}\ + \beta^{she}\ SHE_{i,t}\ + \beta^{sha}\ SHA_{i,t}\ + \beta^{rpop}\ RPOP_{i,t}\ + \beta^{p}\ P_{i,t},\ \beta^{rd}\ RD_{it} + \beta^{t}\ D_t\ + \beta^{c}\ D_c\ + e_{i,t}$

Where

i = 1, 2, 3, 4 denotes country; t = 1,…,41 denotes year.

$D_{i,t}$= aggregated fossil fuels consumption.

$GDP_{i,t}$= gross domestic product per capita.

$SHI_{i,t}$= industrial sector value added as a percentage of GDP.

$SHE_{i,t}$= service sector value added as a percentage of GDP.

$SHA_{i,t}$= agricultural value added as a percentage of GDP.

$RPOP_{i,t}$= population density (people per sq.km of land).

$P_{i,t}$= consumer price index.

$RD_{i,t}$= resource depletion.

D_t= time dummy variables.

D_c= climate categorical variables.

$e_{i.t}$= error term.

The level of Product Generalization Dematerialization (PGD) is estimated according to the:

Equation 26: $$PGD = \Delta\ POP_{i,t} - \Delta\ \widehat{D_{\iota,t}}$$

PGD: product generational dematerialization.

ΔPOP: relative change (ratio) in population between two years (t, and t+1)

$\Delta\widehat{D}$: relative change (ratio) in energy consumption between two years (t, and t+1).

Results

Maximum likelihood estimation of the random effect model is chosen. Spearman's test was then applied to see whether there is any correlation among the coefficients of this model. Although there is no significant correlation among the coefficients, the model is estimated with lagged resource depletion and lagged price as the instrumental variables, for the purpose of comparison.

After estimating fossil fuels consumption without and with lag, the log likelihood and AIC indicators are utilized to find the best model. The model log-likelihood of this essay is positive, so AIC should be negative. It follows that having no instrumental variable is the best model for this essay.

If the chosen base year is further away from the comparison year, we will have a greater level of energy materialization/dematerialization (Ishmael Ackah). Therefore, the chosen base year

Table 13: Estimated coefficients

Variables	MLE[57] (without lag)	MLE (with price lag)	MLE (with resource depletion lag)
GDP	0.242***	0.184***	0.249***
	(6.22)	(5.03)	(6.34)
Industrial value added	1.627***	1.623***	1.664***
	(11.71)	(10.96)	(12.36)
Service value added	-1.255***	-1.440***	-1.268***
	(10.56)	(12.50)	(10.51)
Agriculture value added	0.0962*	-0.0561	0.0523
	(2.25)	(-1.29)	(0.75)
Population	0.551***	0.376*	0.654**
	(3.40)	(2.22)	(2.63)
Price	-0.0808***	-0.00159*	-0.0724***
	(4.00)	(2.33)	(3.54)
Resource depletion	0.0412*	0.0163	-4.27e-13
	(1.41)	(0.55)	(-0.29)
Dc[58]	-0.947***	-0.846***	-1.03***
	(-10.98)	(-10.46)	(-10.46)
Db[59]	1.897***	1.621***	1.779***
	(13.39)	(15.27)	(15.27)
Log-likelihood	152.559	146.531	150.630
AIC	-203.11	-191.06	-201.26

Note: ***, **, and * coefficients are significantly different from zero at the 99%, 95%, and 90% confidence levels respectively.

As we can see from the table (13), all coefficients in the lag and without lag models have the same signs except agriculture value added. All variables are significant with the expected sign except for the agriculture value added and resource depletion variables. Based on log-likelihood and AIC coefficients, the maximum likelihood estimator without any lags is chosen as the model for this essay.

Positive coefficients of GDP, industrial value added, and agriculture value added, show that 1% growth in GDP, industrial value added, and agriculture value added causes 0.242%,

[57] Maximum likelihood estimator
[58] Temperate climates
[59] Dry climates

1.62%, and 0.0962% increase in the aggregated consumption of fossil fuels, respectively. Furthermore, population and price are significant with the expected sign. Aggregated fossil fuels consumption rises by 0.551% and falls by 0.0808% respectively with a 1% increases in population and price. The service value added coefficient is significant and negative. The aggregated fossil fuel consumption of countries would decrease by 1.255% if the service value added of countries increases by 1%. Also, resource depletion is significant with the expected sign. If resource depletion goes up by 1%, aggregated fossil fuels consumption increases by 0.0412%.

Time dummy variables of this essay capture the effect of technical progress, and also other exogenous changes; such as social norms, in countries over time (Hunt and Judge). According to our results, although most of the time dummy coefficients are not significant, they have a negative sign. This means that technical progress effect outweighs social norms in the selected countries. The climate variables are significant with the expected sign.

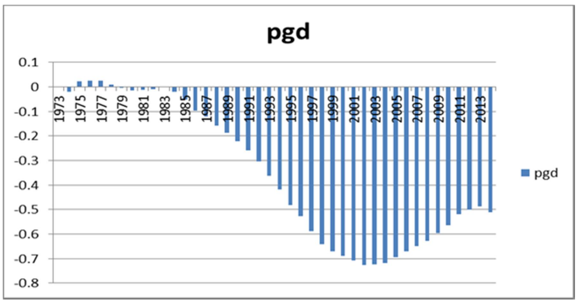
After estimating the fossil fuels consumption, we calculate the PGD indicator according to Equation 4. Results show that Algeria, Indonesia, Iran, Saudi Arabia have experienced 34%, 56%, 30%, and 45% materialization over the selected period of time; respectively.

The trend of PGD indicator is explained for each country in section 5.1.

Product Generational Dematerialization indicator

Algeria

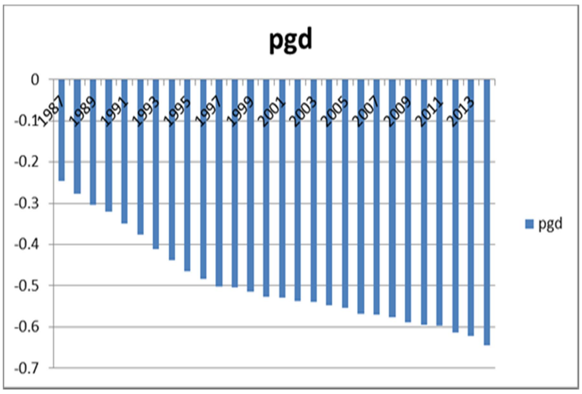
PGD graph shows that Algeria has experienced the materialization from 1979 to 2014. It means that increasing in fossil fuels consumption in Algeria is more than increasing in its total population.



Graph 23: Algeria PGD indicator

Indonesia

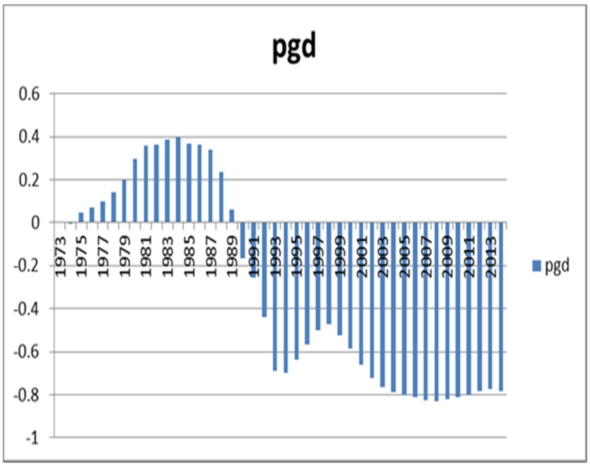
Energy materialization in Indonesia increased over the estimated period. It shows that changes in the fossil fuels consumption in Indonesia increased more than its total population; therefore, growth in industrial value added is acceptable.



Graph 24: Indonesia PGD indicator

Iran

The PGD graph shows that Iran experienced energy dematerialization until 1989. Changes in fossil fuels consumption in Iran started to be greater than the changes in Iran's total population from 1990. Bakhtiari and Shahbudaghlou (2000), showed that the real price of natural gas, oil, gasoline, and electricity in Iran is decreasing from 1990[60].

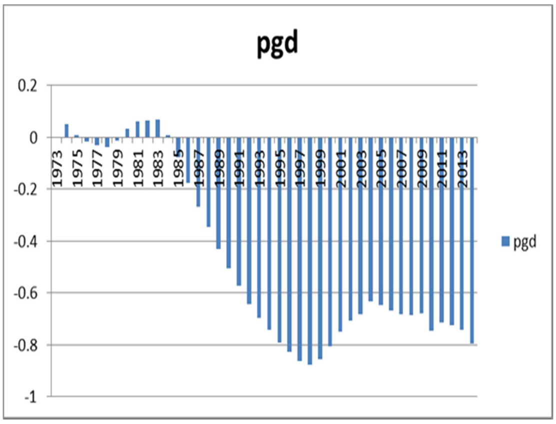


Graph 25: Iran PGD indicator

[60] In 1998 Iran-Iraq war was finished. It had an effect on decreasing the price of energy in Iran.

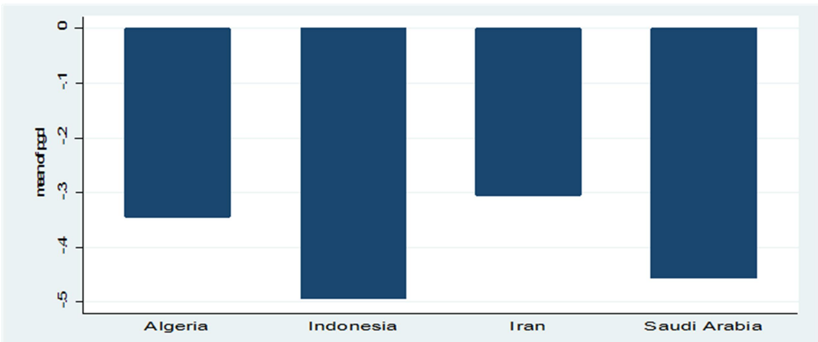
Saudi Arabia

Saudi Arabia has experienced energy materialization most of the time except for the five years between 1980 and 1984. It means that increasing in Saudi's consuming energy is more than increasing in total population over the selected period.



Graph 26: Saudi PGD indicator

The figure below shows means of the energy materialization over the period 1973-2014. The highest energy materialization belongs to Indonesia, and the lowest energy materialization belongs to Iran.



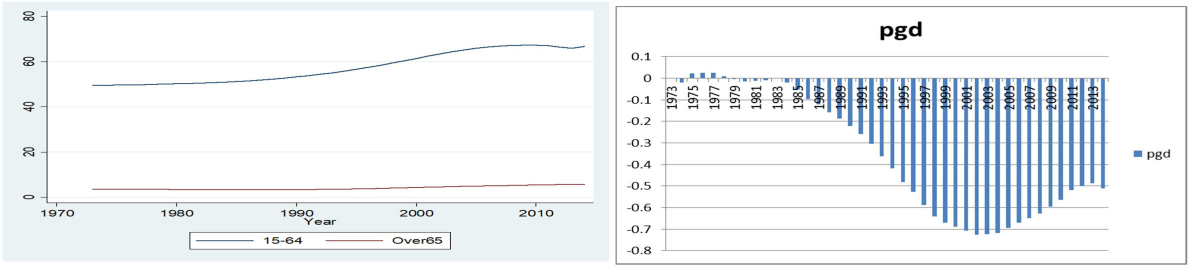
Graph 27: mean PGD indicator

Population age groups and PGD indicator

In this section, the population is divided into the two key age groups: 15-64, and over 65 (knoema 2011). World Bank is defined population aged 15-64 as the working-age population (IEA 2008).

Algeria

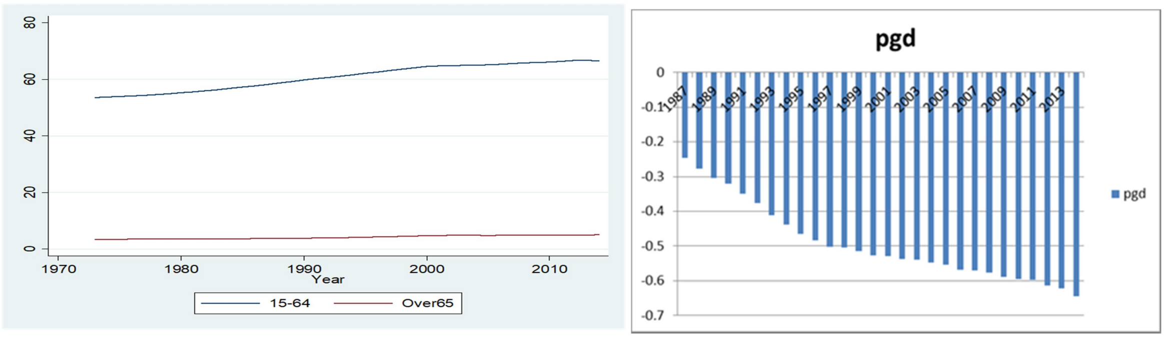
As you can see, the working-age group has a dramatic increase from 1985 to 2008 which in this period of time PGD indicator shows a rise in materialization (from 1984 to 2002). As a result, increasing in the working-age group grows energy consumption in Algeria.



Graph 28: Algeria population groups

Indonesia

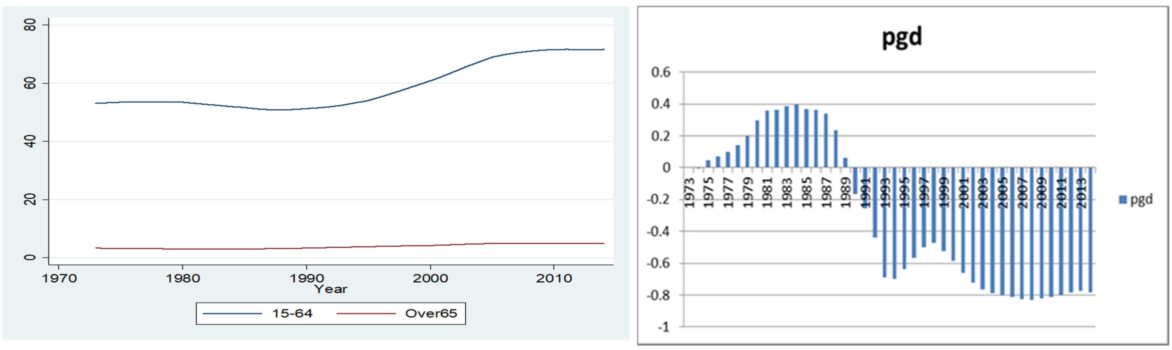
The working-age group is increasing; simultaneously, materialization is enhancing in Indonesia over the time period.



Graph 29: Indonesia population groups

Iran

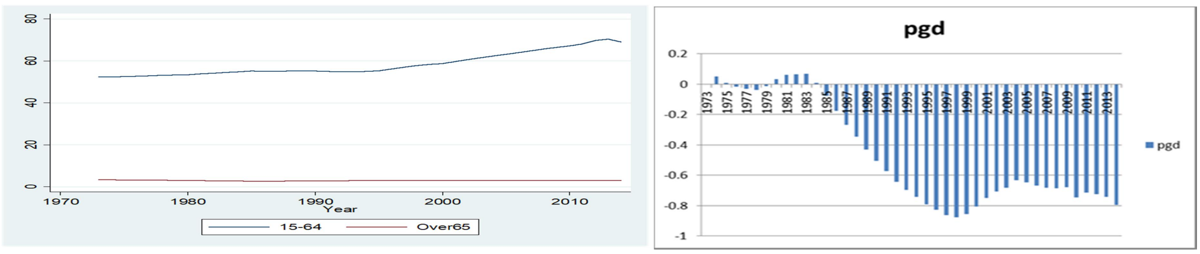
Between 1973 and 1989, the working-age group is decreasing which Iran has experienced the dematerialization in this period of time. Working-age group people are increasing from 1989. Also, the price of energy in Iran decreased from 1990; therefore, PGD indicator indicates that there is the materialization from 1990.



Graph 30: Iran population groups

Saudi Arabia

Since the working-age group is increasing, Saudi has experienced the materialization in most years in the selected time period.



Graph 31: Saudi population groups

York (2007) indicated that increasing the proportion of the old population in EU countries; energy consumption is increasing. Because of the culture of people; for example, old people in European countries tend to have smaller sizes of household, also consuming more energy intensive product; e.g., a private car. However; energy consumption in selected OPEC countries is increasing with rising the proportion of working-age group in the population. Hasanov, Bulut et al. (2016), illustrated that the working-age population consumes energy more than old people in developing countries. They noted that it is reasonable because the working-age population is involving in socio-economic activities more than old population.

Summary and Conclusion

World Energy Council (WEO) (2007) mentioned that 84% of energy consumption will come from fossil fuels up to 2030 worldwide. On the other hand, scientists have claimed that raising the level of CO_2 emissions as the greenhouse gas, significantly contributes to the global warming temperatures. The main reason of an increase in carbon dioxide emissions is fossil fuels consumption (Houghton 1996). Therefore, the productive efficient consumption of energy will be become one of the crucial issues in the world, especially for countries which mainly rely on fossil fuels consumption; such as OPEC countries. Furthermore, finding the relative relationship between population changes and changes in the energy consumption is important for policy makers in their projects about energy demand and energy-related emissions.

In this essay, firstly; we demonstrated the level of inefficient energy consumption in OPEC members; secondly, since population is an effective factor in energy consumption, we illustrated the relationship between increasing in total population and increasing in energy consumption; finally, indicated the effect of different population age groups on energy consumption in selected OPEC countries. In particular, due to the unreliability of energy intensity indicator, the level of inefficient consumption of energy is estimated with utilizing the SFA modeling according to estimating the productive efficient consumption of fossil fuels. Inefficient consumption of energy was decreasing in selected OPEC countries; except Iran, and energy intensity was increasing in all four selected countries. Then, we estimated the PGD indicator to find the relationship between energy consumption and population. We can conclude that the consumption of energy in selected OPEC countries increases when the working-age population rises. This estimated model provides the evidence that energy has been consumed at the higher speed after increasing in working-age population in selected OPEC countries, which is associated with high energy intensity in OPEC countries. However; inefficient consumption of energy in selected OPEC countries is decreasing (according to the productive efficient energy consumption), except Iran.

Finishing Iran-Iraq war in1988 can be a reason of results distinction in Iran. Because after the war, Iran has experienced a decline in the energy price; furthermore, the young population was started to increase.

In general, the limitation for this study was similar to the previous chapter, including lack of energy consumption data set for different end-use sectors of the economy. Developed countries have service-oriented economies while the material-intensive goods are imported from developing countries. OPEC countries have more value-added industries among the developing countries, so they are more concerned with infrastructure development than developed countries (Al□Rashed and León 2015). Future studies could focus on productive efficient fossil fuels consumption in the industrial sector of OPEC members; also, finding the relationship between the working-age population and energy consumption in the industrial sector.

Appendix (B)

Time dummy estimated coefficient:

Table B.1 time dummy variables

Year	**TFE**
1973	0 (.)
1974	-0.00417* (-2.01)
1975	0.0199*** (-1.70)
1976	0.0209 (.)
1977	-0.00409* (-1.99)
1978	-0.00437* (-2.12)
1979	0.0252*** (-1.61)
1980	0.0184 (.)
1981	0.0105*** (-0.03)
1982	0.0130*** (-1.33)
1983	0.0182*** (-2.61)
1984	0.0142*** (-2.65)
1985	0.0133*** (-2.24)
1986	-0.0755 (.)
1987	0.00184 (.)
1988	-0.000825*** (0.12)
1989	0.00186*** (0.39)
1990	0.00800*** (-0.56)
1991	0.0130*** (-1.27)
1992	0.0135*** (-0.65)
1993	0.0186*** (-0.88)

1994	0.0186*** (-1.42)
1995	0.0166*** (-0.93)
1996	0.0223*** (-0.78)
1997	0.0222*** (-1.58)
1998	0.0196*** (-0.84)
1999	0.0170*** (-1.08)
2000	0.0250*** (-1.85)
2001	0.0231*** (-1.75)
2002	0.0230*** (-1.92)
2003	0.0264*** (-1.81)
2004	0.0303*** (-1.91)
2005	0.0369*** (-2.16)
2006	0.0392*** (-1.99)
2007	0.0401 (.)
2008	0.0439*** (-1.74)
2009	0.0381 (.)
2010	0.0430*** (-1.13)
2011	0.0471*** (-0.60)
2012	0.0464*** (-0.08)
2013	0.0431 (.)
2014	0.0423*** (0.28)

V. Conclusion

Research objective

Attention to energy efficiency concept has increased from 1970s oil crisis. Energy efficiency monitoring has become an essential economic and energy policies goals with increasing the global climate warming in late 1980, globally.

Global energy intensity which is measured as the ratio of primary energy demand into per unit of GDP is commonly used as an indicator for energy efficiency (Stern 2012). IEA (2017) reported that energy intensity decreased by 1.8% in 2016; globally. Even though this rate was lower than the rate in 2015, it increased significantly from preceding decades, on average. Moreover, global energy demand increased by 1.1%; however, GDP increased by 3% in 2016(IEA 2017).

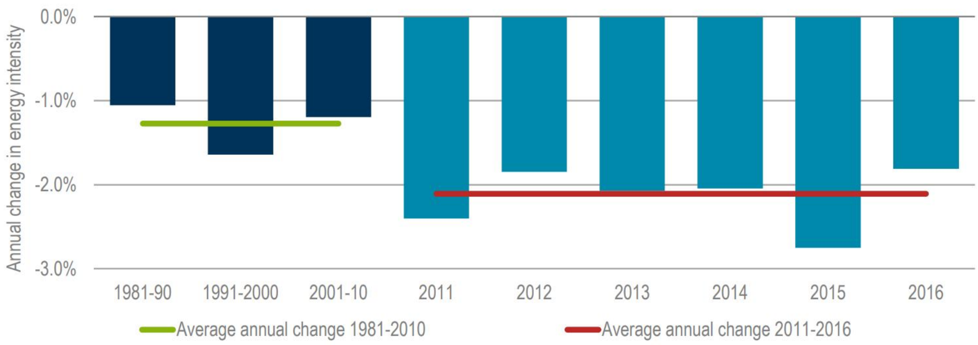


Figure 18: Annual changes in global primary energy intensity, 1981-2016

Improvements in energy intensity can be achieved through improvements in technology, or changes in economic structure; such as an economic activity's movement away from more energy intensive industry to a less energy intensive service sector. Hence, progress in energy intensity does not illustrate solely improvements the inefficient consumption of energy (IEA 2017).

There are several alternatives for estimating energy efficiency. The world is able to produce more output/ GDP from each unit of demand of energy (IEA 2017). Cleveland and Ruth (1998), claimed that different energy types are different in terms of their ability to do work per heat equivalent; therefore, different energy types have different quality. Furthermore, many studies confirmed that different energy resources/ energy mix affect the demand for energy ((Wilson, Trieu et al. 1994), (Tedesco and Thorpe 2003), (Stern 2004), and (Bill 2011)). In this thesis, we hypothesis that each type of energy resources may cause a change in the productive efficient consumption of aggregated energy after holding technology; and an amount of output/GDP constant. The level of inefficiency was measured according to the distance between actual energy demand and the productive efficient energy demand. Based on this hypothesis, we investigated three research questions:

1. The impact of renewables on productive efficient consumption of energy in OECD economies.
2. The impact of renewables on productive efficient consumption of energy in the end-uses sector (residential sector of Australia and New Zealand has chosen as the case study).
3. Estimating the productive efficient consumption of fossil fuels in OPEC countries, and demonstrating the effect of dematerialization on fossil fuels consumption.

The first research question estimated the impact of energy mix on energy efficiency in 28 OECD countries between 1975 and 2011. To the best of my knowledge, this impact on the productive efficient consumption of energy has not been shown, so far. This part of the thesis illustrated whether different sources of energy affect the relative level of inefficiency of OECD countries or not. Stochastic Frontier Analysis (SFA) was used, and the optimal/productive efficient energy consumption for these 28 countries was estimated with using a panel data modeling: the Mundlak version[61] of the True Fixed Effect Model (MTFE)[62].

The second essay estimated the effect of switching to consume more renewables on productive efficient consumption of energy in the residential sector. Australia and New Zealand have chosen as the case study in this essay from 1994 to 2012. The energy ladder model assumes households seek to improve their energy use as incomes rise. Electricity in Australia is mainly generated from fossil fuels; on the other hand, electricity in New Zealand is mainly generated from renewables. To the best of my knowledge, the impact of renewables

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[61] Mundlak, Y. (1978). "On the pooling of time series and cross section data." Econometrica: journal of the Econometric Society.

[62] Greene, W. (2005). "Fixed and random effects in stochastic frontier models." Journal of Productivity Analysis **23**(1): 7-32.

on productive, efficient residential energy consumption has not been shown, so far. Stochastic Frontier Analysis (SFA) was used to estimate the productive efficient household's energy consumption by using BC92[63] panel data modeling.

Finally, the productive efficient consumption of selected OPEC countries was estimated between 1973 and 2014. Since OPEC countries utilize mainly fossil fuels; renewables variables were omitted from the estimation. To the best of my knowledge, productive efficient consumption of fossil has not been shown, so far. True Fixed Effect (TFE) model of Stochastic Frontier Analysis (SFA) has been utilized to estimate the productive efficient consumption of energy. After that, we used Product Generation Dematerialization (PGD) indicator to illustrate the relationship between population and energy consumption in the selected OPEC countries.

	Model	**Variables of interest**	**Sectors**
Essay one	MTFE of SFA	Energy mix	All sectors of OECD
Essay two	BC92 of SFA	Energy mix	Residential sector
Essay three	TFE of SFA	Fossil fuels	All sectors of OPEC
	PGD	Population	

Table 14: comparison of three research questions

Result summary

Overall, results of this thesis confirmed that energy mix is an effective variable on the productive efficient consumption of energy. In particular, increases in the consumption of renewable energy resources are associated with an increase in energy efficiency.

Furthermore, greenhouse gas emissions are caused by the burning of fossil fuels such as gas, oil, and coal. According to the Kyoto protocol, which was signed by nearly all nations in 1992, countries pledged to cut their greenhouse gas emissions averagely 5.2% by 2012; yearly (Guardian 2011). Therefore; shifting toward the consumption of renewable energy resources yields a double dividend viz. to an increase in energy efficiency and a reduction in greenhouse gas emissions.

Since OPEC countries rely on fossil fuels, in the third essay, the productive efficient consumption of fossil fuels is estimated. Productive efficient consumption of fossil fuels in

[63] Battese, G. E. and T. J. Coelli (1992). "Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India." Ibid. **3**(1-2): 153-169.

all selected OPEC countries is increasing, except Iran. The PGD indicator demonstrated that the working-age population is an effective factor in the energy consumption of selected OPEC countries.

Moreover, all three essays confirmed that energy intensity is not the reliable indicator for energy efficiency.

Improves the efficient consumption of energy enhances energy security. Hence, results are a motivation for policymakers to provide some policy regarding shifting toward the consumption of renewable energy resources. In this way, policymakers can address the major environmental challenges while expanding economic opportunities.

First essay: The impact of renewables on productive efficient consumption of energy in OECD economies:

Results of the first essay show that most of the estimated energy variable parameter are significant and negative with the exception of solar thermal. Negative energy coefficients illustrate whenever the primary supply of each energy resource increases over the period, final energy consumption decreases, with the exception of renewable solar thermal. Industrial value-added and population coefficients are positive and significant. Final energy consumption of countries rises by 0.02% and 0.004% respectively with a 1% increase in the industrial value added and population density. The negative coefficient for GDP demonstrates that 1% growth in GDP causes a 0.001% decrease in final energy consumption. We attribute the negative sign to changes in economic structure, notably to growth in the size of the service sector. Price coefficient is negative and significant. If the price of energy increases by 1%, the demand of energy decreases by 0.0013%. The lambda coefficient is 3.64, which shows that the contribution of the one-sided error component is relatively high and the effect on the inefficiency term is positive and significant. Population density is significant and positive. Since in this thesis; increasing in the population density means increasing in the number of people with holding area size constant the positive sign of population density is acceptable. Our results show all of the time dummy coefficients are significant and positive. The positive sign shows that after holding the effect of energy price constant, the effect of exogenous factors; such as consumer taste, outweigh the effect of technical progress.

After estimating the productive efficient consumption of energy, we measured the energy inefficiency. Results show that Korea has the highest and France has the lowest energy inefficiency; averagely.

After comparing the energy mix graph and end energy inefficiency, we concluded that in the majority of OECD countries (except Italy, Finland, Sweden, and Slovakia) increases in the primary supply of renewable energy resources, or decreases in the primary supply of fossil fuel energy resources is associated with an increase the energy efficiency.

Comparisons of energy inefficiency and energy intensity emphasize the unreliability of energy intensity indicator because only 3 countries (Portugal, Germany, and Canada) out of 28 have some degree of similarity between their energy intensity and energy inefficiency.

Second essay: The impact of renewables on productive efficient consumption of energy in the end-uses sector (residential sector of Australia and New Zealand has chosen as the case study):

Results show that the estimated renewables variables were significant with a negative sign. The negative sign of renewables demonstrated that whenever residential consumption of renewables increased over the period, final residential energy consumption decreases. Coal and gas are chosen as the fossil fuels in the residential sector. Coal estimated coefficient is positive and significant which it means if residential consumption of coal rises, final residential energy consumption increases. The estimated coefficient for gas is significant, but with a negative sign. Price, income, population growth, household size, and single houses are significant with the expected sign. Residential energy consumption of the countries rises by 8.82e-08 with a 1% increase in the income and drops by 1.44e-12 with a 1% increase in the building consent. If the price of energy increases by 1%, the demand for residential energy decreases by 0.000337%. Population growth density is significant and positive. The time-fixed effect was designed to capture the effects of technical progress during the selected period. It shows that during that period, due to the technical progress in residential buildings, residential energy consumption decreased.

After estimating productive efficient residential energy consumption, we measured the residential energy inefficiency in Australia and New Zealand. Results show that residential energy inefficiency in New Zealand is less than the residential sector in Australia; on average. The estimated model confirms that shifting toward the consumption of renewable energy resources, as the main energy resources for the residential sector, causes an increase inefficient consumption of energy.

After comparisons of residential energy intensity and the level of residential energy inefficiency; this study found that energy intensity indicator is not a reliable proxy for estimating efficient consumption of energy in end-uses; such as the residential sector.

Third essay: Estimating the productive efficient consumption of fossil fuels in OPEC countries, and demonstrating the effect of population on fossil fuels consumption:

Productive efficient fossil fuels consumption's results showed that aggregate fossil fuels consumption of countries increased by 0.00259, 5.02e-15, and 0.000291 respectively with a 1% rise in agricultural value-added, industrial value-added, and GDP. The negative sign of service value-added shows that whenever service value-added increases by 1% aggregated fossil fuels consumption decreases by -0.000443. If the price of energy increases by 1%, the demand of fossil fuels decreases by -0.000163. Population density is significant with a positive sign, showing that whenever population density increases by 1%, fossil fuel consumption increases by 0.000000526. If depletion of energy resources rises by 1% aggregate fossil fuels consumption increases by 2.53e-13. Most of the time variable coefficients are positive and significant. Lambda was significant with the positive sign.

After estimating the productive efficient consumption of fossil fuels, we measured the energy inefficiency. Results show that Saudi has the highest and Iran has the lowest energy inefficiency; averagely.

Also, we calculated the PGD indicator for selected OPEC countries. Results show that Algeria, Indonesia, Iran, Saudi Arabia have experienced 34%, 56%, 30%, and 45% materialization over the selected period of time; respectively.

We can conclude that the consumption of energy in selected OPEC countries increases when the working-age population rises. This estimated model provides the evidence that energy has been consumed at the higher speed after increasing in working-age population in selected OPEC countries, which is associated with high energy intensity in OPEC countries. However;

inefficient consumption of energy in selected OPEC countries is decreasing (according to the productive efficient energy consumption), except Iran.

Limitations and suggestions for further research

A difficulty with this thesis is that the impact of technological change is captured with time-dummy variables. Countries have different types of technological change, and they are in different stage of technical progress. More accurate capturing the effect of technological changes across countries may result in more precise and reliable results is a challenge for further research.

Availability of country level data is another limitation. Data on energy policies and regulations are limited. Energy policy is one of the effective variables on energy efficiency. Secondly, unavailability of data in Cooling and Heating Degree Days for most countries is another limitation in this thesis. I could find HDD & CDD data only for Australia and New Zealand for 18 years. Third, there is a lack of information and data on all end-use sectors. Residential was the only end-use sector which its data was available. Finally, access to energy data from OPEC countries was limited.

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